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Serum hormones during prolonged training of neuromuscular performance

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Summary. The effects of a 24-weeks' progressive training of neuromuscular performance capacity on maximal strength and on hormone balance were investigated periodically in 21 male subjects during the course of the training and during a subsequent detraining period of 12 weeks. Great increases in maximal strength were noted during the first 20 weeks, followed by a plateau phase during the last 4 weeks of training. Testosterone/cortisol ratio increased during training. During the last 4 weeks of training changes in maximal strength correlated with the changes in testosterone/cortisol ($P < 0.01$) and testosterone/SHBG ($P < 0.05$) ratios. During detraining, correlative decreases were found between maximal strength and testosterone/cortisol ratio ($P < 0.05$) as well as between the maximal strength and testosterone/SHBG ratio ($P < 0.05$). No statistically significant changes were observed in the levels of serum estradiol, lutropin (LH), follitropin (FSH), prolactin, and somatotropin. The results suggest the importance of the balance between androgenic-anabolic activity and catabolizing effects of glucocorticoids during the course of vigorous strength training.

Key words: Strength training – Serum hormones – Detraining

Introduction

The endocrine system is known to respond to an acute bout of exercise (e.g., Kuoppasalmi et al. 1981; Weiss et al. 1983) and long-term physical activity and/or training (e.g., Aakvaag et al. 1978; Remes et al. 1979). Less is known about the hormonal changes during training. Additionally, sometimes inappropriate control of intensity and duration of the training stimulus may have contributed to the relatively great variation in the obtained results (for a review, see e.g., Terjung 1979). Androgens, for example, play a significant role in physical conditioning and especially in strength training. It is therefore natural to examine the effects of strength training on endogenous hormone levels (see also Young et al. 1976; Hetrick and Willmore 1979).

The present investigation was a follow-up of our previous observations about the influences of different training stimuli on the rate of strength development (e.g., Häkkinen and Komi 1981; Häkkinen et al. 1981). Effects of a 24-week progressive training of neuromuscular performance capacity on maximal strength and on hormone balance were investigated periodically during the course of the training, and also during a following detraining period lasting for 12 weeks.

Material and methods

Subjects. The experimental subjects were 21 males (26.3 ± 3.8 years) who were all accustomed to strength training in a noncompetitive manner for their own conditioning purposes. These experimental subjects were divided into two training groups (groups A, $n = 11$, and group B, $n = 10$) equalled in terms of the initial maximal isometric leg extension force. Eight males (27.6 ± 5.1 years) who were also as physically active as those in the two experimental groups served as a control group. Table 1 describes the physical characteristics of the experimental and the control groups.

Training. The controlled experimental training period of the two groups (A and B) lasted for 24 weeks and was followed by a 12-week detraining period, the total duration therefore being 36 weeks. The control subjects maintained their normal physical activities throughout the experimental period but did not participate in the controlled training procedure.

Experimental group A participated in heavy resistance strength training. The training of the leg extensor muscles with barbells three times a week consisted of a dynamic squatlift exercise in which the subject squatted with a loaded barbell on his

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Table 1. Physical characteristics of the experimental groups (A and B) before and after the 24-week strength training and after the following 12-week detraining period. The corresponding values of the control group before and after the 36-week experimental period are also shown in the table. The significance level is given on the right hand side of the arrow

Variable		Before training		After training		After detraining	
		Mean	SD	Mean	SD	Mean	SD
		←	→	←	→		
Age (year)	Group A ($n = 11$)	25.6	4.3	–		–	
	Group B ($n = 10$)	27.1	3.2	–		–	
	Control ($n = 8$)	27.6	5.1	–		–	
Height (cm)	Group A	178.5	6.7	178.6	6.7	178.6	6.6
	Group B	176.3	5.4	176.1	5.4	176.1	5.3
	Control	179.7	3.7	–		179.7	3.5
Mass (kg)	Group A	77.4	6.9	78.5*	6.0	78.9	6.3
	Group B	74.7	9.6	74.3	9.5	75.1	10.4
	Control	75.6	8.2	–		75.8	7.8
Fat (%)	Group A	15.8	5.0	15.0*	3.8	15.3	4.2
	Group B	14.7	2.8	13.3**	2.8	13.6	3.0
	Control	14.2	3.0	–		14.0	2.8

* $P < 0.05$; ** $P < 0.01$

shoulders. The training was progressive with a monthly increase in loads (70–100% of one maximum repetition) and an increasing number of lifts (18–30 contractions per one training session and 1–10 repetitions per set). In addition to this training, the subjects performed three to five heavy eccentric training contractions (with a load of 100–120% of one maximum concentric repetition) during the 3rd, 5th, and 6th training months. To prevent injuries and make the training program more interesting, ligth (60–80% of one maximum repetition) concentric exercises for the trunk, arms, and legs were also included in each training session. During the detraining period strength training was avoided but the subjects maintained their normal daily activities.

Experimental group B participated three times a week in controlled strength training which included various jumping exercises performed without extra load (i.e., using body weight only), and with light extra weights. These exercises were, however, performed with a maximal effort. The jumping exercises included (1) a maximal counter movement jump with a loaded barbell on the shoulders (with the load of 10–60% of one maximum repetition), (2) a maximal standing jump, (3) a maximal five-hurdle jump, (4) a maximal drop jump (from heights of 30–60 cm) followed by immediate maximal rebounds and (5) a maximal drop jump (from heights of 30–40 cm) followed by maximal rebounds which were helped by a rubber band fixed between the waist of the jumper and the roof of the gymnasium. The training program was progressive, with monthly increasing number of contractions performed (100–200 jumps per one training session) and with the aim of performing all the exercises with a maximum effort. This experimental group participated also in a training program which included strengthening exercises (with light weights of 60–80% of one maximum repetition) for the trunk, arms, and legs. During the detraining period the subjects maintained only their normal daily activities without participation in controlled training.

Testing. The experimental groups (A and B) were tested on seven identical occasions at 8- or 4-week intervals (e.g., see Fig. 1) before, during, and after the 36-week period. The control group participated in the first and last tests. In addition to the measurements of weight and height, the percentage of fat in the body was calculated from measurements of skinfold thickness (Durnin and Rahaman 1967). An electromechanical dynamometer (Komi 1973) was used to measure the maximal bilateral isometric

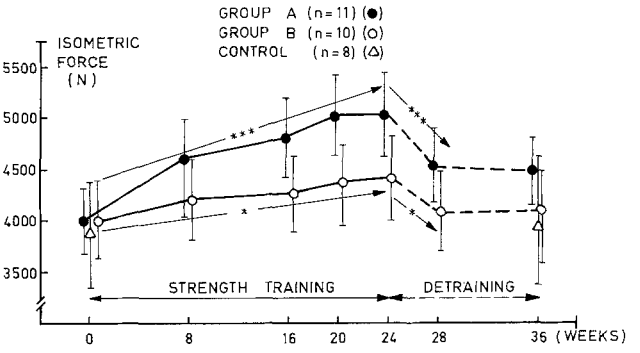

Fig. 1. Mean (± SE) values for maximal isometric force of the leg extensor muscles of the experimental groups and the control group during the course of the 24-week strength training and the 12-week detraining periods (* = $P < 0.05$, *** = $P < 0.001$)

force of the leg extensor muscles (see Viitasalo and Komi 1978; Häkkinen and Komi 1981). The subject performed three to six maximal contractions at knee and hip angles of 107° and 110°, respectively. The force of each contraction was recorded on magnetic tape (Racal Store 7) and analyzed with a HP 1000F computer system. The best reading of each test was taken for analysis.

Analytical methods. After 12 h of fasting and 1 day of reduced training, blood samples were drawn at 8.00 a.m. from the antecubital vein. Serum samples for the hormone determinations were kept frozen at −20° C until assayed. The assays of serum cortisol, testosterone, follitropin (FSH), lutropin (LH), and estradiol were performed by radioimmunoassays using reagent kits from Farmos Diagnostica (Turku and Oulunsalo, Finland), prolactin by radioimmunoassay kits of Diagnostic Products Corporation (Los Angeles, Ca., USA) and somatotropin using the kits of Pharmacia Diagnostics (Uppsala, Sweden). The concentrations of serum sex hormone binding globulin (SHBG) were determined by an immunoradiometric method using reagent kits from Farmos Diagnostica. All the assays were carried out according to the instructions of the manufacturers.

Statistical methods. Ordinary statistical methods were used for the calculations of means, standard deviations, standard errors, and coefficients of correlation. Differences between the values, before and after training and separately after training and detraining, were tested for significance by the Student's *t*-test (two tailed test).

Results

Physical characteristics. The experimental group A gained significantly ($P < 0.05$) in body mass during the 24-week strength training (Table 1) while there were no changes in this parameter in experimental group B or the control group. The percentage of body fat decreased during the experimental training both in group A ($P < 0.05$) and group B ($P < 0.01$), while there was no change in this variable in the control group. During the following 12-week detraining no significant changes were noted in these parameters in either of the experimental groups.

Maximal isometric force. The maximal isometric leg extension force increased during the 24-week strength training in group A from 3,987 (SD, 1,025) to 5,049 ± 1,289 N ($P < 0.001$) and in group B from 4,001 ± 1,112 to 4,434 ± 1,212 N ($P < 0.05$) (Fig. 1). Figure 1 also shows the alteration of this force during the course of experimental period. A plateau phase in force development was noted during the last 4 weeks of training (from the 20th to the 24th week) in both of the experimental groups, occurring more noticeably in experimental group A (from 5,047 ± 1,238 to 5,049

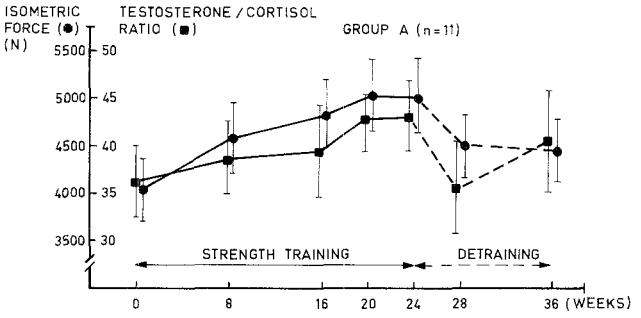

Fig. 2. Mean (± SE) values for maximal isometric force of the leg extensor muscles and for serum testosterone/cortisol ratio of the experimental group A during the course of the 24-week strength training and the 12-week detraining periods

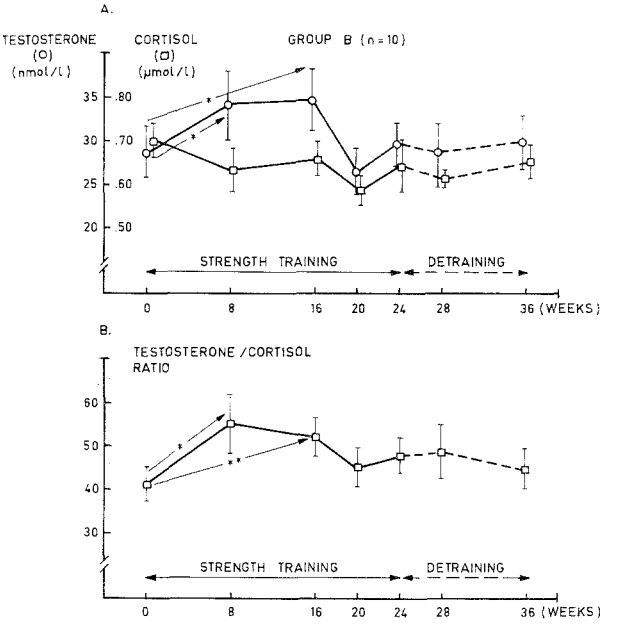

Fig. 3. Mean (± SE) values for serum testosterone and cortisol concentrations (A) and for serum testosterone/cortisol ratio (B) of the experimental group B during the course of the 24-week strength training and the 12-week detraining periods (* = $P < 0.05$, ** = $P < 0.01$)

Table 2. Serum cortisol, testosterone, and SHBG levels in the experimental groups (A and B) before training, after the 24-week, strength training and after the following 12-week detraining period. The values of the control group before and after the 36-week experimental period are also shown in the table. The significance level is given on the right hand side of the arrow

Variable		Before training		After training		After detraining	
		Mean	SD	Mean	SD	Mean	SD
		←		→ ←		→	
Cortisol ($\mu mol \cdot l^{-1}$)	Group A ($n = 11$)	0.74	0.15	0.60**	0.09	0.66	0.18
	Group B ($n = 10$)	0.70	0.13	0.64	0.18	0.65	0.12
	Control ($n = 8$)	0.70	0.18	–		0.71	0.15
Testosterone ($nmol \cdot l^{-1}$)	Group A	25.9	6.3	25.7	7.2	25.5	7.4
	Group B	28.9	9.4	29.5	8.0	29.9	9.9
	Control	28.8	9.8	–		29.6	9.8
SHBG ($nmol \cdot l^{-1}$)	Group A	30.9	12.6	32.8	17.4	32.9	17.5
	Group B	37.5	16.9	38.0	15.4	41.2	22.4
	Control	32.7	14.7	–		33.1	15.8

** $P < 0.01$

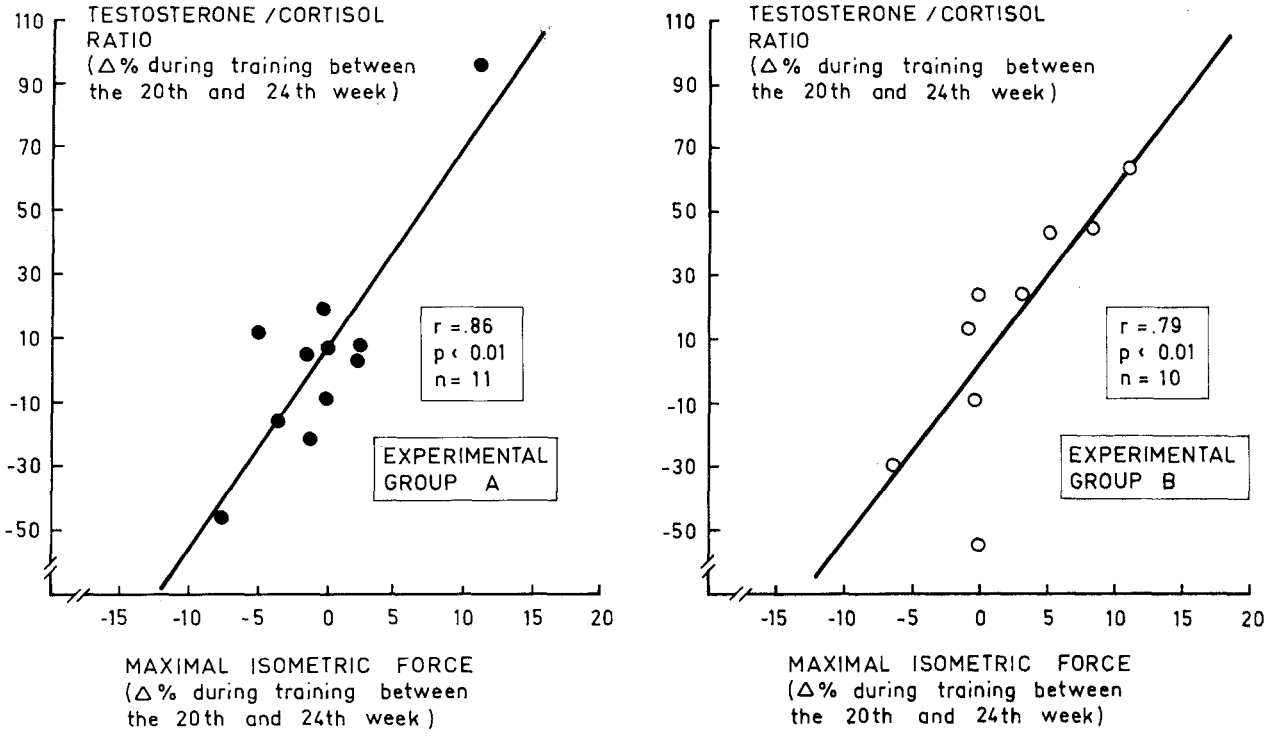

Fig. 4. Relationships between the relative changes in maximal isometric leg extension force and in serum testosterone/cortisol ratio of the experimental groups A and B during the last 4 weeks of training between the 20th and the 24th week of the 24-week experimental strength training period.

± 1,289 N). During the first 4-week detraining (from the 24th to the 28th week) the force decreased to 4,501 ± 1,119 N ($P < 0.001$) in group A and to 4,126 ± 1,116 N ($P < 0.05$) in group B. No changes were noted during the last 8-week detraining period. The control group showed no change in maximal isometric force (from 3,844 ± 1,480 to 3,919 ± 1,657 N) between the two tests performed with this group (Fig. 1).

Serum hormone levels. Cortisol, testosterone, SHBG. In group A a decrase in mean serum cortisol from 0.74 ± 0.15 to 0.60 ± 0.09 μmol · l^{-1} ($P < 0.01$) was observed after the 24-week training period (Table 2). The mean serum testosterone concentration was 25.9 ± 6.3 nmol · l^{-1} before the 24-week training and 25.7 ± 7.2 nmol · l^{-1} after it, and no significant changes were noted at any time. Figure 2 shows the serum testosterone/cortisol ratio, which increased during training and decreased during detraining. The concentration of serum SHBG did not change during the study period (Table 2).

In group B the mean serum cortisol decreased (n.s.) from 0.70 ± 0.13 to 0.64 ± 0.18 μmol · l^{-1} during the 24-week training period (Fig. 3A). There was a significant increase in serum testosterone after the 8 and 16 weeks of training from 28.9 ± 9.4 to 34.5

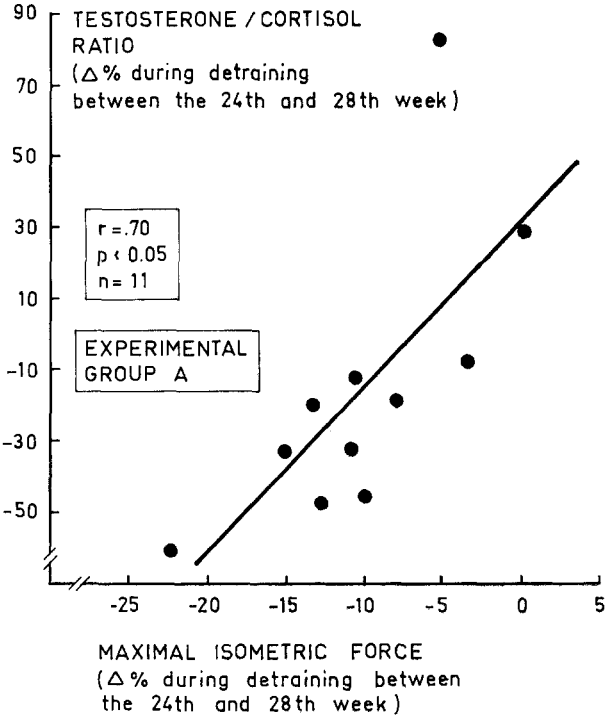

Fig. 5. Relationship between the relative changes in maximal isometric leg extension force and in serum testosterone/cortisol ratio of the experimental group A during the first 4 weeks of detraining between the 24th and the 28th week of the experimental 36-week period

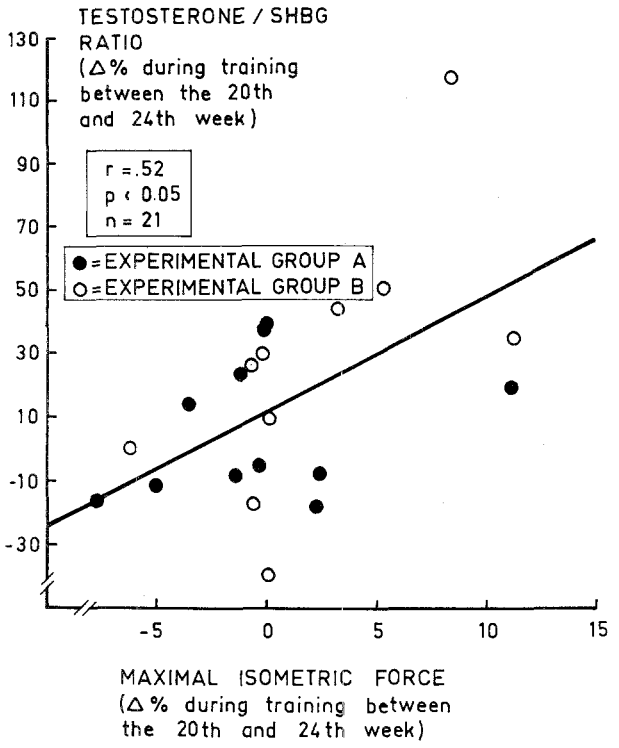

Fig. 6. Relationship between the relative changes in maximal isometric leg extension force and in serum testosterone/SHBG (sex-hormone-binding globulin) ratio of the experimental groups during the last 4 weeks of training between the 20th and the 24th week of the 24-week experimental strength training period

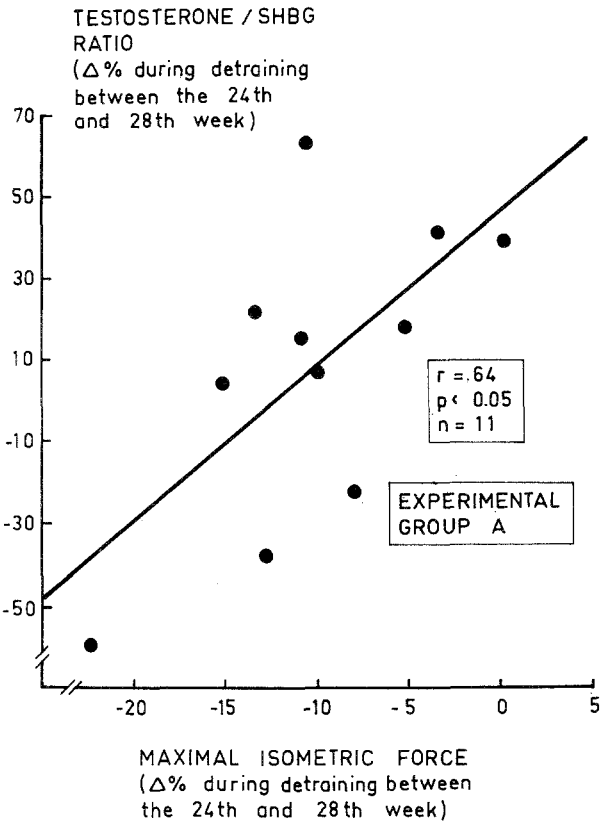

Fig. 7. Relationship between the relative changes in maximal isometric leg extension force and in serum testosterone/SHBG (sex-hormone-binding globulin) ratio of the experimental group A during the first 4 weeks of detraining between the 24th and the 28th week of the experimental 36-week period

$\pm$ 11.4 nmol $\cdot$ l^{-1} ($P < 0.05$) (see Fig. 3A), while at the end of the training the respective value had decreased to 29.5 $\pm$ 8.0 nmol $\cdot$ l^{-1}. Figure 3B shows the alteration of serum testosterone/cortisol ratio in group B during the course of the training and detraining. Significant ($P < 0.05$ and 0.01) increases were noted in this ratio during the first 8 and 16 weeks of training while thereafter a decrease (n.s.) took place during the last 8 weeks of training. Serum SHBG concentration did not change in group B.

During the last 4 weeks of training (from the 20th to the 24th week) significant correlations were observed between the changes in testosterone/cortisol ratio and the change in maximal isometric force both in group A ($r = 0.86$, $P < 0.01$) and in group B ($r = 0.79$, $P < 0.01$) (Figs. 4A and B). During the first 4 weeks of detraining (from the 24th to the 28th week), in group A a significant ($r = 0.70$, $P < 0.05$) correlation between the change in testosterone/cortisol ratio and the change in maximal isometric force was noted (Fig. 5). A significant ($r = 0.52$, $P < 0.05$) correlation was observed in all test subjects ($n = 21$) between the change in testosterone/SHBG ratio and the change in maximal isometric force during the last 4 weeks of training (from the 20th to the 24th week) (Fig. 6). During the first 4 weeks of detraining (from the 24th to the 28th week) a significant ($r = 0.64$, $P < 0.05$) correlation between the change in testosterone/SHBG ratio and the change in maximal isometric force was observed in group A (Fig. 7).

Other hormones. No statistically significant changes were observed in the concentrations of serum estradiol, LH, FSH, prolactin, and somatotropin during the training and detraining periods (Table 3).

Discussion

The magnitudes and alterations of maximal forces during the course of the present training are in line with our previous findings (e.g., Häkkinen and Komi 1981; Häkkinen et al. 1981). After great initial increases, a plateau phase in strength development was observed during later training, being most remarkable especially during the last 6th training

Table 3. Serum estradiol, LH, FSH, prolactin, and somatotropin levels in the experimental groups (A and B) before training, after the 24-week strength training and after the following 12-week detraining period. The values of the control group before and after the 36-week experimental period are also shown in the table. The significance levels between the mean values were calulated according to the arrows

Variable		Before training		After training		After detraining	
		Mean	SD	Mean	SD	Mean	SD
		←		→ ←		→	
Estradiol	Group A ($n = 11$)	0.07	0.04	0.07	0.03	0.06	0.03
(nmol · l^{-1})	Group B ($n = 10$)	0.09	0.05	0.06	0.02	0.07	0.03
	Control ($n = 8$)	0.09	0.11	–		0.10	0.09
LH (U · l^{-1})	Group A	11.3	3.0	10.3	2.9	10.6	3.0
	Group B	10.3	3.4	10.7	5.3	11.2	4.3
	Control	11.3	6.8	–		11.1	5.2
FSH (U · l^{-1})	Group A	4.5	3.0	4.3	3.1	4.5	3.3
	Group B	5.0	3.9	5.2	4.4	5.6	5.0
	Control	4.9	2.4	–		4.8	2.4
Prolactin	Group A	25.4	17.7	18.2	6.8	17.9	6.5
(μg · l^{-1})	Group B	19.0	10.3	17.1	7.6	17.1	8.9
	Control	20.7	7.3	–		20.6	9.0
Somatotropin	Group A	1.1	1.3	0.56	0.80	1.2	2.8
(μg · l^{-1})	Group B	4.3	12.0	0.44	0.22	3.0	6.8
	Control	0.35	0.12	–		0.49	0.47

month. This plateau phase occurred, however, later than in our previous experiments (Häkkinen and Komi 1981; Häkkinen et al. 1981). A plausible reason for this may be a periodical utilization of intensive concentric and eccentric training contractions which may have served as "optimal" training stimuli during most of the training period. However, this plateau phase could not be avoided, being most likely a result of overtraining, because training intensity was maintained (and actually increased) at an extremely high level. A minor increase of maximal force noted in group B in comparison to group A is in agreement with previous findings (e.g.,Viitasalo et al. 1981; Komi et al. 1982) demonstrating the importance of the intensity of muscle contractions for maximal strength development. The alterations in maximal force were, however, similar to those of experimental group A, and no significant improvement was noted during the last (6th) training month.

In all test subjects significant correlations were noted between the change in maximal isometric force and the change in testosterone/cortisol and in testosterone/SHBG ratios during the last 4 weeks of training. In group A (the aim of which was to develop primarily maximal strength) a great decrease in maximal force took place during the first 4 weeks of detraining, correlating significantly with the changes in testosterone/cortisol and testosterone/SHBG ratios.

The increases in testosterone/cortisol ratio in both experimental groups during the first 16–20 weeks (Figs. 2 and 3B) of strength training demonstrate a training-induced increase in anabolic-androgenic activity. As regards the changes in concentrations of these hormones, a significant decrease in cortisol in group A and an increase in testosterone in group B were noted. It is possible that differences in the responses between the groups are due to the type of training.

The present findings also imply that the changes in mean values of the examined serum hormones would not have been observed if only the pre- and post-training values had been compared. Because the training was intense and of long duration one woud expect the serum hormone levels to change in a manner as found in the present study (see correlations in Figs. 4 and 6). This may be one possible reason that no changes in androgen levels have been observed during strength training in some previous studies (Young et al. 1976; Hetrick and Willmore 1979).

When the training was continued, a plateau phase in strength development was found during the last 4 weeks of training (Fig. 1). However, especially during this phase, large individual variations in strength development were observed. Some individuals were able to increase their strength while decreases in strength were noted in others. These

changes occurred concomitantly with the changes in testosterone/cortisol ratios, which was seen as the high correlation between the force development and the changes in this hormone ratio (Figs. 4A and B). This suggests the important roles of androgenic-anabolic activity and catabolic effects of glucocorticoids during an extremely hard training period.

After cessation of strength training, a great decrease in maximal strength was observed during the first 4 weeks (Fig. 1). This same phenomenon has been demonstrated previously in similar experimental conditions (Häkkinen et al. 1981). In parallel with this change in maximal strength a decrease was observed in the testosterone/cortisol ratio in group A (Fig. 2). The high correlation found between these decreases supports the importance of the anabolic-androgenic influence in strength training.

Significant correlations were also found between the changes in maximal isometric force and testosterone/SHBG ratios during both the last 4 weeks of training and during the first 4 weeks of detraining (Figs. 6 and 7). These findings support the concept that, during long-term training, the levels of biologically active unbound testosterone may be of importance for trainability (e.g., Remes et al. 1981).

No significant changes took place in serum LH, FSH, prolactin, or somatrotropin. This suggests that this kind of training of neuromuscular performance capacity has no long-lasting endocrinological effects at pituitary level.

Serum estrogen levels may be changed in different kinds of physical exercise (Opstad and Aakvaag 1982). However, no differences were observed during the strength training in the present study.

In summary, in the present study during prolonged strength training, the hormonal responses occurred as changes in testosterone/cortisol and testosterone/SHBG ratios. The changes in maximal strength correlated significantly with these hormonal changes during both the hardest training period and the detraining phase. The present findings suggest the importance of the balance between androgenic-anabolic activity and the catabolizing effects of glucocorticoids during the course of hard strength training.

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