Quadriiceps Muscle Function in Relation to Habitual Physical Activity and VO₂max in Men and Women Aged More Than 65 Years

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The relationship of quadriceps maximal muscle power (Pmax), corresponding optimal shortening velocity (vopt), and relative fatigability (Pmax%D) to maximal oxygen uptake (VO₂max) and habitual physical activity (PA) was examined in healthy community-dwelling subjects (29 women and 25 men) aged more than 65 years old. PA was evaluated by a questionnaire and expressed using two activity indices: mean habitual daily energy expenditure (MHDEE) and the daily energy expenditure corresponding to leisure time sports activities (Sports Activity). In women, Pmax correlated positively with VO₂max (r = .56) and with Sports Activity (rho = .41). Both Sports Activity and Pmax were significant independent predictors of VO₂max and accounted for 62% of variance in VO₂max. In men, vopt was significantly negatively related to MHDEE (r = -.59) and to Sports Activity (rho = -.40). Neither in women nor in men was Pmax%D correlated with VO₂max or PA indices. The different relationship of Pmax and vopt with VO₂max and PA indices suggests that habitual PA may be sufficient in active older women, but not in men, to positively influence quadriceps muscle function. These gender differences may suggest different approaches in exercise programming for elderly women and men.

Aging is connected with a gradual decline of habitual physical activity (PA) (1–3), maximal oxygen uptake (VO₂max) (4), and muscle function (5). Decreased VO₂max (6) and, especially, impaired muscle function (7) are limiting factors in the functioning of elderly subjects and further limit their daily PA. On the other hand, declining habitual PA causes further reduction of muscle function and aerobic capacity (3,5,6). Physical exercise can influence both aerobic capacity and neuromuscular functioning. Older subjects adapt to the specific exercise training similarly to their younger counterparts (8): with an improvement of VO₂max after endurance-type training (9) and with an increase in muscle strength after resistive-type training (10,11). However, the age-related decline in VO₂max has been attributed in part to a reduction in muscle mass (12). Unlike in younger individuals, it has been shown that resistance training in older subjects not only improves neuromuscular function but increases VO₂max as well (13,14). Therefore, it seems that in older subjects decreased muscle mass and function may contribute to decreased VO₂max. Muscle function may also partially mediate the effects of PA on VO₂max.

From the epidemiological point of view it seems particularly important to know what the influence of habitual level of PA in the elderly population is on both aerobic capacity and muscle function. Regular PA has become widely recommended as an important element of healthy and successful aging (2,3,6,9,15,16). Older subjects are being encouraged to increase their activity level, and many of them spontaneously undertake daily physical exercises (17,18). Hence, a potential positive influence of daily PA on aerobic capacity and muscle function may be more relevant to the lifestyle of elderly people than the data on the effects of formal exercise training.

Habitual PA in elderly subjects is predominantly the endurance-type low-intensity exercise (mainly walking) (2,18,19). It is well documented that habitual PA attenuates the age-related decline of aerobic capacity, and that active elderly subjects have higher VO₂max than their sedentary peers (9,20–22). The influence of habitual PA on neuromuscular function is not so unequivocal. Several studies have concluded that in healthy elderly women the level of habitual PA is connected with better neuromuscular functioning (20,23,24). On the other hand, some recent reports have found that active older men are no stronger than their sedentary peers (21,25,26). Therefore, available evidence suggests that the adaptation of neuromuscular function to an increased level of habitual PA may be different in elderly women and men.

Quadriiceps muscle performance is of particular importance in daily activities. Lower extremity muscle function deteriorates more rapidly than does that of the upper limbs (27), and is highly predictive of subsequent disability among older persons (28). Quadriiceps muscle function has been usually explored by assessing muscle isometric or isokinetic strength. Nevertheless, most of habitual daily activi-
ties require power (i.e., the product of force and speed of movement). Both force (5) and speed of movement (21) decline with age. That is why the decline of maximal muscle power ($P_{\text{max}}$) with age is greater than the decrease of maximal muscle strength (7). It is also probably more closely related to the loss of muscle ability to perform daily exercises (i.e., to accelerate and decelerate a given load such as body mass) (7,29).

Recently, Bosco and colleagues (30) developed a new device that enables exploring muscle function and precise measurement of $P_{\text{max}}$ and corresponding optimal shortening velocity ($V_{\text{opt}}$) during brief maximal exercise under ballistic conditions. This new ergometer allows the assessment of movements similar to those performed in everyday PA. In the present study, we have used this methodology to test the hypothesis stating that the daily PA is related to muscle movements similar to those performed in everyday PA. In the present study, we have used this methodology to test the hypothesis stating that the daily PA is related to muscle function and then to the exercise capacity ($\text{VO}_{2,\text{max}}$) in healthy older men and women. To test this model, the relationship of mechanical properties of quadriceps muscle to habitual PA and $\text{VO}_{2,\text{max}}$ and the relative contribution of mechanical properties to the variability in $\text{VO}_{2,\text{max}}$ have been examined. Previous data suggest that this model will be more significant in women than in men. Comparing men and women would help to identify the determinants of performance and provide some insight into gender influence on these relationships.

**Subjects and Methods**

**Subjects**
Sixty independent, community-dwelling elderly subjects aged from 65 to 84 years were recruited. To form a study population with a wide range of PA, the information about the study was supplied to various associations of elderly people in Lyon (France). Among them, 60 subjects (27 men and 33 women), who considered themselves healthy, agreed to participate in the first phase of the study. All the volunteers underwent physical examination prior to the study. Subjects who demonstrated ischemic heart diseases, severe aortic stenosis, hypertrophic obstructive cardiomyopathy, osteoarthritis, hepatic or renal failures, and any other chronic or evolutive disorder (including chronic pain and biomechanical limitations at the articular level), as well as contraindications to maximal exercise test were excluded. Six subjects met the exclusion criteria and 54 subjects (25 men and 29 women) ultimately participated in the study. They were predominantly of the middle socioeconomic class, having had a middle or higher level of education, with an average of 12 or more years of school. The study was approved by an ethics committee (Comité Consultatif de Protection des Personnes de la Recherche Biomédicale, Lyon, Centre Léon Bérard), and written informed consent was obtained from all the subjects.

**Protocol**

The subjects reported to the laboratory on the 3 days of the study. On the first day, the PA questionnaire was completed and anthropometric measurements were done. On the second day, a maximal aerobic exercise test was done. On the third day, quadriceps muscular testing was performed. Maximal aerobic exercise tests and quadriceps muscular testing were separated by at least a 3-day interval (21).

**Physical Activity**

The Questionnaire d’Activité Physique Saint-Etienne (QAPSE) has been previously described (1,22) and validated in a population of elderly subjects (19). It retrospectively reports activities over a duration of 1 typical week, including the weekend. The QAPSE was completed for all the participants by the same interviewer. Then, the QAPSE scores were calculated by the other researcher, who was not aware of the results of any other measurements performed in the study. In this study, the following two QAPSE activity indices were calculated and used for further comparisons: (i) mean habitual daily energy expenditure (MHDEE); (ii) Sports Activity index (daily energy expenditure corresponding to leisure time sports activities with intensity levels comprising between 4 and 7 metabolic equivalents).

The corrected weekly energy expenditure corresponding to a given activity is divided by $7$ to obtain QAPSE activity indices. In the present study, QAPSE activity indices are expressed relative to body mass in kilojoules per day (kJ $\cdot$ kg$^{-1} \cdot$ d$^{-1}$).

**$\text{VO}_{2,\text{max}}$**

A maximal treadmill exercise test was performed in agreement with the recommendations of Sidney and Shepard (31). $\text{VO}_{2,\text{max}}$ was determined by the standard open circuit method as previously described (19).

**Anthropometric Data**

Anthropometric data were collected by standard methods. Skinfold measurements were taken at four sites: triceps, biceps, subscapula, and suprailleum. The percentage of body fat was estimated from skinfold measurements according to the method of Durnin and Womersley (32). Fat-free mass was calculated by subtracting fat mass from body mass. Height and weight were also measured and the body mass index (BMI – kg $\cdot$ m$^{-2}$) was calculated. Thigh muscle plus bone volume was calculated using the thigh length, three circumferences, and two skinfold measurements (33). Quadriceps muscle mass was calculated from the regression equation derived from autopsy studies (34). This anthropometric approach has been validated against computer-assisted tomography (35). The term “quadriceps’ mass” is used in the present study and denotes the summed mass of the two quadriceps muscles.

**Quadriceps Muscular Testing**

$P_{\text{max}}$, corresponding $V_{\text{opt}}$, and relative fatigability ($P_{\text{max}}$%) were assessed. Quadriceps muscular testing was performed using the recently developed Ergopower dynamometer (30) applied to a leg extensor machine (Leg Extension Basic, Panatta Sport, Apiro, Italy; Figure 1). The subjects were first familiarized with the device during a phase of warming up. The chair of the apparatus was adjusted to give a full utilization of the quadriceps in a range of knee angles from 80° to 180°. After stretching, the subjects were asked to perform leg extensions against increasing loads, each separated by at least a 5-minute rest. This exertion lasts hundreds of milliseconds and activates the quadriceps muscles almost exclusively. The test began with a load of 5 kg and increased by
steps of 5 kg. The subjects were vigorously encouraged to give their maximum effort during each test. Plotting of the force-velocity relationship assured that maximum efforts were systematically obtained. The load displacement was measured every 0.75 mm by means of an optical encoder mounted on an external guide bar. The optical encoder was directly placed on the lifted load. The signal was sampled (200 Hz) and stored on a personal computer (486 DX2, 66 MHz) via an interface card equipped with a 12-bit analog/digital converter. The displacement signal was digitally filtered with a 12-Hz low-pass Butterworth filter with 0 phase lag. The instantaneous velocity, acceleration, force, torque, and power produced were obtained by digital derivation. Accurate measurements of friction and inertial effects during the movement were used in the calculation of the torque and power. The instantaneous values were used to determine the average values of velocity, torque, and power during each contraction. Average power and velocity were used to draw the power-velocity relationship. \( P_{\text{max}} \) and corresponding \( v_{\text{opt}} \) were calculated from a power-velocity curve:

\[
P = a \cdot V^2 + b \cdot V + c,
\]

where \( P \) is the power (watt [W]); \( V \) is the velocity (rad \( \cdot \) s\(^{-1} \)); \( a, b, \) and \( c \) are constants. On this curve, we can show the maximal point that represents the maximal power. The optimal velocity is the velocity at which the maximal power is produced. Full details of the calculation and methods are given in the study by Bosco and colleagues (30). The \( P_{\text{max}} \) is expressed as relative to body mass – \( P_{\text{max/kg}} \) (W \( \cdot \) kg\(^{-1} \)) and relative to the summed mass of the two quadriceps muscles – \( P_{\text{max/Quadr}} \) (W \( \cdot \) kg Quadr\(^{-1} \)). \( v_{\text{opt}} \) is expressed in rad \( \cdot \) s\(^{-1} \).

Then, after a 15-minute rest, the subjects performed the endurance (fatigability) test, which consisted of 10 consecutive leg extensions against the load corresponding to maximal power and lasted on the average 15 seconds. \( P_{\text{max}} \%D \) was assessed as the percentage power decrement from the highest to the lowest contraction.

**Statistical Analysis**

Data were verified for normality of distribution and equality of variances. When these assumptions were met, a one-way analysis of variance (equivalent to an unpaired \( t \) test when used with two groups) was used to compare gender groups. In one instance, for comparison of the Sports Activity index, the Mann-Whitney \( U \) test was used. Spearman correlations were used only for the non-normally distributed Sports Activity index. The analysis of covariance was used to compare the parallelism of the regression lines between men and women and to calculate the interaction between QAPSE activity indices and gender with Ergopower dynamometer measurements as dependent variables (test of homogeneity of slopes). Multiple stepwise regression analysis was performed to determine the relative contribution of selected independent variables to the variance in dependent variables. Results are presented as mean \( \pm \) standard deviation. The level of significance was set at \( p < .05 \).

**Results**

Table 1 shows age, anthropometric characteristics, Ergopower dynamometer measurements, \( V_{\text{O}2\text{max}} \), and QAPSE activity indices in men and women. There was no age difference between the men and women. Men had higher values of body mass, fat-free mass and quadriceps mass; women had higher percentages of body fat. \( P_{\text{max}}, P_{\text{max/kg}}, \) and \( P_{\text{max/Quadr}} \) were higher in men, but \( v_{\text{opt}} \) and \( P_{\text{max}} \%D \) were similar in both genders. \( V_{\text{O}2\text{max}} \) was higher in men, but QAPSE activity indices were similar in both groups.

Tables 2 and 3 present Pearson product moment and Spearman correlation coefficients for Ergopower dynamometer measurements with age, \( V_{\text{O}2\text{max}} \), and QAPSE activity indices in elderly men (Table 2) and women (Table 3). A negative relationship of \( P_{\text{max/kg}} \) with age was found in men, with a similar (but statistically not significant) trend for a negative relationship of \( P_{\text{max/Quadr}} \) and \( v_{\text{opt}} \) with age in both genders.

In men, no relationship for Ergopower dynamometer measurements with \( V_{\text{O}2\text{max}} \) was found. In women, \( P_{\text{max/kg}} \) correlated positively with \( V_{\text{O}2\text{max}} \). In men, a negative relationship for \( P_{\text{max/kg}}, P_{\text{max/Quadr}} \), and \( v_{\text{opt}} \) with QAPSE activity indices was found. The \( v_{\text{opt}}-\text{MHDEE} \) and \( v_{\text{opt}}-\text{Sports Activity} \) correlations were statistically significant (Figure 2). No relationship between \( P_{\text{max/Quadr}} \) and \( v_{\text{opt}} \) with QAPSE activity indices was found in women; however, a positive correlation between \( P_{\text{max/kg}} \) and Sports Activity, with a strong tendency
Tables 1 and 2 show the mean and standard deviation of various anthropometric and physical activity variables in men and women. The table also includes a note that all comparisons were done with Pearson correlation coefficient except Sports Activity, for which a Spearman correlation coefficient was used. Table 3 shows the correlation coefficients for ergopower dynamometer measurements with age, VO_{max}, and QAPSE activity indices in elderly women. The table includes notes that all comparisons were done with Pearson correlation coefficient except Sports Activity, for which a Spearman correlation coefficient was used.

For a similar relationship between P_{max/kg} and MHDEE (p = .06), was obtained in the group of women (Table 3). P_{max/%D} did not correlate with age, VO_{max}, or QAPSE activity indices in either men or women. In addition, no correlation was found between P_{max/Quadr} and P_{max/kg}, or v_{opt} in either group (not shown in tables). VO_{max} was, moreover, more closely related to MHDEE (r = .62, p < .001) and Sports Activity (r = .75, p < .001) in women than in men (r = .35, p = .08) and (r = .30, p = .15).

Table 2: Correlation Coefficients for Ergopower Dynamometer Measurements With Age, VO_{max}, and QAPSE Activity Indices in Elderly Men (n = 25)

<table>
<thead>
<tr>
<th>Variable</th>
<th>P_{max/kg} (W · kg^{-1})</th>
<th>P_{max/Quadr} (W · kg_{Quadr}^{-1})</th>
<th>v_{opt} (rad · s^{-1})</th>
<th>P_{max/%D} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>−0.30</td>
<td>−0.51**</td>
<td>−0.39</td>
<td>0.003</td>
</tr>
<tr>
<td>VO_{max} (ml · kg^{-1} · min^{-1})</td>
<td>0.08</td>
<td>0.21</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>MHDEE (kJ · kg^{-1} · d^{-1})</td>
<td>−0.15</td>
<td>−0.33</td>
<td>−0.50**</td>
<td>0.15</td>
</tr>
<tr>
<td>Sports Activity (kJ · kg^{-1} · d^{-1})</td>
<td>−0.29</td>
<td>−0.24</td>
<td>−0.40*</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Notes: All comparisons were done with Pearson correlation coefficient except Sports Activity, for which a Spearman correlation coefficient was used. QAPSE = Questionnaire d’Activité Physique Saint-Etienne; MHDEE = mean habitual daily energy expenditure.

VO_{max}. In women, Sports Activity and P_{max/kg} were selected to predict VO_{max} variance:

VO_{max} = 17.1 + 0.229 · Sports Activity + 1.86 · P_{max/kg} (standard error [SE] = 0.048; SE = 0.83; adjusted r^2 = .62; standard error of the estimate [SEE] = 2.46).

In men, no independent variable was selected in the stepwise regression analysis to predict VO_{max} variance. As both physical activity and fitness (muscle function and exercise capacity) may influence each other, the model has been also tested in the opposite direction. If P_{max/kg}, P_{max/Quadr}, v_{opt}, P_{max/%D}, and VO_{max} were introduced in the stepwise regression analysis as independent variables to predict QAPSE activity indices, VO_{max} contributed significantly to MHDEE and Sports Activity variances in men:

MHDEE = 50.9 + 2.95 · VO_{max} (SE = 0.80; adjusted r^2 = .33; SEE = 16.4) Sports Activity = 40.3 + 2.10 · VO_{max} (SE = 0.36; adjusted r^2 = .56; SEE = 7.31).

In men, v_{opt} was the only variable that contributed significantly to MHDEE variance:

MHDEE = 189.1 − 23.5 · v_{opt} (SE = 6.93; adjusted r^2 = .32; SEE = 20.3).

No variables were selected for Sports Activity in men.

Discussion

This is the first study that demonstrates the statistically significant gender difference in the relationship of habitual PA to quadriceps P_{max} and v_{opt} in elderly men and women. Our data show that in older women habitual PA, quadriceps P_{max}, and VO_{max} are closely related to each other. In older men, this model is less significant: the relationship of VO_{max} to habitual PA is less robust, with no apparent relationship of P_{max} to the measures of PA and aerobic capacity. In contrast, it seems that older men with higher levels of habitual PA are characterized by a lower v_{opt}.
tion of type II fibers, and a loss of functioning motor units (27). It has been suggested (36) that older subjects who remain physically active have fewer losses in skeletal muscle mass and performance. In fact, several studies have concluded that a maintenance of high habitual PA might protect against some of the age-related decline of muscle mass and strength in older women (23,24,37). Recently, using short sprints on a friction-loaded nonisokinetic cycle ergometer, we found (20) that in healthy elderly women habitual PA simultaneously alleviates the drop in O2 max and the decline of quadriceps muscle P max.

In older men, there is less evidence that habitual PA improves muscle strength and power. In two studies, endurance-trained runners were able to generate significantly more force from their knee extensor muscles in comparison with sedentary controls (38,39). In contrast, in the majority of previous studies, no influence of endurance training on muscle function in men has been observed (25,26,40–42). In our recent report (21), using short sprints on a cycle ergometer, we found that in healthy elderly men, habitual PA alleviated the drop in VO2 max, but did not attenuate the decline in P max of the quadriceps muscles with age.

In the present study, we have assessed quadriceps muscles function by explosive leg extension testing. This exercise lasts less (within hundreds of milliseconds) than 8-second sprints on a cycle ergometer. Furthermore, bicycle tests require the activation of multiple muscle groups of the lower extremity; the presently used test activates the quadri-
ceps muscles among women, a higher level of habitual PA is connected with higher quadriceps $P_{\text{max}}$. The role of habitual PA seems especially important in determining the muscle capacity to move the body from place to place ($P_{\text{max/kg}}$). Furthermore, $P_{\text{max/kg}}$ was also closely related to $V\dot{O}_{2}\text{max}$. Both Sports Activity and $P_{\text{max/kg}}$ were significant independent predictors of $V\dot{O}_{2}\text{max}$ and accounted for 62% of variance in $V\dot{O}_{2}\text{max}$, whereas $V\dot{O}_{2}\text{max}$ contributed significantly to MHDEE (33%) and Sports Activity (56%) variances in women. In healthy elderly men, a higher level of habitual PA was not connected with better $P_{\text{max}}$. Furthermore, quadriceps muscle power was not related to aerobic capacity.

Aging is associated with a decrease of the maximal contraction speed corresponding to a given force (26, 43, 44). Except for our two recent reports (20, 21), we are not aware of any studies investigating the $v_{\text{opt}}$ in older persons. Slowing of $v_{\text{opt}}$ reflects a change in muscle quality (a decrease in the proportion of type IIb fibers) (27, 45). Similarly to $P_{\text{max}}$, our data suggest that habitual PA is not related to higher quadriceps muscle $v_{\text{opt}}$ in active elderly men. In fact, older men with higher habitual PA were characterized by a lower $v_{\text{opt}}$. The $v_{\text{opt}}$ was also the only variable that contributed significantly (but negatively) to MHDEE variance (32%).

Therefore, it seems that in the ranges of PA and fitness of the study sample, mechanical properties of quadriceps muscles in older men, unlike in elderly women, are not positively related to the level of habitual PA and aerobic capacity. Multiple endogenous and exogenous factors can contribute to these gender differences. Among them, different fitness levels and relative physiological loads brought about by PA, different anatomical and physiological muscle characteristics, and different gender hormone profiles seem to be the most plausible at the moment.

MHDEE found in our study is in agreement with the values of total energy expenditure obtained in elderly people using other questionnaires (46), as well as those measured by doubly labeled water technique (47). $V\dot{O}_{2}\text{max}$ values found in this study indicate that our population was at an approximately average level of fitness when compared with the reference values for healthy elderly subjects (4). The men had higher $P_{\text{max}}$ and $V\dot{O}_{2}\text{max}$ than the women. It is possible that the men have such high $V\dot{O}_{2}\text{max}$ values, that limitations in their daily activities are only moderately related to their $V\dot{O}_{2}\text{max}$. In women, the proportion of $V\dot{O}_{2}\text{max}$ required to perform daily tasks is higher, so that in women with lower $V\dot{O}_{2}\text{max}$, exhaustive exertions are probably more often abandoned. Habitual PA also has a stronger influence on their $V\dot{O}_{2}\text{max}$. This speculation may be illustrated by a stronger PA-$V\dot{O}_{2}\text{max}$ relationship in women than in men.

The gender difference in this “ceiling effect” seems to be even more pronounced for muscle function. The gender difference in performance is less pronounced for aerobic than anaerobic power. Men had, on average, 114% of the $V\dot{O}_{2}\text{max}$ of women and as much as 140% of the $P_{\text{max/kg}}$ and 134% of the $P_{\text{max/Quads}}$ of women. On the other hand, energy expenditure as expressed in relative terms (i.e., per kg of body mass) was similar in both genders. Our subjects were healthy, active men and women (though not to a competitive level). Their spontaneous, leisure-time PA consisted mainly of brisk walking and flexibility exercises. None of the subjects were engaged in regular strength training. Therefore, it may be possible that habitual PA is a sufficient stimulus to influence aerobic and anaerobic properties of older women, in whom both properties are at relatively low level. In women, quadriceps functioning is also a limiting factor for both PA and $V\dot{O}_{2}\text{max}$, and partially mediates the influence of habitual PA on cardiorespiratory fitness. In contrast, habitual sports activity in elderly men influences overall cardiorespiratory fitness (but not to such an extent as in women); however, it has no apparent impact on the muscle power. $P_{\text{max}}$ is not a limiting factor for daily PA or $V\dot{O}_{2}\text{max}$.

In older men, the relative area of fast-twitch fibers in the quadriceps muscle is larger than in women (48). $v_{\text{opt}}$ found in the elderly men corresponded to 112% of that found in older women ($p = .11$ for the difference), which gives some support to gender differences in muscle fiber composition of elderly subjects. Men with higher $v_{\text{opt}}$ (and probably higher percentage of fast-twitch fibers) were less active and were especially characterized by a lower sports activity level than the men with lower $v_{\text{opt}}$. Because quadriceps $P_{\text{max}}$ is not a limiting factor for daily PA in older men, it may be that “slow-twitch” older men are more prone to undertake habitual, predominantly endurance-type, exercises. An alternative explanation may be that this habitual sports activity even promotes a more pronounced shift towards a slow-twitch fiber domination in physiological muscle characteristics. Fast-twitch muscles require more intensive, high-speed activations for proper functioning than do slow-twitch muscles. Higher activation threshold (49) of fast-twitch fibers implicates less frequent activation during everyday activities and probably causes their more pronounced dropout.

Muscle composition and function could be also influenced by several other endogenous factors, among them the endocrine system. Sex steroids, growth hormone (GH), and insulin-like growth factor-I (IGF-I) are known to influence muscle and lean body mass (50–53). Several studies have found favorable changes in body composition and/or muscle strength in response to recombinant human GH (53), recombinant human IGF-I (50), testosterone (51), and dehydroepiandrosterone (52), in some studies, accompanied by significant gender dimorphic responses (52). Therefore, different gender hormone profiles may contribute to the gender-specific relationship between PA and muscle function. Changes in sex steroids, GH, and IGF-I secretion with age could be permissive to the loss of muscle mass and modulate the influence of PA on muscle function.

It has been suggested that muscle endurance may provide a more practical measure of muscle function related to normal daily activity than the measures of strength, especially in elderly persons (54). Muscle endurance has been usually assessed as the decline in muscle strength (torque) throughout the test, or the force that can be maintained over a certain period of time. In this study, we have measured fatigue as a failure to maintain power output during 10 repetitive contractions. This measure may more closely resemble muscle performance needed during the functional movements of daily activity (e.g., climbing one flight of the
stairs). As in younger subjects (55), there was no significant sex difference in the rate of fatigue development. No correlation was found between Pmax%D and Pmax/kg, Pmax/Quadr, or Vopt in either group (not shown in tables). These findings are similar to those of previous reports (54) and suggest that no substantial relationship exists between the endurance and muscle power (i.e., the rate of fatigue development is similar in both stronger and weaker subjects). Pmax%D did not correlate with age, VO2max, or QAPSE activity indices in either men or women. The data on the lack of relationship between habitual PA and muscle endurance are somewhat in contrast with the previous studies. Older athletes were usually reported to maintain better muscle endurance than their sedentary peers (56,57). Grimby and coworkers (58) reported that resistive training can improve both muscle strength and endurance in 78- to 84-year-old men. It is possible that our endurance protocol was too short to elicit fatigue detectable during 50 consecutive contractions. The difference in the decline patterns of power and force with repetitive contractions could also be due to the variable contribution of two power components (force and velocity). Because the increased muscle endurance might be of utmost importance to elderly persons (59), further studies with different training and testing protocols should pursue this problem.

Some methodological considerations relevant to the present study should be discussed. We believe that the proposed model is valid in the reported ranges of age, PA, and fitness of the study sample. The reciprocal associations between habitual PA, muscle function, and aerobic capacity may be different in other samples of older adults. Furthermore, this is a cross-sectional study and finding a statistical relationship does not necessarily imply a physiological relationship. The limitation of measurements used in the study should also be taken into consideration. Although QAPSE is a very precise PA questionnaire (19), it reports an actual habitual PA that may not reflect habitual activity over a lifetime. Quadriceps muscle is a key muscle of locomotion, but it is still only one muscle. The reported associations may be different for other muscles. Finally, our subjects were more healthy and fit than a random sample of older people. Undoubtedly, elderly subjects in good health and with good functional capacity are more prone to participate in such studies and especially to undergo the maximal exercise test. Therefore, future studies should address the effects of PA on Pmax and Vopt in both healthy and more frail elderly persons. Future prospective studies are also needed to link the Pmax and Vopt with functional status of older subjects (e.g., walking velocity and falls incidence).

In conclusion, our data show that in older women habitual PA, quadriceps Pmax, and VO2max are closely interrelated. In older men, the relationship of VO2max to habitual PA is less robust, with no apparent relationship of Pmax to the measures of PA and aerobic capacity. In contrast, it seems that older men with higher levels of habitual PA are characterized by a lower Vopt. Furthermore, our data suggest that the relative measures of endurance are similarly maintained in older men and women and are not related to habitual PA or parameters characterizing power and force-velocity relationships.

The gender differences observed in the relationship of PA, muscle function, and aerobic capacity are noteworthy, suggesting different approaches in exercise programming for elderly men and women. It seems that women function in a more narrow reserve of fitness and even moderate exercises stimulate their Pmax and VO2max. In active older women, habitual Sports Activity seems sufficient to alleviate muscle power and VO2max decline. Therefore, a general promotion of an increased, spontaneous PA level among older women seems appropriate. Healthy older men have much higher reserves of VO2max, and especially that of Pmax. Other, probably psychosocial, factors modulate their PA level. In older men, habitual PA may be insufficient and/or inadequate to positively influence physiological muscle properties. A negative Vopt-PA relationship suggests that their habitual PA may be even the wrong type of exercise in optimizing muscle function. Therefore, it seems that in men, a more intensive supplementation of habitual PA with resistive and/or sprint exercises should be considered.

Acknowledgments
Tomasz Kostka was supported by a grant from the Hospices Civils de Lyon and by the Medical University of Lodz (Grant 502-11-449).
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Received July 20, 1998
Accepted February 17, 2000
Decision Editor: Jay Roberts, PhD