# Monitoring strength training: neuromuscular and hormonal profile

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## ABSTRACT

BOSCO, C., R. COLLI, R. BONOMI, S. P. VON DUVILLARD, and A. VIRU. Monitoring strength training: neuromuscular and hormonal profile. *Med. Sci. Sports Exerc.*, Vol. 32, No. 1, pp. 202–208, 2000. **Purpose:** This study investigated changes induced by a single heavy resistance training session on neuromuscular and endocrine systems in trained athletes, using the same exercises for training and testing. **Methods:** Five different groups volunteered: track and field male sprinters (MS, $N = 6$), track and field female sprinters (FS, $N = 6$), body builders (BB, $N = 6$), and weight lifters performing low-repetition exercise (WLL, $N = 4$) and high-repetition exercise (WLH, $N = 4$). In training, the work performed during half and full squat exercise was monitored for mechanical power output as well as EMG analysis on leg extensor muscles of the subjects belonging to the MS, FS, and BB groups. Just before and immediately after the training session, venous blood samples were obtained for RIA determination of testosterone (T), cortisol (C), lutropin (LH), human prolactin (PRL), and follitropin (FSH) in FS and MS. In the other three groups (BB, WLH, and WLL), the hormonal profile was limited to T and human growth hormone (hGH) only. **Results:** After training the power developed in full squat demonstrated a statistically significant decrease ($P < 0.01$) in MS and no changes in FS. The EMG activity remained constant during the training session. Consequently, the EMG/Power ratio increased in both MS and FS, although only in MS a statistical significance was noted ($P < 0.05$). In MS immediately after the session the levels of C, T, and LH were significantly lower ($P < 0.05$). No changes were found in FS. In both groups and in BB significant negative correlation was found between changes in T level and EMG/Power ratio in half squat performance. **Conclusions:** It is likely that adequate T level may compensate the effect of fatigue in FT fibers by ensuring a better neuromuscular efficiency. **Key Words:** SERUM TESTOSTERONE, MUSCLE POWER, FATIGUE, EMG, NEUROMUSCULAR EFFICIENCY

Intensive prolonged strength training is known to induce specific neuromuscular (26) and hormonal (17) adaptive responses in the human body. However, little is known about the hormonal changes that occur during a single strength training session (15). Furthermore, even less knowledge is available with respect to fatigue, relative strength loss, and hormonal changes during acute exercise in both male and female subjects (16). In addition, inappropriate control of the intensity and duration of the training session has contributed to relatively large variation in results. It is noteworthy to mention that in the classic training programs the concept of intensity has been misused. The term "intensity" has been used to define the magnitude of the load employed rather than the rate of the work performed (3). In addition, whenever the effect of acute training session has been examined, no specific muscular evaluation test has been employed. In fact, in spite of using the same machine for training and testing (27), evaluation of muscular function has been performed with a complete different activation pattern (e.g., isometric or isokinetic) than was used for training (isotonic) (16). The present study was designed to investigate changes induced by a single heavy resistance training session on neuromuscular as well as on endocrine systems in male and female well-trained athletes using the same exercises for training and testing. In addition, the athletes were kept informed during training of the magnitude of the power developed during each repetition and for the whole training session period through audio-visual biofeedback.

## METHOD

**Subjects.** Twenty-four athletes volunteered as subjects. All had been competing for several years and were participating regularly in different sport activities. They were divided according to sport events into the following groups: track and field male sprinters (MS, $N = 6$), track and field female sprinters (FS, $N = 6$), body builders (BB, $N = 6$), weight lifters performing low repetitions exercise (WLL, $N = 4$), and weight lifters performing high repetitions

TABLE 1. Physical characteristics of the subjects and type of heavy resistance training performed during the monitoring period.

| Activity | No. of Subjects | Age (yr) | Height (cm) | Mass (kg) | Reps | Series | Rest Between Series (min) | % 1RM | % Power | Type of Exercise |
|---|---|---|---|---|---|---|---|---|---|---|
| MS | 6 | 23.3 ± 2.4 | 183.8 ± 7.3 | 76.0 ± 6.2 | 6+6+4 | 6 | 8 | 80 | 100 | HS-FS |
| FS | 6 | 23.0 ± 2.7 | 169.3 ± 4.7 | 55.5 ± 4.8 | 6+6+4 | 6 | 8 | 80 | 100 | HS-FS |
| BB | 6 | 30.2 ± 6.2 | 175.0 ± 2.5 | 80.0 ± 2.3 | 8–12 | 12 | 1–2 | 70–75 | 65–75 | HS-LP-LE |
| WLL | 4 | 24.8 ± 2.4 | 159.8 ± 3.4 | 62.8 ± 1.7 | 2–3 | 10 | 3–5 | 60–80 | 100 | S-C-J |
| WLH | 4 | 22.3 ± 2.6 | 173.3 ± 2.5 | 74.3 ± 1.7 | 2–4 | 20 | 2–3 | 50–70 | 100 | S-C-J |

BB, body builders; MS, Male sprinters; FS, female sprinters; WLL, weight lifters performing low repetitions; WLH, weight lifters performing high repetition exercises; HS, half squat; FS, full squat; LP, leg press; LE, leg extension; S, snatch; C, clean; J, jerk.

exercise (WLH, $N = 4$). Information was given to the volunteers regarding the possible risks and discomforts that might occur. All subjects gave their written informed consent before participation. All athletes were nonsmokers and did not take any medications. Physical characteristics of the subjects are presented in Table 1.

## Mechanical Power Measurements

All subjects belonging to the MS and FS groups were monitored during one heavy resistance exercise session (lasting about 2.5 h), which was regularly performed twice a week. The athletes performed maximal dynamic half squat exercises on a slide machine (guided horizontal barbell) with extra loads of 200% of the subject's body mass for a total load of three times the subject's body mass (3 bm) acting on the leg extensor muscles and a full squat exercises with extra loads of 100% of the subject's body mass for a total load of twice the subject's body mass acting on leg extensor muscles. The best trial of three measurements of each load and type of exercise was used for statistical analysis. All BB were also monitored during the whole training session. The mechanical power was calculated during half squat exercises and EMG activity was collected from leg extensor muscles.

During the test the vertical displacements of the loads were monitored with simple mechanics and sensor arrangement (Ergopower, Ergotest Technology A.S., Langensund, Norway). The loads were mechanically linked to a sensor, which glided on a track bar. The sensor was interfaced to an electronic device. When the loads were moved by the subjects a signal was transmitted by the sensor every 3 mm of displacement. Thus it was possible to calculate velocity, acceleration, force, power, and work corresponding to the load displacements.

## Electromyographic Analysis

The signals from the vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) were recorded with bipolar surface electrodes (interelectrode distance 1.2 cm) including an amplifier (gain 600, input impedance 2 GW, CMMR 100dB) and a passband filter (6–1500 Hz; Biochip, Grenoble, France) fixed longitudinally over the muscle belly. The subjects wore a skin suit to prevent the cables from swinging and from causing movement artifact. EMG signals were used in combination with biomechanical parameters measured with Ergopower. They were simulta-neously sampled at 100 Hz on a personal computer (PC 486 DX-33MHz) via a 10bit A/D conversion system; thus all EMG recordings were true mean square root converted (10) with a time-averaging period of 100 ms via an electronic converter. The averaged mean square root was integrated and expressed as a function of time expressed in millivolts (mV). The EMG from the three leg extensor muscles were averaged because of the great similarity in their activity pattern (7). The EMG analysis was performed only for the MS and FS groups during the entire training session period and also during leg extensor evaluation.

## Hormonal Measurements

After 12 h of fasting and 1 d of rest, blood samples were drawn at 8:00 a.m. from the antecubital vein before and immediately after the training from all subjects. Serum samples for the hormone determinations were kept frozen at $-20°C$ until assayed. The assays of serum total testosterone (T), cortisol (C), luteinizing hormone (LH), were performed by radioimmunoassays (RIA) using reagent kits from Diagnostic Products Corporation (Los Angeles, CA). Serum prolactin (PRL) and growth hormone (hGH) were measured using RIA reagent kits (Radium, Pomezia, Italy). All samples from each tested subject were analyzed in the RIA counter (COBRA 5005, Packard Instruments Co, Meriden, CT). The intra-assay coefficient of variation for duplicate samples were 3.5% for T, 5.6% for C, 3.5% for LH, 4.9% for PRL, and 2% for hGH. Serum T was analyzed for all five groups studied; in addition, serum hGH was measured for BB, WLL, and WLH. In both groups of MS and FS we also analyzed serum PRL and LH hormones.

## Heavy Training Resistance Protocol

The subjects used different heavy training resistance protocols. The athletes belonging to MS and FS groups performed six series (a total of 16 repetitions were performed for each series: 6 + 6 + 4, rest 3 min). The BB performed 12 series with 8–12 repetitions for each series. The WLL performed 10 series with 2–3 repetitions per series. The WLH performed a total of 20 series with 2–4 repetitions for each series. The training sessions for all groups were performed from 10:00 a.m. to 12:30 p.m. In the present training protocol, the intensity of the work performed was not represented by the magnitude of the load used (% of 1RM) since the speed of the performance was continuously measured. The mechanical power output, developed during each
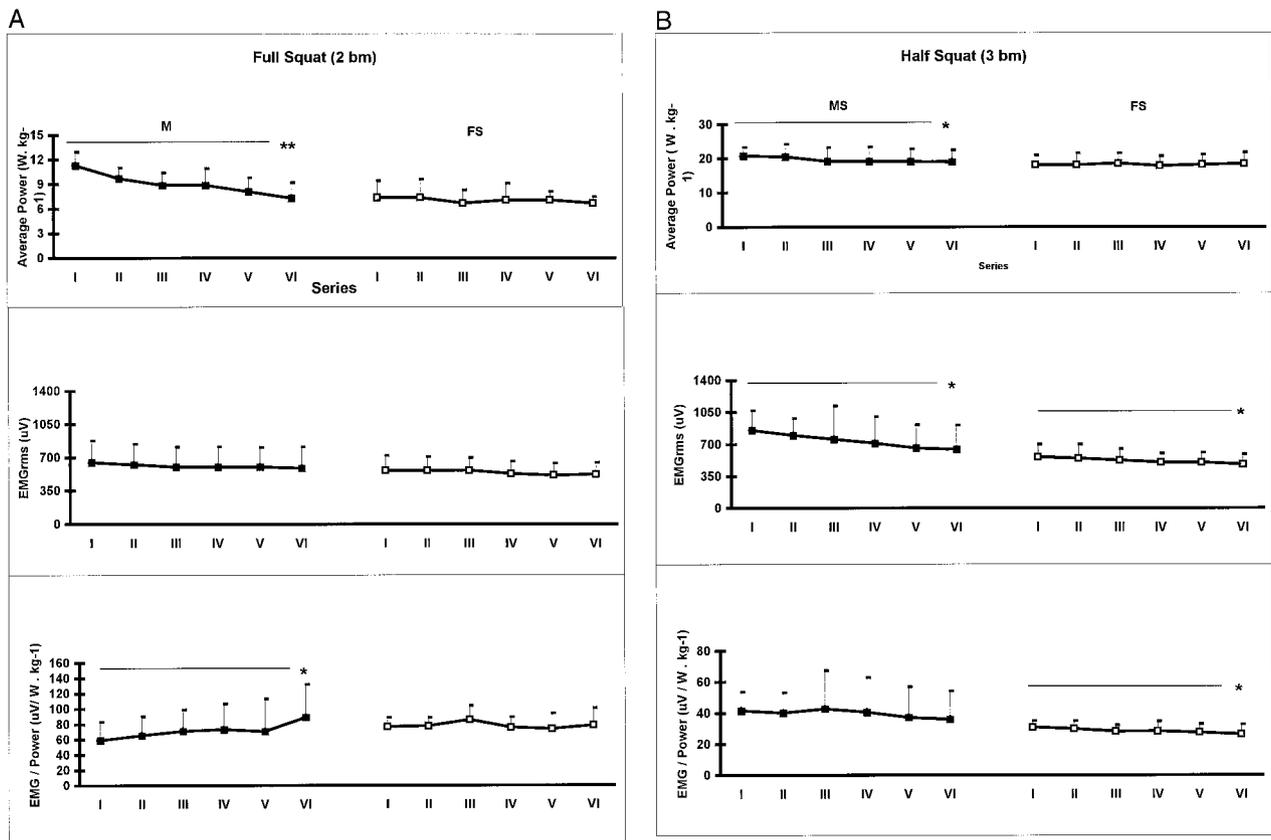
Figure 1—A) Mean (± SD) values for average mechanical power developed during full squat performed with a total load of 2 × body mass, and B) half squat performed with a total load of 3 × body mass, recorded at beginning of each training series in both male (MS) and female (FS) sprinters. Electromyographic recordings of leg extensor muscles and EMG/Power ratio are also shown. The asterisks denote statistically significant changes (ANOVA and Sheffè's test, * $P < 0.05$; ** $P < 0.01$).

repetition by the leg extensor muscles, could be calculated. Therefore, a more complete function of the muscular behavior could be monitored, and thus it was possible to control the intensity of the muscular effort. For detail of volume and intensity see Table 1.

**Reproducibility of the measurements.** The half squat exercises reproducibility yielded a correlation coefficient of r = 0.95 average power (P) (4).

**Statistical analysis.** Ordinary statistical methods were employed, including means ± SD. The Pearson Product Moment correlation coefficient (r) was also used. To determine the possible differences between men and women, Student's $t$-test for unpaired observations were used. Differences between the selected mean values before and after the training period were tested for significance by Student's $t$-test for paired observations. Analysis of variance and the Scheffe $post$-$hoc$ test were employed to detect differences among means for each variable, measured during each series of training. The probability level was set $a$ $priori$ at $P < 0.05$ to determine statistically significant differences.

## RESULTS

### Neuromuscular Behavior

In MS the training session led to a decrease in the average power output developed in full squat test by 55% ($P <$

0.01), while no changes were noted in FS (Fig. 1A). The electromyography activities of leg extensor muscles detected during the same performance demonstrated no statistically significant changes after the training session in both FS and MS. Consequently, the EMG/Power ratio increased in both FS and MS, although only in the latter group a statistical significant difference was obtained ($P < 0.05$). The average power output calculated before and after the training session when the half squat test was analyzed demonstrated a 10% decrease in MS while no changes were noted in FS (Fig. 1B). On the other hand, the EMG values were significantly lower ($P < 0.05$) after training in both groups. Thus the EMG/Power ratio calculated in the half squat test decreased in both MS and FS, although a significant difference was reached only in FS ($P < 0.05$; Fig. 1B).

Continuous monitoring of neuromuscular behavior was monitored for the first 50 repetitions in BB. After 50 repetitions, although no statistically significant changes could be observed, a decrease in mean power output during half squat exercises was noted. In contrast, the EMG activity demonstrated a remarkable enhancement (25%), reaching a statistically significant level of $P < 0.01$ after 50 repetitions. Consequently, the EMG/Power ratio during half squat exercises showed a statistically significant enhancement ($P < 0.01$).
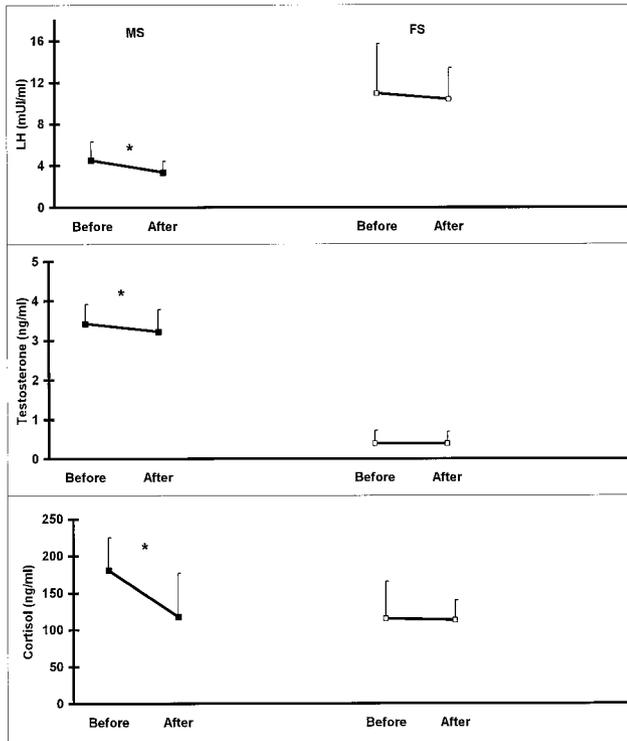
**Figure 2—Mean (± SD) values for serum luteininzing hormone (LH), test osterone (*t*), and cortisol (C) concentrations for male (MS) and female (FS) sprinters collected before and immediately after the training session. The asterisks denote statistically significant changes (Student's *t*-test, paired observations, * $P < 0.05$).**

## Hormonal Profile

In MS immediately after the session, the levels of C, T, and LH were significantly lower ($P < 0.05$) than before (Fig. 2), while modest insignificant changes were noted for PRL. In FS, after the training session the levels of T, C, LH, and PRL showed no statistically significant changes. Decreases in C and T concentrations were correlated only for the MS and FS (r = 0.59; $P < 0.05$). In both groups a significant negative correlation was found between changes in T level and in EMG/Power ratio during half squat performance (r = −0.61; $P < 0.05$) (Table 2).

In WLH the heavy resistance training did not result in a statistically significant change of hGH level, but it did cause an increase of T concentrations (from 2.56 ± 1.03 to 3.65 ± 0.66; $P < 0.01$). In contrast in WLL the levels of T and hGH were not affected by the training session. In BB the levels of serum T and hGH decreased ($P < 0.001$) and increased ($P < 0.05$) after the training period. The changes in the EMG/Power ratio during half squat evaluation demonstrated a positive relationship with the decrease of T caused by the training session in BB (Fig. 3).

## DISCUSSION

The classic heavy strength training in both male and female athletes is known to induce an acute fatigue in the neuromuscular function (18). The magnitude of the neuromuscular perturbation has been shown to be related to

volume, percent of maximal load, type of exercise, and the rest period between contractions as well as to the training curriculum of the athletes (16,18). Surprising, the results of the present investigations suggest that the effect induced by a single strength training session on male sprinters was completely different than the effect on their female counterparts. At the end of the session only men were strongly affected by the fatigue induced by the work performed, whereas the women showed lower neuromuscular impairment. In fact, a remarkable decrease was noted only for MS after the session for the mean mechanical power developed during half squat and full squat test ($P < 0.05$). In contrast, in FS the mechanical behavior of the leg extensor muscles remained unaltered after the training load. It should be pointed out that the electromyogram recorded in both sprinter groups revealed a substantial perturbation of neural behavior during half squat test, while no significant changes could be noted in full squat performances. The decrease in neural activity after the training session observed in both groups during the half squat tests might suggest that at the beginning of the training this type of exercise could be carried out mainly by the recruitment of phasic motor units. As the training continued, it is probable that at the end of the session the intervention of the tonic motor units, which possess low action potential (13), might have played an important role in carrying out the work. It has been demonstrated that the intramuscular recordings of evoked potentials of the gastrocnemius muscles showed greater reduction in amplitude and conduction time than the soleus muscle during simulated maximal contractions induced by supramaximal higher frequency stimulation (22). Furthermore, the extent of the reduction in motor unit activation was also dependent on muscle fibers, which accounted for the reduction in amplitude frequency components of the surface EMG (23). Therefore, it is reasonable to assume that the significant decrease of the mechanical power observed during the half squat test could in large part be accounted for by the progressive reduction activity of phasic motor units to minimize fatigue by avoiding neuromuscular transmission failure (2,22). In contrast, the changes observed after the training in the full squat exercise test are likely to have been caused by fatigue, which has been known to occur in a different biological structure. In this case it is likely that the effect of fatigue might have been localized at a peripheral level more than at the central level. This notion is supported by the fact that the decrease in mechanical power was not associated with a decrease in neural activity. In fact, the relationship between the EMG and the mechanical power (neuromuscular efficiency) showed that more neural energy was needed for the development of certain magnitude of mechanical power (Fig. 1A). These observations suggest that full squat exercises could be carried out mainly by the recruitment of tonic motor units which possess low action potential (13). Furthermore, the effect of fatigue induced by the training session may account for the accumulation of lactic acid inside the muscle cells with a corresponding decrease in pH level. Depression in $Ca^{2+}$ transport after fatiguing exercises may have resulted in reduced contractile

TABLE 2. Correlation matrix in neuromuscular parameters and serum hormones concentrations induced by one heavy resistance exercise session (r > 0.56; $P < 0.05$; $N = 12$).

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 1 | Full Squat (W) | 1 | | | | | | |
| 2 | Full Squat (EMG/W) | −0.88 | 2 | | | | | |
| 3 | Half Squat (W) | 0.37 | −0.56 | 3 | | | | |
| 4 | Half Squat (EMG/W) | −0.19 | 0.42 | −0.64 | 4 | | | |
| 5 | T | 0.29 | −0.23 | 0.27 | −0.61 | 5 | | |
| 6 | C | 0.33 | −0.09 | −0.05 | −0.06 | 0.59 | 6 | |
| 7 | PRL | −0.33 | 0.06 | 0.13 | −0.34 | 0.30 | 0.15 | 7 |
| 8 | LH | −0.07 | 0.25 | −0.03 | 0.20 | 0.23 | 0.18 | 0.15 |

characteristics (25), including impaired excitation-contraction coupling such that less force is generated for each individual membrane excitation (12). Therefore, it is likely that full and half squat exercises are influenced by the involvement of different muscle fiber population. Indirect evidence supports this notion. Phasic motor units (FT fibers) are able to develop faster contraction, while in slow muscular activity mainly ST fibers are involved. It should be pointed out that the contraction time required to perform half squat exercises was much shorter (518 ± 92 ms) than that required in full squat contractions (1671 ± 263 ms). These observations again support the notion that half squat exercises were performed with high rate of force development since the contraction time was no longer than 500 ms (29). On the other hand, full squat exercises were characterized by a long contraction time; thus it is likely that different muscle type (ST fibers) were involved. Therefore, it can be suggested that fatigue was likely induced by the heavy strength training session and thus induced different effects according to the morphological structure of the muscles involved during each exercise performed. Fatigue in general affects FT fibers more than ST fibers (14). It should be pointed out that the training session in addition to affecting the neuromuscular behavior of the sprinters induced also strong hormonal response.

In MS the strength training session led to depressed activity of pituitary-adrenocortical and pituitary-testicular systems indicated by decreased concentration of C, T, and LH in blood after the training session. Different results were observed in FS subjects since no changes were detected in hormone levels (Fig. 2). Hormonal profile changes during strength training activity in MS and FS were related to neuromuscular performances. We found a negative relationship between the changes in T concentrations and the EMG/Power ratio during half squat test. After the training the decrease in testosterone concentration level required an exaggerated activation to maintain the necessary power output. As discussed earlier, in the half squat the contribution of FT fibers and their fatigue was more pronounced than in full squat exercises. Therefore, the relationship may be connected mainly to the possible influence of T on FT fiber activity. Animal experiments have demonstrated the role of T in maturation of FT fibers (11). Human experiments have resulted in a positive correlation between basal level of T and both sprinting and explosive power performances (6). In addition, both power and work performed during 60-s continuous jumping efforts were positively related to changes in the T levels (5). Previous observations indicated a positive relationship between explosive strength performance and serum T level, both in prepubescent boys (21) and adult sports men (19). These findings have been interpreted to have a positive influence of T on FT fiber development (6,17).

Therefore, if these observations are correct, it can be suggested that an adequate male sex hormone level may compensate for the effect of fatigue by ensuring a better neuromuscular efficiency in FT fibers. We should not exclude the possibility that fatigue may induce a reduction in sensitivity of the contractile elements to $Ca^{2+}$ (28). Testosterone compensates the disorder in the excitation-contraction coupling caused mainly in FT fibers by enhancing $Ca^{2+}$ handling mechanism in the muscle (24). However, it is not clear how T can exert rapid molecular effect in FT fibers during acute effort since various studies have demonstrated physiological effect in the whole body level without any information on the events at molecular level.

The results obtained in BB support the significance of the effect of adequate level of T for an efficient neuromuscular function. The relationship shown in Figure 3 demonstrates that decrease in male sex hormone during may induce higher EMG activity to keep the same muscle power output developed in normal conditions.

Comparing the results obtained in the WLH group with those found in the BB group, we suggest the importance of the content of the training program. WLH were characterized by a statistically significant enhancement of the serum T induced by the training session. The same athletes demonstrated nonsignificant changes in hGH. In contrast, BB exhibited a dramatic decrease in the male sex hormone and a remarkable enhancement of hGH after the training session. Although the hormonal changes were opposite, the actual
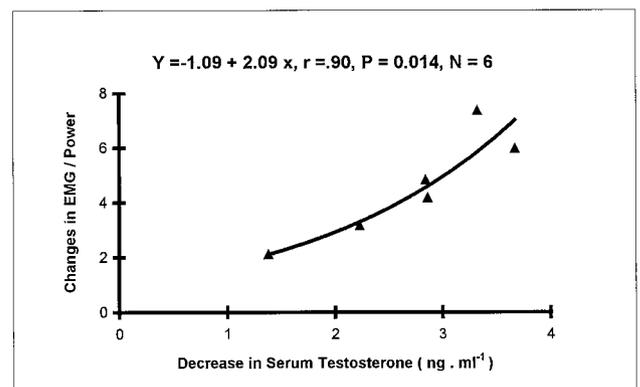


Figure 3—Relationship between the changes in EMG/Power ratio, registered during half squat exercises performed by body builders and the decrease of serum testosterone found after the training session.
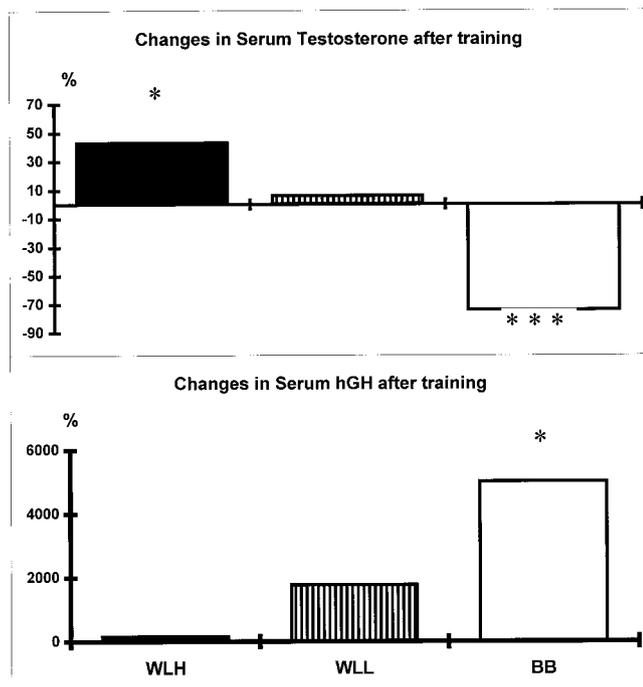
**Figure 4—Mean relative changes in serum testosterone and growth hormone in response to strength training session observed in weight lifters performing high repetitions exercises (WLH), weight lifters performing low repetitions exercises (WLL), and body builders (BB). The asterisks denote statistical significant changes (Student's $t$-test, paired observations * $P < 0.05$, *** $P < 0.001$).**

magnitude of the loads were almost the same (approximately 60–70% of 1RM, Table 1). However, the volume of work performed by the BB group was double that executed by the WLH group. The intensity (muscle power output) of the work performed by WLH was remarkable greater than that developed by BB (100% vs 70% for WLH and BB). Therefore, whenever heavy resistance loads are used (60–100% 1RM), it is likely that the hormonal responses reflect the magnitude of the power developed when the same work volume is executed. Thus, when high power (90–100%) output is developed during each repetition, the level of serum T may increase, while hGH increases mainly with a large number of repetitions developed at moderate power (70% of the maximum power developed with that load). Different responses in hGH have been obtained with changing only the rest periods between the training series and keeping the total volume constant (20). High work volume may cause also a strong inhibition of the T (Fig. 4). In this case the situation resembles those found in prolonged endurance exercises (9).

It should be noted that hormonal response is not only caused by the magnitude of the load or the intensity of the work performed. The volume developed during the training session seems to play an important role. Comparing the hormonal changes that occurred in WHL with those found in WLL, only in the former group was an enhancement in T noted. Athletes belonging to WLL demonstrated no statistically significant changes in hormonal profile. Therefore, it can be suggested that to induce hormonal response it is necessary that a large number of repetitions be performed. The 25 repetitions performed by WLL were not enough to stimulate hormonal response.

In regard to hormonal regulation during fatigue, a depressed level in T secretion may be induced by excessive low or high circulating level of PRL (1), high level of C, or in elevated opioid peptide levels (8). None of these explanations can completely account for the decrease in the level of T found in MS and BB. Indeed, PRL level did not change significantly, while the changes in C were positively related to T (r = 0.50, $P < 0.05$, Table 2). Since production of $\beta$-endorphin and corticotropin in adenohypophysis is stimulated by the same neurohormone (corticotropin releasing factor) and both originate from the same precursor (propiomelanocortin), we should not conclude that there is an association between high level of $\beta$-endorphin and low level of C in the blood.

It is possible that there is hormonal action conducted by the Leyding cells; however, we need to address the decrease in LH concentration. Old evidence suggested that the reduction in adrenocortical function in fatigue is related to inhibitory influence from the hippocampus to neurosecretory cells producing corticotropin realizing factor (30). Similarly it is possible to assume the central inhibition of gonadotropic function and thereby the reduction in T secretion during fatigue.

In conclusion, the effect of fatigue may induce different responses on neuromuscular behavior and hormonal system activity. Therefore, the parallel reduction in pituitary-adrenocortical and pituitary-testicular system should be emphasized. In addition, it is likely that an adequate level of T may favor neuromuscular efficiency specifically in the FT fiber type.

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