

Skeletal Muscle Fatigue and Endurance in Young and Old Men and Women

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The effects of increasing age on skeletal muscle fatigue and endurance were assessed in 22 healthy young (14 men and 8 women; mean age, 28 ± 6 years) and 16 healthy old (8 men and 8 women; mean age, 73 ± 3 years) individuals. All subjects performed 100 repeated maximum dynamic knee extensions at 90 °·s⁻¹ (1.57 rad·s⁻¹) using an isokinetic dynamometer (Cybex II). Peak torque was recorded during every contraction, and for each individual the maximal voluntary contraction (MVC), the fatigue rate, the endurance level, and the relative reduction in muscle force were determined. MVC and endurance level were significantly lower in old men and women, but there was no discernible difference in relative muscle force reduction and fatigue rate between young and old individuals. We conclude that thigh muscles of older individuals are weaker than those of younger individuals, but relative to their strength, older individuals have similar properties as younger individuals with respect to muscle fatigue and endurance.

WITH advancing age, muscle volume is reduced, and this aging atrophy — referred to as “sarcopenia” (Dutta and Hadley, 1995) — is accompanied by a decrease in muscle strength (Porter et al., 1995). The reduction in strength seems to be equal for both sexes, but women are generally weaker than men throughout all ages (Porter et al., 1995). As the gait pattern also changes with age, especially in older women (Hageman and Blanke, 1986; Blanke and Hageman, 1989), older individuals have an increased risk of falls and hip fractures (Tinetti et al., 1988). Both arm and leg muscles in aging men and women can adapt successfully to increased use, in particular following a period of heavy-resistance training (Lexell et al., 1995). Physical exercise is therefore considered beneficial in reducing the risk of falls among older men and women (Province et al., 1995).

Our knowledge of the effects of increasing age on the fatigability of skeletal muscle — its ability to maintain force or power output (Edwards, 1981) — is, however, much more limited, and the few human studies that have been performed are inconclusive. Using a 30-Hz stimulation protocol, Narici et al. (1991) observed an age-related decrease in fatigability in the adductor pollicis in men. Lennmarken et al. (1985) observed increased fatigability in a similar study done at 20 Hz, while Cupido et al. (1992) found no effect of age on the fatigability of the tibialis anterior muscle with stimulation rates of 20, 30, and 40 Hz. Klein et al. (1988) found no differences between younger and older men in fatigability of the triceps surae muscle using intermittent submaximal 20-Hz tetani, while Davies et al. (1986) reported an age-related enhanced fatigability for the same muscle group at 10-, 20-, and 50-Hz stimulation. When sustained or intermittent isometric contractions, or repeated dynamic contractions, in upper or lower limb muscles were studied, no material differences in muscle fatigability have been found between younger and older individuals (Larsson

and Karlsson, 1978; Laforest et al., 1990; Hicks et al., 1992).

The overall aim of this study was therefore to assess muscle fatigue and endurance in healthy younger and older men and women. A method that assesses muscle fatigue and endurance throughout 100 repeated dynamic maximal knee extension contractions was used (Lindström et al., 1995). With this method, muscle performance is expressed in peak torque of every contraction, and the data are divided into two parts: the “fatigue phase,” the initial 40 contractions, and the “endurance level,” the last 30 contractions. As this type of analysis may be profligate with data, an assessment that summarizes all the 100 contractions would give a more detailed account of muscle fatigue and endurance. The analysis is here extended, to use the data from all 100 contractions, and then to assess muscle fatigue and endurance in 38 healthy young and old individuals.

METHOD

Subjects. — A total of 38 physically healthy individuals — 22 young and 16 old — volunteered for the study. There were 14 men (mean age, 28 ± 5 years; mean height, 180 ± 8 cm; mean weight, 76 ± 12 kg) and 8 women (mean age, 28 ± 7 years; mean height, 166 ± 5 cm; mean weight, 59 ± 6 kg) in the young groups, and 8 men (mean age, 73 ± 2 years; mean height, 175 ± 6 cm; mean weight, 80 ± 10 kg) and 8 women (mean age, 73 ± 4 years; mean height, 159 ± 6 cm; mean weight, 60 ± 6 kg) in the old groups. The young individuals were students or staff at the University Hospital, Umeå. All young individuals were healthy and on no regular medication. The old individuals were recruited from the Boden community. The medical history of all old individuals was assessed from a questionnaire, by physical examination, by routine blood and urine tests, and by an electrocardiogram (ECG) at

rest. Except for mild hypertension for which some older men and women were treated, all older individuals were healthy and considered sufficiently fit to participate in the study. None of the 38 volunteers were elite athletes, but all of them participated regularly and to a similar extent (1–3 times/week) in low-intensity aerobic exercise (e.g., walking, cycling, swimming, skiing). Before the start of the study, each individual was informed of the testing procedures, and thereafter gave written consent. The study was approved by the Umeå University Ethical Committee.

Fatigue tests. — Each experiment consisted of 100 repeated maximum knee extension contractions at 90°s^{-1} ($1.57\text{ rad}\cdot\text{s}^{-1}$) using an isokinetic dynamometer (Cybex II, Lumex Inc., New York). At this angular velocity, all individuals, irrespective of age, are able to complete 100 repeated contractions; at the same time, a substantial reduction in strength can be detected. During the experiment, peak torque (PT; Nm) was recorded. The right and left limbs of the young healthy individuals were tested randomly on the same day; these data have been presented separately (Lindström et al., 1995), and no significant differences have been found between the dominant and nondominant side. Therefore, only data for one limb from the young men and women (the nondominant side) were used in this study. The dominant side was decided to be the hand and foot that would be used for writing and kicking a ball, respectively. Three of the young individuals used their left hand and foot; the remaining 19 individuals used the right. For the old individuals only the nondominant side was tested. As all 16 old individuals used their right hand and foot, testing was done on the left side.

The individuals were lying supine with the hip of the investigated thigh flexed 20 degrees. The hip and the tested thigh were fixed with belts. Great care was taken to align the flexion–extension axis of the knee joint with the movement axis of the dynamometer, and belts ensured that the position was maintained throughout the experiment. The true weight of the leg was measured before the actual test, to compensate for gravity.

The first encounter with the equipment and test procedures was on the day of testing. During a warming-up maneuver at submaximal level, the individuals were instructed how to achieve the standardized range of motion and how to completely rest during the passive flexion of the contraction cycle, which was powered by the gravity of the lower limb. The contraction frequency was standardized (i.e., 30 contractions per minute), and no rest was allowed between the passive flexion and active extension phase. During the experiment individuals were frequently encouraged verbally to perform maximally. In all old individuals, the heart rate was recorded immediately at the completion of the 100 contractions.

One contraction cycle is defined as the total movement throughout the predetermined range of motion and back again (i.e., from 90° flexion to full extension of the leg). Only data within the position window are used for the analysis — i.e., the range between a predetermined start-and-stop position. This is illustrated in Figure 1. A position window is used to verify that a contraction has a minimum range, which eliminates values outside the active part of the contraction cycle (for further details, see Karlsson et al.,

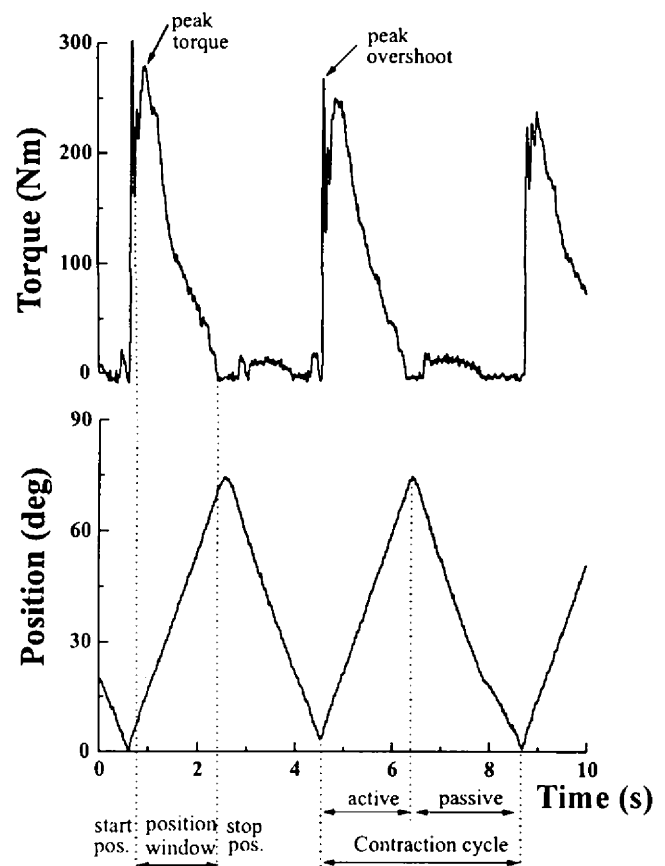


Figure 1. Schematic illustration of the recording of an isokinetic muscle contraction using a dynamometer. The upper tracing shows the torque of the knee extensor muscles and the lower tracing the corresponding position. In the lower tracing both the contraction cycle and the selected position window are shown. The selected position window eliminates the peak overshoot, which is illustrated in the upper tracing. (Reproduced from Karlsson et al., 1994, with permission.)

1994). The present method of a preset window is also an advantage as it eliminates the peak overshoot that has been reported for the Cybex II dynamometer (Figure 1).

Prior to the fatigue test, each individual performed three single maximal voluntary isokinetic contractions at 90°s^{-1} . The best of these three measurements was recorded as PT and compared with the estimated PT obtained from the fatigue test (see below).

A special data acquisition system for the analysis was used (Karlsson et al., 1994). Data acquisition and the immediate calculations are done on the data acquisition processor (DAP 2400/6, Microstar Laboratories, Bellevue, WA). This system includes its own operating system, DAPL, which performs a wide range of standard acquisition tasks that process data in real-time. The processed data are buffered before being sent to the PC and saved on the hard disk. We used the menu-based program MYSAS (myoelectric signal acquisition system), developed by S. Karlsson, University Hospital of Northern Sweden, Umeå, for registration and analyses of electromyography (EMG) and of PT and position; in this study only the PT was used. The program also made it possible to perform calibration, list data, and view graphically the variates in real-time.

Analysis. — The PT value at each of 100 consecutive contractions for each tested limb was used in the analyses. With the PT value the ordinates, and the contraction numbers the abscissa, a set of data (i.e., profile) is formed (Figure 2). Such a profile is then obtained for each tested limb. It would be convenient to summarize each profile by parameter estimates obtained from a suitable model. The following assumptions define such a model: (1) after many contractions the PT value becomes constant; (2) the rate at which each set of PT values approaches the constant is proportional to the difference between the PT value and the constant. From these assumptions, it can be shown that:

$$y(n) = A + Be^{-cn}, \quad (1)$$

where $y(n)$ is the PT value at the n^{th} contraction. The least squares fit of the data to Equation (1) is represented by the curve in Figure 2.

As n becomes large, $y(n)$ tends to A ; $A + B$ is the intercept of the line at $n = 0$; C represents the rate of approach to the constant, A . The values of A , B , and C for each profile are estimated by minimizing

$$\sum_{n=1}^{100} \{y(n) - A - Be^{-cn}\}^2, \quad (2)$$

with respect to A , B , and C . The estimated parameters A , $A + B$, and C are represented in Figure 2 and each has a physiological meaning or interpretation:

- A*: endurance level [the muscle force (Nm), obtained from Equation (1), that each individual maintains throughout the fatigue test];
- A + B*: maximal voluntary contraction, MVC (Nm) [the estimated muscle force, obtained from Equation (1), at the beginning of the fatigue test, i.e., the estimated PT value at "contraction zero"]; and
- C*: fatigue rate (the rate of reduction in muscle force, obtained from Equation (1), recorded during the fatigue test; the larger the numeric value, the greater is the rate of reduction).

From these parameters we can also calculate the relative reduction (%) in muscle force from the estimated MVC until an individual reaches the endurance level, i.e., $100 \times B/(A + B)$. This value, D , the *fatigue index*, represents the percentage loss of muscle strength throughout the fatigue test.

The sum of squares (RSS), i.e., the minimum value of expression 2, is an indicator of the goodness of the fit for a profile. The mean of this value provides a measure of the variability of a profile about its fitted line; we found it convenient to consider the square root of this mean value (RMSE).

Because of the uncertainty of the distributional properties of the parameter estimates, the four groups — young men, young women, old men, and old women — were compared using Kruskal-Wallis and the one-way analysis of variance; there were no material differences between these results. Differences between the four groups were tested pairwise by a t -statistic and Scheffé's test. As there were no material differences between the two tests, only the results of the t -tests are reported. To compare the relationship between the

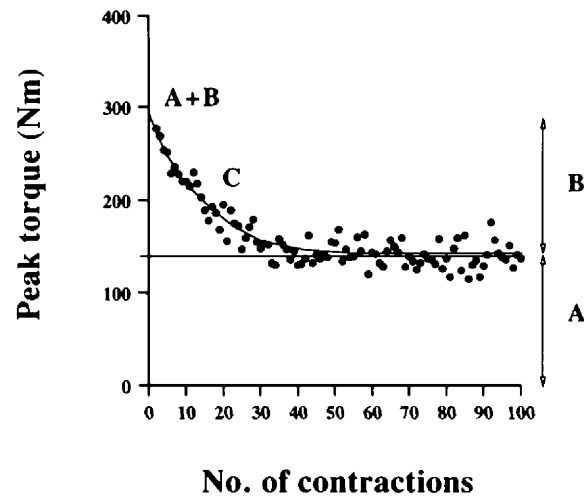


Figure 2. Summary of the fatigue test and data analysis. For each tested limb, the peak torque value at each of 100 consecutive contractions was recorded. Each set of data (i.e., profile) is summarized by parameter estimates obtained from a suitable model, and the least squares fit of the data is represented by the curve. Parameters A , $A + B$, B , and C are obtained from each profile and the values for each parameter are used throughout the analyses and presentation. (The data in the figure are obtained from one of the young men.)

MVC measurements obtained prior to the fatigue test and the MVC measurements estimated from the fatigue test, Pearson's correlation coefficient was calculated for each of the four groups. Throughout, exact significance levels are given for values between .001 and .20; $<.001$ is given for smaller values, while NS represents significance levels $>.20$. The statistical package SYSTAT (version 5.2, Systat Inc., Evanston, IL) was used for the calculations. The nonlinear optimization routine was particularly easy to apply when minimizing expression 2.

RESULTS

All 38 individuals completed the entire test procedure. No muscle or joint pain was reported during or after the study for any of the subjects.

Individual profiles, representative for each of the four groups — young men, young women, old men, and old women — are shown in Figure 3. The appearances of the curves are similar although the estimated parameter values vary.

The means and standard deviations of parameters A , $A + B$, C , and D for young and old men and women are presented in Table 1. In Figure 4 (A–D) the four parameters are plotted for each individual against age, and in Table 2 the significance levels of the pairwise comparison of the four parameters between each of the four groups are presented.

For parameter A , the endurance level (Nm), the largest value and the greatest variation were found among young men, while young women and old men had similar values, and old women had the smallest value (Table 1; Figure 4A). The difference between young and old men and between young and old women was 39%, respectively. There was a significant difference between young men and the other

groups, between young women and old women, and between old men and old women (Table 2).

For parameter *A + B*, the estimated MVC (Nm), the difference between young and old men was 32%, and between young and old women it was 46%. The same significant differences as for parameter *A* were also found for parameter *A + B* (Tables 1 and 2; Figure 4B). For each of the four groups, there was a very strong relationship between the MVC measurements obtained prior to the fatigue test and the MVC measurements estimated from the fatigue test (young men: $r = .94, p < .001$; young women: $r = .85, p = .007$; old men: $r = .73, p = .038$; old women: $r = .97, p < .001$).

For parameter *C*, the fatigue rate, there were no significant differences between the four groups (Tables 1 and 2; Figure 4C); the difference between young and old men was 29%, and between young and old women it was 7%.

For parameter *D*, the fatigue index (the relative reduction in muscle force), there was a significant difference only between old men and old women (Tables 1 and 2; Figure

4D); the difference between young and old men was 8%, and between young and old women it was 13%.

A power analysis revealed that for the available number of individuals, the difference in the fatigue rate, parameter *C*, between younger and older individuals must be about 25 for detection at the 5% significance level and with 80% power (note that the maximum difference is 16). For the fatigue index, parameter *D*, the equivalent difference is approximately 11. The detectable difference is dependent upon the standard deviation which tended to be large for younger men.

The RMSE value shows how much the muscle force varies from one contraction to the other during the fatigue test; the more spread the data are, the higher is the value. For young men the RMSE value (mean \pm SD) was 13.2 ± 3.3 , for young women 4.6 ± 1.3 , for old men 6.9 ± 1.9 , and for old women 4.6 ± 1.5 .

The mean heart rate at the completion of the 100 contractions was 108 (± 17) for older men and 126 (± 26) for older women.

DISCUSSION

The overall aim of this study was to assess muscle fatigue and endurance in healthy younger and older men and women, and to determine the effects of increasing age on these parameters. The term *fatigue* is here defined as failure to maintain force or power output, in contrast to *weakness*, which is failure to generate force (Edwards, 1981). The definition of fatigue used here is generally accepted and similar to that in previous studies of younger and older individuals, although the methods to induce and to measure fatigue have differed.

Our method of assessing muscle fatigue has been in use over 10 years (Fugl-Meyer et al., 1985; Elert and Gerdle, 1989; Lindström et al., 1995) and measures primarily the reduction in muscle force during 100–200 repeated contractions. It also allows us to estimate indirectly the maximal voluntary contraction and to determine muscle endurance—the muscle force that can be maintained over a period of time. Although the method is considered sufficiently sensitive to detect the changes in fatigue and endurance that occur with increasing age, it could be that one single test may not reflect the “true” results for an individual. The method is, however, easy to learn, and from our own experiences there is no significant learning effect when the fatigue test is repeated. We are also confident that all individuals started out as hard as they could, as the estimated PT was very similar compared to the PT measured prior to the fatigue test. Another factor that may influence the results

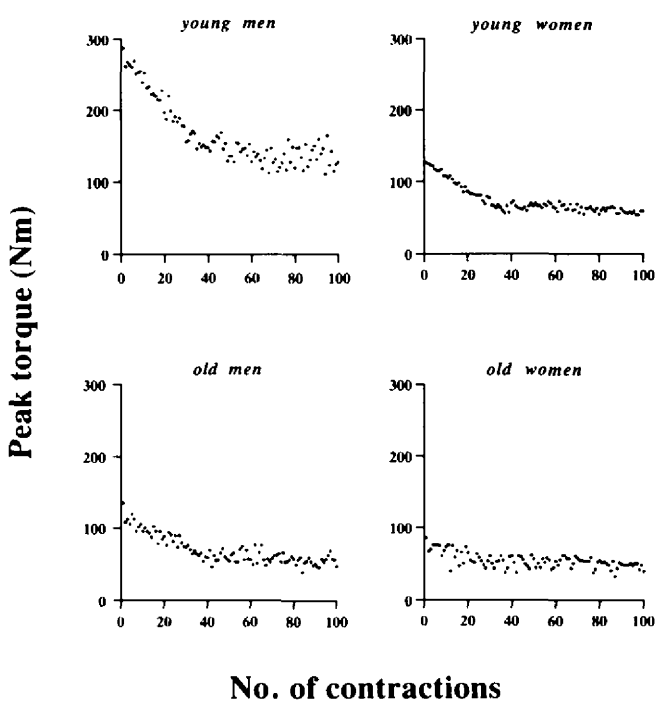


Figure 3. Individual profiles, representative for each of the four groups: young men, young women, old men, and old women.

Table 1. Means and Standard Deviations of Parameters *A*, *A + B*, *C*, and *D* for 38 Young and Old Men and Women

	Young Men (<i>n</i> = 14)		Young Women (<i>n</i> = 8)		Old Men (<i>n</i> = 8)		Old Women (<i>n</i> = 8)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	28	± 5	28	± 7	73	± 2	73	± 4
Endurance level (<i>A</i>) (Nm)	93	± 29	62	± 9	57	± 9	38	± 9
Maximal voluntary contraction (<i>A + B</i>) (Nm)	220	± 51	140	± 22	149	± 22	75	± 19
Fatigue rate (<i>C</i>) ($\times 10^{-3}$)	39	± 14	42	± 10	55	± 23	39	± 23
Fatigue index (<i>D</i>) (%)	57	± 12	55	± 9	62	± 6	48	± 9

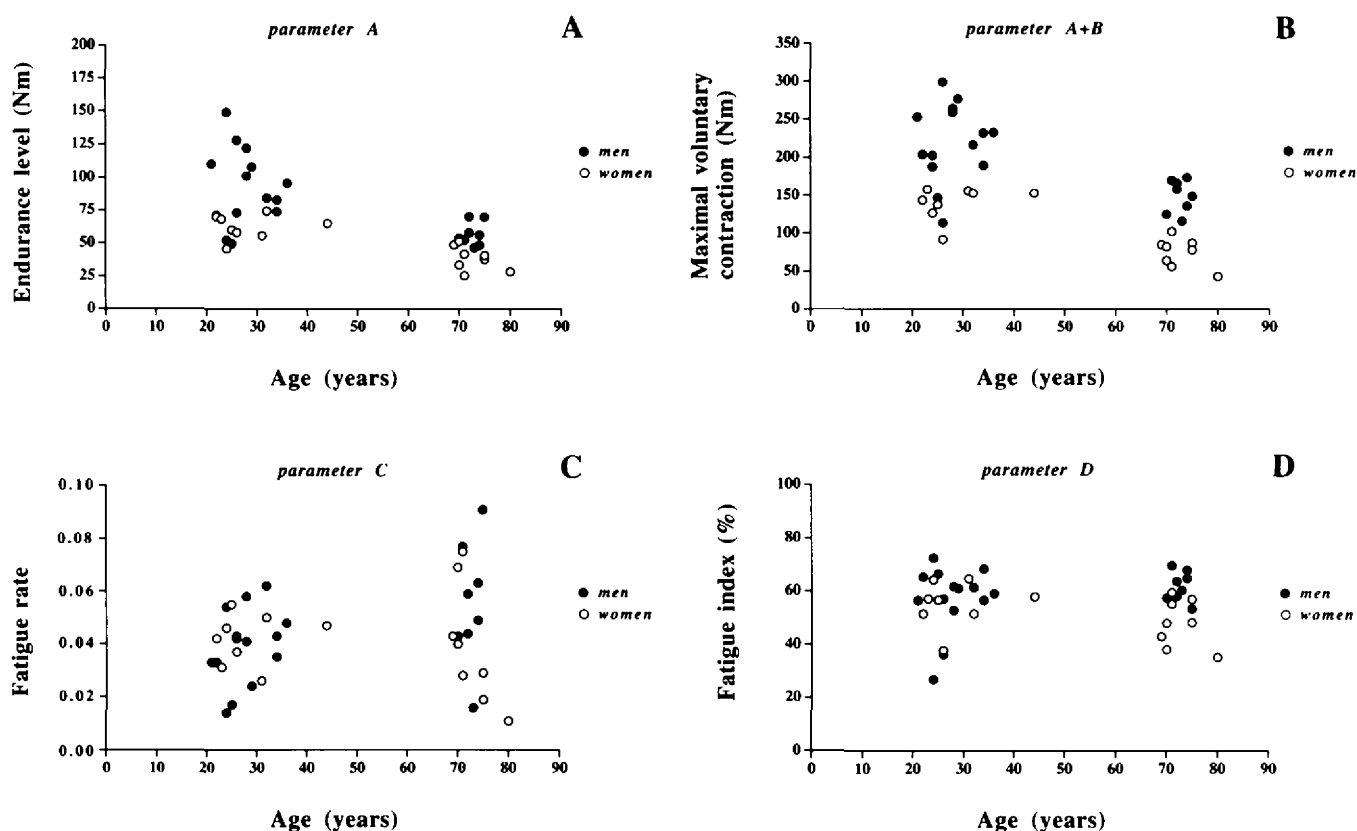


Figure 4 (A-D). The four parameters — A, A + B, C, and D — for men and for women plotted against age.

Table 2. Significance Levels of Pairwise Comparison of Parameters A, A + B, C, and D Between 38 Young and Old Men and Women

	Young Men vs Young Women	Young Men vs Old Men	Young Men vs Old Women	Young Women vs Old Men	Young Women vs Old Women	Old Men vs Old Women
Endurance level (A) (Nm)	.002	<.001	<.001	NS	<.001	.001
Maximal voluntary contraction (A + B) (Nm)	<.001	<.001	<.001	NS	<.001	<.001
Fatigue rate (C) ($\times 10^{-3}$)	NS	.08	NS	NS	NS	.17
Fatigue index (D) (%)	NS	NS	.06	.09	.12	.003

Note: Exact significance levels are given for values between .001 and .20; <.001 is given for smaller values, and NS represents significance levels >.20.

is the choice of angular velocity. There is some evidence that the contraction speed decreases with increasing age. Davies et al. (1986) and Vandervoort and McComas (1986) have both reported a significant increase in time to peak tension as well as relaxation time following evoked twitches. Muscle performance at a chosen velocity could therefore be relatively different in older than in younger individuals. Further studies are therefore needed before we can accurately accommodate such an age-related effect in the analysis also of fatigue and endurance.

Previously, fatigue and endurance in humans have most often been assessed during isometric contractions, either in combination with electrical stimulation (Lennmarken et al., 1985; Davies et al., 1986; Narici et al., 1991) or without electrical stimulation (Larsson and Karlsson, 1978; Hicks et

al., 1992). In studies based on dynamic contractions (Larsson and Karlsson, 1978; Laforest et al., 1990), fatigue and endurance have been assessed during 50 contractions. In such studies, the functional movements of everyday activities are more closely mimicked and could be considered a more natural and realistic way to assess fatigue than studies based on isometric contractions. In practice, however, the differences between these methods, the results obtained, and the conclusions drawn are seemingly small, so the variety of methods used to induce and to measure muscle fatigue and endurance can only partly account for the divergent results concerning the effects of increasing age.

In this study, muscle fatigue and endurance were assessed in the knee extensors. Previously, muscles in the thigh (Larsson and Karlsson, 1978; Laforest et al., 1990), in the

lower part of the leg (Davies et al., 1986; Hicks et al., 1992) and in the hand (Narici et al., 1991; Hicks et al., 1992), from younger and older individuals, have been studied. These muscles have different actions and different muscle fiber type compositions, and the results may not necessarily be comparable. Moreover, a common and well-known problem studying human muscles in general, and the aging muscle in particular, is the difficulty controlling factors such as the individual's nutritional status, level of physical activity, etc. Some previous studies have used individuals not older than 65 years of age, despite the fact that many age-related structural and functional alterations do not become clearly apparent until after the age of 70 years (Porter et al., 1995). Our group of older individuals were all above the age of 70 years, and represented a sample from the population of healthy older men and women; as with every similar study the validity of the conclusions depends on how well the sample represents the population — the randomness of the sample. The reasons for the divergent results and conclusions concerning muscle fatigue and endurance with increasing age are clearly multifactorial. However, from our own experience and review of the literature, we believe that the choice of muscle and selection of individuals are of greater importance for the results and conclusions than the method used to induce and to measure muscle fatigue and endurance.

The extension of the analytical method presented here takes into account all values recorded for an individual throughout the fatigue test and so summarizes much better the performance of the muscle throughout the test. Similar ways of assessing fatigue have been described previously (Merletti et al., 1991; Rabischong and Guiraud, 1993), and a precedent for this kind of analysis has also been presented in the animal literature (Brooks and Faulkner, 1991). For each profile in our study, an exponential curve could be fitted, and the fit was in general very good, as seen in the RMSE value; for brevity, the actual RMSE values are not given. Another advantage with the model and method is that it allows us to express fatigue and endurance in terms of several indices instead of just one, a concept that has been proposed recently (Merletti et al., 1991). This describes the different components of muscle fatigue and endurance and provides a greater understanding of the underlying mechanisms of increasing age and changes in muscle performance.

One of the most prominent effects of advancing age is the reduction in muscle strength. Most often the knee extension strength has been measured, either isometrically, concentrically, or eccentrically (Porter et al., 1995). Generally, decreases in muscle strength are seen after the age of 60 years (Porter et al., 1995). Above the age of 70 years, the average reduction in isometric muscle strength is 25–45%, with no apparent difference between men and women (Porter et al., 1995). Underlying this reduction in quadriceps muscle strength, at least in men, are major structural changes that take place in the muscle throughout life. It is now known that the aging atrophy of the vastus lateralis muscle, and the resultant reduction in strength in the quadriceps, are due mainly to a loss of muscle fibers, but also to a reduction in area of the remaining fibers, particularly of type 2 fibers (Lexell et al., 1988; Lexell and Downham, 1992).

The data in this study are in close agreement with the

published reduction in muscle strength. The values of isokinetic strength, and the marked reduction with increasing age (represented by the MVC measurements), are similar to those previously reported for younger and older men and women (Laforest et al., 1990; Vandervoort et al., 1990; Overend et al., 1992; Poulin et al., 1992; Stanley and Taylor, 1993). In our study, there was also a clear indication that older women were relatively weaker than older men; concentric isokinetic strength for older men was 68% of that in younger men, compared to 53% for older women of that in younger women. This is also in agreement with earlier studies which have indicated that the reduction in isokinetic muscle strength is more pronounced in women (Vandervoort et al., 1990; Overend et al., 1992; Poulin et al., 1992; Stanley and Taylor, 1993). The reduction in strength is seen as one of the most important aspects of increasing age and is considered to influence other parameters related to physical function in older individuals. The results and conclusions in the present study correspond well with these inferences.

Estimates of the relative loss of strength, either isometric or dynamic, throughout a fatigue test is a common method to assess muscle fatigue (Dvir, 1994). This allows us to compare the reduction in muscle strength throughout a test, for groups of individuals with different MVC. Only a few studies have used this type of assessment in an older population, but despite this paucity of investigations the results are fairly consistent. Larsson and Karlsson (1978) assessed dynamic endurance from 50 maximal knee extensions at $3.14 \text{ rad}\cdot\text{s}^{-1}$ in men and determined the relative decline in peak torque from the mean of the three initial contractions to the mean of the three final contractions. They found only a slight, nonsignificant age-related increase in dynamic endurance. Laforest et al. (1990) derived a cumulative fatigue index by dividing the sum of the peak torque obtained from the last 25 (out of 50) knee extensions at $3.14 \text{ rad}\cdot\text{s}^{-1}$ by the sum of the peak torque from the first 25 contractions. These authors found no age- or sex-related difference for their cumulative fatigue index. Hicks et al. (1992) assessed fatigue from maximal 3-sec isometric contractions followed by a 2-sec rest for a total time of 2 min, and found no difference in muscle performance between young and old male and female individuals. These results and conclusions are in close agreement with ours. When all young individuals were compared with all old individuals, the fatigue index (parameter *D*) — the percentage loss of muscle strength throughout the fatigue test — was almost identical. However, when men and women were separated, a slightly different pattern emerged. Older men had a significantly larger fatigue index than older women, indicating a greater relative loss of strength throughout the fatigue test. Despite this greater relative loss of force, older men had a significantly higher endurance level (parameter *A*) than older women. In addition, the relative difference between younger and older men and women was the same. All these findings can be explained by the difference in quadriceps MVC between younger and older men and women: men were in general stronger than women, a difference that became even more pronounced with increasing age.

The lack of any obvious differences between young and old men and women (except for the MVC) is also seen for the

fatigue rate (parameter *C*) — the rate of reduction in muscle force recorded during the fatigue test. On its own, it is a parameter independent of the determination of the MVC, the endurance level, and the fatigue index. It was found that the rate at which muscle force was lost during the fatigue test was unaffected by increasing age. The only noticeable difference between younger and older individuals was the larger variability in fatigue rate among both older men and older women compared to younger men and younger women, as seen in Figure 4C and expressed as an increased standard deviation in Table 1.

This increased variability in fatigue rate in older individuals could be due to age-related alterations in fiber-type composition. In a previous study of the effects of increasing age on the male vastus lateralis muscle (Lexell et al., 1988), no significant change in the mean fiber-type proportion from 20 to 80 years of age was found, but a considerable increase in variability in mean fiber type proportion in the older age groups compared to the younger. Muscle performance in younger individuals, in particular muscle endurance, has been reported to be related to the fiber-type proportion (Thorstensson and Karlsson, 1976). If the same relationship exists for older individuals, the increased variability in fatigue rate among older men and women could then be explained by the structural changes that take place in the muscle with increasing age (Lexell et al., 1988; Porter et al., 1995).

In summary, the results in this study imply that increasing age does not markedly alter the ability of the quadriceps muscle to maintain force throughout repeated dynamic contractions; this is in agreement with a majority of previous studies. Both the fatigue rate and the fatigue index, the two principal indicators of muscle fatigue, were not significantly different between young and old men and women. From the power analysis, the differences between younger and older individuals for the fatigue index (parameter *C*) and the fatigue rate (parameter *D*) would need to be at least 25×10^3 and 11%, respectively, to be detected; alternatively, for the obtained differences and standard deviations, the sample sizes must be at least doubled, except for the young men. The only significant differences for parameters *C* and *D* were found between old men and old women: the fatigue index of old women was lower than that for old men, indicating that older women may, in fact, be less susceptible to muscle fatigue than older men. However, in practice, it could well be the opposite. To perform activities of daily living, a given strength is needed. The stronger an older individual is the greater is the force that can be maintained over a short period, as seen in the MVC and the endurance level. The endurance level of old women was significantly lower than that of both young women and old men because of their considerably lower MVC. Consequently, weaker older women will use a larger proportion of their MVC for everyday tasks compared to stronger older men and women, and older women may therefore be unable to perform these activities over a longer period. If similar results are obtained in studies of other muscles, further investigations of the differences between muscle performance measured in the laboratory environment and in functional everyday situations are required. An increased knowledge of the effects of

aging on the structure and function of skeletal muscles will then enable us to identify more clearly the problems related to old age muscular impairment and so to select the most appropriate intervention programs.

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