Neuromuscular adaptations during bilateral versus unilateral strength training in middle-aged and elderly men and women

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Twelve middle-aged men and 12 middle-aged women in the 50-year-old age group (M50; range 44–57 years; W50; 43–57), and 12 elderly men and 12 elderly women in the 70-year-old age group (M70; 59–75; W70; 62–75) volunteered as subjects in order to examine effects of 12-week progressive heavy resistance strength training on electromyographic activity (EMG), muscle cross-sectional area (CSA) of the quadriceps femoris and maximal concentric force in a one repetition maximum (1 RM) test of the knee extensor muscles. One half of the subjects in each group performed the knee extension (and flexion) exercises only bilaterally (BIL), while another half performed the exercises only unilaterally (UNIL). None of the subject groups demonstrated statistically significant changes in any of the 1 RM values during the 2 week control period with no training (between week −2 and 0) preceding the actual experimental training. However, the 12-week training resulted in increases \(P < 0.05–0.001\) in 1 RM values in each group so that the average relative increase of \(19 ± 12\% (P < 0.001)\) in bilateral 1 RM in all BIL trained subjects was greater \((P < 0.05)\) than that of \(13 ± 8\% (P < 0.001)\) recorded for all UNIL trained subjects. The average relative increases of \(17 ± 11\% (P < 0.001)\) and \(14 ± 14\% (P < 0.001)\) in unilateral 1 RM values of the right and left leg in all UNIL trained subjects were greater \((P < 0.05)\) than those of \(10 ± 18\% (P < 0.001)\) and \(11 ± 11\% (P < 0.001)\) recorded for all BIL trained subjects, respectively. The relative average increase of \(19 ± 19\% (P < 0.001)\) observed in the maximum averaged IEMG of both legs during the bilateral actions in all BIL trained subjects was greater \((P < 0.05)\) than that of \(10 ± 17\% (P < 0.05)\) recorded for all UNIL trained subjects. The relative increases of \(14 ± 12\% (P < 0.001)\) and \(11 ± 6\% (P < 0.001)\) recorded for the CSA in all BIL and UNIL trained subjects did not differ significantly from each others. The present findings suggest that progressive heavy resistance strength training leads to great increases in maximal dynamic strength of the trained subjects accompanied by both considerable neural adaptations and muscular hypertrophy not only in middle-aged but also in elderly men and women. Both bilateral and unilateral exercises are effective to produce functional and structural adaptations in the neuromuscular system, although the magnitude of functional strength increase seems to be specific to the type of exercise used, further supporting the principle of specificity in the design of strength programmes.

Keywords aging, muscle cross-sectional area, electromyography, bilateral and unilateral strength, strength training.

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On the other hand, it has been rather well established that considerable increases in muscle strength may take place due to progressive strength training not only in young but also in older people. The increase in strength during strength training in middle-aged and also in elderly people might result both from increased motor unit activation of trained muscles and hypertrophy of muscle fibres. The basic requirements for this are that both the overall training intensity and the duration of the training period are sufficient (Frontera et al. 1988, Grimby 1988, Fiatarone et al. 1990, Charette et al. 1991, Rogers & Evans 1993, Roman et al. 1993, Håkkinen & Pakarinen 1994, Treuth et al. 1994, Håkkinen & Häkkinen 1995, Siplärä & Suominen 1995).

Since the early 1960s (Asmussen & Heeboll-Nielsen 1961), the bilateral deficit in which the bilateral force of the knee extensors is smaller than the sum of the unilateral forces has been shown to occur both in large and small muscle groups as well as in athletic and non-athletic populations (Secher 1975, Ohtsuki 1981, Vandervoort et al. 1984, Secher et al. 1988, Schantz et al. 1989, Howard & Enoka 1991, Koh et al. 1992). The bilateral deficit is suggested to be caused by the inability of the central nervous system to activate maximally a large number of bilateral muscle groups at the same time, especially of the fast motor units and/or that the decreased ability for the maximal neural activation may be associated with an alteration in peripheral neural control (Vandervoort et al. 1984, Howard & Enoka 1991, Archontides & Fazey 1993). However, there are also studies which demonstrate that while the bilateral deficit could be observed in multi-joint force production tasks, it did not necessarily occur in some simple single joint force production tasks or that some subjects may have even exhibited a bilateral facilitation (Secher 1975, Schantz et al. 1989, Howard & Enoka 1991). Presently, only limited data are available on the phenomenon of the bilateral deficit in aging men and women after their sixth decade (e.g. Håkkinen et al. 1996) but the data seem to suggest that the bilateral deficit may not be found in a simple joint force production task and this might not be influenced by aging. Effects of actual bilateral or unilateral strength training on the bilateral/unilateral force ratio have received limited research attention (e.g. Enoka 1988, Rube & Secher 1990) and only during the short-term training periods of 3–6 weeks in duration (Coyle et al. 1981, Howard 1987). Coyle et al. (1981) reported in young adult subjects comparable increases in 1- and 2-legged strength with 2-legged strength training, while Howard (1987) found a training induced increase of the bilateral/unilateral force ratio for the group that trained with two legs. Whether specific changes in the bilateral/unilateral force ratio could actually take place, when the principle of specificity in the design of strength programmes is utilized during a prolonged training period should be of some interest both from the scientific and practical points of view.

The present study had two major purposes. The first was to further investigate neuromuscular adaptations in middle-aged and elderly men and women during 12-weeks of heavy resistance strength training of the leg extensor muscles. Our second interest was to compare these neuromuscular adaptations caused by bilateral strength training with those produced by strength training utilizing only unilateral exercises.

METHODS

Subjects

The subjects in this study were 12 middle-aged men in the 50-year-old age group (M50) (range 44–57), 12 middle-aged women in the 50-year-old age group (W50) (range 43–57), 12 elderly men in the 70-year-old age group (M70) (range 59–75), and 12 elderly women in the 70-year-old age group (W70) (range 62–75). The physical characteristics of the subject groups are

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presented in Table 1. The volunteers were informed of possible risks and discomforts that might result and all subjects gave their written informed consent to participate in this investigation. The study was conducted according to the declaration of Helsinki and was approved by the Ethics Committee of the University of Jyväskylä.

All the subjects were healthy and living independently in the town of Jyväskylä, Finland. The subjects were habitually physically active. Recreational fitness activities involved participation in physical activities such as walking, jogging, swimming, biking and aerobics. It is therefore likely that the present subjects may have had a higher level of motivation and/or training-responsiveness compared with normal, more sedentary age-matched subjects. However, none of the subjects had any background in regular strength training or competitive sports of any kind. No medication was being taken by the subjects which would have been expected to have affect physical performance. This work is a part of a larger research project. Some of the results obtained with these subjects from the first measurements of the present follow-up design have been used earlier for various cross-sectional comparative purposes between the two different age-groups of both genders (Häkkinen et al. 1996).

### Experimental design and testing

The total duration of the present follow-up period was 14 weeks. The subjects were tested on five occasions using identical protocols. The first 2 weeks of the follow-up (between the measurements at week -2 and at week 0) was used as a control period during which time no strength training was carried out but the subjects maintained their normal recreational fitness activities (e.g. walking, jogging, biking, swimming and aerobics). Thereafter the subjects went through an experimental training period by performing supervised strength training for 12 weeks. The measurements were repeated during this period at 4 week intervals (at weeks 4, 8 and 12).

The subjects were carefully familiarized with the testing procedures of voluntary concentric force production during a few warm-up contractions separately for both the bilateral and unilateral conditions. A David 200 dynamometer modified for strength testing (Häkkinen et al. 1987) was used. The subject was in a seated position so that the hip angle was 110 degrees. On verbal command the subject performed a concentric knee extension starting from a flexed position of about 70 degrees trying to reach a required extension of a minimum of 170 degrees (full extension 180 degrees) against the resistance de-
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Figure 1 Mean (± SD) maximal bilateral 1 RM (kg) of the knee extensor muscles in middle-aged (50 years) and elderly (70 years) men (M50, M70) and women (W50, W70) for the bilaterally (BIL; ⋄) and unilaterally (UNIL; ▼) trained subgroups during a 2-week control period and during the course of the 12-week strength training period.

The possible effects of fatigue. The last acceptable extension with the highest possible load was determined as 1 RM. The range of knee extension was analysed indirectly using the signal recorded from the moving resistance bar of the dynamometer. In the analysis of the data the differences in the range of motion between the bilateral and unilateral conditions for the right and left leg extensions were not allowed to be greater than 10 degrees within each subject.

Electromyographic activity (EMG) was recorded telemetrically (Glonner, München, Germany) during the bilateral and unilateral testing contractions from the vastus lateralis (VL), vastus medialis (VM) and rectus femoris (RF) muscles of the right and/or left leg. Bipolar (20-mm interelectrode distance) surface EMG recording (Beckman miniature-sized skin electrodes 650437, Illinois, USA) was employed. The positions of the electrodes were marked on the skin by small ink tatoos (Häkkinen & Komi 1983). These dots ensured the same electrode positioning on each test throughout the 14-week experimental period. The electrodes were placed longitudinally on the motor point area determined by a Disa stimulator. The EMG signal amplification was 200 (Glonner, Biomes 2000; cut off frequency 360 Hz 3 dB−1) and digitized at the sampling frequency of 1000 Hz by an on-line computer system. EMG was full wave rectified, integrated (IEMG) and time normalized for 1 s for each muscle separately and then averaged for the entire range of motion of the concentric knee extensions.

The cross-sectional area (CSA) of the quadriceps femoris (QF) muscle group (rectus femoris, vastus lateralis, vastus medialis and vastus intermedius muscles) was measured with a compound ultrasonic scanner (Aloka FANSONIC, SSD-190) and a 5 MHz convex transducer. Two consecutive measurements were taken separately from both the left and the right thighs and then averaged for the left and right thigh, respectively. The CSA was measured at the mid-point between the greater trochanter and lateral joint line of the knee. The CSA was then calculated from the image by the computerized system of the apparatus (Ruyshi et al. 1988). The CSA measurements were taken before (at week 0) and after the strength training period (at week 12).

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

Experimental strength training

The subjects participated in a supervised strength training two times a week for 12 weeks. Each training session the subjects performed knee extension, knee flexion, trunk extension and flexion and two upper
extremity exercises. One half of the subjects in each group performed the knee extension and flexion exercises only bilaterally (BIL), while another half performed the exercises only unilaterally (UNIL). The UNIL trained subjects trained also both legs but they performed it only unilaterally so that number of repetitions per leg was comparable between the bilaterally trained legs.

During the first 4 weeks of the training the subjects trained with the loads of 40–50% of 1 RM. The subjects performed 10–12 repetitions per set and performed altogether 3–4 sets in each exercise. During the second 4 weeks of the training (weeks 5–8) the subjects used the loads in all exercises except the two trunk exercises between 60 and 80% of 1 RM by performing 6–8 reps per set altogether for 3–5 sets per exercise. In the trunk flexion and extension exercises the subjects still performed 10–12 reps per set (with the load of 10–12 RM) altogether for 3–4 sets. During the last 4 weeks of the training (weeks 9–12) the subjects trained with the loads of 70–90% of 1 RM by performing 3–6 reps per set altogether for 4–6 sets in each exercise except the two trunk exercises. In these latter two exercises they performed 12–15 reps per set (with the load of 12–15 RM) altogether for 3–4 sets.

In general, the strength training program utilized in the present study was a so-called periodized program. The overall training loading was progressively increased throughout the training period and periodized by also paying attention to enhance recovery and reduce boredom in order to promote ‘optimal’ strength development.

During the present 12-week experimental strength training period the subjects also continued to take part in recreational physical activities such as walking, jogging, swimming, biking or gymnastics 1–2 times a week in a similar way they used to do before the experiment.

Statistical methods
Conventional descriptive statistical methods were used for calculation of means, standard deviations (SD) and Pearson product moment correlation coefficients. The data were then analysed utilizing a multivariate analysis of variance (MANOVA) with repeated measures. Probability adjusted t-tests (two-tailed) were used for pairwise comparisons when appropriate. The significance was chosen at $P \leq 0.05$ for this investigation.

RESULTS

Maximal bilateral and unilateral strength
No statistically significant changes took place during the control period (between week −2 and 0) in the

Figure 2 Mean (±SD) relative (from the initial value of 100%) maximal bilateral 1 RM (Δ%) of the knee extensor muscles in middle-aged (50 years) and elderly (70 years) men and women for the bilaterally (BIL) and unilaterally (UNIL) trained subgroups and for the average of all BIL and UNIL trained groups during the control period of 2 weeks and during the 12-week strength training period (*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$).
Bilateral and unilateral strength training


Figure 3 Mean (± SD) relative maximal unilateral knee extension 1 RM (%) of the right leg in middle-aged (50 years) and elderly (70 years) men and women for the bilaterally (BIL) and unilaterally (UNIL) trained subgroups and for the average of all BIL and UNIL trained groups during the control period of 2 weeks and during the 12-week strength training period (*P < 0.05; **P < 0.01).

Figure 4 Mean (± SD) relative changes in bilateral/unilateral (left + right) 1 RM ratio (Δ%) of the knee extensor muscles in middle-aged (50 years) and elderly (70 years) men and women for the bilaterally (BIL) and unilaterally (UNIL) trained subgroups and for the average of all BIL and UNIL trained groups during the 12-week strength training period (*P < 0.05; **P < 0.01).

maximal voluntary bilateral concentric 1 RM values in the BIL and UNIL trained groups of W50, M50, W70 or M70 (Fig. 1). This was true also for the unilateral 1 RM values of the right and left leg in all subgroups.

The maximal voluntary bilateral 1 RM values increased during the 12-week training significantly (P < 0.05–0.001) in all subgroups (Figs 1, 2). The average relative increase of 19 ± 12% (P < 0.001) in bilateral strength in all BIL trained subjects was greater (P < 0.05) than that of 13 ± 8% (P < 0.001) recorded for all UNIL trained subjects (Fig. 2, bottom panel).

The maximal unilateral strength of the right leg also increased significantly (P < 0.05–0.001) during the 12-week training in all subgroups (except for BIL M70). The average relative increase of 17 ± 11% (P < 0.001) in the right unilateral 1 RM values in all UNIL trained subjects was greater (P < 0.05) than that of 10 ± 18% (P < 0.001) recorded for all BIL trained subjects (Fig. 3, bottom panel). The maximal unilateral strength of the left leg increased in all subgroups but it was significant (P < 0.05–0.01) only in BIL and UNIL W50, M50, BIL and UNIL M70. The average relative increase of 14 ± 14% (P < 0.001) in the unilateral left leg strength value in all UNIL trained subjects was slightly (n.s.) greater than that of 11 ± 11% (P < 0.001) recorded for all BIL trained subjects.

None of the subgroups demonstrated a value lower than 1 in the bil/unil strength ratio in the beginning of the follow-up period of the study. The average relative increase of 7 ± 11% (P < 0.01) in the bil/unil strength ratio in all BIL trained subjects during the 12-week training differed significantly (P < 0.01) from
Figure 5 Mean (± SD) relative maximum integrated electromyographic activity (IEMG) (averaged for the VL, VM and RF muscles of both legs) during the bilateral 1 RM knee extension (A%) in middle-aged (50 years) and elderly (70 years) men and women for the average of all BIL and UNIL trained groups during the 12-week strength training period (*P < 0.05).

The maximum averaged IEMG values of both legs during the bilateral conditions increased during the 12-week training in all subgroups being statistically significant (P < 0.05) for BIL trained groups of W50, W70 and M70 and for UNIL trained M50 and for the left leg of BIL trained M50 (P < 0.05). The average relative increase of 19 ± 19% (P < 0.001) in the maximum averaged IEMG of both legs during the bilateral condition in all BIL trained subjects was greater (P < 0.05) than that of 10 ± 17% (P < 0.05) recorded for all UNIL trained subjects (Fig. 5).

The maximum averaged IEMG values of the right leg during the unilateral conditions increased during the 12-week training significantly (P < 0.05) in UNIL trained groups of M50 and W70. The average relative increases in the maximum averaged IEMG of the right leg was 9 ± 15% (P < 0.05) for all UNIL trained subjects and 7 ± 11% (P < 0.05) for all BIL trained subjects (Fig. 6). The maximum averaged IEMG values of the left leg during the unilateral conditions...
increased during the 12-week training significantly (P < 0.05) only in UNIL trained group of M50. The average relative increase of 11 ± 18% in the maximum averaged IEMG of the left leg for all UNIL trained subjects was significant (P < 0.05), while the corresponding relative change of 8 ± 22% for all BIL trained subjects did not reach a statistically significant level.

In the total sample of BIL trained subjects the individual changes during the 12-week training in the maximum averaged IEMG of both legs recorded during the bilateral conditions correlated significantly (r = 0.59; P < 0.01) with the individual changes in the bilateral concentric 1 RM values. In the total sample of UNIL trained subjects the individual changes during the 12-week training in the maximum averaged IEMG values of the right leg during the unilateral conditions correlated significantly (r = 0.52; P < 0.05) with the individual changes in the unilateral concentric 1 RM values of the right leg. The corresponding correlation in the total sample of UNIL trained subjects for the left leg during the unilateral conditions was also significant (r = 0.59; P < 0.01).

**Muscle CSA**

Significant (P < 0.05–0.01) enlargements took place during the 12-week training in the averaged CSA of the quadriceps femoris muscle of both legs in BIL trained groups of W50, W70 and M70 (Fig. 7), while the increase in BIL M50 was significant (P < 0.05) for the left leg. In UNIL trained subjects the increases in the average CSA of both legs were significant (P < 0.01–0.001) for all groups of W50, M50, W70 and M70. The relative increase of 14 ± 12% (P < 0.001) recorded for the averaged CSA of both legs in all BIL trained subjects did not differ significantly from that of 11 ± 6% (P < 0.001) recorded for all UNIL trained subjects.

The individual changes during the 12-week training in the averaged CSA of both legs did not correlate significantly with the individual changes in the bilateral or unilateral 1 RM values recorded during the training neither in all BIL (r = 0.23; n.s.) nor in all UNIL trained subjects (r = 0.14; n.s. and 0.20; n.s. for the right and left leg, respectively).

**DISCUSSION**

The primary results of the present study demonstrated that both the unilateral and bilateral type of progressive heavy resistance strength training programs led to substantial gains in maximal strength of the trained muscles both in the middle-aged and elderly men and women. The strength gains were selectively accompanied by considerable increases in the voluntary neural activation of the trained muscles and also with considerable enlargements in the cross-sectional areas of the muscles not only in the middle-aged subjects but in the elderly men and women as well. Interestingly, a training specificity effect was also observed such that the increases in bilateral strength were greater in BIL than in UNIL trained subjects, while the increases in unilateral strength tended to be greater in UNIL than BIL trained subjects.

It is a common belief that in previously untrained young and old men and women great initial increases in maximal strength observed during the first few weeks of strength training can be attributed largely to the increased motor unit activation of the trained muscles (Moritani & DeVries 1980, Häkkinen & Komi 1983, Komi 1986, Sale 1988, Häkkinen 1994, Häkkinen & Häkkinen 1995). Learning effects (Rutherford & Jones 1986) in terms of an optimized activation of synergists and/or reduced coactivation of the antagonist muscles (Carolan & Cafarelli 1992) probably also play an important role. Significant increases took place in the averaged maximal IEMG of the trained muscles also in the present middle-aged and elderly male and female subjects during the course of the 12-week training period as a result of both BIL and UNIL programs. In general, this finding supports well the concept that increases in maximal strength during strength training in previously untrained subjects, independent of the age and sex, would be attributed in part to considerable training-induced...
increases in the voluntary activation of the trained muscles (Moritani & DeVries 1980, Håkkinen & Håkkinen 1995). The increases in the maximum IEMGs took place not only during the initial phases but during the entire course of the 12-week training, probably due to the fact that the training loads were progressively increased throughout the training period. The present 12-week progressive strength training of both programs led also to considerable enlargements in the CSA of the trained muscles in all subject groups of both sexes and both age groups. Therefore, the present findings support well the concept that skeletal muscle of elderly men and women retains the capacity to undergo hypertrophy, when both the loading intensity and the duration of the strength training period are sufficient (Frontera et al. 1988, Fiatarone et al. 1991, Charette et al. 1991, Rogers & Evans 1993, Roman et al. 1993, Treuth et al. 1994, Håkkinen & Håkkinen 1995, Siipilä & Suominen 1995). The magnitude of training-induced muscular hypertrophy, however, does not necessarily correlate significantly with the increases obtained in maximal strength of the trained muscles during a training period of some weeks or a few months (Frontera et al. 1988, Fiatarone et al. 1990, Charette et al. 1991, Håkkinen & Håkkinen 1995). Anyway, the overall enlargements of 10–14% took place in the CSA of the trained muscles over the entire 12-week training period, while the average increases in maximal strength of the subject groups were within 14–19%. This finding also supports the suggestion that adaptation of the nervous system as well as that of muscle hypertrophy are both important for strength development in previously untrained subjects, independent of their age and sex. However, to what extent the degree of training-induced muscle hypertrophy and/or strength development is limited in magnitude due to hormonal factors, such as serum basal levels of anabolic hormones and growth factors, and alterations in their acute responsiveness to exercise, during more prolonged strength training especially in women and in older men needs to be examined in more detail in the future (Kraemer et al. 1990, Håkkinen & Pakarinen 1993, 1994, Treuth et al. 1994).

Our special interest in this study was also to investigate training-induced neuromuscular adaptations caused by strength training utilizing only unilateral exercises in comparison with training in which only unilateral exercises were used for the leg extensor muscles. Actually, a specificity effect was observed such that the average increase of 19% in the bilateral 1 RM strength recorded for all BIL trained subjects was significantly greater than that of 13% obtained for all UNIL trained subjects. Accordingly, the increases of 17 and 14% in the unilateral strength recorded for all UNIL trained subjects were greater than those of 10 and 11% noted for all BIL trained subjects. Although none of the present subject groups demonstrated a bilateral deficit as such (Archontides & Fazey 1993), probably due to the simple single joint concentric 1 RM force production task utilized (Håkkinen et al. 1996), the bilateral/unilateral strength ratio increased during the 12-week training period by 7% in BIL trained subjects, while it decreased slightly (n.s.) by 2% in UNIL trained subjects. The latter observation, although statistically insignificant, is in line with the data by Howard (1987) obtained during a shorter training period of 3 weeks.

The increases in the averaged maximum IEMG recorded during the bilateral contractions were also greater in BIL than UNIL trained subjects, while increases in the averaged maximum unilateral IEMG were significant for both the right and left leg only in UNIL trained subjects. Although the EMG is a complicated signal and represents only an average of the maximal neural activation of the muscle, the present results suggest that the specificity between the bilateral and unilateral strength increases seems to have a neural basis. This suggestion is further supported by the observation that the degree of muscular hypertrophy, as indicated by the enlargement in the CSA of m. quadriceps femoris, did not differ significantly between BIL and UNIL trained subjects during the present 12-week experimental period. In addition, the significant correlation coefficients observed between the individual training-induced changes in the bilateral strength and the changes in the averaged bilateral IEMG as well as between the individual changes in the unilateral strength and the changes in the unilateral IEMGs lie well within concept of a neural basis for the specific training-induced changes in the bilateral/unilateral force ratio. However, to what extent these specific neural adaptations take place at various levels in the central nervous system and/or how much the specificity in the increased activation of the muscles may be associated with peripheral neural control are difficult to interpret due to the limitations of the methods utilized in the present study. Nevertheless, the present findings argue in favour of the principle of specificity in the design of strength programmes in order to optimize the training process. Thus, these specific adaptations should be considered when designing exercise programmes for rehabilitation or the prevention of injury and loss of function in elderly people. However, whether this type of strength training utilizing either unilateral or bilateral exercises only during a much more prolonged training period would lead to an actual bilateral deficit or a bilateral facilitation, respectively, remains to be answered after a series of controlled longitudinal
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studies. Strength athletes such as weightlifters, who use a lot of bilateral squats in their training have been reported to be able to produce even a bilateral facilitation instead of a deficit (Howard & Enoka 1991). To what extent the activation and force production of the muscles would be different in terms of the bilateral deficit during various multi-joints exercises utilizing higher velocity concentric, eccentric or various stretch-shortening cycle movements and to what extent the degree of the specificity of the training under these types of conditions would possibly differ from that of the present one awaits further study.

In summary, the present findings suggest that progressive heavy resistance strength training leads to great increases in maximal strength of the trained muscles accompanied by both considerable neural adaptations and muscular hypertrophy not only in middle-aged but also in elderly men and women. Since older people may usually be involved more in endurance type physical activities, one could therefore suggest that to minimize the effects of aging on the neuromuscular system, strength training could well be recommended as a part of an overall physical training programme to maintain the functional capacity among elderly people at as high a level as possible for as long as possible. Strength training among aging people can be utilized as a preventive, therapeutic and rehabilitative method to optimize neuromuscular function and enhance physical performance. Both bilateral and unilateral exercises are effective to produce functional and structural adaptations in the neuromuscular system but the magnitude of functional strength increase is specific to the type of exercise used, further supporting the principle of specificity in the design of strength programmes.

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