High responders to hypertrophic strength training also tend to lose more muscle mass and strength during detraining than low responders

ABSTRACT

This study investigated differences in individual responses to muscle hypertrophy during strength training and detraining. 10 weeks of resistance training was followed by six weeks of detraining in men (n=24). Bilateral leg press (LP) 1RM and maximal EMGs of vastus lateralis (VL) and medialis (VM), maximal voluntary activation (VA), transcranial magnetic stimulation for corticospinal excitability (CE), cross-sectional area of vastus lateralis (VLCSA), selected serum hormone concentrations were measured before and repeatedly during training and detraining. In the total group VL CSA increased by 10.7 % ($p=0.025$) and LP 1RM 16.3% ($p<0.0001$) after training. The subjects were split into three groups according to increases in VL CSA: High Responders (HR) >15%, (n=10), Medium (MR) 15-4.5% (n=7) and Low (LR) <4.5% (n=7). VL CSA in HR and MR increased statistically significantly from pre to post-training, but not in LR. Only HR increased LP 1RM statistically significantly from pre to post. Maximal EMG activity increased 21.3 % ± 22.9 from pre to post training for the total group ($p=0.009$) and for MR ($p<0.001$). No significant changes occurred in VA and CE or serum hormone concentrations. During detraining HR showed a decrease of -10.5% in VLCSA, while MR and LR did not. None of the subgroups decreased maximal strength during the first three weeks of detraining, while HR showed a slight (by 2.5%) rebound in strength. The present results suggest that strength gains and muscle activation adaptations may take place faster in HR and decrease also faster compared to other subgroups during detraining.

Keywords: strength training, hypertrophy, high and low responders, detraining

INTRODUCTION

Resistance training induces adaptations in the neuromuscular system. However, the magnitude of specific adaptations between individuals varies noticeably. Different responsiveness of human beings was first noted (39) in 1954, when it was found that people with different physiques had different abilities to gain morphological adaptations in response to training. These responses might be affected by gender, age, previous training history, physical activity level, and the endocrine status (13). However, data from the HERITAGE study presents that age, gender, and race have only a minor impact on interindividual differences in training responses. On the other hand, previous training history, environment, and genetic factors might have a greater influence on the magnitude of adaptations (9).

Resistance training has been shown to induce adaptations of various scales (22, 3). In the largest study to date with the total number of 585 subjects, 232 subjects showed increases in the cross-sectional area of trained elbow flexor muscles between 15-25 %, 10 subjects gained over 40 %, and 36 subjects gained less than 5 % (22). There were high ranges in strength gains as well. It can be concluded that there is a large variation between responsiveness to a certain stimulus. Additionally, Ahtiainen et al. found considerable inter-individual variation (n=287) in both muscle size and strength adaptations (3). Some individuals responded favorably by gaining muscle size but not strength, whereas others responded in strength but not size. They also noted that 30 % of subjects were low-responders to lower body hypertrophy, but only 7 % were low-responders to strength adaptations. It is more common to be a low responder to muscle size than muscle strength (3).

Skeletal muscle tissue has extraordinary plasticity and can adapt to variable states of neuromuscular activity. It will readjust to reduced physiological stress during a reduced use

of muscles (35). Detraining is the phase when subjects do not train. During detraining, the decrease in muscle force is explained by both neural and muscular adaptations caused by the inactivity period (24). Häkkinen et al. (25) reported that after 24 weeks of strength training, a 12-week detraining period led to the great decrease in maximal strength, and individual strength decreases correlated with individual decreases in the maximum iEMG of the leg extensor muscles. It seems that beginners may maintain their maximal strength without training up to two or three weeks and that short-term detraining will lead only to minor changes, while prolonged detraining resulted also in muscle atrophy and further decreases in strength (26). Moreover, four weeks of detraining may induce larger declines in muscle power output than in maximal strength after 16 weeks of resistance training (31). After 60 days of unilateral strength training, 40 days of detraining led to decreases in muscle cross-sectional area (CSA), maximal muscle iEMG, and maximum voluntary force with about a similar time course compared to the training period. In addition, the kinetics of changes in CSA, force, and neural drive during training and detraining seem rather similar (36).

Strength-trained men can retain strength and muscle mass during a two-week period of detraining (23). Short-term detraining may specifically affect eccentric strength and the size of the Type II muscle fibers, leaving other aspects of neuromuscular performance uninfluenced (21). Muscle fiber CSA declines rapidly in strength and sprint athletes (35). In general, strength performance may be retained for up to 3-4 wks of inactivity, but highly trained athletes' eccentric force and sport-specific power may suffer significant declines (35). It is possible that different responders might react differently to a detraining phase.

It could be concluded that human beings can respond rather individually to strength training. However, less is known about responders' adaptations to the following detraining phase. The

purpose of the present study was to investigate whether subgroups of different individual responders could be observed in muscle hypertrophy and strength during ten weeks of progressive hypertrophic strength training and how those different responders would behave during the detraining phase following the training period.

METHODS

Experimental Approach to the Problem

In order to study whether different responders can be observed during the training and detraining periods, a total of a 16-week intervention was designed. The study included two measurement points before the intervention. The actual intervention included ten weeks of progressive hypertrophic resistance training and six weeks of detraining. The control measurements were performed first. Thereafter, a one-week control period (with no strength training) took place, and the measurements were repeated at the pre-tests. The control period was used as a reference in the figures and tables for the measurement error size. Thereafter, the strength training period started lasting for 10 weeks, and the mid-tests were performed at week five. The post-measurements were performed after the training period. Thereafter, the detraining period started lasting for six weeks. During the detraining period, the measurements were performed also in the middle of the detraining (at week 13) and after the end of the detraining at week 16 (Figure 1). The measurement sessions for individual subjects were performed at the same time of day during the study period.

FIGURE 1 about here

After the strength training intervention, the subjects were split into three different subgroups: high responders (HR), medium responders (MR), and low responders (LR). The level of responsiveness was determined based on how much muscle growth took place in VLCSA. Panoramic ultrasonography was used to measure VLCSA.

Subjects

Twenty-six healthy young men (age 19-30 years) from the city of Jyväskylä, Finland, were recruited to participate in the study. Recruitment was done through advertisements in a local newspaper, websites, and bulletin boards of the University of Jyväskylä, on the social media and the University of Jyväskylä staff- and student e-mail lists.

The exclusion criteria included cardiovascular diseases, problems with the respiratory system, impaired musculoskeletal and /or endocrine functions, diabetes, or any other condition that may limit performing the measurements or training intervention. Subjects needed to be recreationally physically active but without a systematic strength training background. The subject was considered physically active if they had moderate activity weekly. Performing endurance training or team sports more than once a week was also an exclusion criterion. In addition, subjects were advised not to participate in any endurance or team sports activities during the intervention.

All recruited participants attended a screening session for resting ECG and resting blood pressure. Furthermore, they were interviewed about their general health and motivation towards the study. A cardiologist went through the participants' ECG data before they were given a position as a subject. Overall, 32 participants went through pre-screening, and out of

these, 26 healthy subjects (age 24.6 years ± 3.8, height 180 cm ± 7.3, weight 77.0 kg ± 10.0) started the study. Each subject was informed of all potential risks and discomforts of the study, and the possibility to drop out from the research project at any time. After that, they signed an informed consent document. Two subjects dropped out of the study due to health problems unrelated to the study.

The study received ethical approval from the Ethics Committee of the University of Jyväskylä and was conducted according to the declaration of Helsinki.

Procedures

Training

The intervention lasted 16 weeks including ten weeks of strength training. The subjects trained three times per week. There was always at least one full day of rest between training sessions. The first session of the week was held either on Tuesday or Wednesday depending on the subject's availability. The second training session was held on Friday and the subjects started each their training session from the legs and moved on to the upper body. On the third session of the week, which was held on Sunday, it was vice versa to minimize the order effect.

Overall, 30 training sessions were conducted during the intervention. The average participation number in the training sessions was 29.1±0.93 sessions resulting in the participation rate of 96.9 %. All the training sessions were supervised by an expert from the study group.

The training program consisted of three initial medium weeks so that the volume of training was progressively increased, and one set was added to both bench press and leg press exercises every week, followed by four hard weeks, when the volume and intensity were both raised. The intensity was increased in bench press and leg press 5 % every week, and the volume was raised so that one set was added to accessory exercises every week. It was followed again by three medium weeks with the same volume but with a progressively rising intensity. The intensity was raised again in both bench and leg press by 5 % every week. A medium week was described, when only one variable increased (volume or intensity). A hard week was described when two variables were increasing (volume and intensity). Overall, the volume of training (sets) increased over the first seven weeks, and thereafter, the volume remained approximately the same and the training intensity increased (percentage loads from the 1RM). The intensity was increased by increasing the percentage load. The subjects trained either unilaterally or bilaterally. The overall training volume was carefully equated between the groups.

The training program consisted of leg press and bench press three times per week (Table 1). The training program included also knee extension, knee flexion, dumbbell bench press, seated French press, elbow flexion and extension movements, horizontal row, and core exercises. The eccentric portions of the lift were always done with the 3s tempo and the concentric portion of the lift as fast as possible. Rest time between the main exercises was 3 minutes and between the accessory exercises 60s. Rest time between the sets remained the same during the whole intervention. In addition, the subjects did isometric training in the knee extension and in knee flexion machines. The knee angle was 90 degrees in both exercises. The subjects also did isomeric bench press with the elbow angle of 90 degrees. The isometric training covered approximately 5 % of the whole volume of the intervention. The results of the isometric

training were always shown to the participant and he was then encouraged to go over the previous value.

Table 1 about here

The subjects received protein and carbohydrate supplementation after every training session. They were given protein bar, which included 203 kcal, 7 g of fat, 20.1 g of carbohydrate, and 19.6 g of protein per one bar. They were also given an individual example of the nutritional plan before the training intervention, and they were advised to follow it during the intervention. However, implementation of the nutritional plan was not controlled in this study.

Detraining

The subjects were advised to continue their life in the same way as they did before the training intervention. However, they were instructed not to do any strength training or high-intensity physical activity. They were allowed to do normal daily physical activities, for example, short commute biking (<5km) and physical activity related to household chores. The detraining process was controlled by a subjective questionnaire at week three and again at week six. Every subject replied that they had followed the instructions given for the detraining period and had not performed any strength training or other intensive physical activities.

Data collection and analyses

Whole body composition and lean body mass. Dual-energy X-ray Absorptiometry (DXA) (LUNAR Prodigy Advance, GE Medical Systems, Madison, USA) was used to measure whole

body composition and lean mass before and after the intervention. DXA was used only at before and after the 10-week training intervention because of the adverse radiation. Software's general recommendations were used to isolate legs and arms from the trunk (enCORE 2005, version 9.3). The legs were secured by using Styrofoam and elastic straps and the arms by rice bags to prevent any movement during the scan. The subjects came to the DXA-scan overnight fasted and they had been 24 hours without training. They could have one cup of water in the morning before the scan. Prior to the measurement, all metal objects were removed from the subject, and they were instructed to be in their underwear. The same investigator performed all the measurements and analyses.

Muscle cross-sectional area. Vastus lateralis cross-sectional area (CSA) was assessed using B-mode axial-plane ultrasound (model SSD-a10, Aloka Co Ltd, Japan). Subjects laid supine with the legs strapped to polystyrene moulds. Anatomical landmarks for the CSA determination were measured from the middle section between the joint space on the lateral side of the knee and to the greater trochanter. The 40 % of femur length was marked, and the line was drawn from the lateral to medial diaphysis of the right tight. A 10 MHz linear-array probe (60 mm width) was moved very slowly and continuously manually along the marked line. A custom-made probe support was used to assure perpendicularity and the extended-field was utilized. Great care was taken not to compress the muscle tissue. Ultrasound images were combined automatically to a panorama view in the device. Three panoramic CSAs were measured and the mean of those was used in the analyses. The CSA was then determined with Image-J - program (version 1.37, National Institute of Health, USA). Within Image-J the analysis was done with polygon selection - tool, which enabled manual tracing along the border of the vastus lateralis muscle. The investigator followed the inner line of fascia and when the fascia was not seen, the predicted route was chosen according to previous images

(2). Great care was used to complete the analyses. The same investigator performed all the measurements and analyses.

Echo intensity. Echo intensity was assayed by mean grayscale analysis using the standard histogram function in Image-J. The mean echo intensity was used in the analyses. It is the number between 0 and 255 (a complete black is 0 and a complete white is 255). In vastus lateralis the echo intensity was determined from the same area as CSA. This procedure has been used successfully in a couple of studies (6, 10, 19).

Electromyography (EMG) and isometric force. Maximal bilateral leg extensor strength was measured on the custom-built horizontal leg press (Biology of Physical Activity, University of Jyväskylä) at a knee angle of 107 °. Muscle activity was recorded during the isometric strength testing from the agonist muscles vastus lateralis (VL) and vastus medialis (VM) of the right leg. Skin was prepared by shaving, scraping and disinfecting. Thereafter, the electrodes were placed according to SENIAM guidelines (20). On the first time, the positions of the electrodes were marked on the skin by ink dots to ensure always the same location of electrodes in each measurement during the study (24). Electrodes were bipolar Ag/AgCl electrodes with 5 mm diameter and 20 mm inter-electrode distance.

During the measurements the raw signals were amplified (500 gain) at a bandwidth of 10–500 Hz, the sampling frequency was 3000 Hz. Thereafter, the signals went through the transportable pack to the receiving box (Telemyo 2400R, Noraxon, Scottsdale, USA), and then to an AD converter (Micro1401, Cambridge Electronic Design, UK) and recorded by Signal 4.04 software (Cambridge Electronic Design, UK). EMG signals were analyzed by a customized script. Maximum IEMG values were obtained at the contraction time period of

500-1500 ms. The highest values of the VL and VM were combined and expressed as a mean value.

Quadriceps muscle electrical stimulation. Constant current stimulator (Digitimer Stimulator Model DS7AH; Digitimer Ltd., United Kingdom) was used to stimulate the quadriceps muscle group of the right leg. Four, galvanically paired electrodes (6.98 cm V-trodes, Mettler Electronics Corp, USA) were placed on the proximal and middle regions of the quadriceps muscle, so that they would cover up muscle CSA as much as possible. Skin under the electrodes was shaved and disinfected.

The resting stimulation was performed first. The subjects sat on the custom-made chair with the knee angle of 107. Their right leg was strapped into the chair and the left leg was placed to the platform in front of them, so that it could be relaxed. Upper limbs were crossed in the lap. Single 1ms pulses were given by a constant-current stimulator until a force plateau was found. Thereafter, the maximum voluntary contraction was produced, and an additional 25 % of stimulation was added to the identified current. During the MVC, hands were instructed to keep on the side of the bench. The stimulation was given during the plateau of peak torque and then one more pulse 2 sec after a contraction to assess voluntary activation. The subjects were given three trials and with one-minute rest in between, but if the force rose more than five percentage, they were given another trial. Voluntary activation level (AL) was calculated as follows: Activation level %= $[1 – (Pts/Pt)] \times 100$, where Pts is the difference between the voluntary torque and the stimulation created additional torque, and Pt is the resting twitch after the maximum voluntary contraction (7).

Dynamic strength testing. Maximal bilateral concentric of 1 repetition maximum (1RM) was measured in the leg press (David 210, David Health Solutions Ltd, Helsinki, Finland). In the starting position, each subject was seated in the device with a knee angle of 60°. They were required to lift the load to a fully extended position. The weight was progressively increased using 5kg increments, until the subjects could no longer lift the load. The rest time between efforts was three minutes.

Transcranial magnetic stimulation. Transcranial magnetic stimulation (TMS) was delivered using double pulse, Magstim Bistim² Stimulator with a 7-cm figure-eight shaped double cone coil (Magstim, Whitland, UK). The coil was positioned on the participant in the place that elicited the greatest motor-evoked potential (MEP) at rest, furthermore, subjects' scalps were marked in order to keep the coil position constant and ensure corrected re-positioning. Resting motor threshold (RMT) was defined as the lowest stimulus intensity to elicit a visible MEP with a peak-to-peak amplitude of 50μV in three out of five consecutive trials. MEPs of vastus lateralis muscle were elicited at 100, 110, 120, 130 and 140% of RMT. Ten trials for each intensity was recorded. The order and timing of these stimulation were randomized to prevent any anticipatory reactions by the subject. During these measurements, the subjects were asked to perform an attention task, which consisted of silently counting backwards from 200.

MEP responses to TMS were measured with the same EMG electrodes and settings as during the MVC measurements. Peak-to-peak amplitudes of each MEP were analyzed, and finally, an average of all the MEPs of different intensities were calculated.

Blood samples. Blood samples were collected from antecubital vein via sterile techniques. Blood samples were drawn into serum tubes (Venosafe, Terumo Mediacl Co., Leuven,

Belgium) by a qualified lab technician. Overall, six millilitres (ml) of blood were collected, which included approximately 2.5 ml serum. Resting serum blood samples were obtained in the morning in the fasted state to determinate basal hormone concentrations. The subjects fasted approximately twelve hours. The subjects could drink a glass of water before coming to the blood collection. All food and other liquids were prohibited. The collected blood was held for 15 min at room temperature before it was centrifuged for 10 minutes at the speed of 3500 rpm (Megafuge 1.0R, Heraeus, Germany). Serum samples were then placed into the refrigerator (-80°C) and stored for future analysis. Serum testosterone (TT), cortisol (C), growth hormone (GH), and sex hormone-binding globulin (SHGB) were analyzed from the samples. Analyses were accomplished by immunomeric chemiluminescence techniques (Immulite 2000) and hormone specific immunoassay kits (Immulite, Siemens, Illinois, USA)). Analytical sensitivity was 0.01 ng/mL for growth hormone, 0.5 nmol/L for total testosterone, 0.02 nmol/L for SHBG, 5.5 nmol/L for cortisol and 0.05 mlU/mL for LH. Intra- and Inter-assay reliability (CV%) were within acceptable limits (Total testosterone = 8.3%, Cortisol = 6.1%, SHBG = 2.5% and LH = 3.6%).

Statistical Analyses

Standard statistical analyses were used for descriptive variables of means and standard deviations (SD). Normal distributions were determined through the Shapiro-Wilk test, and acceptable levels of skewness and kurtosis was also checked. All dependent variables were evaluated by using a two-way analysis of variance (Anova) with repeated measures. When a significant F-value was found using an ANOVA with repeated measures with a Greenhouse-Geisser correction, the post hoc tests using the Bonferroni correction was used to locate the pair-wise differences. Differences between the subgroups were analysed by the oneway

ANOVA. SPSS Statistics version 24 (IBM corp., New York, NY, USA) was used for statistical analyses. For all tests, the alpha level was set at $p \leq 0.05$.

RESULTS

Vastus lateralis cross-sectional area (VLCSA) increased in the total group of subjects statistically significantly by 10.7 % ±12.5 after ten weeks of strength training (Table 2). Relative changes in VL CSA in each individual are shown in Figure 2. Both total lean mass and legs lean mass increased significantly from pre to post (Table 3). Dynamic bilateral 1RM strength increased significantly by 16.3 % ±11.8 after the ten-week intervention (Table 2).

TABLE 2 about here

TABLE 3 about here

FIGURE 2 about here

After the intervention, subjects were split into three groups according to the magnitude of the increase of the VL CSA during the 10-week training period (Fig. 3) as follows: High Responders >15%, (n=10), Medium Responders 15-4, 5% (n=7) and Low Responders <4,5% (n=7). High responders showed a significant increase in VL CSA from pre to mid (+14.9 % ± 5.1, p=0.008), from pre to post-training (+23.0 % ± 6.3, p=0.002), from pre to detraining 1 (+10.0 % ± 7.2, p=0.021) and from pre to detraining 2 (+12.7 % ± 4.9, p=0.002). Medium Responders reached a statistically significant increase from pre to post (+ 7.2 % ± 3.1, p=0.017), while Low responders did not reach a significant change in VL CSA.

FIGURE 3 about here

Only High responders to hypertrophy increased their bilateral leg press 1RM significantly from pre to post by 21.1 % ± 11.7 ($p=0.001$), pre to detraining 1 by 23.8 % ± 12.3 ($p=0.001$) and pre to detraining 2 by 19.1 % ± 13.2 ($p=0.004$) (Fig. 4). During the detraining phase, High Responders showed a decrease of -10.5% in their VLCSA, while Medium and Low Responders maintained their VLCSA (-0.7% and -0.6%, respectively). High and Medium Responders lost more strength (-2.0% and -2.5%), respectively than Low Responders (+0.9%), although not significantly (Fig. 4).

FIGURE 4 about here

There was a statistically significant increase in maximal EMG activity (mean of VL and VM muscles) of 21.3 % ± 22.9 from pre to post training for the whole group in the bilateral leg press ($p=0.009$) (Fig. 5). For the different subgroups, Medium Responders increased significantly their pre to post maximum mean IEMG value in bilateral leg press ($p<0.001$) (Fig. 5).

FIGURE 5 about here

None of three subgroups showed significant changes in the maximal voluntary activation level after the 10 weeks of strength training (Fig. 6). In High, Medium and Low responders, maximal activation level decreased at week 10 slightly by -3.25% ± 5.79, -0.52% ± 3.06 and by -1.82% ± 3.49, respectively. However, all subgroups showed some rebounds in maximal activation back at week three of detraining from post training and in Medium Responders this change was significant ($p=0.038$).

FIGURE 6 about here

The average MEP values of the different subgroups did not show any significant changes during different time points or differences between the groups (Fig.7). However, a decreasing trend in MEPs towards the end of the strength training intervention could be seen in all the groups. This reduction was significant at week 10, when the groups were calculated as one ($P<0.01$). In addition, a clear recovery in MEPs could be observed at week three of detraining, especially for High responders. This was not significant within or between the groups, but again a significant joint effect could be found ($p<0.01$).

FIGURE 7 about here

In the total group of subjects, no significant changes occurred during the study period in serum basal hormone concentrations and SHBG (Table 4). Serum basal testosterone/cortisol ratio increased slightly from the pre value of 0.043 (±0.02) to the post value of 0.049 (±0.025) during the 10-week training period (Table 4). After six weeks of detraining the testosterone/cortisol ratio slightly decreased close to the baseline. After the strength training period the testosterone/SHBG ratio increased from 0.567 (±0.165) to 0.664 (±0.481) and further slightly increased after the detraining period up to 0.705 (±0.381).

TABLE 4 about here

No significant changes were observed in the serum testosterone/SHBG ratio in three different subgroups during the 10-week strength training and 6-week detraining periods (Fig 8). The High responder subgroup showed a higher, but not significant, testosterone/SHBG ratio

throughout the training period until week 3 of detraining. There was a trend of a significant correlation ($r = .365$ $p=0.079$) during the 10-week strength training period between individual changes in VLCSA and average individual values in the testosterone/SHBG ratio for the whole group (Fig. 9).

FIGURE 8 about here

FIGURE 9 about here

DISCUSSION

The present ten-week hypertrophic strength training intervention increased maximal concentric 1 RM strength significantly from pre to post by 16% in the total subject group. In addition, VL-CSA increased in the total group by 10.7 % indicating that our intervention was effective. The present subjects could be split into three subgroups according to the magnitude of increase in VL CSA: HR >15%, (n=10), MR 15-4.5% (n=7) and LR <4.5% (n=7).

The HR and MR subgroups increased VLCSA significantly from pre to post by 23% and 7%, whereas the LR did not achieve a statistically significant change. Mobley et al. (32) have found similar results in the responder subgroups, although all their subgroups increased statistically significantly VL thickness from pre to post. During the six-week detraining phase, HR lost -10.5% of their VLCSA, while MR and LR lost only -0.7% and -0.6% of their VLCSA. In addition, both HR and MR lost during detraining more strength than LR. Thus, the HR group tended to lose muscle mass and strength faster than the other two responder groups during the detraining phase. It seems that strength training adaptations in muscle mass and strength take place more quickly for HR and MR in both directions. For LR, these adaptations seem to occur more slowly. LR might just be “slow responders” and might need more training time for adaptations to occur. During the detraining phase, the present LR did not lose those minor adaptations gained as much as the other two subgroups indicating a slower adaptation time course. A longer strength training intervention period is needed for a better understanding of this phenomenon. To the best of our knowledge, these results are, however, quite unique and probably published for the first time that the different responder groups also demonstrated different degrees of muscle mass loss during the detraining phase.

The present study additionally showed that none of the subgroups displayed decreases in maximal dynamic strength during the first three weeks of detraining, and HR showed a slight (by 2.5%) rebound in their strength (Fig. 4). The time course of this finding is interesting since Häkkinen et al. (1985a) (25) showed a very large decrease in both strength and maximal EMG after 4 weeks of detraining. A significant training induced increase took place in maximal EMG (mean of VL and VM muscles) in bilateral leg press for the present whole group (Fig. 5) and for MR after 10 weeks of strength training. Minor increases in the maximum voluntary AL in all subgroups occurred after strength training at week 5, while at week 10 a slightly decreased value (-3.3% ± 5.8, ns.) was observed especially in HR (Fig. 6). This probably indicates that the neuromuscular system of the high responders was most stressed by the end of the present strength training period.

Interestingly, during the first three weeks of detraining, no significant changes occurred in maximal EMGs in the bilateral leg press, and maximal voluntary AL turned into slight increases for all subgroups, with Medium responders showing a significant difference. Only slight (ns.) decreases in maximal EMGs occurred during the latter three weeks of detraining and no changes in maximal AL. The data during the detraining suggests that the maximal neuromuscular performance in HR and MR may bounce somewhat back and up from strenuous strength training at week three of the detraining period compared to LR.

The present results also showed that MEP averages were at the lowest (-10.8%) also for HR right after the strength training period (Fig. 7). Interestingly, HR MEP increased very fast after three weeks of the detraining (+19.6 % compared to the previous value) but decreased back close to the baseline value. LR remained again rather steady and increased by +3.1 % of their MEP averages after the first part of the detraining but remained approximately in the same

condition during the second part of the detraining. Thus, when all the data is taken into account, it seems that HR have more fluctuation in all of these values measured. Muscle hypertrophy, strength gains, and muscle activation adaptations may occur faster in HR, and that peak maximal dynamic strength may be reached, not right after the strenuous strength training period, but after 2-3 weeks of detraining.

The present training program was effective for the needs of HR leading to considerable gains in muscle mass and maximal strength. For LR, the training program utilized might not have been that suitable. Manipulation of training variables could have induced different outcomes for different individuals. Manipulation of resistance training frequency can alter individual responsiveness to strength training (12). Higher training frequency may also confer a potentially superior hypertrophic adaptation (42). On the other hand, although higher training frequencies can accumulate greater volumes of training, the weekly resistance training frequency may not meaningfully impact muscle hypertrophy, when the volume is equated (40). However, the training volume might have a considerable impact on hypertrophic adaptations (16). Higher training volume is also associated with increased ribosomal biogenesis (18). HR might have optimal ribosome biogenesis for hypertrophy. Ribosome biogenesis has occurred as an important regulator of muscle hypertrophy and maintenance by altering the translational capacity of muscle cells (17). There is also a difference in the overall signalling pathways as the high responders´ cellular responses seem to be more like a growth response and in the non-responders more like a magnified inflammatory response (41). The effect of training variables to the individual adaptations remains to be elucidated.

Other factors, such as nutritional intake, daily rhythm, sleep habits, genetic environment, stress, etc., could also affect the ability of subjects to adapt to strength training. Thus, changing

the training variables might have had an impact on the present results. The level of responsiveness has been suggested to be strongly affected by the duration of the exercise intervention, with more positive responses, when subjects train more (11, 33). This may indicate that LR would just need more specific training. Furthermore, it must be taken into consideration that the results reflect the adaptive capacity of individuals at a given time. In addition, in the total group of subjects there was no correlation between individual baseline strength levels and individual gains in strength during the present strength training intervention. Thus, baseline values did not predict which responder group the individual subject ended. Subjects did or did not respond to our intervention training program, but they might behave differently if the intervention would be repeated (38).

Our results also indicate that HR gained more muscle mass already during the firsts two weeks of strength training. HR gained 9.2 % (±8.3) in their VL CSA, and even MR gained 6.3 % (±9.1). Even though individual variation was rather large, the possibility to gain muscle mass during the hypertrophic type of strength training sooner than usually proposed (e.g. 34), may thus be possible. However, we measured hypertrophy only from one muscle (VL), while the whole quadriceps hypertrophy was not measured. The results must, therefore, be interpreted with care. Few studies have also detected early adaptations in skeletal muscle size (30, 37). Illera-Domínguez et al. found that only after 14 days of strength training a large change in the quadriceps CSA took place (5.5% ± 1.9%) (30). In the present study, ultrasound scans were performed after ≥48 h from the last strength training session, but we used the echo intensity method to measure whether there would be any muscle swelling in the muscles. These echo intensity scans revealed no statistically significant changes after the first two weeks of strength training. This suggests that muscle hypertrophy may have taken place. However, there was the

decrease of - 3.1 % (±5.5) in echo intensity from pre to week 2 (ns.) indicating possibly that some muscle swelling may have taken place. Thus, the results should be interpreted with care.

Gains in strength during the present training period seemed to be as variable as hypertrophic adaptations and highly individual. We found that the gains in dynamic strength in bilateral leg press after the ten-week intervention ranged as much as from -9.7 % to + 41.7 %. Other investigations have also noted that the changes in muscle force and physiological cross-sectional area vary substantially between individuals (3, 14, 22). Thus, it seems that although larger variability exists, nearly everyone will get stronger when they start to train. However, hypertrophic adaptations do not occur so easily, and almost every study has found some "non-responders" to hypertrophy (3). However, the resistance training-induced muscle hypertrophy can explain notable proportions of inter-individual changes in isometric and isoinertial strength (15). Overall, it seems that in previously untrained subjects hypertrophy can explain to a rather low extent the strength gains in strength during initial weeks of training. However, in strength trained athletes muscle size and strength have correlated more strongly, and these correlations have varied between r=0.59 and r=0.692 (4, 5).

Bickel et al. (8) have observed as the primary finding that a once-per-week exercise dose was generally sufficient to maintain positive neuromuscular adaptations (both strength and muscle mass) during the 32-week long maintenance training (with a lowered training frequency) period. We detected similar results, when strength decreased only by -1.2 % ± 3.7 during the detraining period, whereas VL CSA decreased by -4.9 % ± 7.3. In addition, strength can remain elevated during the 3-week detraining period despite some decrease in muscle CSA (26). Thus, strength may be easier to maintain, at least for 2-3 weeks or so, compared to muscle CSA.

In the present study, we also measured serum testosterone concentrations and testosterone /SHBG ratios repeatedly throughout the experimental period. The average serum testosterone/SHBG-ratio was somewhat higher for HR during the entire experimental period compared to other two responder groups (Fig. 8). Interestingly, the standard deviation in the testosterone/SHBG-ratio in HR increased throughout the present hypertrophic strength training intervention. There was also a modest correlation ($r=0.37$, $p=0.079$) between individual levels in the testosterone/SHBG-ratio and individual muscle hypertrophy in the total group of subjects (Fig. 9). Häkkinen et al. (27) have earlier reported that in elite weightlifters, individual changes in the testosterone/SHGB ratio have correlated significantly with changes in weightlifting performance during the very stressful training period of some weeks. Ahtiainen et al. (1) also found a significant correlation between averaged individual testosterone concentrations and individual changes in isometric strength in strength-trained athletic men (1).

In the present study, serum testosterone concentrations increased slightly during the present strength training intervention for the whole group. Ahtiainen et al. (1) have reported similar results, with no significant changes in basal serum concentrations, when untrained and strength-trained men trained for 21 weeks. However, basal testosterone and free testosterone increased during the first 14 weeks (with the increase of training volume), and decreased from week 14 to week 21 in strength-trained men (with the decreased volume) (1). In addition, the volume and/or intensity of strength training has been shown to affect serum testosterone concentrations (27, 29). These findings suggest that serum testosterone concentrations can differ with regard to the volume of strength training and can be an important factor for strength development in strength-trained men. Häkkinen et al. (28) found earlier that individual

changes in maximal strength and individual changes in anabolic hormonal concentrations correlated significantly during the later stressful training weeks of the prolonged 6-month strength training intervention indicating the possible importance of serum testosterone for trainability.

The present study had some limitations that must be considered when attempting to draw evidence-based conclusions. Firstly, the low sample size of 24 participants was a limitation when divided into three subgroups. Furthermore, the strength training intervention lasted only 10 weeks and, although this period was sufficient to achieve significant increases in muscular strength and hypertrophy for three subgroups, it is possible that the results between the groups could have diverged with a longer intervention protocol. The subjects also trained either unilaterally or bilaterally. Even though the training volume was carefully equated between the groups, the different training styles might have influenced the results. Muscle hypertrophy was measured using ultrasound at the middle length of the QF, and not using e.g. by using MRI. It should also be pointed out that the corticospinal excitability was measured on a passive muscle, which is usually the case in similar experiments. However, it is possible that the passive condition is not able to reveal neural adaptation processes. In the future, it would be interesting to measure corticospinal excitability during high muscle contractions in strength training experiments. Additionally, we gave protein and carbohydrate supplementation to the subjects, and the participants also received an individual diet plan before the intervention began. However, the following of the diet was not controlled in any way. The diet is an important part of any kind of strength training and can influence the results of the intervention. Moreover, there were only subjective questionnaires during the detraining process, and no actual activity tracking was done during that period.

In summary, the present study included ten weeks of progressive hypertrophic resistance training followed by six weeks of detraining. After the strength training period, we were able to identify three different responder groups for the present hypertrophic strength training program. Our results also indicate that a subgroup of HR in the gains in muscle CSA during the present training were the ones who also tend to lose muscle mass somewhat faster than LR during the detraining phase. In addition, strength gains and maximal muscle activation adaptations may take place faster in HR, and a peak in maximal dynamic strength may be reached, not right after the strenuous strength training period, but after 2-3 weeks of detraining. The present results highlight the different adaptation capabilities of different individuals. In addition, it expresses the need for personal training programming as well as tapering for maximum development in hypertrophy and maximal strength in the long term.

PRACTICAL APPLICATIONS

Different responders and actually three responder subgroups were observed in our strength training program. Some subjects responded well to our intervention, whereas others did not. In addition, differences in maintaining muscle cross-sectional area and maximal strength were found during the detraining. A peak in maximal dynamic strength may be reached, not right after the strenuous strength training period, but after 2-3 weeks of detraining and/or with lowered volume training. It is important to create individualized strength/hypertrophy programs to maximize the effectiveness of each strength-training period. Furthermore, the time-period for tapering, detraining, and off-season could also be individualised so that the long-term development would be optimal for every individual. Future research is required to determine more accurately the optimal training intensity, volume, exercise selection, and programming for different responder groups.

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FIGURE LEGENDS:

FIGURE 1: Overview of the experimental design of the study. The control tests lasted one week, thereafter, the control period was one week, the strength training intervention lasted 10 weeks, the detraining period was 6 weeks and overall, the timeline covered 18 weeks.

FIGURE 2: Individual relative changes for VL CSA in each subject from pre to post 10 weeks of strength training.

FIGURE 3: Relative changes (mean and SD) in VL CSA in three different subgroups after 2, 5 and 10 weeks of strength training and 3 and 6 weeks of detraining. Con refers to the control measurements before Pre measurements. *Significantly greater than the corresponding pretraining value.

FIGURE 4: Relative changes (mean and SD) in dynamic bilateral 1RM leg press strength in three different subgroups after 10 weeks of strength training and 3 and 6 weeks of detraining. Con refers to the control measurements before Pre measurements. *Significantly greater than the corresponding pretraining value.

FIGURE 5: Relative changes (mean and SD) in maximal EMG (mean of VL and VM) in bilateral isometric leg press in three different subgroups and in the total group after 10 weeks of strength training and 3 and 6 weeks of detraining. Con refers to the control measurements before Pre measurements. *Significantly greater than the corresponding pretraining value.

FIGURE 6: Relative changes (mean and SD) in maximal voluntary activation level of quadriceps femoris muscle group in unilateral isometric knee extension in three different subgroups after 5 and 10 weeks of strength training and 3 and 6 weeks of detraining. Con refers to the control measurements before Pre measurements. *Significantly greater than the corresponding ST +10wk value.

FIGURE 7: MEP average during the entire intervention in three different subgroups based on muscle hypertrophy during 10 weeks of strength training and 6 weeks of detraining. Con refers

to the control measurements before Pre measurements. ST = strength training, DT = detraining.

FIGURE 8: Serum testosterone/SHBG ratio (mean and SD) during the entire intervention in three different subgroups based on muscle hypertrophy during 10 week of strength training and 6 weeks of detraining. Con refers to the control measurements before Pre measurements. ST = strength training, DT = detraining.

FIGURE 9: The relationship between individual serum testosterone/SHBG ratios (mean of pre, mid and post strength training) and individual relative changes in VLCSA after the 10-week strength training intervention.