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Bilateral and Unilateral Neuromuscular Function and Muscle Cross-Sectional Area in Middle-Aged and Elderly Men and Women

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Forty-eight healthy men (M) and women (W), divided into two different age groups, i.e., M50 yrs (range 44–57; n = 12), W50 yrs (range 43–57; n = 12), M70 yrs (range 59–75; n = 12), and W70 yrs (range 62–75; n = 12), volunteered as subjects for examination of muscle cross-sectional area (CSA), maximal voluntary forces, force-time curves, and electromyographic activity of the knee extensor muscles during bilateral and unilateral isometric contractions. The maximal bilateral knee extension force and the average CSA values in M50 were greater (p < .05) than in M70 and in W50 were greater (p < .05–.001) than those recorded for W70. The early forces in the force-time curve were greater (p < .05) for M50 than for M70 and in W50 were greater (p < .05) than in W70. The individual values of the CSA of the left and right quadriceps femoris (QF) correlated (p < .05–.001) with the individual values of maximal unilateral knee extension forces in M50 (r = .87 and r = .87), M70 (r = .61 and r = .80), W50 (r = .79 and r = .58), and W70 (r = .56 and r = .54). When the force values were related to the CSA of the muscle, W70 demonstrated a lower (p < .05) value than the other three groups. Maximal voluntary bilateral forces didn't differ from those of the summed unilateral forces, and the maximal integrated EMG values during the bilateral and unilateral contractions of the same leg were also the same. The results suggest that the decline in maximal strength with increasing age could be related to the decline in the CSA of the muscle, but in older people, especially women, strength decreases seemed to be multifactorial, including possibly a decrease in voluntary neural drive or changes in "qualitative" characteristics of the muscle tissue. Explosive strength may decrease with aging even more than maximal strength, suggesting that atrophying effects of aging may be greater on fast-twitch muscle fibers than on slow-twitch fibers and/or that the rate of neural activation of the muscles may also be influenced by aging. On the other hand, the central nervous system in a simple single joint isometric force production of the knee extensors seems to be capable of activation of the two bilateral QF muscle groups to the same degree in comparison to that of the unilateral activation only.

HUMAN muscle strength in men and women reaches its peak normally between the ages of 20 and 30 years. It then remains relatively stable with only slight decreases for more than 20 years. However, with increasing age, normally at the onset of the sixth decade, a steeper decline in maximal strength begins (Larsson, 1978; Asmussen, 1980; Heikkinen et al., 1984; Young et al., 1984; Viitasalo et al., 1985; Vandervoort et al., 1986; Gandee et al., 1989; Rice et al., 1989; Frontera et al., 1991; Häkkinen and Häkkinen, 1991; Narici et al., 1991; Häkkinen and Pakarinen, 1993). However, the age-related decrease in strength may be slightly different in different muscle groups (e.g., Viitasalo et al., 1985; Frontera et al., 1991). The decrease in maximal strength has been related, to a great extent, to a reduction in muscle mass in both men and women. This appears to be often associated with a decline in normal daily physical activities and/or with a decline in the intensity of these activities. The decline in muscle mass is thought to be mediated by a reduction in the size of individual muscle fibers, especially of fast-twitch fibers, and/or a loss of individual fibers (Larsson et al., 1978; Aniansson et al., 1981; Lexell et al., 1983, 1988; Essen-Gustavsson and Borges, 1986; Grimby, 1988). This results in a decrease in explosive muscular strength whether determined using dynamic muscle actions (Larsson et al., 1979; Bosco and Komi, 1980; Davies et al., 1982; Bassey and Harries, 1987; Viitasalo et al., 1989) or as a lengthening in the time of rapid isometric force production (Clarkson et al., 1981; Häkkinen and Häkkinen, 1991; Häkkinen and Pakarinen, 1993). Thus, aging results in both structural and functional changes in the neuromuscular system.

As early as 1961, Asmussen and Heeboll-Nielsen demonstrated that the maximal voluntary force during the bilateral isometric knee extension was lower than the sum of the maximal unilateral forces. Since then, the bilateral deficit has been shown to occur both in large and small muscle groups as well as in athletic and nonathletic populations (Secher, 1975; Ohtsuki, 1981; Vandervoort et al., 1984; Secher et al., 1988; Schantz et al., 1989; Howard and Enoka, 1991; Koh et al., 1992). The bilateral deficit is suggested to be primarily due to the inability of the central nervous system to activate maximally a large number of bilateral muscles/muscle groups simultaneously and/or that this decreased activity may be related to peripheral neural control (Vandervoort et al., 1984; Howard and Enoka, 1991; Koh et al., 1992; Archontides and Fazey, 1993). However, there are studies which demonstrate that the bilateral deficit could be observed in multi-joint force production tasks but not in some simple single joint force production tasks or that some subjects may even exhibit a bilateral facilitation (Secher, 1975; Schantz et al., 1989; Howard and Enoka, 1991). Presently, no data are available on the phenomenon of the bilateral deficit in aging men and women after their sixth decade.

The purpose of the present study was to further examine age-related changes in muscle cross-sectional area, maximal and explosive force production characteristics of the knee extensor muscles in middle-aged and elderly men and women. A secondary purpose was to examine the phenomenon of the bilateral deficit by recording electromyographic activity and force production during the bilateral and unilateral conditions.

Methods

Subjects. — The subjects in this study were 12 middle-aged men in the 50-year-old age group (range 44–57), 12 middle-aged women in the 50-year-old age group (range 43–57), 12 elderly men in the 70-year-old age group (range 59–75), and 12 elderly women in the 70-year-old age group (range 62–75). The physical characteristics of the four subject groups are 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 the 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, but 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 affect physical performance. Maximal voluntary force data obtained with the present group of the middle-aged men have been presented elsewhere with a different hypothetical context (Häkkinen et al., 1995).

Testing. — The subjects were carefully familiarized with the bilateral and unilateral testing procedures of voluntary force production during several warm-up contractions which preceded the actual maximal contractions. A David 200 dynamometer (David Fitness and Medical Ltd), modified for the isometric testing (Häkkinen et al., 1987), was used to measure maximal voluntary bilateral and unilateral isometric peak force, force-time, and relaxation-time parameters of the knee extensor muscles (Viitasalo et al., 1980; Häkkinen et al., 1988). The subject was in a sitting position so that the knee and hip angles were 107 and 110 degrees, respectively. The subjects were carefully instructed to respond to an auditory signal by exerting their maximal force as rapidly as possible during a time period of 2.5–5.0 s. They were also instructed to relax the force as fast as possible after the required contraction time and having reached their maximal peak force of each contraction. Three to four maximal testing contractions were first recorded until maximal bilateral peak force was obtained. Thereafter, two to three maximal unilateral isometric testing contractions were recorded separately for the right and left leg. In the unilateral testing, the subject was in the same sitting position on the dynamometer as during the bilateral conditions. The time period of rest between the maximal contractions was always 1.5 minutes.

The force was recorded on magnetic tape (Racal 16) and thereafter digitized and analyzed with a Codas TM computer system (Data Instruments, Inc.). Maximal peak force was defined as the highest value of force (as Newtons; N) recorded during the bilateral and the two unilateral isometric contractions. The force-time analysis on the absolute scale included the calculation of average force produced during the consecutive time periods of 100 ms in duration from the start of the contraction up to 500 ms, as well as the force attained after the first 500 ms. The maximal rate of rise of force production ($N \cdot s^{-1}$) in the force-time curve was also analyzed (Viitasalo et al., 1980).

Table 1. Physical Characteristics of Middle-Aged (50 yrs) and Elderly (70 yrs) Men and Women

Variable		Men 50 yrs (*n* = 12)	Men 70 yrs (*n* = 12)	Women 50 yrs (*n* = 12)	Women 70 yrs (*n* = 12)	Significance of Difference
Age (yrs)	Mean	49.6	66.8	48.1	67.9	M50/M70***
	SD	4.1	3.7	4.9	3.7	W50/W70***
Body height (cm)	Mean	176.0	168.7	164.5	157.8	M50/M70**
	SD	5.6	5.2	4.9	4.9	W50/W70**
						M50/W50***
						M70/W70***
Body mass (kg)	Mean	83.5	75.5	68.9	68.7	M50/W50**
	SD	13.6	9.3	7.2	8.1	M70/W70**
Body fat (%)	Mean	16.6	15.1	28.6	29.2	M50/W50***
	SD	3.5	3.5	3.1	2.8	M70/W70***

**$p < .01$; ***$p < .001$.

Electromyographic activity (EMG) was recorded from the vastus lateralis (VL), vastus medialis (VM), and rectus femoris (RF) muscles of the left or right leg separately during the corresponding maximal isometric unilateral contraction and from all six muscles simultaneously during the maximal isometric bilateral contraction. Bipolar (20-mm interelectrode distance) surface EMG recording (Beckman miniature-sized skin electrodes) was employed. The electrodes were placed longitudinally on the motor point areas determined by a DISA stimulator. EMG signals were recorded telemetrically (Glonner Biomes 2000). In order to calculate maximum EMG activity, the EMG was integrated (IEMG) by the computer system and expressed for 1 s for each muscle separately during the maximal peak force phase (500–1500 ms) of the isometric contraction. The analysis also included IEMG produced during the consecutive time periods of 100 ms in duration from the start of the contraction up to 500 ms (IEMG-time curve) as well as for the first 500 ms (Häkkinen et al., 1987). The average IEMG values of the three muscles calculated separately for the right and left leg were then used for further analysis.

The cross-sectional area (CSA) of the quadriceps femoris (QF) muscle group (rectus femoris, vastus lateralis, vastus medialis, and vastus intermedialis muscles) was measured with a compound ultrasonic scanner (Aloka FANSONIC, SSD–190) and a 5 MHz convex transducer. Three consecutive measurements were taken separately from both the left and right thighs and then averaged for the left and right thigh, respectively. The CSA was measured at the midpoint 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 (Ryushi et al., 1988).

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

Statistical methods. — Conventional statistical methods were used for calculation of means, standard deviations (*SD*), and Pearson product moment correlation coefficients. The data were then analyzed utilizing analysis of variance. Probability adjusted *t*-tests were used for pairwise comparisons when appropriate. The significance was chosen at $p < .05$ for this investigation.

RESULTS

The maximal bilateral voluntary isometric knee extension force of 1094 ± 228 N in M50 was significantly ($p < .05$) greater than that of 888 ± 174 N recorded for M70 (Figure 1). The maximal force of 763 ± 116 N in W50 was much greater ($p < .001$) than that of 565 ± 109 N recorded for W70. The maximal force values differed greatly between M50 and W50 ($p < .001$) as well as between M70 and W70 ($p < .001$).

The maximal unilateral forces of both left and right leg differed also in a similar way between the subject groups, so that the forces in M50 were greater ($p < .05$ and NS) than in M70 and in W50 were greater ($p < .001$ and .01) than in W70 (Figure 1). The unilateral forces in M50 were also much greater ($p < .001$) than in W50 and in M70 were much greater ($p < .001$) than in W70.

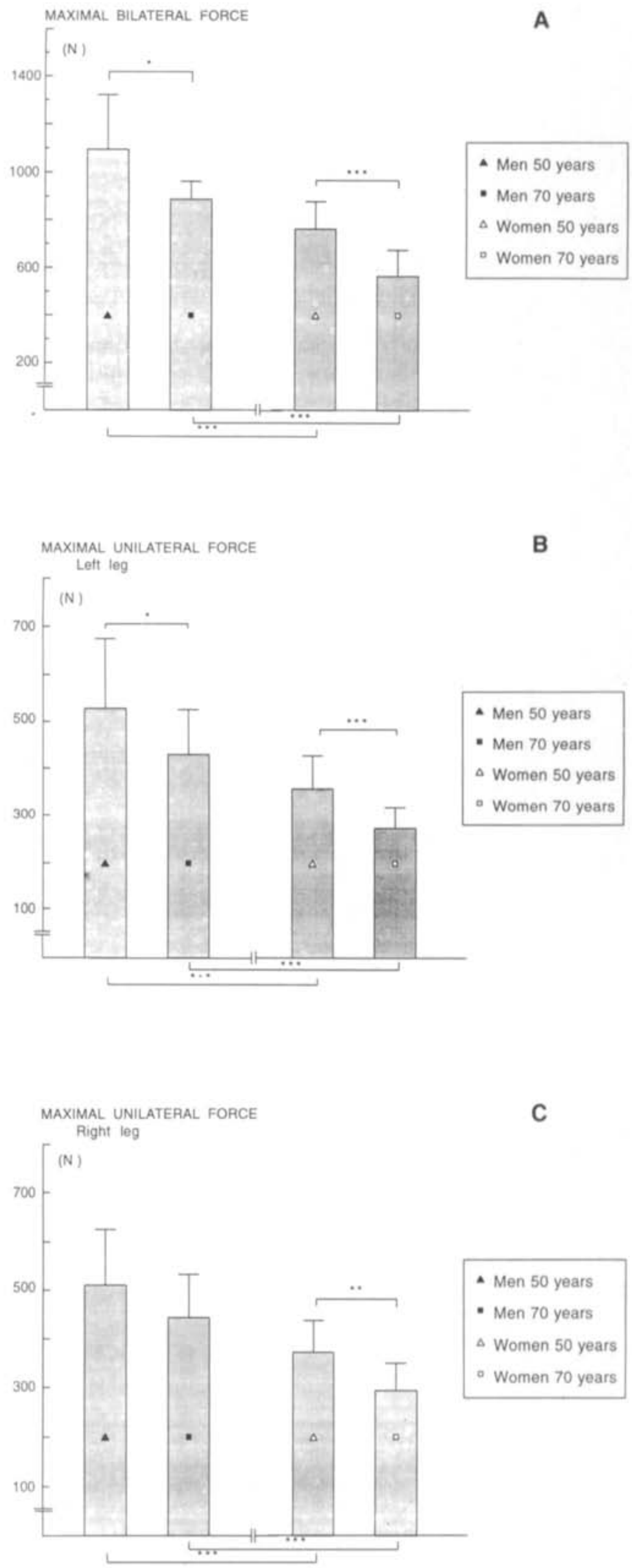

Figure 1. Mean (±*SD*) maximal voluntary isometric force of the knee extensor muscles in the bilateral (**A**) and unilateral contractions for the left (**B**) and right (**C**) leg in middle-aged (50 yrs) and elderly (70 yrs) men and women (*$p < .05$; ***$p < .001$).

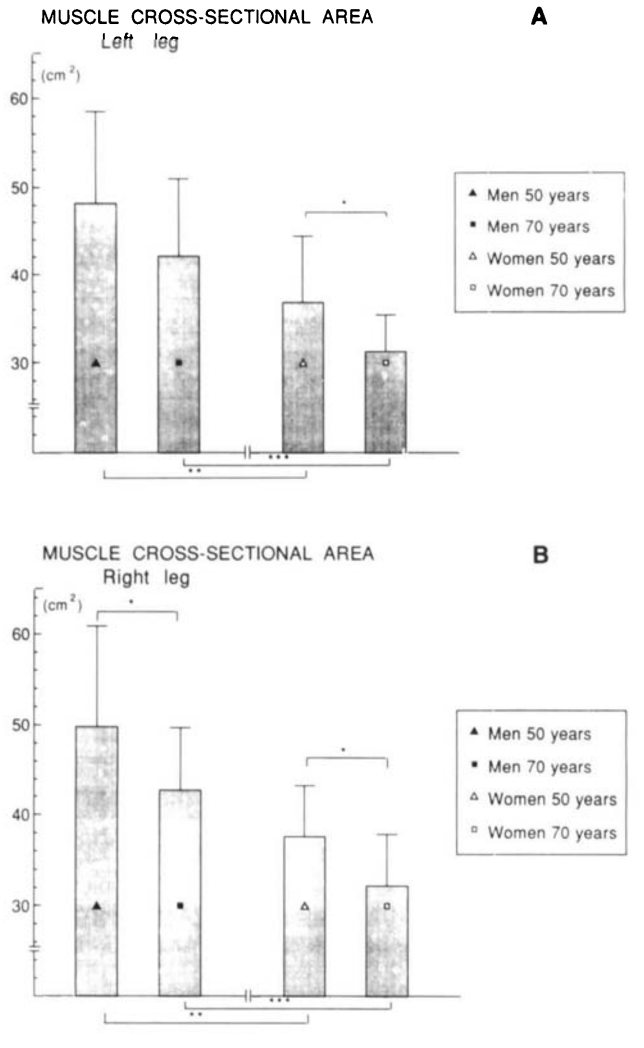

Figure 2. Mean (±*SD*) cross-sectional area of the quadriceps femoris muscle for the left (**A**) and right (**B**) leg in middle-aged (50 yrs) and elderly (70 yrs) men and women (*$p < .05$; **$p < .01$; ***$p < .001$).

Table 2. Correlation Coefficients for Maximal Isometric Force and Muscle Cross-Sectional Area (CSA) of the Knee Extensor Muscles (for the Left and Right Leg and the Average Value of Both Legs) During the Unilateral and Bilateral Contractions in Middle-Aged (50 yrs) and Elderly (70 yrs) Men and Women

	Unilateral Force		Bilateral Force
	Left Leg	Right Leg	
	CSA		
Men 50 yrs	.87***	.87***	.92***
Men 70 yrs	.61*	.80***	.58*
Men 50 + 70 yrs	.79***	.86***	.83***
Women 50 yrs	.79***	.58*	.67**
Women 70 yrs	.56*	.54*	.73**
Women 50 + 70 yrs	.78***	.66***	.76***

$p < .05$; **$p < .01$; ***$p < .001$.

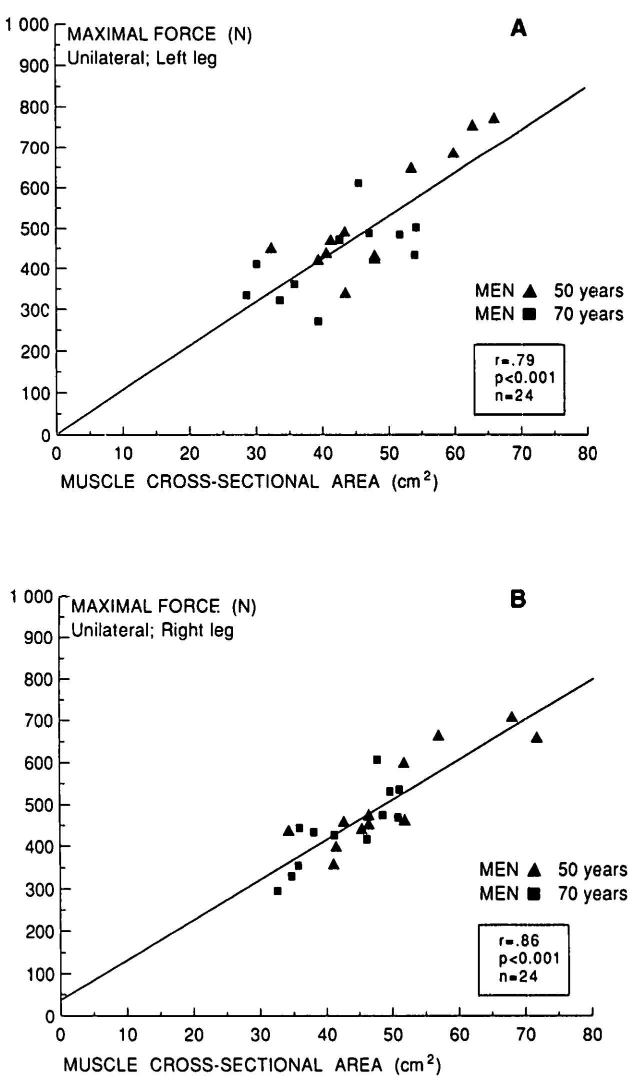

Figure 3. The relationship between the cross-sectional area of the quadriceps femoris muscle and maximal voluntary isometric knee extension force for the left (**A**) and right (**B**) leg in middle-aged (50 yrs) and elderly (70 yrs) men.

The average values of 48.2 ± 10.3 cm^2 and 49.8 ± 11.1 cm^2 for the CSA of the left and right QF in M50 were greater (NS and $p < .05$) than those of 42.1 ± 8.9 cm^2 and 42.7 ± 7.0 cm^2 recorded for M70 (Figure 2). The corresponding values of 36.8 ± 7.6 cm^2 and 37.6 ± 5.6 cm^2 in W50 were greater ($p < .05$) than those of 31.2 ± 4.2 cm^2 and 32.3 ± 5.7 cm^2 recorded in W70. The CSA values in M50 were greater ($p < .01$) than in W50 and in M70 were greater ($p < .001$) than in W70. The individual values of the CSA of the left and right QF correlated significantly with the corresponding individual values of maximal unilateral knee extension forces in M50 ($r = .87$; $p < .001$ and $r = .87$; $p < .001$), in M70 ($r = .61$; $p < .01$ and $r = .80$; $p < .001$), in W50 ($r = .79$; $p < .001$ and $r = .58$; $p < .05$), and in W70 ($r = .56$; $p < .05$ and $r = .54$; $p < .05$) (Table 2). The individual values of the CSA and force are plotted together for the whole sample of male subjects in Figure 3 and for all the female subjects in Figure 4.

When the maximal force values were related to the CSA of QF, the average values of 22.4 ± 2.0 N • cm^{-2} in M50

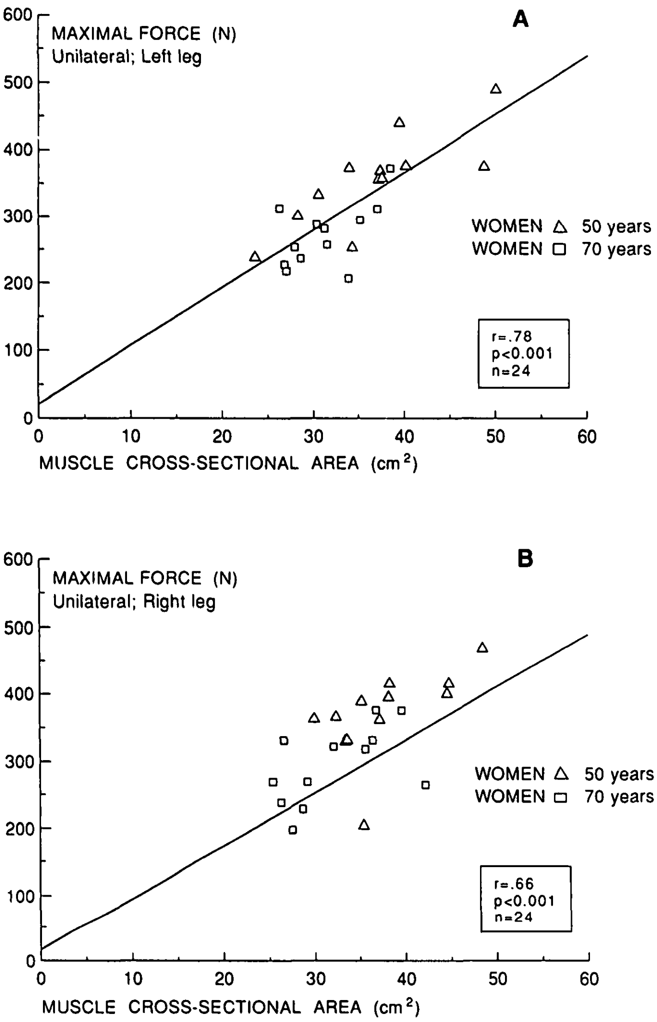

Figure 4. The relationship between the cross-sectional area of the quadriceps femoris muscle and maximal voluntary isometric knee extension force for the left (**A**) and right (**B**) leg in middle-aged (50 yrs) and elderly (70 yrs) women.

calculated in the bilateral condition didn't differ significantly from that of 21.2 ± 3.8 N • cm^{-2} recorded for M70 or that of 20.8 ± 2.9 N • cm^{-2} recorded for W50 (Figure 5). The average value of 17.8 ± 2.5 N • cm^{-2} in W70 was significantly ($p < .05$) smaller than that of W50 as well as that of M70. In both unilateral conditions the average force values per CSA recorded for W70 were smaller than in the other groups, differing significantly ($p < .05$) from that recorded for the left leg in M70.

The maximum IEMG averaged for the VL, VM, and RF muscles of the right leg during the maximal voluntary unilateral contraction didn't differ significantly from that recorded for the right leg during the corresponding bilateral contraction in either M50, M70, W50, or W70 (Figure 6). This was also true in all groups for the maximum averaged IEMG for the left leg between the maximal voluntary unilateral and bilateral contractions.

Maximal voluntary isometric bilateral force didn't differ significantly from that of the summed unilateral force in M50 (1.07 ± .10), M70 (1.02 ± .07), W50 (1.05 ± .05), or in

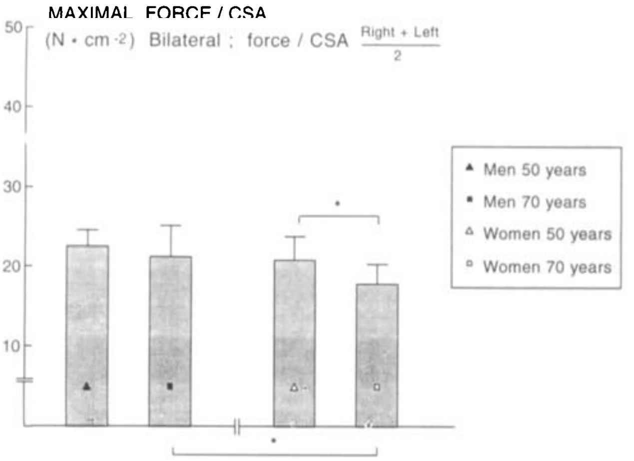

Figure 5. Mean (± *SD*) maximal voluntary bilateral isometric force of the knee extensor muscles per the cross-sectional area of the quadriceps femoris muscle averaged for the right and left leg in middle-aged (50 yrs) and elderly (70 yrs) men and women (*$p < .05$).

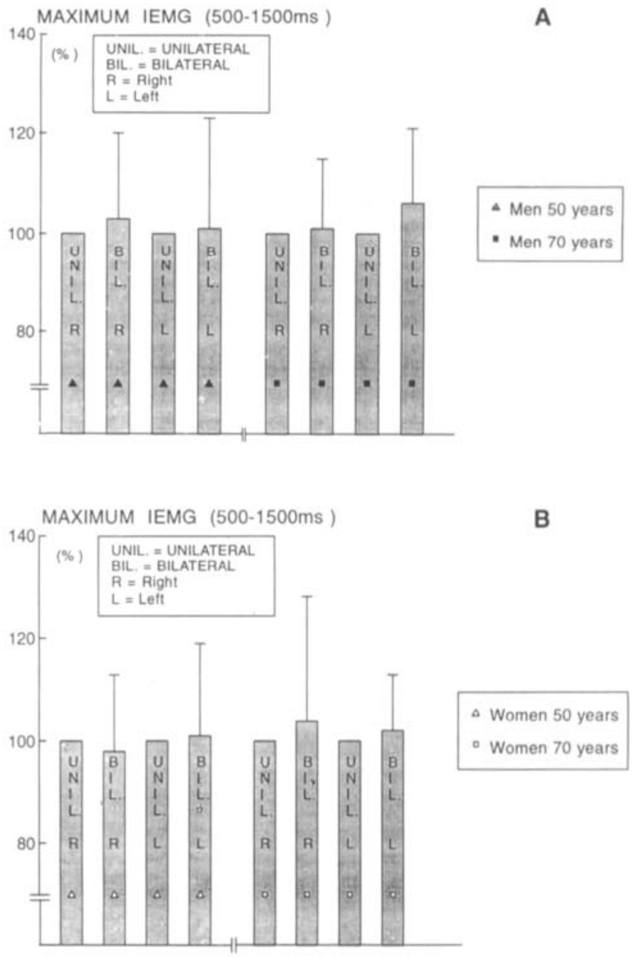

Figure 6. Mean (±*SD*) relative integrated electromyographic activity (IEMG) averaged for the vastus lateralis, vastus medialis, and rectus femoris muscles in the maximal voluntary isometric bilateral knee extension for the right and left leg in comparison to that recorded for the respective unilateral contractions in middle-aged (50 yrs) and elderly (70 yrs) men (**A**) and women (**B**).

W70 (.99 ± .05) (Figure 7). This was also true for all groups with regard to the averaged maximum IEMG of the muscles between the bilateral and summed unilateral contractions. The only difference between the groups was that of the force ratio between W50 and W70.

The shapes of the average bilateral isometric force-time curves in absolute values differed between the groups, such that the forces produced during the early (up to 500 ms) portions of the curve were in M50 greater ($p < .05$) than in M70, and in W50 were greater ($p < .05$) than in W70 (Figure 8). These early forces were in M50 much greater ($p < .001$) than in W50 and in M70 were much greater ($p < .001$) than in W70. The values of 10195 ± 5474 in M50, 6624 ± 4032 in M70, 5851 ± 3271 in W50, and 4479 ± 2893 $N \cdot s^{-1}$ in W70 in the maximal rate of rise of force development differed ($p < .05$–.001) correspondingly between the groups. In the unilateral contractions the corresponding differences in the shape of the curves were significant between M50 and M70 ($p < .05$), M50 and W50 ($p < .001$), and M70 and W70 ($p < .01$) for the left leg and between W50 and W70 ($p < .05$), M50 and W50 ($p < .05$), and M70 and W70 ($p < .001$) for the right leg. The same differences were also observed in the maximal rate of rise of force development.

Voluntary explosive bilateral force produced in 500 ms did not differ significantly from that of the summed unilateral force in any of the present subject groups (Figure 9). This was also true with regard to corresponding averaged IEMG of the muscles produced in 500 ms between the bilateral and the summed unilateral contractions.

Discussion

Human muscle strength in both men and women decreases with increasing age. A steeper decline in maximal force begins at the onset of the sixth decade of life (Larsson, 1978; Asmussen, 1980; Heikkinen et al., 1984; Young et al.,

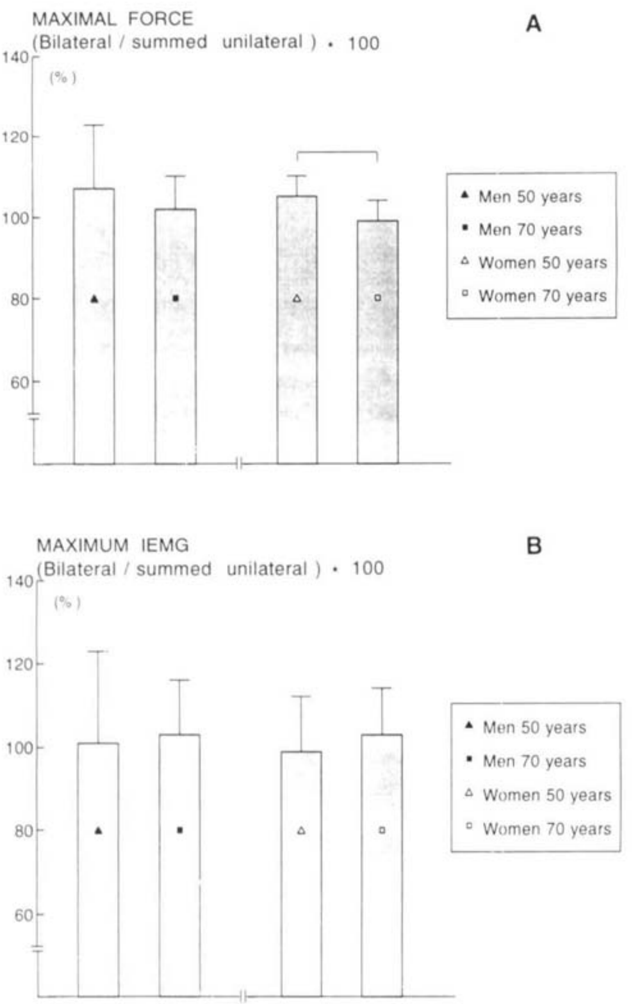

Figure 7. (A) Mean (±*SD*) maximal voluntary isometric bilateral knee extension force per the summed unilateral force and (B) mean (±*SD*) maximum bilateral integrated electromyographic activity (IEMG) per the summed unilateral activity of the knee extensor muscles in middle-aged (50 yrs) and elderly (70 yrs) men and women (*$p < .05$).

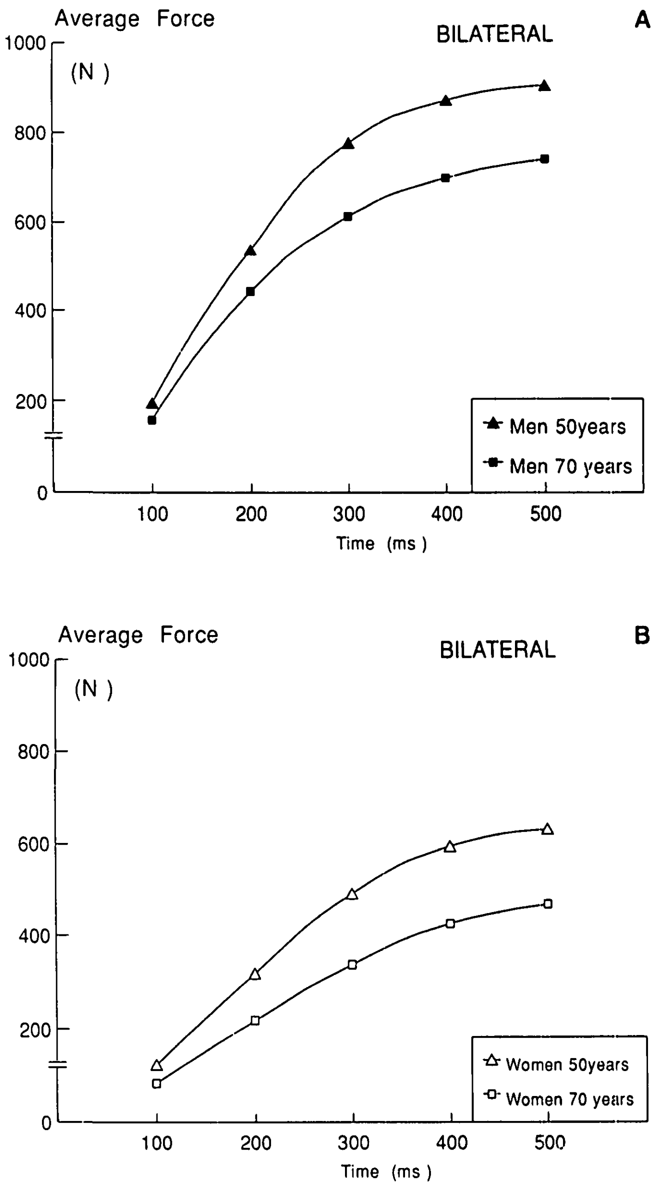

Figure 8. Average force-time curves of the knee extensor muscles in the maximal explosively produced voluntary isometric bilateral contraction in middle-aged (50 yrs) and elderly (70 yrs) men (A) and women (B).

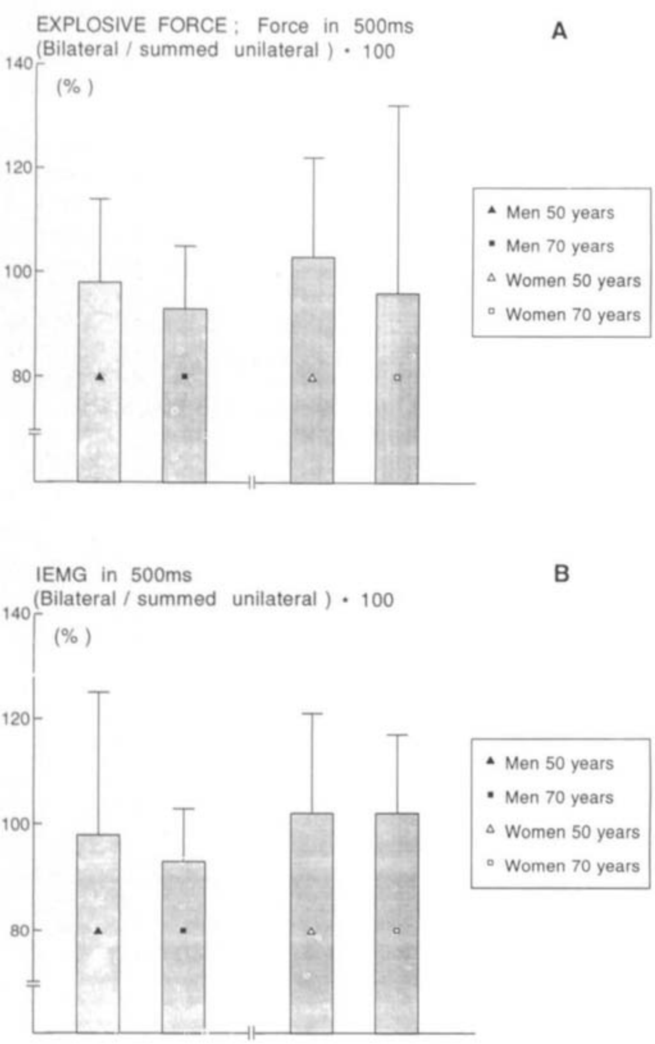

Figure 9. (**A**) Mean (±*SD*) maximal voluntary explosive bilateral isometric knee extension force produced in 500 ms per the summed unilateral explosive force, and (**B**) mean (±*SD*) bilateral integrated electromyographic activity (IEMG) produced in 500 ms per the summed unilateral activity of the knee extensor muscles in middle-aged (50 yrs) and elderly (70 yrs) men and women.

1984; Vandervoort et al., 1986; Gandee et al., 1989; Rice et al., 1989; Frontera et al., 1991; Häkkinen and Häkkinen, 1991; Narici et al., 1991; Häkkinen and Pakarinen, 1993). Although the present results should be treated with caution due to the limited number of subjects, the strength data obtained from our middle-aged and elderly subjects of both genders presented in Figure 1 provide added support for this concept. Maximal bilateral isometric force of the knee extensor muscles in M70 was 19% lower than in M50, and in W70 was 26% lower than W50. Accordingly, the maximal unilateral forces differed considerably between the two age groups of the same sex both for the left and right leg. As one could also expect, the two male groups studied differed clearly from the two female groups in terms of the absolute strength values, with the bilateral force of W50 69% of M50 and W70 exhibiting 64% of the maximal force recorded for M70. These data are remarkably consistent with male-female strength comparisons in younger individuals (Laubach, 1976) and demonstrate that age does not change this relationship.

The decrease in maximal strength with increasing age is influenced by a reduction in muscle mass in both men and women. The results presented in Figure 2 indicate an age-related loss of muscle mass, with the CSA of the QF muscle in M70 smaller than in M50 and CSA of W70 smaller than in W50. As one might expect, the differences in the CSA between the genders of the same age groups were also very clear. The present results further demonstrated that the individual values of the CSA of the left and right QF correlated highly significantly with the corresponding individual values of maximal unilateral knee extension forces in the total samples of male (Figure 3) and female subjects (Figure 4). This finding further supports the concept that the decrease in muscle mass with increasing age is accompanied by a parallel decline in maximal strength in both men and women. However, the present results also demonstrated that the correlation coefficient between the CSA and maximal force of the muscle group was somewhat lower in the two elderly subject groups, especially in W70, than in the two middle-aged subject groups (Table 2). Furthermore, when the individual maximal force values were related to the individual values in the CSA of the muscle, the force per CSA in W70 was significantly smaller than those recorded for the other three groups (Figure 5). This finding indicates that in addition to a decrease in muscle mass, a decline in maximal strength, especially in older women, might also be, in part, due to a decrease in maximal voluntary neural input to the muscles and/or in "qualitative" characteristics of the muscle tissue itself (Häkkinen and Häkkinen, 1991). It is likely that the amount of intramuscular fat and/or connective tissue may, in part, invalidate the ratio between muscle CSA and force, especially in older women. Because there are some data to indicate that aging would not necessarily impair voluntary ability to maximally activate some muscles (Enoka et al., 1992), the possible decrease in the activation ability as well as the degree of muscle atrophy and a decline in strength in aging people may vary between the different muscles and muscle groups in relation to their decreased use in normal daily physical activities.

In addition to age-related declines in muscle mass and maximal strength of the muscles, aging has been shown to lead to great decreases in explosive strength characteristics of the neuromuscular system (Larsson et al., 1979; Bosco and Komi, 1980; Clarkson et al., 1981; Davies et al., 1982; Bassey and Harries, 1987; Viitasalo et al., 1989; Häkkinen and Häkkinen, 1991; Häkkinen and Pakarinen, 1993). Explosive strength or power of the neuromuscular system to contribute to locomotion and a role in the prevention of falls has been hypothesized to be as important as maximal strength in aging populations (Bassey et al., 1992). The differences in the shapes of the force-time curves of the bilateral contractions presented in Figure 8 indicate that explosive force production capacity of the knee extensor muscles decreases greatly in aging people, both men and women. Actually, the average differences in these forces of 20% between M70 and M50 and of 29% between W70 and W50 were even slightly greater than the corresponding difference in maximal strength. Although no muscle biopsy samples were taken in the present study, the data support the concept that atrophying effects of increasing age may be greater on fast-twitch fibers than on slow-twitch fibers, that there is a loss of fast-twitch fibers (Larsson et al., 1978; Aniansson et al., 1981; Lexell et al., 1983, 1988; Essen-Gustavsson and Borges, 1986; Grimby, 1988; Evans, 1992), and/or that the maximal rate of voluntary neural activation of the muscles could also be influenced by aging (Häkkinen and Häkkinen, 1991). The reduction in fiber number could be caused by either an irreparable damage of the fibers or a loss of the contact between the nerves of the muscle fibers (Lexell et al., 1988). It is possible that part of the fiber population undergoes a denervation process, although a reinnervation phenomenon may also occur with increasing age (Lexell et al., 1988). Both a denervation process and inactivity underlie the change in fiber size with increasing age, but whether the fiber type proportion of the muscle is actually altered during aging is a difficult question to answer. According to Lexell et al. (1988), there may be several processes affecting the properties of individual fibers, and alterations due to a specific loss of a motor unit type may be undetected.

The results presented in Figure 6 demonstrate clearly that the maximal relative IEMG averaged for the three knee extensor muscles was approximately the same between the unilateral and bilateral isometric contractions in the case of the right thigh musculature as well as for the left thigh musculature both in the two middle-aged and two elderly subject groups. Accordingly, maximal voluntary isometric bilateral force didn't differ significantly from that of the summed unilateral force in any of the subject groups (Figure 7). Actually, the bilateral forces in M50, M70, and W50 were slightly greater than the summed unilateral force, and in W70 the bilateral force was very similar to that of the summed unilateral force. However, considerable interindividual variation was observed within each subject group. Schantz et al. (1989) demonstrated, using young male and female subjects, that the bilateral deficit was not observable in a simple single joint task of force production, such as the isometric knee extension. The present data showed this to be true both in middle-aged and elderly men and women. The present EMG data further indicate that the CNS would be capable of maximal activation of the two bilateral QF muscle groups simultaneously and/or that probably no decrease in activation was related to peripheral neural control during the bilateral contractions. The results presented in Figure 9 further showed that no bilateral deficit was observed in either force or in IEMG during the explosive force production phase of the maximal isometric force production of the knee extensors, when the voluntary activation of the muscles takes place rapidly. To what extent the activation and force production of the muscles during the present single joint isometric exercise would differ, in terms of the bilateral deficit, from those of multi-joint exercises utilizing concentric, eccentric, and various stretch-shortening cycle movements, needs to be examined in detail in the future.

In summary, the present results suggest that the decline in maximal strength with increasing age, both in men and women, could be primarily related to the decline in the CSA of the muscle, whereas, especially in older women, this decline in strength could be multifactorial, including possibly a decrease in maximal voluntary neural activation or changes in "qualitative" characteristics of the muscle tissue. The finding that explosive production of the neuromuscular system also decreases greatly with aging indicates that atrophying effects of aging may be greater on fast-twitch muscle fibers than on slow-twitch muscle fibers and/or that the rate of neural activation of the muscles may also be influenced by the aging process in untrained or even just the recreationally active individuals utilized in this study. On the other hand, the observation that no bilateral deficit was found in any of the present subject groups in simple single joint isometric force production of the knee extensors indicates that the CNS would be capable of activation of the two bilateral QF muscle groups simultaneously to the same degree in comparison to that of the unilateral activation only.

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