

## The effect of short-term strength training on human skeletal muscle: the importance of physiologically elevated hormone levels

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The effect of strength training and endogenously elevated hormone levels (plasma testosterone, growth hormone (GH) and cortisol) was studied in 16 young untrained males, divided into an arm only training group, A, and a leg plus arm training group, LA, in order to increase circulating levels of anabolic hormones. Both groups performed the same one-sided arm training for 9 weeks, twice a week. Group A trained only one arm (AT), the contralateral arm serving as control (AC), whereas group LA additionally trained their legs following the training of the one arm (LAT), with the contralateral arm serving as control (LAC). In spite of the attempt to match the two groups, the initial isometric arm strength was 20–25% lower for group LA compared to group A (significant for the arm to be trained). Isometric strength increased significantly in LAT and LAC by 37% and 10%, respectively, while the 9% and 2% increases in AT and AC, respectively, remained insignificant. Isokinetic strength increased at

one out of three velocities tested for the trained arm relative to the untrained arm in both group A and group LA ( $P < 0.05$ ). Functional strength increased significantly by 20% in LAT, 18% in LAC, 19% in AT, and 17% in AC. Hormonal responses were monitored during the first and last training sessions. Resting hormone levels remained unchanged for both groups. However, during the first training session plasma testosterone as well as plasma cortisol increased significantly in group LA but not in group A. Plasma GH rose in all exercise tests, except during the last test in group LA, but was significantly higher in group LA than in group A in the first training session. In conclusion, a larger relative increase in isometric strength was found in the group having the highest hormonal response. However, due to the initial difference in isometric strength caution must be taken with the interpretation of this finding, which may only indicate a possible link between anabolic hormones and muscle strength with training.

Strength training leads to neural and morphological adaptations that may lead to increased strength and hypertrophy with specific time patterns. Neural factors may play a role beyond that of hormones, especially in early phase adaptations, but the specific mechanisms and the interaction between strength training, levels of circulating hormones, receptor binding, hypertrophy and increased strength still needs to be examined. The majority of studies with young men show that the circulating concentrations of anabolic hormones as well as catabolic hormones such as cortisol acutely increase during strength training (Kraemer et al., 1990, 1995; Häkkinen & Pakarinen, 1993). Furthermore, strength training may lead to changes in the concentrations of testosterone and cortisol also at rest (Staron et al., 1994; Kraemer et al., 1998). It has been observed that the type of strength training protocols influences the magnitude of hormonal responses, especially that of growth hormone (GH). Protocols using moderate to heavy resistance, but multiple sets of 10–12 repetition

maximum (RM) and shorter rest periods (1–2 min of rest between sets and exercise) have been shown to produce higher concentrations of both anabolic and catabolic hormones than during heavier resistance (1–5 RM), longer rest periods (>3 min), and fewer sets (1–3). Furthermore, it has been demonstrated that the magnitude of the hormonal responses is proportional to the size of the muscle volume activated relative to the intensity (Kraemer et al., 1990, 1991, 1993, 1996b; Fleck & Kraemer, 1997; Häkkinen & Pakarinen, 1993). Also, a larger amount of total work has been shown to produce significantly greater increases in hormonal responses compared to strength training protocols with a smaller amount of total work (Gotshalk et al., 1997).

Testosterone and GH are known to be involved in the anabolic processes in the muscle cell and therefore hypertrophy may be stimulated by these hormones (Kraemer et al., 1996a, 1996b). In this context MacDougall et al. (1995) observed elevated protein synthesis in the trained muscle up to 36 h after com-

pletion of strength training. Furthermore, studies with supraphysiological doses of testosterone have documented the anabolic effect on muscle tissue, although the anabolic effect of GH shows equivocal results (Bhasin et al., 1996; Thomis et al., 1998; Yarasbeski et al., 1993a). Finally, strength gains and hypertrophy of small muscle groups have been observed in studies where the acute anabolic hormonal response might have been insignificant (Moss et al., 1997; Thomis et al., 1998).

Against this background, the hypothesis was that strength training with a high acute hormonal response and possible increases in resting levels would lead to a larger increase in muscle strength than strength training with a minor hormonal response and unchanged resting levels. Thus, the aim of this study was to investigate the consequence of hormonal stimuli for muscle adaptation to strength training of the arm muscle, *m. biceps brachii*, by manipulating endogenous hormone levels in half of the subjects performing additional leg exercise.

## Material and methods

### Subjects

Sixteen young untrained men volunteered after written informed consent to participate in the study which was approved by the local Ethics Committee. To follow the Ethical Instructions, the subjects' health was examined before the testing procedure started and no subjects disqualified due to the exclusion criteria – hypertension, angina pectoris, lower back disorders, prescribed heart or lung medicine, and trauma to any part of the body.

The subjects were divided into two groups: an arm training group, A, and a leg and arm training group, LA, both of which trained one-sided *m. biceps brachii* (AT and LAT), using exactly the same protocol. In both groups, the untrained arm served as control (AC and LAC). The two groups were carefully matched with regard to age, height, weight, and arm strength according to a functional 1 RM test. The dominant or non-dominant arm was randomly chosen to be trained or to serve as control. Unfortunately, two subjects dropped out from the LA group, one after the first test series (due to leaving the country) and one just prior to the last tests (due to a traffic accident). Therefore, most of the data presented is for  $n=8$  in group A and  $n=6$  in group LA. In a few relevant cases data from all subjects were included, and in a few cases there were some missing data for one subject in group A. Thus, for some mean values  $n$  may deviate from 8 and 6, respectively, which is specified whenever this is the case.

The initial mean ( $\pm$ SD) for group A ( $n=8$ ) was: age 24.4 ( $\pm 3.1$ ) years, height 1.81 ( $\pm 0.04$ ) m, body mass 78.2 ( $\pm 8.0$ ) kg, Pre 1 RM strength for AT 17.9 ( $\pm 2.5$ ) kg and for AC 17.3 ( $\pm 2.0$ ) kg. The correspondingly values for group LA ( $n=6$ ) were: age 23.3 ( $\pm 4.6$ ) years, height 1.79 ( $\pm 0.08$ ) m, body mass 81.1 ( $\pm 25.2$ ) kg, Pre 1 RM strength LAT 17.3 ( $\pm 1.5$ ) kg and LAC 17.2 ( $\pm 1.6$ ) kg. Two of the subjects were familiar with strength training but in general none had practised or were currently practising strength training.

### Procedure

The 1st week hormonal response and isometric, isokinetic and functional strength were tested. Throughout the 2nd to 9th

weeks subjects trained twice a week and there was an additional training session in the 1st and 10th weeks. Also, the subjects were tested for isometric strength in the 5th week (Mid) and functional strength every 4th training session. In the 10th week the procedure from the 1st week was repeated. Both arms of the subjects were strength tested using the 3 different strength tests on separate days. Before testing the subjects warmed up with 3 sets with 10 repetitions of double-handed biceps curl with a lever of 11 kg.

The hormonal response was analysed from blood plasma samples taken during the first (Pre) and last (Post) strength training session of the 9 week training period described above. In both of these training sessions 5 blood samples were obtained: resting level after 15 min of rest (T-rest), immediately after the strength training session (T-0) and subsequent samples at 15, 30 and 60 min after training (T-15, T-30, T-60). The blood samples (T-0, T-15, T-30, and T-60) were obtained after different exercise durations as group A trained for 20–25 min whereas group LA trained for 40–45 min in all because of the extra leg training. On the testing days including blood samples the subjects arrived after an overnight fast where they were allowed only to drink water. The blood samples were taken in the time interval from 09:00 to 13:30. Thus, blood samples were obtained at different times during the day among subjects but at the same time of the day for each subject (within a 2 h window) during the experiment to limit the influence of any diurnal variations.

### Hormonal analysis

Blood samples were analysed using immunoradiometric assays for: Testosterone (REF: CA-1558, DiaSorin, Stillwater, Minnesota 5582-0285, U.S.A., Clinical Assays – GammaCoat), Human Growth Hormone (immunoradiometric assay, Euro-Diagnostica B.V., P.O. Box 5005, NL 6802 EA Arnhem, Clinical Assays – GammaCoat) and Cortisol (REF: CA-1529, CA-1549, DiaSorin, Stillwater, Minnesota 55082-0285, U.S.A.). All blood parameters were determined by duplicate analysis. Inter- and intra-assay coefficient of variances were 9.0% and 6.0% for plasma testosterone, 5.9% and 2.2% for plasma GH and 6.0% and 4.0% for plasma cortisol.

### Training programme

The subjects were all familiarised with the exercises before start and all training sessions were individual supervised. They trained twice a week from 10:00 to 12:00, Monday and Thursday, for 9 weeks and both group A and group LA trained one-sided *m. biceps brachii* according to exactly the same protocol. To stimulate higher plasma hormonal levels after arm training, group LA in addition trained their legs immediately after the arm training. The training protocol was composed on the basis of earlier research previously outlined to match former studies and to achieve a dramatic hormonal response.

*Arm training protocol:* Two sets of seated biceps curl at 60% of 1 RM were followed by 2 sets of seated biceps curl at 60% of 1 RM–1 kg, 2 sets of standing biceps curl at 60% of 1 RM–2 kg and 2 sets of standing biceps curl at 60% of 1 RM–3 kg. A total of 8–12 repetitions were performed in each set with a 1½ min rest between sets. The range of motion for the concentric part was from fully extended to 145–155° flexed and mean velocities for one repetition including concentric and eccentric motion were in the order of 100–150°/s with the fastest repetitions in the beginning of the set and slowing down as the muscle fatigued.

*Leg training protocol:* Two sets of seated leg press at 10 RM were followed by 2 sets of seated leg press at 10 RM–10 kg, 2 sets of seated leg press at 10 RM–20 kg, 2 sets of seated leg press at 10 RM–30 kg. A total of 8–12 repetitions were per-

formed in each set with 1 min rest between sets. The range of motion for the concentric part was from 90–100° flexed to fully extended and mean velocities for one repetition including concentric and eccentric motion was in the order of 80–120°/s with the fastest repetitions in the beginning of the set and slowing down as the muscle fatigued.

The load for the arm training was adjusted every fourth training session based on a 1 RM test. If no gain in arm strength had occurred, the same 1 RM was used again. The load for the leg training was correspondingly adjusted every fourth training session by a 10 RM test. The reason for the design of the arm and leg protocol with the continuous decrease in load within the same training session was that the subjects should maintain a 10–12 RM load (60–65% of 1 RM×10–12 repetitions) for each set throughout the training session.

### Strength tests

Subjects refrained from ingestion of alcohol and caffeine for 24 h before isometric and isokinetic strength tests. The subjects did not train for two days after a strength training session, before the isometric and isokinetic tests and for one day between these tests, to make sure the muscles were recovered. Isometric strength was measured with a Darcus Dynamometer. The elbow was fixed in a position of 120°. Three maximal isometric contractions with 1 min of recovery between trials were conducted, and the largest value was recorded.

Isokinetic strength was measured with a Cybex II Isokinetic Dynamometer, at three different angular velocities: 22°/s, 85°/s and 170°/s. After three maximal dynamic contractions at each velocity with 1 min of recovery between each attempt the best result for each angular velocity was recorded.

Functional strength was tested by a functional 1 RM test, where the subjects performed biceps curl in a standing position. The test was performed before a strength training session and after warm-up by 5 min of cycling and 3 sets of 10 repetitions of biceps curl with a lever of 10 kg. The 1 RM was achieved when the weight was lifted from the vertical position and until the elbow was fully flexed without any rotation of the forearm or any compensating movements from the body. Two attempts were allowed with each 1 RM test, which was re-tested every 4th training session, 5 times in all. The 1 RM test was also done for both the trained and untrained arm.

### Statistics

The Mann-Whitney U test was used for non-paired inter-group comparison, and the Wilcoxon Signed Rank Test for paired samples was used for paired intra-group comparison. The Friedman test was used for multiple paired inter-group comparison. Statistical analyses is based on Kirkwood (1988) and Stat View 5.0, SAS Institute INC. Statistical significance was set at  $P < 0.05$  in all tests.

## Results

Isometric strength in the LA group increased significantly for the trained arm, LAT, from  $45.4 \pm 6.2$  Nm to  $62.2 \pm 8.3$  Nm,  $n = 6$ , ( $P < 0.05$ ) after 9 weeks of strength training, while in the A group isometric strength of the trained arm, AT, did not increase significantly (from  $61.7 \pm 12.5$  Nm to  $67.0 \pm 10.6$  Nm,  $n = 7$ ). More details showing the relative changes, including changes after 5 weeks of training, are given in Fig. 1. In spite of the attempt to match the groups, the difference between the Pre values for AT and LAT

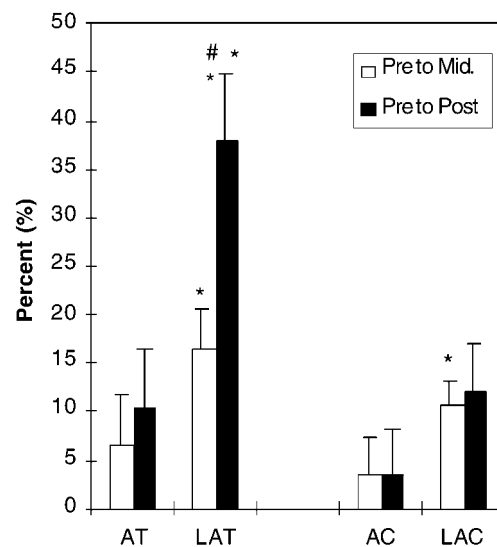


Fig. 1. Isometric strength. Changes in proportion to initial level in isometric strength for the trained arms (AT and LAT) and control arms (AC and LAC) in the groups A ( $n = 7$ ) and LA ( $n = 6$ ) respectively (mean  $\pm$  SEM). \*Significant increase from Pre to Mid and Pre to Post, respectively, #Significantly different from percentage increase in AT, Pre to Post,  $P < 0.05$ .

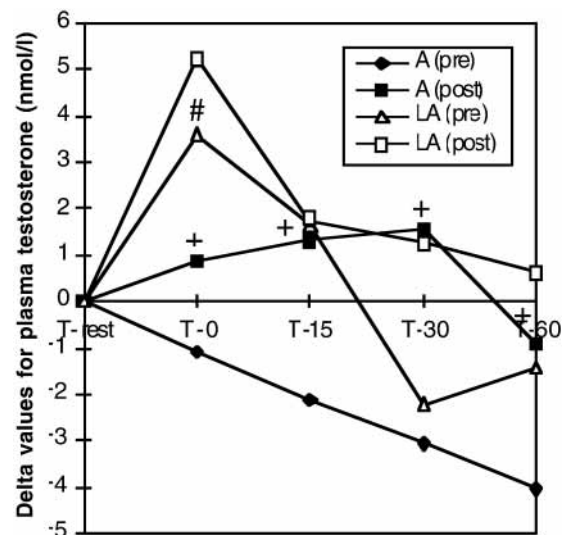


Fig. 2. Plasma testosterone. Delta values for testosterone measured in plasma Pre and Post the strength training period in group A ( $n = 8$ ) and LA (Pre,  $n = 8$ , Post,  $n = 6$ ). For ( $\pm$ SD) see Table 2. +Significant difference between Pre and Post in A. #Significantly different from the T-rest value,  $P < 0.05$ .

were significant ( $P < 0.05$ ), probably due to the drop outs. Isometric strength increased significantly in the LA group's control arm, LAC ( $52.7 \pm 8.0$  Nm to  $58.1 \pm 9.1$  Nm,  $n = 6$ ) after 5 weeks of strength training, whereas no increases were found in the A group's control arm, AC ( $65.0 \pm 11.8$  Nm to  $66.5 \pm 8.0$ ,  $n = 7$ ). Only in the LA group was there a significant increase in isometric strength, calculated as the delta value be-

Table 1. Pre and Post values for dynamic strength

Angular velocity (° s <sup>-1</sup> )	Peak torque, Nm				Peak torque, Nm			
	Pre		Post		Pre		Post	
	AT	AC	AT	AC	LAT	LAC	LAT	LAC
22	54.1±18.7	62.3±18.3	61.0±19.1	56.7±16.2*	48.5±8.8	55.2±14.4	52.9±11.6	50.2±13.2*
85	45.9±12.1	53.4±14.5	47.5±8.4	52.0±17.9	39.8±8.1	47.5±9.2	43.3±9.1	44.4±8.8*
170	38.9±10.7	43.3±9.2	36.4±10.1	37.0±12.9	30.7±8.3	35.7±6.7	35.8±3.6	33.1±6.8*
	(kg)				(kg)			
1 RM	17.9±2.5	17.3±2.0	21.3±2.4*	20.3±2.0*	17.3±1.5	17.2±1.6	20.7±1.0*	20.3±2.4*

Isokinetic strength for group A, n=8, and LA, n=6, (±SD). Functional strength (1 RM) for group A, n=8, and LA, n=7, (±SD). \*Significantly different from the corresponding Pre value, P<0.05.

tween the LAT and the LAC from Pre to Post of the 9 week training period (P<0.05).

Isokinetic strength did not increase significantly in the trained arms, AT and LAT (Table 1), although there was a significant increase in isokinetic strength, calculated as the delta value between the trained and control arm from Pre to Post of the 9 week training period at 170°/s in group A and at 22°/s in the LA group.

The functional strength for both AT, AC, LAT and LAC showed significant improvements in response to training (Table 1). There was no significant difference in functional strength in the delta value between the trained and untrained arm for the first 1 RM test compared with the delta value between the trained and untrained arm for the last 1 RM test in either group A or group LA.

The hormone levels at rest did not show any significant differences between groups and neither between Pre and Post training (Table 2). However, significant hormonal responses were seen during and after training sessions, which are presented as delta values between rest and exercise in Fig. 2, 3 and 4. Only group LA showed a significant acute hormonal

Table 2. Mean resting values for plasma testosterone, growth hormone and cortisol (±SD)

	Mean resting values Pre	Mean resting values Post
Testosterone (nmol/l)		
Group A	24.1±6.4	28.7±11.6
Group LA	22.1±13.3	21.8±11.4
Growth hormone (µg/l)		
Group A	0.9±2.3	0.1±0.04
Group LA	0.2±0.2	0.6±1.0
Cortisol (nmol/l)		
Group A	412.5±93.6	320.7±103.2
Group LA	370.1±116.5	341.2±107.7

For all Pre values and group A Post values, n=8. For group LA Post values, n=6.

response in plasma testosterone during the Pre test (P<0.05) and a tendency during the Post test (P=0.07) (Fig. 2). Plasma GH rose in all exercise tests, except during the Post test in group LA, which only showed a tendency to increase (P<0.1). The increases for plasma GH in group LA were significantly larger than the increases in group A during the Pre test (Fig. 3). Only group LA showed a significant acute hormonal response in terms of an increase in plasma cortisol during the Pre test (Fig. 4). In contrast, group A showed a decrease during both Pre and Post tests.

Discussion

The main finding of the present study is that there is a larger relative increase in isometric strength when

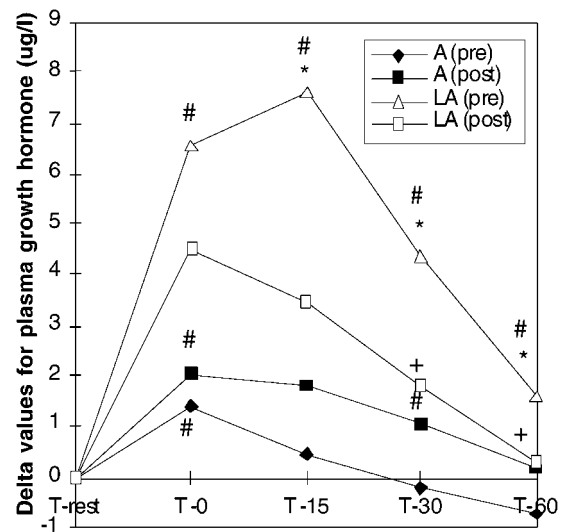


Fig. 3. Plasma growth hormone. Delta values for growth hormone measured in plasma Pre and Post the strength training period in group A (n=8) and LA (Pre, n=8, Post, n=6). For (±SD) see Table 2. +Significant difference between Pre and Post in group LA. \*Significant difference between group A (Pre) and LA (Pre). #Significantly different from the T-rest value, P<0.05.



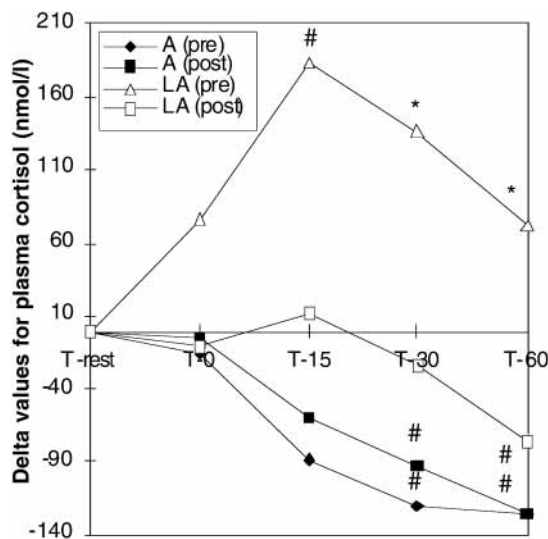


Fig. 4. Plasma cortisol. Delta values for cortisol measured in plasma Pre and Post the strength training period in group A ( $n=8$ ) and LA (Pre,  $n=8$ , Post,  $n=6$ ). For ( $\pm$ SD) see Table 2. \*Significant difference between group A (Pre) and LA (Pre). #Significantly different from the T-rest value,  $P<0.05$ .

anabolic hormonal responses are enhanced by training a larger muscle group additional to strength training of the arms. This indicates a link between the magnitude of hormonal responses and strength improvement, occurring within hormonal levels that can be activated physiologically. The magnitude of the strength increments in the isometric and functional strength tests after the 9 week period were in good agreement with the findings of previous research with comparable strength training protocols and duration (McCall et al., 1999; Coyle et al., 1981; Kaneko et al., 1983; Moss et al., 1997). Concerning isokinetic strength, some increases were seen between trained versus control arm from before to after training. However, the larger variability in this data set does not allow to be fully conclusive.

In the present study acute hormonal responses were higher for plasma testosterone, GH and cortisol when leg training, was added to the arm training compared to arm training only. Other investigations that tested the acute hormonal response to leg training with similar protocols have demonstrated the same pattern of response (Häkkinen & Pakarinen, 1993; Kraemer et al., 1998). In our study no increase in resting levels of hormones was documented during the 9 weeks of strength training. To our knowledge, the resting level of GH in general does not change in relation to such short periods of strength training (Kraemer et al., 1998; Staron et al., 1994; Komi, 1996) and unaltered resting levels of testosterone and cortisol after a training period have previously been observed (Häkkinen et al., 1988, 1989; Kraemer et al., 1995).

The aim of the study was to investigate the consequence of hormonal stimuli for muscle adaptation to short-term strength training of the m. biceps brachii. In this context the significant elevations in plasma concentrations of testosterone and GH in group LA and the minor but significant elevation in GH in group A could mediate an anabolic phase after each strength training session. The acute elevation in plasma concentrations of these anabolic hormones, however, only exposes the muscle tissue for a relatively short period of time. Whether this results in a stimulation of contractile proteins is unknown, but interaction between hormones and muscle cell receptors could in theory have an effect in the subsequent phase of recovery and stimulate hypertrophy through increased protein synthesis (Kraemer et al., 1990; Häkkinen & Pakarinen, 1993; Kadi, 2000). This may explain the increased protein synthesis which has been observed in the stimulated muscle in the hours after strength training (Yarasheski et al., 1993b; MacDougall et al., 1995; Kadi, 2000). Changes in the muscle cell receptors for testosterone and GH have also been shown to affect hypertrophy. Inoue et al. (1993) observed that the muscle cell receptors for testosterone and GH increased 25% after three days of training by electrical stimulation in rats. In another study, Inoue et al. (1994) observed that the increase in muscle mass induced by electrical stimulation was effectively suppressed in the group of rats given an androgen receptor blockade.

McCall et al. (1999) have demonstrated a correlation between changes in acute exercise induced GH concentrations and hypertrophy of type I and II muscle fibres in a 12 week strength training period. Testosterone has also been associated with early phase adaptations to strength training. Staron et al. (1994) connected transformations in muscle fibre type and increases in strength to increases in serum testosterone and decreases in serum cortisol. Thus, it may be reasonable to consider a link between training induced anabolic hormones and increased protein synthesis, and thereby increased strength.

These adaptations coincide with early neural adaptations of the trained muscles (Moritani & de Vries, 1979; Sale, 1988). Early neural adaptations accompanying short-term strength training are at the same time influenced by the anabolic hormones, especially testosterone (Kraemer et al., 1998, 1999). The initial increase in strength in groups A and LA, illustrated by significant improvements from the 1st to the 3rd 1 RM tests, may be caused by neural factors. A second finding that can be attributed to neural factors concern are the control arms (AC and LAC), which show nearly as large improvements as AT and LAT in the functional strength test. This phenomenon is known as the contralateral effect (Cannon & Cafarelli, 1987; Ploutz et al., 1994). The more pronounced contra-

lateral effect in the functional strength test compared with the isometric strength test may be explained by training specificity. The neural factors have pronounced effect on contralateral muscle but with only little or no transfer from the legs to the arms. However, theoretically, it cannot be excluded that the leg training in group LA could influence the arm strength. In line with this, intensive training over a longer period of time may cause the inhibitory feedback from the Ib afferent nerves to be reduced – modulated via central descending pathways (Aagaard et al., 2000). This suggests that the intensive leg training in group LA could influence the arm strength because the reduced inhibitory feedback from the Ib afferent nerves is reduced during the contraction in both LAC and LAT.

The acute hormonal responses in plasma testosterone and GH were larger during the Pre training session compared with the Post training session (see Fig. 2, 3). This indicates that the physical stress was larger in the initial phase of the strength training period although the relative training loads were retained in proportion to the running 1 RM and 10 RM tests throughout the period. The decreased acute response to strength training could be caused by an increased hormone receptor sensitivity in the stimulated muscle (Kjær, 1992). Alternatively, an up-regulation in the number of testosterone and GH receptors in response to exercise has been suggested (Inoue et al., 1993). A smaller acute response could, accordingly, stimulate to a similar degree as before training, and the muscle could have thereby increased its efficiency in relation to anabolism. However, in contrast to this, Kraemer et al. (1998) observed that the magnitude of the acute response in testosterone and GH was larger at the end of the 8 weeks of strength training.

Only in group LA during the Pre test did the acute hormonal response in plasma cortisol increase (see Fig. 4). This could indicate that a certain amount of physical stress is needed to trigger a cortisol response, and that this increase may show a catabolic state and thereby stimulate the protein catabolism (Guyton & Hall, 1996). While there is no sign of changes in the resting level of plasma cortisol and the concentration decreases during the 60 min of recovery, it cannot be excluded that the response reflects the metabolic demands rather than a catabolic phase. The same kind of response in cortisol was seen by Hickson et al. (1990), where cortisol increased significantly in the initial phase of the training period but no acute changes were seen after 3 weeks of training. Hickson et al. (1990) and Häkkinen & Pakarinen (1993) suggest that the temporary elevation in cortisol might be a response to the physiological stress caused by the strength training.

To confirm our hypothesis, it can be discussed

whether the strength training period of 9 weeks is sufficient. If the hypothesis is to be documented it should be possible to register the hormonal effects on the muscle cells also in the 9 week period. This is likely as previous studies have shown that a 10 week strength training period together with administration of supraphysiologic doses of testosterone resulted in significant increases in strength (Bhasin et al., 1996; Kadi, 2000).

In conclusion, the significantly larger relative increase in isometric arm strength found in the leg and arm training group compared with the arm alone training group was related to the larger hormonal responses in the former compared to the latter group. However, one has to be careful with the interpretations, because the two groups did not have the same strength level before the strength training period, and because the dynamic strength data did not support the isometric strength development. Therefore, the present findings may only indicate a link between increase in muscle strength and anabolic hormones, which are within hormonal plasma levels to be reached physiologically by adding the training of extra muscle groups to the regular strength training protocols.

### Perspective

Based on this study, when practising strength training in order to increase strength of the arm muscles, it can be recommended to include training of large muscle groups in order to induce a greater anabolic hormonal response and thereby influence muscle strength to a greater extent. Thus, when using a split-routine during strength training, it may be an advantage to combine smaller muscle groups (arms, shoulders etc.) with larger muscle groups (chest, back, thighs etc.) to optimise the training effect.

Future research with a similar design supplemented with assessment of cross-sectional area of the arms and measuring of IEMG during strength testing pre and post could illustrate the area more precisely. Furthermore, the effect of the hormones on target tissues could be assessed by muscle biopsies analysed for hormone sensitivity, hormone receptors and in addition measure mRNA and cAMP.

**Key words:** m. biceps brachii; isometric, isokinetic and functional strength; plasma testosterone; growth hormone (GH); cortisol.

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