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# Contraction-specific differences in maximal muscle power during stretch-shortening cycle movements in elderly males and females

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**Abstract** Elderly people (age 75 years; $n = 48$ males and 34 females) were studied in order to elucidate gender differences in elderly subjects on the determinants of muscle power (force and velocity) during a stretch-shortening cycle. All subjects performed three maximal counter-movement vertical jumps using both legs, on a force platform (Kistler 9281 B). The eccentric (Ep) and concentric (Cp) phases of the jumps were analyzed. The Ep was further divided into an acceleration phase ($Ep_{acc}$: from the start of the downward movement to the maximal negative velocity) and deceleration phase ($Ep_{dec}$: from the maximal negative velocity to the end of the downward movement). Jump height for the men was higher than for the women ($P < 0.001$). During both $Ep_{acc}$ and $Ep_{dec}$ no significant differences were observed between males and females in force and power generation. However, the men had a higher peak muscle power during the Cp, which may be explained exclusively by the velocity determinant ($P < 0.001$). No specific gender-related strategy appeared to influence the motor pattern of the movement. The comparable eccentric force generation of the leg extensors in both genders suggests a similar ability to cope with eccentric muscle actions during everyday activities. In contrast, the marked lower capacity for concentric contractions in women may result in an impaired performance, especially in activities where intense and rapid movements are essential, for example when reversing a forward fall. This may be one reason why elderly women are more prone to falls than are elderly men.

**Key words** Aging · Muscle power · Stretch-shortening cycle · Eccentric muscle actions · Concentric contractions

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## Introduction

Intense, short-lasting muscle exertions are required frequently during everyday activities. Obvious examples are when rising from a chair or ascending stairs. These exertions depend upon the ability of the muscles to generate mechanical power, which involves the product of contractile force and contraction velocity (i.e., speed of movement; Kostka et al. 1997). In younger people such movements are normally trivial, but they may become challenging for the elderly person, since muscle power deteriorates with aging (Skelton et al. 1994).

The age-related decrease in muscle power is more pronounced than the decrease in muscle strength (3.5% versus 1.5–2% per year from the age of 65 years; Skelton et al. 1994). Therefore, the decreased muscle power may predispose a person to a higher risk of functional limitations in everyday activities than is implied by the loss in muscle strength (Bassey 1997; Bassey et al. 1992; Rantanen et al. 1994).

Differences in muscle power between males and females are evident in all age groups, even when values are normalized for body mass (Bosco and Komi 1980; Skelton et al. 1994). Females generally have a 20–30% lower muscle power than males in 65- to 89-year-old subjects (Skelton et al. 1994). In one study (Skelton et al. 1994), a similar leg extensor muscle power was observed in healthy women aged 65–69 years as in 85- to 89-year-old men. An even more marked gender difference was reported in very old, frail people with low health status, with females having approximately half the muscle power of that of the males (Bassey et al. 1992).

The reduced muscle power of women during aging renders them more prone than men to experience a reduced ability in managing simple everyday activities. This may result in pronounced differences in the ability to cope with more demanding tasks, including various "emergency situations" where rapid execution and high muscle forces are required (e.g., when regaining balance after tripping or a quick stop to avoid unexpected obstacles; Dutta 1997; Schultz et al. 1997). This predisposes women to a greater and earlier risk of loss of independence than their peer males during aging, and may represent an important factor for the higher rate of falls in women (Suzuki et al. 1992).

Weight-bearing tests, which appear more relevant for evaluating functional capacity, have rarely been used to assess muscle power in healthy old people. To our knowledge, only a single study has compared men and women using this approach (Bosco and Komi 1980). Furthermore, only few studies have involved coupled eccentric muscle actions and concentric muscle contractions (so-called stretch-shortening cycles: SSC), as performed in a counter-movement jump test. Indeed, we are not aware of any study in which the specific determinants of the force and power generated during the eccentric versus the concentric phases has been investigated in elderly people performing such SSC tests.

Eccentric muscle actions often precede concentric contractions during everyday movements based on a normal control strategy. The mechanical output of such coupled eccentric muscle actions and concentric contractions is known to be superior to isolated concentric contractions (Bosco and Komi 1980; Komi 1987). This fact is frequently utilized during everyday activities (e.g., when climbing a relatively high step, as when alighting a bus). Eccentric muscle actions are also used frequently to control or attenuate impact forces (e.g., when stepping down from a stair or sidewalk, when providing stabilization during locomotion, or when trying to reverse the movement during a forward fall).

There may be substantial differences in the mechanical muscle performance of males and females in all phases of a given movement (eccentric, concentric) and/or in one or both determinants of muscle power. Indeed, this could reflect a specific gender-related motor control strategy. A further understanding of these mechanisms would be beneficial for the development of specific training programs for preventive and rehabilitative strategies.

The aim of this study was to elucidate gender differences in the determinants of muscle power during the eccentric and the concentric phases of a counter-movement jump in a group of 75-year-old men and women.

## Methods

### Subjects

Community-dwelling elderly people, 48 men and 34 women, all aged 75 years, volunteered for this study. Participants were recruited from the Danish National Civil Register (CPR), and all were residents in the town of Odense, Denmark.

An interview based on questionnaires of activities of daily living (ADL) (Avlund and Schultz-Larsen 1991) and a mini mental state examination (MMSE; Folstein et al. 1975), combined with a physical performance test (PPT; Reuben and Siu 1990) was performed in the participants' own home. The PPT test included timed items such as rising from a chair five times consecutively at a chosen speed, walking a distance of 2.8 m, putting on and removing a jacket, and picking up a coin from the floor. A medical doctor performed a medical evaluation, including an electrocardiogram and anamnesis, in order to exclude any disease that could interfere with the tests. Subjects taking medication were only included in the experiment if they were medically stable. At the time of the experiment the subjects did not participate in any regular physical activity. All subjects gave their informed written consent to participate, and the local ethical committee approved the study.

### Measurements

#### *Anthropometry*

Height was measured to the nearest 0.5 cm and body mass was measured on digital scales, with participants lightly dressed. Anthropometric data are reported in Table 1.

#### *Muscle power*

Muscle power was assessed during a standardized both-legs counter-movement jump performed on a force platform (Kistler 9281 B, 40 × 60 × 5 cm) (Fig. 1). Starting from a standing position, the subjects (who were wearing comfortable shoes) were instructed to perform a fast downward movement (to about 90° knee flexion) immediately followed by a fast upward movement, and to jump as high as possible. Hands were kept on the hips to minimize any influence of the arms. The jump was demonstrated to the subject, who subsequently performed two submaximal trials. Following a short rest, three maximal jumps were performed at 1-min intervals, and the highest jump was selected for further analysis.

**Table 1** Physical anthropometric characteristics of the 75-year-old men and women who participated in this study. The data are given as the mean (SD) and range

| Characteristic | Females ($n = 34$) | | Males ($n = 48$) | |
|---|---|---|---|---|
| | Mean (SD) | Range | Mean (SD) | Range |
| Height (cm) | 159.6 (5.6) | 144–169 | 172.3 (5.4)*** | 161–187 |
| Body mass (kg) | 70 (14.8) | 40.6–97.8 | 79.5 (12.1)*** | 57–109.6 |
| Body fat (%) | 40.4 (8.2) | 16.6–52.6 | 31.1 (4.7)*** | 19.2–40.7 |
| Lean body mass (%) | 59.6 (8.2) | 47.4–83.4 | 68.9 (4.7)*** | 59.3–80.8 |

Differences between females and males: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

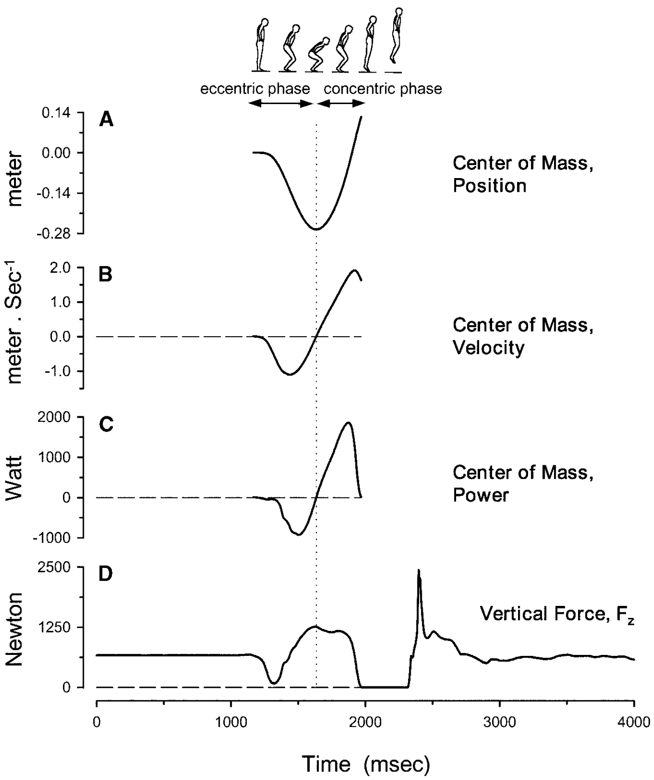


**Fig. 1** Representative counter-movement jump divided into the eccentric and concentric phases, showing the vertical position (**A**), velocity (**B**), power (**C**) and vertical force (*Fz*; **D**) of the center of mass, recorded in a 75-year-old man

The vertical force signal (*Fz*) was fed from the kistler amplifier to an A/D converter in a personal computer (dt28ez Data Translation) at a 1000-Hz sampling rate. The *Fz* signal was later analyzed according to the method of Davis and Rennie (1968). In brief, the vertical velocity ($v$) of the body center of mass was obtained by time integration of the instantaneous acceleration:

$$v = \int_0^t a(t)\mathrm{d}t = \int_0^t [F(t)/m - g]\mathrm{d}t$$

where $a$ is the vertical acceleration, $F$ is the vertical force measured directly by the platform, $m$ is the body mass of the subject and $g$ is the acceleration due to gravity (9.81 m $s^{-2}$). Power was calculated continuously throughout the movement as the product between $F$ and $v$. Subsequently, the position signal was obtained by time integration of the velocity signal.

All jumps were analyzed for the eccentric (Ep) and concentric (Cp) phases (i.e., the phases of downward, negative velocity, and upward, positive velocity, movement of the center of mass, respectively). Ep was further divided into an acceleration ($Ep_{acc}$) and deceleration ($Ep_{dec}$) phase (Fig. 2). $Ep_{acc}$ was defined as the interval between the start of the downward movement, when the velocity ($m \cdot s^{-1}$) increased negatively, and the instant of maximal negative velocity ($0 > v_{acc} = \max$). $Ep_{dec}$ was defined as the interval between the moment of maximal negative velocity and the time when the velocity reached zero (i.e., at the end of the downward movement). Peak downward acceleration ($a_{peak}$) and minimum vertical force ($Fz_{min}$) were determined for $Ep_{acc}$. Likewise, peak deceleration ($d_{peak}$), and maximal vertical force ($Fz_{max}$) were identified for $Ep_{dec}$ (Fig. 1). Peak power ($\dot{W}_{peak}$) was identified in the concentric phase, and the corresponding velocity and force at $\dot{W}_{peak}$ ($v_{\dot{W}peak}$ and $Fz_{\dot{W}peak}$, respectively) were determined. Furthermore, peak velocity and peak force and take-off velocity during Cp were calculated and compared to the velocity and the force obtained at $\dot{W}_{peak}$.

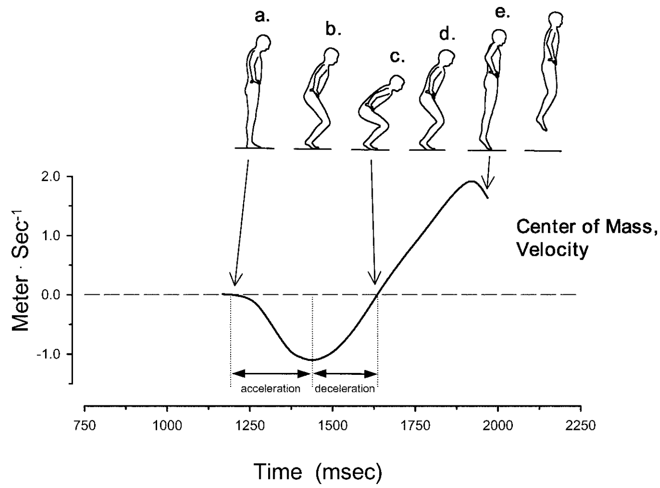


**Fig. 2** The eccentric movement phase divided into phases of acceleration and deceleration (see Methods for details). The movement starts at position *a*. At the instant of peak negative velocity (*b*), acceleration shifts from negative (i.e., accelerating downwards) to positive (i.e., accelerating upwards while still moving downward – deceleration). At the point of transition from negative to positive velocity (*c*), the center of mass is at its lowest position. Subsequently, the body is accelerated upwards (*d*). At the instant of takeoff (*e*) there is a slight loss in vertical velocity, presumably due to low levels of plantar flexor muscle strength

*Body composition*

Lean body mass (LBM) was measured in each subject under fasting conditions by a conventional bioimpedance arm-to-leg method, with a custom-built apparatus (Puggaard et al. 1999). Prior to the test, all subjects were asked to empty their bladder. The calculations were derived from the equations elaborated by Heitmann (1991) for elderly Danish people. This method has been cross-validated with elderly subjects against a four-compartment model based on measurements of total body water and potassium, with a reliability of body fat evaluated by a regression analysis of $R^2 = 0.89$ (Heitmann 1991).

### Statistical analysis

Results are expressed as the mean (SD) and range. Comparisons of the results were performed using the Mann-Whitney test for unpaired observations. Correlations between variables were assessed using Spearman's Rho. The level of statistical significance was set at $P < 0.05$.

## Results

### ADL, MMSE, PPT

No differences were observed in the ADL, MMSE and PPT questionnaires between elderly men and elderly women. Furthermore, no correlation was observed between items from the PPT test (e.g., rising from a chair five times at a chosen speed) and the results of muscle power.

### Anthropometric values

The men were heavier, taller and had a higher LBM and less body fat than the women ($P < 0.001$; Table 1). For that reason, force values measured during the jumps are expressed per kg body mass ($\cdot kg^{-1}$) and per kg lean body mass ($\cdot kglbm^{-1}$).

Eccentric and concentric phases of a jump

The parameters of the Ep and Cp of a jump are shown in Table 2. On average, the men jumped higher than the women ($P < 0.001$). During $Ep_{acc}$, $Fz_{min}$ normalized to body mass and $a_{peak}$ were similar for men and women (Table 2). Likewise, no differences were observed during the phase of $Ep_{dec}$, showing that men did not reach a higher level of vertical force per kg body mass prior to the start of the Cp. However, when $Fz_{min}$ was normalized to LBM, men showed a significantly lower value compared to women ($P < 0.05$), whereas women exhibited a higher $Fz_{max}$ ($P < 0.05$) compared to men.

$\dot{W}_{peak}$, $Fz_{\dot{W}peak}$, and $v_{\dot{W}peak}$

During the Cp, $\dot{W}_{peak}$ per kg body mass was higher in men ($P < 0.001$). However, this difference disappeared when this value was normalized to LBM (Table 2).

Further analysis of the two determinants of power, $Fz_{\dot{W}peak}$ and $v_{\dot{W}peak}$, revealed similar $Fz_{\dot{W}peak}$ values for both genders, whereas $v_{\dot{W}peak}$ differed ($P < 0.001$), explaining the higher $\dot{W}_{peak}$ in men during the Cp (Table 3). In contrast, $Fz_{\dot{W}peak}$ and $v_{\dot{W}peak}$ expressed as a percentage of maximal force ($Fz_{max}$) and velocity ($v_{max}$), were similar in both men and women (Table 4). During the interval between $\dot{W}_{peak}$ and take-off, however, women exhibited a greater decrease ($P < 0.001$) in vertical velocity compared to men (Table 5).

## Discussion

The major finding of the present study was that elderly males achieved greater muscular $\dot{W}_{peak}$ than elderly females during maximal SSC work, as assessed by the performance of a counter-movement jump. This difference was primarily attributed to the velocity determinant of the $\dot{W}_{peak}$ during the Cp (Table 3). Furthermore, in the last part of the Cp, females showed a lower efficiency in the jump than males, as demonstrated by a reduced ratio of take-off velocity/maximal concentric velocity (Table 5).

Both groups showed similar values in the items from the PPT test, ADL questionnaire and MMSE, suggesting that these tests were inappropriate for detecting differences in a selected population of elderly people.

During the Ep of a counter-movement jump, two major events can be identified, both of which influence the subsequent Cp: (1) the body mass is accelerated downward, and (2) the body mass is decelerated (i.e., accelerated upward) and brought to a stop. It is important to note that both events occur while the subject is moving downward. The potentiating effect of the Ep of the movement is related to the speed of muscle lengthening and shortening and to the length excursion of the muscle (Bosco et al. 1982). $Fz_{min}$ is an indirect index of the ability to accelerate the body mass downward. Thus, the vertical ground reaction force decreases with the increase in downward acceleration during the first part of the downward phase.

It is evident that for a high value of downward acceleration, $Fz$ becomes small, and vice versa. The magnitude of acceleration (i.e., $a_{peak}$) reflects the velocity at the end of the acceleration phase, as supported by a significant relationship between maximal eccentric velocity and $a_{peak}$ ($r = 0.83$, $P < 0.05$). The work produced over this first part of the movement has now to be reversed by the muscles of the subject by producing identical work in the opposite direction in order to stop the downward movement. The muscles therefore have to produce tension by increasing their level of active state. The rate of this work, directed downward on the force platform, is reflected by the magnitude of the deceleration (i.e., $d_{peak}$), as supported by a moderate relationship between $\dot{W}_{peak}$ and $d_{peak}$ in the Ep ($r = 0.60$, $P < 0.05$).

**Table 2** Eccentric acceleration (*Ecc<sub>acc</sub>*), deceleration (*Ecc<sub>dec</sub>*) and concentric (*Conc*) phases of a jump in the 75-year-old men and women who participated in this study. Values are given as the mean (SD) and range. ($Fz_{min}$ Minimal vertical force, $Fz_{max}$ maximal vertical force, $a_{peak}$ peak acceleration, $d_{peak}$ peak deceleration, $\dot{W}_{peak}$ peak power, *kglbm* kg lean body mass)

| Variable | Females ($n = 34$) | | Males ($n = 48$) | |
|---|---|---|---|---|
| | Mean (SD) | Range | Mean (SD) | Range |
| $Ecc_{acc}$ | | | | |
| $Fz_{min}$ ($N \cdot kg^{-1}$) | 5.57 (2.0) | 1.13–8.98 | 4.9 (1.7) | 0.62–8.3 |
| $Fz_{min}$ ($N \cdot kglbm^{-1}$) | 9.89 (4.0) | 2.08–19.23 | 7.41 (2.7)* | 0.88–12.77 |
| $a_{peak}$ ($m \cdot s^{-2}$) | 4.2 (2.0) | 0.82–8.66 | 4.9 (1.7) | 1.78–9.19 |
| $Ecc_{dec}$ | | | | |
| $Fz_{max}$ ($N \cdot kg^{-1}$) | 15.3 (2.7) | 10.97–20.9 | 16.01 (2.48) | 11.8–23.48 |
| $Fz_{max}$ ($N \cdot kglbm^{-1}$) | 26.77 (5.44) | 18.31–38.24 | 23.92 (3.6)* | 17.79–32.77 |
| $d_{peak}$ ($m \cdot s^{-2}$) | 5.46 (2.64) | 1.15–10.95 | 6.18 (2.47) | 1.99–13.61 |
| Conc | | | | |
| Jump height (cm) | 5.93 (2.43) | 1.39–12.73 | 9.85 (3.51)*** | 3.56–17.91 |
| $\dot{W}_{peak}$ ($W\ kg^{-1}$) | 18.67 (3.27) | 13.06–26.62 | 23.01 (4.09)*** | 14.44–33.88 |
| $\dot{W}_{peak}$ ($W\ kglbm^{-1}$) | 32.56 (5.81) | 22.42–45.85 | 34.30 (5.6) | 24.74–45.86 |

Differences between females and males: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

**Table 3** $\dot{W}_{peak}$, and force ($F_{\dot{W}peak}$) and velocity ($v_{\dot{W}peak}$) at $\dot{W}_{peak}$ of a jump performed by 75-year-old female and male subjects. Values are given as the mean (SD) and range

| Variable | Females ($n = 34$) | | Males ($n = 48$) | |
|---|---|---|---|---|
| | Mean (SD) | Range | Mean (SD) | Range |
| $\dot{W}_{peak}$ (W kg$^{-1}$) | 18.67 (3.27) | 13.06–26.62 | 23.01 (4.09)*** | 14.44–33.88 |
| $F_{\dot{W}peak}$ (N kg$^{-1}$) | 14.92 (1.25) | 12.77–17.84 | 15.39 (1.38) | 13.41–20.04 |
| $v_{\dot{W}peak}$ (m s$^{-1}$) | 1.25 (0.15) | 1.01–1.63 | 1.50 (0.20)*** | 1.03–1.93 |

Differences between females and males: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

**Table 4** Maximal force ($F_{maxcon}$), maximal velocity ($v_{maxcon}$) and take-off velocity ($v_{take\text{-}off}$) during the concentric phase of a jump performed by 75-year-old women and men. Values are given as the mean (SD) and range

| Variable | Females ($n = 34$) | | Males ($n = 48$) | |
|---|---|---|---|---|
| | Mean (SD) | Range | Mean (SD) | Range |
| $F_{maxcon}$ (N · kg$^{-1}$) | 17.14 (2.11) | 14–21.79 | 17.72 (2.07) | 14.1–25.26 |
| $v_{maxcon}$ (m · s$^{-1}$) | 1.38 (0.17) | 1.09–1.77 | 1.64 (0.21)*** | 1.14–2.09 |
| $v_{take\text{-}off}$ (m · s$^{-1}$) | 1.06 (0.22) | 0.52–1.58 | 1.36 (0.26)*** | 0.73–1.86 |

Differences between females and males: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

**Table 5** Force at $\dot{W}_{peak}$ ($Fz_{\dot{W}peak}$) expressed as the percentage of maximal concentric force ($Fz_{max}$), velocity at $\dot{W}_{peak}$, ($v_{Wpeak}$), and $v_{take\text{-}off}$ expressed as the percentage of maximal concentric velocity ($v_{max}$) recorded during the concentric phase of a jump performed by 75-year-old men and women

| Variable | Females ($n = 34$) | Males ($n = 48$) |
|---|---|---|
| $Fz_{\dot{W}peak}/Fz_{max}$ | 87% | 87% |
| $v_{\dot{W}peak}/v_{max}$ | 91% | 92% |
| $v_{take\text{-}off}/v_{max}$ | 77% | 83%* |

Difference between females and males: *$P < 0.001$

For $d_{peak}$ we obtain:

$$Fz_{max} = (m \times g) + m \times (+d_{peak})$$

In many cases, in this phase of the jump the center of mass of the subject is at the lowest position, where vertical velocity reaches 0, changing from a negative to a positive sign (Fig. 1). This represents the transition between the Ep and the Cp of the jump. $Fz_{max}$ exerted on the platform in this phase of the jump would correspond to the maximal activated state of the subject's leg extensor muscles due to a high fraction of attached cross-bridges (Bobbert et al. 1996) immediately prior to the Cp. Thus, a higher level of activation at the end of the Ep would seem to determine the ability to produce greater amount of work over the first part of the Cp (Bobbert et al. 1996).

In addition, the two Ep of the jump are inter-related. A high acceleration would transform into a high velocity at the end of the acceleration phase, developing a high level of kinetic energy. The kinetic energy is reversed by the opposing work generated during the deceleration phase. In order to obtain a high value of $Fz_{max}$, and develop the highest possible muscle tension (Svantesson and Grimby 1995), the kinetic energy must be reversed rapidly by means of a forceful eccentric muscle contraction.

Our study revealed that both women and men developed a similar level of vertical force (normalized to body mass) at the end of the Ep, in agreement with earlier findings (Komi and Bosco 1978). Using a "sledge ergometer" it has previously been shown that at low levels of prestretch loads, young women (22 years old) exhibited a better use of the eccentric prestretch compared to young men (23 years old), whereas greater potentiating effects were observed in the young men at high prestretch loads (Aura and Komi 1986). In addition, elderly women were reported to have a greater relative capability for eccentric torque generation than elderly men (Porter et al. 1995). In the present study, a tendency for men to accelerate and decelerate their body mass faster than women was revealed ($a_{peak}$ $P < 0.08$; $d_{peak}$ $P < 0.1$). However, at the end of the Ep, the value of $Fz_{max}$ per kg of body mass was slightly higher in the men. When this value was normalized to LBM, the women exhibited a higher $Fz_{max}$ ($P < 0.05$), which may indicate that more motor units were activated. Alternatively, these differences may simply reflect the fact that the female subjects would have a greater ratio of leg muscle mass to LBM (due to less upper body muscle mass).

Differences in neural activation of the muscles between elderly males and females may contribute to higher eccentric/concentric peak torque ratios, as suggested by Porter et al. (1995). In young subjects, the neural drive was reported to be lower during maximal eccentric than concentric contraction (Aagaard et al. 2000; Westing et al. 1991). This has been suggested to represent a mechanism to prevent injuries when high tension is developed, especially in strong subjects (Stauber 1989). Compared to female subjects, male subjects may exhibit lower eccentric/concentric ratios as a consequence of reduced neural drive during maximal eccentric contraction (Porter et al. 1995).

Maximal eccentric muscle strength appears to be less reduced with aging in women as compared to men

(Hurley 1995; Lindle et al. 1997). Furthermore, no correlation appears to exist between total muscle mass and eccentric muscle strength in men and women at any age (Hortobágyi et al. 1995). Our study confirmed that women have a lower muscle mass. However, when $Fz_{max}$ was normalized to LBM, women showed markedly higher values, suggesting that factors other than muscle mass influence the difference in $Fz_{max}$.

During the Cp, the elderly women exhibited a significantly lower muscle power (expressed in terms of body mass) and jumped lower than males, in agreement with previous studies (Bassey et al. 1992; Bosco and Komi 1980; Rantanen and Avela 1997). When $\dot{W}_{peak}$ was divided into the components of force and velocity, women exhibited a significantly lower $v_{Wpeak}$ ($P < 0.001$), whereas $Fz_{Wpeak}$ was similar for the two groups (Table 3). Furthermore, the ratio of $Fz_{Wpeak}$ and $v_{Wpeak}$ to maximal force and velocity obtained during the Cp, respectively, did not differ between the groups (Table 5). This suggests an absence of a gender-specific strategy in the motor pattern.

No gender difference was observed when $\dot{W}_{peak}$ was normalized to LBM. Despite an absence of a significant difference in $\dot{W}_{peak}$ normalized to LBM between males and females, it is important to consider that during daily tasks the elderly women have to carry a larger body mass, corresponding to a higher energy demand when performing the same task.

In the present study, the velocity determinants (i.e., maximal concentric velocity, $v_{Wpeak}$ and take-off velocity) appeared to represent a limiting factor for muscular power production and jump performance in the elderly women. In particular, the female subjects exhibited a marked reduction in the velocity component in the final part of the Cp, considered as the interval between $v_{Wpeak}$ and the instant of take-off, as demonstrated by a reduced ratio of take-off velocity to maximal concentric velocity. This phase roughly corresponds to semi-extended positions of the legs (Fig. 1), where small muscle groups are primarily involved in the extension prior to take-off (i.e., the ankle extensors). The possibility exists that elderly women may be more affected by age than men during explosive movements involving these muscle groups. A previous study on forward falls demonstrated a reduced "maximum response execution speed" by showing a different ability to regain balance of an old versus a young group of males (Thelen et al. 1997). Thus, the lower values of velocity observed in elderly women during the Cp in the present study may represent an important factor associated with the higher rate of falls in elderly females (Suzuki et al. 1992).

In summary, the findings of the present study suggest that the differences in leg muscle power during the concentric phase of a SSC movement between elderly males and females may primarily be attributed to the velocity component, whereas during the eccentric phase no differences were seen in acceleration or deceleration. No gender-specific strategy appears to be present for the counter-movement jump, since muscle power normalized to LBM was similar for males and females. The comparable eccentric force generation of the leg extensors in the elderly male and female subjects suggests a similar ability to cope with eccentric contractions in everyday activities, such as stepping down stairs. In contrast, the elderly women seem to demonstrate a markedly reduced mechanical muscle performance during intense concentric contractions involving fast movement, thereby potentially impairing their performance in activities such as when rapidly trying to regain postural balance. This may contribute to the higher incidence of falls observed in elderly females.

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## References

Aagaard P, Simonsen EB, Andersen JL, Magnusson SP, Halkjær-Kristensen J, Dyhre-Poulsen P (2000) Neural inhibition during maximal eccentric and concentric quadriceps contraction: effect of resistance training. J Appl Physiol (89: 2249–2257)

Aura O, Komi PV (1986) The mechanical efficiency of locomotion in men and women with special emphasis on stretch-shortening cycle exercises. Eur J Appl Physiol 55: 37–43

Avlund K, Schultz-Larsen K (1991) What do 70-year-old men and women actually do? And what are they able to do? From the Glostrup survey in 1984. Aging 3: 39–49

Bassey EJ (1997) Measurement of muscle strength and power. Muscle Nerve Suppl 5: S44–S46

Bassey EJ, Fiatarone MA, O' Neill EF, Kelly M, Evans W, Lipsitz LA (1992) Leg extension power and functional performance in very old men and women. Clin Sci 82: 321–327

Bobbert MF, Gerritsen KGM, Litjens MCA, Van Soest AJ (1996) Why is countermovement jump height greater than squat jump height? Med Sci Sports Exerc 28: 1402–1412

Bosco C, Komi P (1980) Influence of aging on the mechanical behavior of leg extensor muscles. Eur J Appl Physiol 45: 209–219

Bosco C, Viitasalo JT, Komi PV, Luhtanen P (1982) Combined effect of elastic energy and myoelectrical potentiation during stretch-shortening cycle exercise. Acta Physiol Scand 114: 557–565

Davis CTM, Rennie R (1968) Human power output. Nature 217: 770–771

Dutta C (1997) Significance of sarcopenia in the elderly. J Nutr 127: 992S–993S

Folstein MF, Folstein SE, McHugh PR (1975) 'Mini-Mental State'. A practical method for grading the cognitive status of patients for the clinicians. J Psychiatr Res 12: 189–198

Heitman BL (1991) Evaluation of body fat estimated from body mass index, skinfolds and impedance. A comparative study. Eur J Clin Nutr 44: 831–837

Hortobágyi T, Zheng D, Weidner M, Lambert NJ, Westbrook S, Houmard JA (1995) The influence of aging on muscle strength and muscle fiber characteristics with special reference to eccentric strength. J Gerontol 50A: B399–B406

Hurley BF (1995) Age, gender, and muscular strength. J Gerontol 50A: 41–44

Komi PV (1987) Neuromuscular factors related to physical performance. Med Sport Sci 26: 48–66

Komi PV, Bosco C (1978) Utilisation of stored elastic energy in leg extensor muscles by men and women. Med Sci Sports 10: 261–265

Kostka Tomasz, Bonnefoy MA, Laurent M, Berthouze SE, Belli AL, Jean-Renè (1997) Habitual physical activity and peak

anaerobic power in elderly women. Eur J Appl Physiol 76: 81–87
Lindle RS, Metter EJ, Lynch NA, Fleg JL, Fozard JL, Tobin J, Roy TA, Hurley BF (1997) Age and gender comparisons of muscle strength in 654 women and men aged 20–93 years. J Appl Physiol 83: 1581–1587
Porter MM, Myint A, Kramer JF, Vandervoort AA (1995) Concentric and eccentric knee extension strength in older and younger men and women. Can J Appl Physiol 20: 429–423
Puggaard L, Larsen JB, Ebbesen E, Jeune B (1999) Body composition in 85-year-old women: effects of increased physical activity. (Milano) Aging 11: 307–315
Rantanen T, Avela J (1997) Leg extension power and walking speed in very old people living independently. J Gerontol 52A: M225–M231
Rantanen T, Era P, Heileleinen E (1994) Maximal isometric strength and mobility among 75-year-old men and women. Age Ageing 23: 132–137
Reuben DB, Siu AL (1990) An objective measure of physical function of elderly outpatients. The physical performance test. JAGS 38: 1105–1112
Schultz AB, Ashton-Miller JA, Alexander NB (1997) What leads to age and gender differences in balance maintenance and recovery? Muscle Nerve Suppl 5: S60–S64
Skelton DA, Greig CA, Davies JM, Young A (1994) Strength, power, and related functional ability of healthy people aged 65–89 years. Age Ageing 23: 371–377
Stauber WT (1989) Eccentric action of muscles: physiology, injury, and adaptation. Exerc Sport Sci Rev 157–185
Suzuki M, Okamura T, Shimazu Y, Takahashi H, Eguchi K, Kano K (1992) A study of falls experienced by institutionalised elderly. Jpn J Pub Health 39: 927–940
Svantesson U, Grimby G (1995) Stretch-shortening cycle during plantar flexion in young and elderly women and men. Eur J Appl Physiol 71: 381–385
Thelen DG, Wojcik LA, Schultz AB, Ashton-Miller JA, Alexander NB (1997) Age differences in using a rapid step to regain balance during a forward fall. J Gerontol 52A: M8–M13
Westing SH, Cresswell AG, Thorstensson A (1991) Muscle activation during maximal voluntary eccentric and concentric knee extension. Eur J Appl Physiol 62: 104–108