Effects of Heavy Resistance/Power Training on Maximal Strength, Muscle Morphology, and Hormonal Response Patterns in 60–75-Year-Old Men and Women


Catalog Data

Key words: aging, strength training, power training, muscle hypertrophy, serum hormones
Mots clés: vieillissement, entraînement à la force, entraînement à la puissance, hypertrophie musculaire, hormones sériques

Abstract/Résumé
Eleven women (TRW; 64 ± 4 yrs) and ten men (TRM; 65 ± 5 yrs) participated in the strength/power training twice a week for 24 weeks. Basal concentrations of serum total and free testosterone, growth hormone (GH), dehydroepiandrosterone sulfate (DHEAS), cortisol and

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sex hormone binding globulin (SHBG) as well as acute responses of serum total and free testosterone, growth hormone (GH) were measured. Maximal 1RM strength in the squat, chair rise time and muscle fibre distribution and areas of type I and IIa and IIb of the vastus lateralis were also examined. IRM squat increased in TRW by 26 (SD10) % (p < .001), and in TRM by 35 (7) % (p < .001) and chair rise time improved in both groups (p < .001). Fibre areas increased in type I, (p < .01), IIa (p < .01) and IIb (p < .01) in TRM and type I (p < .05) and IIa (p < .05) in TRW. The proportion of type IIa increased from 31% to 43% (p < .05) in TRW and that of type IIb decreased from 27% to 17% (p < .05) in TRW and from 25% to 17% (p < .05) in TRM. Individual concentrations of testosterone/cortisol ratios correlated (r = 0.63; p < .05) with the individual increases in 1RM strength in TRW. The exercise sessions resulted in acute increases in serum GH in both groups (p < .05) with a further increase (p < .01) up to 10 minutes post-loading in TRM at post-training.

Onze femmes et dix hommes dans la soixantaine (TRW, 64 ± 4 ans ; TRM, 65 ± 5 ans) participent deux fois par semaine à une programmé d’entraînement à la force d’une durée de 24 semaines ; le groupe témoin est constitué de cinq femmes et de cinq hommes aussi dans la soixantaine (CW, 65 ± 6 ans ; CM, 64 ± 5 ans). Les variables suivantes sont mesurées tant au repos qu’à la suite d’une séance d’entraînement : testostérone total et testostérone libre sérique, hormone de croissance (GH) ; le sulfate de déhydroépiandrostérone (DHEAS), le cortisol, la globuline de liaison des hormones sexuelles (SHBG) ne sont mesurées qu’au repos. La force maximale (IRM) au cours d’une flexion accroupie des jambes, le temps pour se lever d’une chaise et la proportion ainsi que la surface de coupe des fibres de type I, IIa et IIb du vastus lateralis sont aussi mesurées. Chez les TRW, IRM augmente de 26 % (é-t, 10 %) et chez les TRM, de 35 % (7 %) (p < 0,001) ; le temps pour se lever d’une chaise s’est amélioré dans les deux groupes (p < 0,001). Chez le groupe TRM, la surface de coupe de tous les types de fibre augmente : type I, (p < 0,01), IIa (p < 0,01) et IIb (p < 0,01) ; chez le groupe TRW, l’augmentation ne concerne que les fibres de type I (p < 0,05) et de type IIa (p < 0,05). La proportion de fibres du type IIa passe de 31 % à 43 % (p < 0,05) chez le groupe TRW et celle des fibres du type IIb passe de 27 % à 17 % (p < 0,05) ; chez le groupe TRM, cette dernière proportion passe de 25 % à 17 % (p < 0,05). On n’observe aucun changement au niveau des concentrations sériques des hormones, mais les ratios individuels de testostérone/cortisol sont corrélés aux augmentations de la force (IRM) chez le groupe TRW (r = 0,63; p < 0,05). Dans les deux groupes, la séance d’entraînement fait augmenter la concentration d’hormone de croissance (p < 0,05) ; à la fin de l’entraînement, on observe une augmentation supplémentaire de l’hormone de croissance (p < 0,01) pendant les dix dernières minutes de la séance. À la suite du programme d’entraînement à la force, à raison de deux fois par semaine seulement, on observe chez les deux groupes, en plus d’une hypertrophie, une importante augmentation de la force des muscles entraînés. On n’observe aucun changement au niveau de repos des hormones sériques : un faible ratio testostérone/cortisol peut être un facteur limitatif de l’amélioration de la force musculaire chez les femmes âgées.

Introduction

Muscular strength and power decline with aging. The decline in maximal strength is associated with a decrease in muscle mass mediated by a decrease in the size and a loss of individual muscle fibres, especially those of type II fibres (Lexell et al., 1988). The decrease in muscle mass and strength can be as large as 30–40%
from the age of 20–30 years to that of 70–80 (e.g., Häkkinen, 1994; Porter et al., 1995). In general, the loss of strength is rather minor from the age of 20 years to that of 50 but accelerates drastically from the sixth decade on. With aging, blood concentrations of circulating anabolic hormones and growth factors (e.g., testosterone, growth hormone, and insulin-like growth factor-I) are diminished (Copeland et al., 1990; Gray et al., 1991; Häkkinen and Pakarin, 1993; Kraemer et al., 1998). The decrease in strength and power performances can also be explained in part by the decreased maximal voluntary activation of the agonist muscles and/or changes in the degree of agonist-antagonist coactivation (Häkkinen et al., 1998a; Harridge et al., 1999; Kamen et al., 1994). However, it appears that much of the age-related losses in strength and muscle mass can be explained by lifestyle factors (e.g., a decline in the intensity of daily physical activities) since, with resistance training, a great amount of the strength can be regained. However, because age-related decreases in explosive strength and power are known to be even larger than those of muscle strength and mass (e.g., Bosco and Komi, 1980; Häkkinen et al., 1998a), there is a need to examine also the effects of power type of training regimen on the neuromuscular system in older men and women.

Heavy resistance exercise is a potent stimulus for acute increases in circulating anabolic hormones in young men, but it has not been shown to elicit the same magnitude of hormonal responses in older men (Craig et al., 1989; Häkkinen and Pakarin, 1995; Häkkinen et al., 2000; Kraemer et al., 1998; Nicklas et al., 1995). The responses are very minor or no response is necessarily observed at all in older women (Häkkinen and Pakarin, 1995; Häkkinen et al., 2000). With regard to heavy resistance training no systematic changes have been reported to take place in basal blood concentrations of circulating anabolic hormones during strength training for 12 to 24 weeks in older men (Craig et al., 1989; Häkkinen and Pakarin, 1994; Häkkinen et al., 2000; Kraemer et al., 1999; Nicklas et al., 1995) or in older women (Häkkinen and Pakarin, 1994; Häkkinen et al., 2000). It has been also shown that the acute exercise-induced minor GH response in 60–72 year old men has not changed after 12 to 24 weeks of strength training compared to that recorded before the training (Craig et al., 1989; Häkkinen et al., 2000; Nicklas et al., 1995). Since not only maximal strength but the ability of the leg extensor muscles to develop force rapidly are both important performance characteristics contributing to several tasks of daily life such as climbing stairs, walking, or even prevention of falls and/or trips (Bassey et al., 1992; Izquierdo et al., 1999), this should be taken into consideration when constructing strength training programs for both middle-aged and older men and women. In order to induce increases in explosive strength and power capacities, heavy resistance training also in older people should be combined with power type of strength training performed with lower-load exercises but emphasizing higher action/movement velocities of the exercises performed (Häkkinen and Häkkinen, 1995; Häkkinen et al. 1998b; Jozsi et al., 1999). There is a paucity of research reporting the effects of power training on hormonal response patterns in older men and especially older women. Moreover, to what extent this type of training stimuli (i.e., lighter loads but faster movement speed) would contribute to maximal strength development and/or its maintenance in older men and women was also within our interests.

Since blood concentrations of circulating anabolic hormones and growth factors are also diminished with aging, it was our purpose to examine in older men
and women the possible effects of strength training on basal concentrations and acute responses of serum hormones and their possible interrelationships with strength gains and muscle hypertrophy during a prolonged heavy resistance and power training period of 24 weeks.

**Methods**

Sixteen healthy, mildly physically active older women and 15 older men aged 60–75 yrs participated in this investigation. Eleven women and 10 men underwent the training program (TRW and TRM, respectively), while 5 subjects from both groups (CW, CM) served as controls. The demographic data of the study groups are shown in Table 1. Subjects were recruited through newspaper advertisements and medically screened through questionnaire and interview. None of the subjects had contraindications to perform rigorous resistance exercise. All subjects were deemed fit to participate in the 24-week resistance training program and signed an informed consent document prior to any testing or training. Approval for this study was granted by the Southern Cross University Ethics Committee on Human Experimentation.

**Table 1** Mean (SD) Demographic Data of the Groups Studied: Training Old Women (TRW) and Men (TRM) and Old Control Women (CW) and Men (CM)

<table>
<thead>
<tr>
<th></th>
<th>At week</th>
<th>TRW (n = 11)</th>
<th>CW (n = 5)</th>
<th>TRM (n = 10)</th>
<th>CM (n = 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (yrs)</strong></td>
<td>0</td>
<td>64.4 (3.5)</td>
<td>65.2 (6.1)</td>
<td>65.4 (4.7)</td>
<td>63.8 (4.4)</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>0</td>
<td>162.4 (5.4)</td>
<td>162.0 (3.5)</td>
<td>172.6 (6.5)</td>
<td>171.1 (3.9)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>162.6 (5.5)</td>
<td>161.1 (3.8)</td>
<td>172.6 (6.1)</td>
<td>172.3 (4.0)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>162.7 (5.2)</td>
<td>162.0 (3.8)</td>
<td>172.6 (6.1)</td>
<td>172.6 (4.0)</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>0</td>
<td>70.5 (9.1)</td>
<td>64.7 (5.1)</td>
<td>83.8 (11.7)</td>
<td>83.2 (9.2)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>70.0 (8.6)</td>
<td>63.8 (5.3)</td>
<td>84.5 (12.0)</td>
<td>83.9 (8.2)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>69.4 (8.7)</td>
<td>64.0 (4.6)</td>
<td>83.6 (11.1)</td>
<td>82.6 (7.9)</td>
</tr>
<tr>
<td><strong>Fat (%)</strong></td>
<td>0</td>
<td>33.4 (3.3)</td>
<td>32.1 (4.1)</td>
<td>22.8 (4.1)</td>
<td>21.9 (3.0)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>33.0 (3.8)</td>
<td>31.4 (4.6)</td>
<td>22.1 (4.4)</td>
<td>22.0 (2.6)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>32.6 (3.6)</td>
<td>31.4 (5.0)</td>
<td>21.9 (4.5)</td>
<td>21.5 (2.9)</td>
</tr>
<tr>
<td><strong>Lean body mass (kg)</strong></td>
<td>0</td>
<td>46.8 (4.7)</td>
<td>43.8 (1.3)</td>
<td>64.4 (7.8)</td>
<td>64.8 (5.1)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>46.9 (4.6)</td>
<td>43.6 (1.1)</td>
<td>65.0 (7.7)</td>
<td>65.3 (5.0)</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>46.6 (4.9)</td>
<td>43.7 (0.5)</td>
<td>65.0 (7.2)</td>
<td>64.7 (4.9)</td>
</tr>
</tbody>
</table>

*Difference between the measurements p < .05.*
MEASUREMENTS

One-repetition maximum strength. Subjects were assessed for 1RM strength (i.e., the heaviest load that could be correctly performed for one repetition) in the Smith machine squat (starting from the knee angle of 90°) prior to training, after weeks 6, 12, 18, and 24. Low-resistance warm-up sessions were conducted before 1 RM strength testing so that the subjects would be familiar with the equipment and the proper exercise techniques. On verbal command the subject then performed a bilateral concentric hip and leg extension (squat) starting from a flexed position of 90 degrees trying to reach a full extension 180 degrees against the resistance determined by the weights loaded on the barbell (on the shoulders). In the testing of the maximal load, separate 1 RM (repetition maximum) contractions were performed allowing 1.5 minutes for recovery between the trials. After each repetition the load was increased until the subject was unable to extend the knees to the required standing position. The last acceptable extension with the highest possible load was determined as the 1-RM.

Chair rise. The subjects performed 3 stand-ups (in quick succession) from the 40-cm height chair as fast as possible. They started from the sitting position, hands crossed on their chest and they stood up extending their knees and back after every stand up. Total time for 3 chair raises was measured and used for as a score.

Muscle biopsy. Muscle biopsies were obtained before and after the 24-week experimental strength training period. The samples were obtained from the superficial portion of the vastus lateralis muscle of the left leg utilizing the percutaneous needle biopsy technique of Bergström (1962) with suction (about 100 mls) as modified by Evans et al. (1982). Special care was taken to extract tissue from approximately the same location each time using the prebiopsy scar (approximately 0.5 cm from previous scar going from medial to lateral) and marked needle depth of 2 cm. Muscle tissue samples were frozen in isopentane cooled with liquid Nitrogen and stored at −80 °C until analyzed. Serial cross-sections (10 μm thick) were cut on a cryostat at −20 °C for histochemical analyses. Histochemical staining for myofibrillar adenosinetriphosphatase (ATPase) was used to classify the fibers as I, IIA and IIB (based on the stability of their ATPase activity at pH 4.3, 4.6, and 10.3, in the preincubation medium, as well as an NADH stain) according to Brooke and Kaiser (1970). Fiber type percentages were calculated from the mean number of fibers (at pre- and post-training) of 256 and 291 recorded for TRW, 161 and 177 for TRM, 213 and 326 for CW and 296 and 293 for CM, respectively. For the calculation of mean fibre areas, an average number of fibres analysed were 107 and 106 for TRW, 70 and 70 for TRM, 103 and 108 for CW and 102 and 92 for CM, respectively. A loaded image of stained cross-sections were analyzed by NIH Image Software (Version 1.62 the public Domain) to calculate the mean fibre areas of each fibre types.

Anthropometric measurements. The percentage of fat in the body was estimated from the measurements of skinfold thickness from four different sites (Durnin & Womersley 1967).

Basal blood samples during the 6-month strength training. To examine the basal concentrations of serum hormones, morning blood samples (between 7:30 a.m. and 8:30 a.m.) were taken after 8–10 hour fast from the antecubital vein.
Blood samples were taken before the start of the training period and thereafter after every sixth week (weeks 0, 6, 12, 18, and 24).

**Blood samples during the heavy resistance loading protocol.** To examine acute hormone responses to heavy-resistance loading, blood samples were drawn immediately before and after the loading, and also after 10 minutes of recovery. The loading protocol was performed both before the training (week 0) and after the experimental training period (week 24). The fatiguing loading protocol was performed between 9:00 a.m. and 6:00 p.m., but always at the same time of day for each subject. The subjects were instructed to maintain their normal food intake prior to the loading protocol and to have their light meal during that day no later than 2 hours before the session.

**Acute heavy resistance loading.** The heavy-resistance protocol before and after the 24-week training period consisted of the squats using the Smith machine. Each subject performed a few warm-up squats with light loads before the first set of the loading. For each subject the actual loads were always the repetition maximums (RM) so that the subjects performed 10 repetitions with the maximal load possible (10 RM). Five sets were performed with the recovery time of two minutes between the sets. The loads were adjusted during fatigue so that each individual was able to perform the required 10 repetitions in each set (5 x 10 RM). The subjects were requested not to perform any physical training during the day preceding the loading.

**Analytical methods.** Serum samples for the hormonal analyses were kept frozen at −20 °C until assayed. The concentrations of serum free testosterone were measured by radioimmunoassays using kits obtained from Diagnostic Products Corp. (Los Angeles, CA). The sensitivity of the assay was 0.52 pmol·L⁻¹ and the intra-assay variation was 3.8%. Serum sex hormone binding globulin (SHBG) concentrations were measured by two-site fluoroimmunometric method with kits obtained from Wallac Ltd (Turku, Finland) using the 1235 AutoDELFIA automatic immunoassay system. The sensitivity of the SHBG assay was 1.2 nmol·L⁻¹ and the intra-assay variation was 2.0%. All samples for each test subject were analyzed in the same assay for each hormone.

The concentrations of serum testosterone, growth hormone (GH), cortisol, and dehydroepiandrosterone sulfate (DHEAS) were measured by enzyme-linked immunosorbent assay (ELISA) using kits obtained from Diagnostic Systems Laboratories (Webster, TX). The sensitivity of the testosterone assay was 0.14 nmol·L⁻¹ and the intra-assay and inter-assay variances were 4.1% and 2.8%, respectively. The sensitivity of the growth hormone assay was 0.07 µg·L⁻¹ and the intra-assay and inter-assay variances were 5.1% and 4.8%, respectively. The sensitivity of the cortisol assay was 2.8 nmol·L⁻¹ and the intra-assay and inter-assay variances were 4.9% and 4.2%, respectively. The sensitivity of the DHEAS assay was 40.6 nmol·L⁻¹ and the intra-assay and inter-assay variances were 4.1% and 6.3%, respectively.

**Experimental strength training.** The 6-month supervised resistance training period was divided into 2 phases and was designed to promote maximal strength as well as power. Weeks 1–12 consisted of high-load resistance training, and weeks 13–24 involved primarily power training with lower loads but higher movement velocities. The training program consisted of twice-weekly workouts of six exercises. In addition to warm-up on a cycle ergometer, warm-up sets were performed on exercises where the muscle had not previously been used for that session.
The exercises included Smith machine squat (down to a 90° knee angle), leg press or leg extension, leg curl, deadlift (from the knee height), an upper body exercise (bench press or shoulder press or lat pull down), and abdominal crunch. The high-load resistance training began at 10–12 repetition maximum (RM) for the first 4 weeks, then 6–8 RM for the next 6 weeks for 2–4 sets per exercise, and 3–5 RM for 3–4 sets per exercise for the last 2 weeks. The program then shifted to a power development routine consisting of performing the Smith machine squat and the leg press as explosively as possible at 30–50% (either 30-40-30%, or 40-40-40%, or 30-40-50%) of the 1-RM strength for 3-4 sets and for 6-10 repetitions per set. The other exercises were performed similarly to the first 12 weeks, with the periodization cycle repeated for the second 12 weeks. During the power training period every sixth workout performed for the legs was heavy (4–6 RM). Moreover, the subjects continued their ordinary daily chores and physical activities. The control subjects maintained their earlier physical activities including no strength training.

Statistical analysis. The means and standard deviations (SD) are given as descriptive statistics. To determine the effects of strength training the data were analyzed by multivariate analysis of variance with repeated measures (training vs control groups, sex, and time). The probability adjusted t-tests were used for pairwise comparisons when appropriate. The significance level was set at \( p \leq 0.05 \). Correlation coefficients were calculated by the Pearson method.

Results

The increase of 1 RM squat during the high-load resistance training (weeks 1–12) was 38.4 (25.6) % \( (p < .001) \) in TRW and 35.0 (6.7) % \( (p < .001) \) in TRM, respectively (Figure 1). No statistically significant changes took place either in CW or CM during the experimental period. The experimental groups differed \( (p < .05) \) from the control groups.

The percentage decreases in chair rise time during the 24 weeks were –24.8 (12.3) % for TRW \( (p < .001) \) and –25.4 (9.1) % \( (p < .001) \) for TRM (Figure 2). No statistically significant changes occurred in the chair rise times of the control groups. TRM differed \( (p < .05) \) from CM.

The relative proportion of type I muscle fibres remained unchanged both in the control and training groups (Table 2). In TRW the relative proportion of type IIa increased from 31.3 % to 43.4% \( (p < .05) \) and that of IIb decreased from 27.2% to 16.9% \( (p < .05) \). In TRM the decrease of type IIb was from 25.4% to 17.1% \( (p < .05) \). In both control groups the relative proportions of type I or type II fibers remained unchanged. Significant increases were recorded in the mean muscle fibre areas of type I, \( (p < .01) \), IIa \( (p < .01) \) and IIb \( (p < .01) \) in TRM and type I \( (p < .05) \) and IIa \( (p < .05) \) in TRW during the 24-week experimental period (Table 3), while no changes occurred in the controls.

Table 4 depicts the basal serum hormone concentrations at weeks 0, 6, 12, 18 and 24. The baseline concentrations in TRW were 1.6 (0.9) nmol·l\(^{-1}\), 1.7 (1.2) pmol·l\(^{-1}\), 2.0 (1.4) γmol·l\(^{-1}\), and 62.2 (21.0) nmol·l\(^{-1}\) for total testosterone, free testosterone, DHEAS and SHBG, respectively. The corresponding values for TRM were 14.6 (7.3) nmol·l\(^{-1}\), 45.3 (13.5) pmol·l\(^{-1}\), 2.8 (2.3) γmol·l\(^{-1}\) and 38.4 (16.0) nmol·l\(^{-1}\). No significant changes were observed either in TRW or TRM in any of
Figure 1. Mean (± SD) maximal concentric 1 RM strength in the squat-lift in older training men (TRM; 65 yrs, n = 10) and women (TRW, 64 yrs, n = 11), older control men (CM, 64 yrs, n = 5) and women (CW, 65 yrs, n = 5) during the 12-week heavy resistance (weeks 0–12) followed by the 12-week power (weeks 13–24) training period.

Figure 2. Mean (± SD) chair rise time in older training men (TRM; 65 yrs, n = 10) and women (TRW, 64 yrs, n = 11), older control men (CM, 64 yrs, n = 5) and women (CW, 65 yrs, n = 5) during the 12-week heavy resistance (weeks 0–12) followed by the 12-week power (weeks 13–24) training period.
Table 2  Mean (SD) Fibre Distribution of the Vastus Lateralis Muscle Before and After the 24-Week Strength Training Period in Old Training Women (TRW) and Men (TRM) and in Old Control Women (CW) and Men (CM)

<table>
<thead>
<tr>
<th></th>
<th>TRW (n = 8)</th>
<th>CW (n = 4)</th>
<th>TRM (n = 8)</th>
<th>CM (n = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I (%)</td>
<td>pre 41.5 (6.7)</td>
<td>31.8 (13.7)</td>
<td>42.5 (15.4)</td>
<td>44.0 (13.3)</td>
</tr>
<tr>
<td></td>
<td>post 39.8 (12.6)</td>
<td>32.8 (6.8)</td>
<td>44.0 (13.3)</td>
<td>44.1 (10.0)</td>
</tr>
<tr>
<td>Type IIa (%)</td>
<td>pre 31.3 (12.7)</td>
<td>41.3 (6.8)</td>
<td>32.1 (11.9)</td>
<td>26.0 (13.8)</td>
</tr>
<tr>
<td></td>
<td>post 43.4 (11.8)*</td>
<td>45.3 (5.4)</td>
<td>38.9 (10.2)</td>
<td>37.7 (5.1)</td>
</tr>
<tr>
<td>Type IIb (%)</td>
<td>pre 27.2 (14.8)</td>
<td>27.0 (9.6)</td>
<td>25.4 (8.2)</td>
<td>30.0 (10.4)</td>
</tr>
<tr>
<td></td>
<td>post 16.9 (13.0)*</td>
<td>22.0 (4.3)</td>
<td>17.1 (12.6)*</td>
<td>18.0 (14.7)</td>
</tr>
</tbody>
</table>

*Difference between the measurements p < .05.

Table 3  Mean (SD) Fibre Area (μm²) of the Vastus Lateralis Muscle Before and After the 24-Week Strength Training Period in Old Training Women (TRW) and Men (TRM) and in Old Control Women (CW) and Men (CM)

<table>
<thead>
<tr>
<th></th>
<th>TRW (n = 8)</th>
<th>CW (n = 4)</th>
<th>TRM (n = 8)</th>
<th>CM (n = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>pre 2283 (562)</td>
<td>2197 (349)</td>
<td>2589 (529)</td>
<td>2396 (295)</td>
</tr>
<tr>
<td></td>
<td>post 2936 (728)*</td>
<td>2047 (119)</td>
<td>3900 (856)**</td>
<td>2380 (180)</td>
</tr>
<tr>
<td>Type IIa</td>
<td>pre 2389 (551)</td>
<td>2354 (188)</td>
<td>2727 (606)</td>
<td>2567 (539)</td>
</tr>
<tr>
<td></td>
<td>post 3184 (682)*</td>
<td>2157 (48)</td>
<td>4048 (728)**</td>
<td>2369 (498)</td>
</tr>
<tr>
<td>Type IIb</td>
<td>pre 2176 (436)</td>
<td>1824 (42)</td>
<td>2336 (678)</td>
<td>2004 (383)</td>
</tr>
<tr>
<td></td>
<td>post 2589 (531)</td>
<td>1819 (811)</td>
<td>3416 (811)**</td>
<td>2013 (395)</td>
</tr>
</tbody>
</table>

*Difference between the measurements p < .05; **p < .01.

the hormone concentrations examined during the 24-week training period. The initial testosterone/SHGB ratio of 0.06 (0.04) in TRW and that of 0.43 (0.21) in TRM remained statistically unaltered during the follow-up period. No significant changes took place in the basal concentrations of total and free testosterone, DHEAS, SHBG, or testosterone/SHBG ratio in the control groups during the experimental period.
Table 4  Basal Serum Hormone Concentrations During the Course of 24-Week Strength Training Period in Old Training Women (TRW) and Men (TRM) and in Old Control Women (CW) and Men (CM)

<table>
<thead>
<tr>
<th></th>
<th>0 weeks</th>
<th>6 weeks</th>
<th>12 weeks</th>
<th>18 weeks</th>
<th>24 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Testosterone (nmolL⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRM</td>
<td>14.6 (7.3)</td>
<td>17.9 (10.4)</td>
<td>12.8 (4.3)</td>
<td>12.1 (1.3)</td>
<td>14.6 (9.5)</td>
</tr>
<tr>
<td>CM</td>
<td>14.8 (4.7)</td>
<td>16.1 (9.1)</td>
<td>15.9 (7.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRW</td>
<td>1.6 (0.9)</td>
<td>1.8 (1.0)</td>
<td>1.5 (1.1)</td>
<td>1.8 (0.7)</td>
<td>1.4 (0.7)</td>
</tr>
<tr>
<td>CW</td>
<td>1.7 (0.7)</td>
<td>1.9 (0.5)</td>
<td>1.8 (1.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Free testosterone(pmolL⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRM</td>
<td>45.3 (13.5)</td>
<td>51.3 (16.0)</td>
<td>44.5 (13.1)</td>
<td>48.3 (12.0)</td>
<td>45.0 (12.5)</td>
</tr>
<tr>
<td>CM</td>
<td>41.5 (10.0)</td>
<td>49.1 (10.0)</td>
<td>55.2 (15.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRW</td>
<td>1.7 (1.2)</td>
<td>1.9 (1.4)</td>
<td>1.8 (1.8)</td>
<td>1.4 (1.2)</td>
<td>1.4 (0.7)</td>
</tr>
<tr>
<td>CW</td>
<td>1.8 (1.1)</td>
<td>2.0 (2.0)</td>
<td>2.0 (1.9)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DHEAS (nmolL⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRM</td>
<td>2798 (2309)</td>
<td>2593 (1440)</td>
<td>3325 (1669)</td>
<td>2958 (1748)</td>
<td>2843 (1725)</td>
</tr>
<tr>
<td>CM</td>
<td>3475 (3135)</td>
<td>3474 (3136)</td>
<td>2599 (1532)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRW</td>
<td>2009 (1387)</td>
<td>2149 (1910)</td>
<td>1931 (1379)</td>
<td>2287 (1524)</td>
<td>1999 (1353)</td>
</tr>
<tr>
<td>CW</td>
<td>2212 (1387)</td>
<td>2250 (1742)</td>
<td>1887 (1792)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SHBG (nmolL⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRM</td>
<td>38.4 (16.0)</td>
<td>41.2 (18.0)</td>
<td>36.5 (12.1)</td>
<td>37.9 (16.4)</td>
<td>37.9 (16.4)</td>
</tr>
<tr>
<td>CM</td>
<td>47.2 (23.7)</td>
<td>45.5 (23.7)</td>
<td>44.1 (21.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRW</td>
<td>62.2 (16.0)</td>
<td>69.7 (18.7)</td>
<td>71.3 (12.4)</td>
<td>71.2 (16.4)</td>
<td>85.0 (16.3)</td>
</tr>
<tr>
<td>CW</td>
<td>76.0 (23.2)</td>
<td>65.0 (15.0)</td>
<td>67.9 (27.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Testosterone/SHBG ratio</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRM</td>
<td>0.43 (0.21)</td>
<td>0.51 (0.40)</td>
<td>0.37 (0.11)</td>
<td>0.44 (0.23)</td>
<td>0.56 (0.63)</td>
</tr>
<tr>
<td>CM</td>
<td>0.38 (0.22)</td>
<td>0.45 (0.36)</td>
<td>0.35 (0.08)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRW</td>
<td>0.06 (0.04)</td>
<td>0.06 (0.04)</td>
<td>0.05 (0.05)</td>
<td>0.04 (0.05)</td>
<td>0.04 (0.05)</td>
</tr>
<tr>
<td>CW</td>
<td>0.05 (0.03)</td>
<td>0.07 (0.02)</td>
<td>0.07 (0.03)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GH (μgL⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRM</td>
<td>0.342 (0.911)</td>
<td>0.176 (0.270)</td>
<td>0.431 (0.679)</td>
<td>0.075 (0.135)</td>
<td>0.348 (0.824)</td>
</tr>
<tr>
<td>CM</td>
<td>0.057 (0.070)</td>
<td>0.113 (0.203)</td>
<td>0.191 (0.228)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRW</td>
<td>1.174 (1.276)</td>
<td>0.739 (0.439)</td>
<td>0.872 (0.932)</td>
<td>0.797 (1.045)</td>
<td>1.362 (1.507)</td>
</tr>
<tr>
<td>CW</td>
<td>0.211 (0.202)</td>
<td>0.714 (0.984)</td>
<td>0.759 (0.819)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cortisol (nmolL⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRM</td>
<td>345 (86)</td>
<td>366 (102)</td>
<td>332 (99)</td>
<td>350 (130)</td>
<td>323 (86)</td>
</tr>
<tr>
<td>CM</td>
<td>344 (72)</td>
<td>277 (45)</td>
<td>332 (99)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRW</td>
<td>422 (134)</td>
<td>380 (83)</td>
<td>361 (77)</td>
<td>292 (37)</td>
<td>370 (71)</td>
</tr>
<tr>
<td>CW</td>
<td>296 (89)</td>
<td>348 (158)</td>
<td>320 (54)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The initial concentrations of GH of 1.1 μg l⁻¹ in TRW and that of 0.3 μg l⁻¹ in TRM remained statistically unaltered during the experimental period. The concentration of serum cortisol decreased from 422 (134) nmol l⁻¹ to 292 (37) (p < .01) between the weeks 0 and 18 in TRW, while no difference was observed between week 0 and week 24. The initial concentration of 345 (85) nmol l⁻¹ of cortisol in TRM remained statistically unaltered. The testosterone/cortisol ratios remained statistically unaltered in both TRW and TRM during the 24-week training period. In both control groups no significant changes took place in GH and cortisol concentrations or testosterone/cortisol ratios during the experimental period.

The individual (averaged) basal concentrations of testosterone/cortisol ratios correlated significantly (r = 0.63; p < .05) with the individual increases obtained in 1RM strength in TRW during the 24-week training period.

The mean concentration of serum testosterone did not change during the heavy resistance loading protocol at pre-training, while at post-training the increase (p < .05) in TRM was significant (Figure 3). The mean concentration of serum free testosterone increased during the loading in TRM at both pre- (p = .014) and post-training (p < .05) (Figure 4). The mean concentration of GH increased in TRW at both pre- (p < .05) and post-training (p < .05) and in TRM at

**Figure 3.** Mean (± SD) values for serum testosterone concentrations in older training women (TRW, 64 yrs, n = 11) and older training men (TRM; 65 yrs, n = 10) before (pre), immediately after the heavy resistance sessions (post) and after 10 minutes of recovery (post 10) both before (pre-training) and after (post-training) the 24-week strength training (heavy resistance for weeks 0–12 followed by power training for weeks 13–24) (*p < .05).

**Figure 4.** Mean (± SD) values for serum free testosterone concentrations in older training women (TRW, 64 yrs, n = 11) and older training men (TRM; 65 yrs, n = 10) before (pre), immediately after the heavy resistance sessions (post) and after 10 minutes of recovery (post 10) both before (pre-training) and after (post-training) the 24-week strength training (heavy resistance for weeks 0–12 followed by power training for weeks 13-24) (*p < .05).
Figure 5. Mean (± SE) values for serum growth hormone (GH) concentrations in older training women (TRW, 64 yrs, n = 11) and older training men (TRM; 65 yrs, n = 10) before (pre), immediately after the heavy resistance sessions (post) and after 10 minutes of recovery (post 10) both before (pre-training) and after (post-training) the 24-week strength training (heavy resistance for weeks 0–12 followed by power training for weeks 13–24) (*p < .05; **p < .01).

post-training (p < .05) with a further increase (p < .01) up to 10 minutes post-loading (Figure 5).

Discussion

The primary findings of the present study showed that the 24-week strength and power training performed only two times a week resulted primarily during the first 12-week heavy resistance training period in the following:

1. There were great gains in maximal concentric strength of the trained lower extremity extensor muscles with the same relative increases in the older men and women.
2. The strength gains were accompanied by significant improvements in the chair rise time in both groups.
3. The 12-week heavy resistance training followed by another 12-week power training period led to significant increases in the mean areas of type I and type II muscle fibres in both older men and older women.
4. The subject groups did not demonstrate systematic changes during the entire 24-week strength training period in mean serum concentrations of testosterone, free testosterone, DHEAS, GH, cortisol or SHBG.
5. The mean levels of individual serum testosterone/cortisol ratios correlated significantly with the individual changes recorded during the 24-week training period in maximal strength in the older women.
6. During the acute heavy resistance loading protocol the mean concentration of serum testosterone did not change either in the older women or men at pre-training, while at post-training the increase in the older men was significant as was also serum free testosterone at both pre- and post-training. The mean concentration of GH increased in the older women at both pre- and post-training and in the older men at post-training immediately post-loading, and it increased further up to 10 minutes post-loading.

The present progressive initial 12-week heavy resistance strength training led to great gains in the concentric 1 RM strength in the older subjects of both
genders (Figure 1). The relative magnitudes of the increases in maximal strength did not differ significantly between the two subject groups. The results are thus well in line with previous observations that maximal muscle strength of the leg extensors can be increased during progressive strength training independently of age and gender (Charette et al., 1991; Fiatarone et al., 1990; Frontera et al., 1988; Häkkinen and Häkkinen, 1995; Häkkinen et al., 1998b, 1998c, 2000; Kraemer et al., 1999; Lexell et al., 1995; McCartney et al., 1996; Morganti et al., 1995). It is of some importance to point out that the present increases in maximal strength during the initial 12-week training period were as large as 35–38%, although the subjects trained only two times a week. Thus, it seems that the frequency of strength training, at least in previously untrained older subjects, can be rather low such as twice a week, when the loading intensity of training is relatively high and increased progressively throughout the training period. It was an important finding that these strength gains in our older subjects were accompanied by the significant improvement in the chair rise time indicating improved functional capacity of the neuromuscular system in both groups. This is also in line with other studies that have shown increased walking speed or stair climbing speed due to strength training (Fiatarone et al., 1990; Sipilä et al., 1995; Taaffe et al., 1999; Verfaillie et al., 1997).

It has been shown that in previously untrained young and older subjects great initial gains in maximal strength can be attributed largely to the increased motor unit activation of the trained muscles, possibly resulting from the increased number of active motor units and/or the increase in their firing frequency (Häkkinen, 1994; Häkkinen et al., 1998b, 1998c; Komi, 1986; Moritani and DeVries, 1979, 1980; Sale, 1991). Because no EMG data were recorded in the present study, it was not possible to evaluate the magnitudes and time courses of training-induced increased activation of the agonists and those of training-induced learning effects in terms of reduced co-activation of the antagonist muscles shown to take place especially in older subjects (Häkkinen et al., 1998b). Because muscle biopsies were taken only at weeks 0 and 24, it was not possible to evaluate the actual degree of muscle hypertrophy contributing to maximal strength development separately during the initial heavy resistance or the latter power training periods. The entire training period of the 12-week heavy resistance training followed by the second 12-week power training period did lead to significant increases in the mean areas of type I and type II muscle fibres in both older men and older women. However, during the final 12-week power training period no further increases took place in maximal strength. This might be related in part to the fact that the training loads used for power training were lower than those used for maximal strength training. Second, it is likely that the specific nature of the training program which was composed of lower load exercises, might have led to only minor hypertrophy during the second 12-week power training period (Häkkinen, 1994). It has been shown that although neural activation during lower load exercises but with high movement velocities can be quite high even in older subjects (Häkkinen et al., 1998a), the duration of the activation during each single rapid muscle action remains much shorter than that of a typical heavy resistance training program. This may cause some limitations to maximal strength development and/or muscle growth (Häkkinen, 1994; MacDougall, 1991). It is possible that the frequency and/or type of training performed may not provide sufficient/proper training stimuli for continued strength gains and muscle growth in older men and women over prolonged
training periods. Nevertheless, skeletal muscles of older men and women retain
the capacity to undergo hypertrophy, when both the type, volume (and frequency),
and load level of heavy resistance loading as well as the duration of training period
are optimized for hypertrophic purposes (Frontera et al., 1988; Häkkinen, 1994).
However, some caution must be exercised when interpreting the muscle fibre data
obtained only at one particular portion of the thigh.

As expected, no changes in the percent of type I fibers were observed pre-to
post-training for the present subject groups. However, type II subtype transforma-
tion going from type IIb to IIa has been previously observed in younger
(Adams et al., 1993; Kraemer et al., 1995; Staron et al., 1991, 1994) and older men
(Häkkinen et al., 1998c). In the present study, the relative proportion of type IIa
increased from 31.3 % to 43.4 % (p < .05) and that of IIb decreased from 27.2 % to
16.9 % (p < .05) in our older women. In the older men the decrease of type IIb
from 25.4 % to 17.1 % was also significant (p < .05). However, some caution has
to be exercised when interpreting the present muscle fibre data, because the changes
in the control groups appeared to be in the same direction as the changes in the
experimental groups (Table 2). Second, the numbers of subjects and muscle fibres
included in the present analysis were rather low. Previous studies in younger men
with long training periods have typically demonstrated the absence or very low
percentages (< 2%) of type IIb muscle fibers after a heavy resistance training pro-
gram (Adams et al., 1993; Kraemer et al., 1995; Staron et al., 1991). Since no
muscle biopsies were taken after the first 12-week training period, the roles of
duration and/or mode of resistance training in muscle fiber transformation in the
subtypes needs further examination in older men and women.

No systematic changes were observed either during the first 12-week heavy
resistance or the second 12-week power training period in the concentrations of
serum testosterone, free testosterone, DHEAS, GH, cortisol, nor in the testoste-
ron/cortisol or testosterone/SHBG ratios. In general, these observations are rather
similar to those found earlier in both middle-aged and older subjects of both gen-
ders, when they have utilized typical heavy resistance training programs over a
period of a few months (Häkkinen and Pakarinen, 1994; Häkkinen et al., 2000;
Kraemer et al., 1999; Nicklas et al., 1995). The overall loading of the present
training program during both training periods may have been within normal physi-
ological range, because maximal strength increased greatly during the first 12-
week heavy resistance training and chair rise time changed further, although to a
lesser degree, also during the second 12-week power training period with no sys-
tematic changes in the concentrations of anabolic and catabolic hormones. How-
ever, the lack of changes in immunoreactive GH may not present the complete
picture of the adaptational responses of GH variants to resistance training. Actu-
ally, strength training in older people has been shown to lead to a substantial in-
crease in the presence of IGF-I in skeletal muscle tissue (Fiatarone et al., 1999).
Nevertheless, our data further showed that in the older women a significant corre-
lation was observed between the individual serum testosterone/cortisol ratio and
the individual changes in maximal strength during the entire 24-week strength
training period. A low level of the anabolic hormone testosterone in older women
may be a limiting factor in strength development, although the magnitudes of
strength gains between the two groups remained the same utilizing the present low
volume total body strength training protocol over the 24-week training period.
However, it is possible that even though the blood testosterone levels would remain unaltered, strength and/or power training can induce changes e.g. at the receptor level.

In addition to the basal levels of the hormones, serum total and free testosterone as well as GH concentrations were measured in the present study during the single heavy resistance exercise session before and after the 24-week strength training period. Serum testosterone concentration is known to increase during a typical heavy resistance session in young men, while the response in women may be minor (Fahey et al., 1976; Häkkinen and Pakarin, 1995; Kraemer et al., 1991; Weiss et al., 1983). The acute exercise-induced testosterone response is usually lower in older than in younger men (Craig et al., 1989; Häkkinen and Pakarin, 1995; Kraemer et al., 1998). In the present study no acute responses were observed in serum total and free testosterone in our older women. This is in line with previous observations (Häkkinen and Pakarin, 1995; Häkkinen et al., 2000). In our older men no significant acute response was either observed in serum total testosterone at pre-training, while the response was significant after 24 weeks of strength training. With regard to the free testosterone the increases were significant at both pre-training and post-training conditions. It is difficult to conclude the physiological significance of the difference in serum testosterone responses between older men and women with regard to the trainability of their muscle strength. It is also unclear whether the lack of serum testosterone response in our older women in both loading conditions is a limiting factor in strength development as it seems to be the case for the low basal serum testosterone level (Häkkinen et al., 2000).

It has been shown previously that the acute response of GH to heavy resistance loading is decreased due to aging in both men and women (Häkkinen and Pakarin, 1995). The results presented in Fig. 5 show that the present loading did result in increases in serum GH concentrations, although minor in magnitude, in both pre- and post-training conditions in both older subject groups. However, in the older men the response at post-training was significant not only immediately at post-loading but increased further, at least up to 10 minutes post-loading. This observation can be considered as an indication of the training-induced adaptation of the endocrine system showing that the acute GH hormone response may become more systematic after progressive strength training even in older men. It is possible that the magnitude of the response as well as the time duration of the response are both important physiological indicators of training-induced anabolic adaptations.

In summary, the primary findings of this study showed that the 24-week strength training performed only two times a week resulted primarily during the first 12-week heavy resistance training period in large gains in maximal concentric strength of the trained lower extremity extensor in both the older men and women. The strength gains associated also by the improved chair rise performance may have been explained by both training-induced neural and muscular adaptations, since the entire 24-week resistance training period led to significant increases in the mean areas of type I and type II muscle fibres in both genders. No changes occurred during the training period in the mean serum concentrations of hormones examined, but a low basal testosterone/cortisol ratio in older women may be a limiting factor in strength development. During the acute heavy resistance loading protocol the mean concentration of serum testosterone did not change either in the
older women or men at pre-training, while at post-training the increase in the older men was significant as was also for serum free testosterone at both pre- and post-training. The mean concentration of GH increased in the older women at both pre- and post-training and in the older men at post-training, not only immediately post-loading but increased further up to 10 minutes post-loading. It is possible that the magnitude of the acute testosterone and GH hormone response as well as the time duration of the response are both important physiological indicators of training-induced anabolic adaptations. Finally, the overall data indicate that frequency and/or type of training performed may not provide sufficient/proper training stimuli for continued strength gains and muscle growth in older men and women over longer training periods.

References


Acknowledgment

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