Gender-Related Differences in Physical Performance Among Seniors

Kristin Musselman and Brenda Brouwer

This study examined gender differences in balance, gait, and muscle performance in seniors and identified gender-specific factors contributing to physical performance. Forty (20 men, 20 women) healthy, community-dwelling seniors (74.5 ± 5.3 years) participated. Limits of stability, gait speed, lower limb flexor and extensor isokinetic concentric peak torques, self-reported activity level, and balance confidence were measured. No gender differences were detected in gait speed, limits of stability when normalized to height, activity level, or balance confidence ($p \geq .188$). Women were weaker than men ($p \leq .007$), even after controlling for weight and body-mass index, suggesting that other gender-related factors contribute to strength. Gender accounted for 18–46% of the variance in strength and served as a modifier of the relationship between activity level and strength in some muscle groups. The primary factors relating to gender-specific strength was activity level in men and body weight in women.

Key Words: physical function, stability, activity level, aging

With advanced age there is progressive deterioration in physical capacity associated with limitations in the ability to perform everyday activities including walking and stair climbing (see Brouwer & Olney, 2004, for review). Such declines are a major health concern because they threaten independence and well-being and increase the risk of physical injury (Carmeli, Reznick, Coleman, & Carmeli, 2000; Vandervoort & Symons, 2001). As an example it is well documented that the risk of falling increases with age and that about one in three seniors over the age of 65 years will experience a fall in a given year (Howland et al., 1998; Vellas, Wayne, Romero, Baumgartner, & Garry, 1997). It is also noteworthy that most of those who fall are women (Colledge et al., 1994; Prudham & Evans, 1981). It has been postulated that the gender bias in postural ability might stem from gender-related distinctions in physical ability such as strength (Wolfson, Judge, Whipple, & King, 1995), although others argue that accounting for anthropometric differences eliminates any distinction in physical performance between men and women (Era et al., 1996; Maki, Holliday, & Fernie, 1990).

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Measures of postural sway during quiet stance have generally failed to identify gender differences (Baloh et al., 1994; Colledge et al., 1994; Kinney LaPier, Liddle, & Bain, 1997; Maki et al., 1990; Wolfson, Whipple, Derby, Amerman, & Nashner, 1994); however, outcomes relating to more challenging balance tasks such as weight-shifting ability, response to perturbations, and functional reach have demonstrated that men outperform women (Hageman, Leibowitz, & Blanke, 1995; Wolfson et al., 1994). Anthropometric differences likely contribute to the discrepancies in balance performance because normalizing the excursion of the center of gravity or the center of pressure to height or the base of support eliminates gender as a factor (Era et al., 1996; Maki et al., 1990). In contrast, Kinney LaPier and colleagues (1997) reported that normalizing maximum anterior–posterior COG excursion to height was crucial to distinguishing balance ability between men and women, and they resolved that gender differences in strength most likely explained their findings. Others have drawn similar conclusions (Schultz, Ashton-Miller, & Alexander, 1997; Wolfson et al., 1994, 1995).

Gender disparities in muscle strength are well documented—men outperform women in tests of muscle strength (Andrews, Thomas, & Bohannon, 1996; Aniansson, Grimby, & Rundgren, 1980; Aniansson, Sperling, Rundgren, & Lehnberg, 1983; Frontera, Hughes, Lutz, & Evans, 1991; Frontera et al., 2000; Kent-Braun & Ng, 1999; Pedersen, Ovessen, Schroll, Avlund, & Era, 2002; Pincivero, Gandaio, & Ito, 2003; Rantanen, Era, & Heikkinen, 1997; Skelton, Greig, Davies, & Young, 1994). What is less clear is the extent to which these gender differences can be explained by anthropometric factors. Some researchers contend that normalizing torque to body mass, cross-sectional area, or lean muscle mass eliminates strength differences between men and women (Frontera et al., 1991; Ivey et al., 2000; Kent-Braun & Ng; Neder et al., 1999). Others have found gender differences in strength to persist even after adjusting for weight, height, muscle mass, and muscle cross-sectional area (Andrews et al.; Frontera et al., 2000; Pedersen et al.; Pincivero et al.; Rantanen et al.; Skelton et al.). The controversy around whether or not muscle quality (strength per unit of muscle) and changes in muscle quality over time are similar for older men and women is fueled in part by the existence of regional anatomical differences in rates of strength decline with age, thus limiting generalizability from one study to another (Frontera et al., 1991; Lindle et al., 1997; Lynch et al., 1999; Rantanen et al.). In addition, age-related decline in muscle quality is influenced by the nature of the contraction, with less reduction demonstrated in eccentric than concentric contractions (Vandervoort, 2002), particularly in women (Lynch et al.).

The inconsistency in the research literature relating to gender and physical performance underscores the complexity of the relationship and raises the possibility that there might be a unique set of factors for men and women that contribute to physical-performance ability. Such information would be useful in developing strategies to enhance physical performance. This study examined whether gender differences in balance ability and confidence, gait speed, strength, and activity levels were evident in healthy, community-dwelling seniors. In addition, analyses were carried out to identify gender-specific factors contributing to performance ability.
Methods

PARTICIPANTS

Community-dwelling seniors 65 years of age and older were recruited from the Kingston community through newspaper and posted advertisements seeking healthy individuals who did not report any lasting concern about falling associated with activity curtailment. Respondents were asked if they had any neurological condition, vestibular disorder, activity-restricting arthritis; used an assistive device for ambulation; or were taking medications that could affect balance—a positive reply excluded them from the study. Participants were screened by one of the authors (K.M.) to exclude those who tested positive for postural hypotension (drop of ≥20 mmHg or ≥10 mmHg in systolic or diastolic pressure, respectively, on rising from sitting to standing or after 2 min of standing; Caird, Andrew, & Kennedy, 1973) or impaired sensation or proprioception (assessed position sense of great toes). Recruitment continued over a 2-month period until 20 men and 20 women were entered into the study (mean age 74.5 ± 5.3 years). The sample size was determined based on preliminary data relating to anteroposterior (AP) limits of stability (LOS) in 14 older women and 13 older men who were involved in another study (Binda, Culham, & Brouwer, 2003). An effect-size index of .97 was calculated, indicating that approximately 17 participants per group were required to detect a gender difference with a power of .80. All participants provided informed consent, and the protocol was approved by the university ethics review board.

PROTOCOL

Participants came to the motor-performance laboratory on one occasion for about 1.5 hr. They had been asked to refrain from engaging in any exercise or strenuous physical activity on the day of testing. Anthropometric measures of height and weight were recorded for each individual while he or she stood barefoot. These measurements were used to calculate body-mass index: BMI = weight (kg)/height (m²). Participants were then asked to perform a series of physical tests (in random order) to evaluate balance ability, gait speed, and lower limb muscle strength. Participants also completed two questionnaires relating to balance confidence and activity level because these variables are known to influence physical function (Howland et al., 1998). The same trained individual administered all physical tests and questionnaires.

PHYSICAL MEASURES

Limits of stability were measured as participants stood barefoot on a force platform, which measures forces and moments about the x, y, and z axes from strain gauges positioned at each corner (Advanced Medical Technology, Inc., Watertown, MA). Participants stood with their medial malleoli aligned with the x axis (medial–lateral) and the lateral borders of their feet positioned according to their height and adopted a comfortable amount of forefoot splay (Brouwer, Culham, Grant, & Liston, 1998).
Data were collected (60 Hz) for 1 min while participants stood quietly with their arms at their sides while focusing on a point on the wall in front of them. The \( x,y \) coordinates of the center of pressure (COP) and the average COP position over the trial period were calculated (BioAnalysis, Advanced Medical Technology, Inc.). Participants then leaned as far as they could forward, backward, to the left, and to the right (order determined randomly). They were instructed to keep both feet in contact with the force platform and move about the ankles with their knees, hips, trunk, and neck straight. A researcher was on hand to stabilize the participant if needed. The maximum COP excursion relative to the average standing COP position from three 5-s trials was measured for each of the leaning conditions. Summing the COP excursions in forward and backward directions provided the AP COP displacement, and, similarly, the COP shifts in left and right directions determined the mediolateral COP displacement (Binda et al., 2003; Brouwer, Musselman, & Culham, 2004).

Gait speed was determined by timing the participants as they traversed the central 10 m of a 15-m walkway. Participants wore comfortable flat-soled shoes and were instructed to walk at their natural pace. Three trials were performed, and the average gait speed was calculated.

Strength was measured isokinetically (60°/s) during reciprocal concentric contractions of the lower limb flexors and extensors of the hip, knee, and ankle of the dominant leg (random order) using a Biodex dynamometer. The hip muscles were tested in a standing position, and the other muscle groups were evaluated while participants were seated. The axis of rotation of the joint of interest was aligned to the mechanical axis of the dynamometer. Straps were used to isolate activity to the target muscles and to provide restraint and stability for the participants. Each joint tested involved five consecutive repetitions of maximal effort—participants were instructed to flex and extend as hard and as fast as they could through 95% of their available range of motion. Participants were verbally encouraged throughout the testing and then were able to rest for 2–4 min as they were repositioned as necessary in order to test the next joint. This provided ample time for recovery and minimized the potential for fatigue (Parcell, Sawyer, Tricoli, & Chinevere, 2002). For each muscle group the peak torque (corrected for gravity) was recorded as an absolute value and normalized to body weight and BMI, the latter having been shown to parallel changes in fat-free mass (Sartorio et al., 2004).

**QUESTIONNAIRES**

The Activities-Specific Balance Confidence scale (ABC) was used to evaluate participants’ confidence in their balance abilities (Myers et al., 1996). The ABC requires participants to rank on a continuum their confidence (0 = no confidence, 100 = complete confidence) in performing 16 specific activities of daily living without losing their balance or falling. The average score has strong discriminant validity, thus distinguishing between seniors with and without a fear of falling (Myers et al.), and yields excellent retest reliability (\( r = .89 \); Topping, 1994). Fear of falling
indicated by ABC scores is known to be associated with lower limb weakness and slow gait speed (Brouwer et al., 2004), so it was important to determine whether scores were comparable among the men and women involved in this study.

Activity level was assessed using the Human Activity Profile, a survey of 94 activities related to self-care, home maintenance, entertainment/social activities, transportation, and physical exercise that are rank-ordered by increasing metabolic demands (Fix & Daughton, 1988). For each activity, respondents indicated whether they were still performing the activity, had stopped performing the activity, or had never performed it. The maximum activity score is the rank of the most demanding activity still performed, and an adjusted activity score was calculated by subtracting the number of activities an individual had stopped doing from the maximum activity score. The maximum activity score and adjusted activity score have high test–retest reliability ($r = .84$ and $.79$, respectively; Fix & Daughton).

**DATA ANALYSIS**

All data were tested for normality to ensure the appropriateness of parametric analysis. Independent sample $t$ tests were used to identify gender-related differences in dependent variables and determine whether differences were sustained after scaling the data to anthropometric measures. A significance level of .05 was adopted, and a Bonferroni correction was applied when analyzing the strength data to adjust the $p$ value to .008. Forward, stepwise, multiple regressions were performed to identify variables that could be used to predict outcomes yielding a gender bias. Additional analyses were carried out on the data from men and women separately to determine whether a unique set of factors emerged. In all cases the alpha was set at .05 to enter and 1.0 to remove.

To minimize the risk of including variables in the regression model that were related to each other, variance inflation factors reflecting the correlation between one variable and the remaining independent variables were calculated (SPSS® version 12.0, Chicago). Values of 1.0 indicated no correlation and values exceeding 10.0 suggested problems resulting from multicollinearity. To account for any relationships between independent variables identified as predictors that might influence the outcome, interaction terms were calculated as the product of two individual variables and entered into the model. Significant interactions ($p < .05$) were left in the final regression model to ensure the validity of the beta weight estimates.

**Results**

The participating men and women were similar in age (men $75.4 \pm 5.5$ years, women $73.6 \pm 5.0$ years; $p = .272$), although the men were heavier ($p = .029$) and were on average about 11 cm taller ($p < .001$). The mean BMI values, which normalize mass to body height, were similar for men and women ($p = .305$). In terms of balance, women were less able to displace their COP in both AP ($p = .012$) and mediolateral ($p = .022$) directions than were men. This was not accompanied by any gender-
related difference in resting COP position \( (p > .124) \). When COP excursion was expressed relative to height, gender differences were no longer detected \( (p \geq .188) \). Height accounted for 15\% and 18\% of the variance in maximal AP and mediolateral COP displacement, respectively. These data are summarized in Table 1.

There was no evidence suggestive of gender differences in balance-confidence scores (men 91.5 ± 5.5, women 91.8 ± 8.1; \( p = .905 \); maximum score = 100) or the maximum activity level that men (79.2 ± 6.2) and women (76.4 ± 6.9) felt able to achieve \( (p = .185 \), maximum score = 94). Furthermore, the adjusted activity score provided no indication that one gender was more or less inclined to curtail activities (men 72.8 ± 8.4, women 70.1 ± 10.5; \( p = .368 \)).

The seniors in this study adopted a natural walking speed of 1.3 m/s, regardless of gender \( (p = .946) \). Pronounced gender-related differences, however, were observed in relation to muscle strength. Men exerted significantly higher concentric peak torques for all lower limb flexor and extensor muscle groups \( (p \leq .007) \). Accounting for body mass reduced the disparity between men and women but failed to abolish it, except in the case of the plantar flexors \( (p = .068 \); see Figure 1). Normalizing torque values to BMI produced similar results, but the gender differences in plantar-flexor strength remained significant.

The persistence of the strength differential between men and women despite normalizing torque to anthropometric measures provided impetus for further exploration of the factors contributing to torque production. All outcome measures except those relating to strength were entered into the regression model and revealed gender as the most prominent factor, accounting for 18–46\% of the variance in torque measures. In terms of physical dimensions, only weight was a significant factor in determining knee-extensor and knee- and hip-flexor strength. Activity level was an important predictor of torque production at the hip and of knee-flexor strength. Variance-inflation factors associated with multiple regressor variables ranged between 1.02 and 1.39, indicating that the precision of the models generated was unlikely affected by problems resulting from collinearity. Significant

### Table 1  Participant Characteristics \( (M \pm SD) \) and Maximal Displacement of the Center of Pressure

<table>
<thead>
<tr>
<th>Variable</th>
<th>Men</th>
<th>Women</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>75.4 ± 5.5</td>
<td>73.6 ± 5.0</td>
<td>.272</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.6 ± 5.8</td>
<td>162.2 ± 6.3</td>
<td>.001</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.5 ± 8.4</td>
<td>65.4 ± 11.0</td>
<td>.029</td>
</tr>
<tr>
<td>Body-mass index (kg/m(^2))</td>
<td>24.1 ± 3.2</td>
<td>25.3 ± 3.8</td>
<td>.305</td>
</tr>
<tr>
<td>Mediolateral limits of stability (cm)</td>
<td>21.3 ± 2.7</td>
<td>19.0 ± 3.4</td>
<td>.022</td>
</tr>
<tr>
<td>Mediolateral limits of stability/height ( \times 10^{-2} )</td>
<td>12.2 ± 1.5</td>
<td>11.7 ± 2.0</td>
<td>.324</td>
</tr>
<tr>
<td>Anteroposterior limits of stability (cm)</td>
<td>12.4 ± 1.7</td>
<td>10.8 ± 2.1</td>
<td>.012</td>
</tr>
<tr>
<td>Anteroposterior limits of stability/height ( \times 10^{-2} )</td>
<td>7.1 ± 1.0</td>
<td>6.6 ± 1.4</td>
<td>.188</td>
</tr>
</tbody>
</table>
interactions between gender and activity, however, revealed that the relationship between activity level and both knee-flexor and hip-extensor strength were modified by gender. Indeed, in men, activity was a major factor associated with strength measured in most muscle groups but not so in women. Weight emerged as a strong predictor of strength in women, accounting for as much as 60% of the variance in torque, but also proved to be an independent factor influencing strength in both men and women. No significant interactions between gender and weight or any other combination of factors were found.

Identifying variables predictive of plantar-flexor and hip-extensor torques proved most difficult. It should be noted that intraparticipant variability in peak-torque values was highest for these muscle groups (coefficients of variation of 11.4% and 14.5%, respectively), in contrast to the consistency exhibited in others muscles (coefficient of variation ≤6.9%). The factors contributing to torque outcomes are summarized in Table 2.
Table 2  Summary of the Stepwise Regression Analyses Identifying Predictors of Muscle Strength for All Subjects (N = 40) and for Men (n = 20) and Women (n = 20) Separately

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Group</th>
<th>Variable entered</th>
<th>$R^2$</th>
<th>$R^2$ change</th>
<th>SEE</th>
<th>beta</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantar flexors</td>
<td>All</td>
<td>Gender</td>
<td>17.9</td>
<td>—</td>
<td>10.9</td>
<td>0.423</td>
<td>.007</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>—</td>
<td></td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>AAS</td>
<td>21.1</td>
<td>—</td>
<td>12.4</td>
<td>0.460</td>
<td>.041</td>
</tr>
<tr>
<td>Dorsiflexors</td>
<td>All</td>
<td>Gender</td>
<td>37.5</td>
<td>—</td>
<td>3.6</td>
<td>0.613</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>Weight</td>
<td>36.4</td>
<td>—</td>
<td>2.6</td>
<td>0.806</td>
<td>.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AP LOS</td>
<td>70.4</td>
<td>34.0</td>
<td>1.8</td>
<td>0.679</td>
<td>.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAS</td>
<td>81.3</td>
<td>10.9</td>
<td>1.5</td>
<td>0.342</td>
<td>.007</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>MAS</td>
<td>21.2</td>
<td>—</td>
<td>3.6</td>
<td>0.460</td>
<td>.041</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>All</td>
<td>Gender</td>
<td>39.7</td>
<td>—</td>
<td>19.1</td>
<td>0.586</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>Weight</td>
<td>57.0</td>
<td>17.3</td>
<td>16.3</td>
<td>0.356</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age</td>
<td>66.3</td>
<td>9.3</td>
<td>15.4</td>
<td>-0.319</td>
<td>.003</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>Weight</td>
<td>60.5</td>
<td>—</td>
<td>9.8</td>
<td>0.712</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age</td>
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<td>9.4</td>
<td>8.8</td>
<td>-0.314</td>
<td>.034</td>
</tr>
<tr>
<td>Knee flexors</td>
<td>All</td>
<td>Gender</td>
<td>46.2</td>
<td>—</td>
<td>10.4</td>
<td>1.242</td>
<td>.127</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>Weight</td>
<td>55.0</td>
<td>8.8</td>
<td>9.6</td>
<td>0.240</td>
<td>.028</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AAS</td>
<td>62.0</td>
<td>7.0</td>
<td>9.0</td>
<td>0.561</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gen_AAS</td>
<td>67.0</td>
<td>5.0</td>
<td>8.5</td>
<td>-1.810</td>
<td>.029</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>Weight</td>
<td>35.8</td>
<td>—</td>
<td>6.0</td>
<td>0.599</td>
<td>.005</td>
</tr>
<tr>
<td>Hip extensors</td>
<td>All</td>
<td>Gender</td>
<td>24.2</td>
<td>—</td>
<td>23.3</td>
<td>1.753</td>
<td>.088</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>AAS</td>
<td>35.7</td>
<td>11.5</td>
<td>21.7</td>
<td>0.695</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gen_AAS</td>
<td>43.4</td>
<td>7.7</td>
<td>20.7</td>
<td>-2.189</td>
<td>.033</td>
</tr>
<tr>
<td>Hip flexors</td>
<td>All</td>
<td>Gender</td>
<td>34.6</td>
<td>—</td>
<td>19.5</td>
<td>0.435</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Women</td>
<td>Weight</td>
<td>47.6</td>
<td>12.4</td>
<td>16.3</td>
<td>0.378</td>
<td>.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AAS</td>
<td>56.7</td>
<td>9.1</td>
<td>18.3</td>
<td>0.317</td>
<td>.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AP LOS</td>
<td>52.9</td>
<td>19.3</td>
<td>12.5</td>
<td>0.477</td>
<td>.017</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td>AAS</td>
<td>39.9</td>
<td>—</td>
<td>17.2</td>
<td>0.631</td>
<td>.003</td>
</tr>
</tbody>
</table>

Note. SEE = Standard error of the estimate; beta = standardized coefficient; VIF = variance inflation factor; AAS = adjusted activity score; AP LOS = anterior-posterior limits of stability; AAS = adjusted activity score; MAS = maximum activity score; Gen_AAS = interaction terms for gender and AAS.
Discussion

The major findings of this study were that accounting for physical body dimensions was effective in eliminating gender-related differences in balance ability, but not in isokinetic lower extremity strength. Even after controlling for body weight and BMI, men were stronger than women. Gender emerged as the primary predictor of strength at all lower limb joints and was synergistic with activity level in influencing knee-flexor and hip-extensor strength. When torque data were grouped by gender, body weight and activity level were the strongest contributors to torque production in women and men, respectively.

The ability to maximally shift one’s COP relates to balance confidence (Maki, Holliday, & Topper, 1991), height, and the size of the base of support, the latter two being correlated (Blaszczyk, Hansen, & Lowe, 1993; Kinney LaPier et al., 1997). The men and women participating in our study demonstrated similarly high levels of balance confidence, which was therefore not considered relevant in accounting for the larger LOS achieved by men. Because the men were taller than the women, COP excursion would be expected to be greater for a given angular displacement about the ankle because the center of mass would move a longer horizontal distance. The fact that balance performance between men and women was equalized by expressing COP excursion relative to height, despite differences in other body dimensions (e.g., weight) and physical-performance indicators (e.g., strength), supports this view. In contrast, Kinney LaPier et al. found gender differences in AP LOS when expressed relative to height, which they explained might relate to musculoskeletal factors. Our data indicate that LOS measures in older men and women do not reflect the gender-related disparities observed in strength to any significant degree. It might be that unless strength falls below some minimum level required to maximally shift the COP, balance ability will be largely unaffected (Chandler, Duncan, Kochersberger, & Studenski, 1998).

It is not a new finding that older men are stronger than older women (Andrews et al., 1996; Aniansson et al., 1980, 1983; Frontera et al., 1991, 2000; Kent-Braun & Ng, 1999; Pedersen et al., 2002; Pincivero et al., 2003; Rantanen et al., 1997; Skelton et al., 1994). It has been attributed to differences in body composition, dimension, and mass (Fukagawa, Bandini, & Young, 1990; Lynch et al., 1999; Neder et al., 1999). It follows that various normalization strategies have been adopted as a means of controlling for anthropometric factors. In the current study, scaling strength to body weight or BMI reduced the magnitude of the gender differences in torque but failed to eliminate their significance. Neder et al. demonstrated that dividing isokinetic, concentric knee-flexor and -extensor torque measurements by bone-free lean leg mass eliminated gender differences in young and elderly participants. Paradoxically, the inclusion of bone-free lean leg mass into regression models of knee-flexor and -extensor torques contributed little more to explaining the variance in strength measures than was achieved by the combined factors of gender, age, height, and weight.

It is not known whether predictive accuracy in the current study would have been improved if body composition had been incorporated into the regression
models. Neder et al argued that fat-free-mass estimates might be more appropriate than total mass when participants are overly obese (BMI ≥ 40). In the present study only 3 participants had BMI values in excess of 30 (obesity cut-off; Sartorio et al., 2004; Wellens et al., 1996) and none over 31.6. BMI and fat-free mass are strongly associated at lower BMI levels (Wellens et al.), so the benefit of including more technically advanced indicators of body composition would likely be limited. Indeed, mass rather than BMI emerged as a significant predictor of strength, although not more so than gender. The absence of any interactive effect between gender and mass on strength outcomes reaffirms their importance as independent predictors. Similarly, Neder et al. identified gender and mass as important variables in determining knee-flexor and -extensor strength; we extend these observations to include other lower limb flexors and extensors. What remains to be explored is whether there are factors that determine strength that are gender specific.

Body weight accounted for 8–12% of the variance in torque values measured at the knee and for the hip flexors. When the torque data were grouped by gender, weight accounted for 33–60% of the variance in torque values attained by women but yielded no significant predictive value for men. This disparity likely limited the effectiveness of normalizing torque to body weight or BMI as a means of minimizing gender differences in strength, the latter further compromised by the failure of height to emerge as an explanatory variable of torque. The explanation of why weight was a significant predictor of torque in women but not in men might lie in the complex interactions between muscle mass, estrogen levels, and preservation of muscle strength (Phillips, Rook, Siddle, Bruce, & Woledge, 1993). It is conceivable that in aging women, in whom muscle atrophy has been shown to be greater than in men (Doherty, 2001), those who maintain muscle mass would be not only stronger but also heavier because muscle weight exceeds that of body fat.

It is not surprising that activity level was related to strength; this independently explained as much as 40% of lower limb torque values in men. When the data from men and women were pooled, the interaction between gender and activity level influenced the nature of the relationship between activity and strength, although activity remained an important variable in the regression model. Strength is fundamental to physical function and mobility (Carmeli et al., 2000; Chandler et al., 1998) and is highly modifiable through training and activity in people of all ages (Brouwer & Olney, 2004; Vandervoort, 2002). It follows that those able to perform more demanding physical activities (maximum activity score) or maintain a higher level of activity (adjusted activity score) are generally stronger. Neder et al. (1999) explored this relationship but were unable to link physical activity level with knee-flexor or -extensor torques of the dominant leg in 20- to 80-year-old men and women. In our sample of seniors (65–85 years of age) activity might be a more salient factor, given its potential counteractive effect on age-related loss of strength, which declines steadily by 1–2% per year after the 6th decade (Vandervoort; Vandervoort & McComas, 1986). In fact, Rantanen and colleagues (1997) found muscle strength to be positively correlated with daily physical activity in seniors age 75–80 years. Our findings reaffirm the significance of the association
between activity level and torque, although the gender-specific analysis indicated activity to be particularly important in predicting lower limb strength in men.

Nearly 41% of men over the age of 65 years are physically active and are 60% more likely to be active than women of similar age (Statistics Canada, 2000–2001). Furthermore, men demonstrate a broad range in the intensity of activities that they regularly engage in compared with active women. If such a profile represented the participants in the current study, the diversity in activity among the men would be a desirable characteristic when exploring associations between variables. The current data indicate that men and women were similar in the level of activity they felt capable of doing, although arguably this is not an indicator of actual physical activity. Richardson, Ainsworth, Jacobs, and Leon (2001) recently revealed that men are more accurate in self-reporting their physical activity capability and intensity than women are, which might explain the interaction between gender and activity level in predicting strength. Further study is required to explore these relationships in more detail.

Age is a strong predictor of muscle strength throughout the adult lifespan (Aniansson et al., 1980, 1983; Neder et al., 1999); however, when the age range of participants is narrow, as in the current study, the emergence of age as a predictor of torque would be considered unlikely. Explanation is therefore warranted for the unexpected finding that age accounted for a significant portion of the variance in knee-extensor torque values whether all data were pooled or men and women were considered independently. Deficits in knee-extensor (not flexor) strength have been found in community-dwelling seniors with radiographically confirmed knee osteoarthritis, the severity of which is age related (Hassan, Mockett, & Doherty, 2001; Slemenda et al., 1998). We do not know the incidence or extent of knee osteoarthritis in our sample, but none of our participants indicated that arthritis limited their activities and only 2 were taking prescribed medications for arthritis. Nonetheless, it is possible that the relationship between age and strength could reflect an underlying association between strength and osteoarthritis, which most commonly affects the knee joint (Oliveria, Felson, Reed, Cirillo, & Walker, 1995). Because age only emerged as a factor associated with knee-extensor torques and no other lower limb muscle group, the hypothesis is compelling and worthy of future evaluation.

The relationship between AP limits of stability and dorsiflexor and hip-flexor strength in women is rather difficult to explain. Strength has certainly been implicated in the ability to shift COP (Binda et al. 2003; Kinney LaPier et al., 1997), and although weakness of the ankle dorsiflexors and hip flexors has been identified as a factor contributing to poor balance (Wolfson et al., 1994) and fear of falling (Brouwer et al., 2004), direct associations with AP limits of stability remain elusive (Binda et al.). Perhaps this stems from the fact that previous studies exploring these relationships tested strength isometrically, whereas COP excursion relies on dynamic strength. It follows that COP excursion is likely influenced by strength rather than the other way around; the findings from the present study are limited in that causality cannot be established.
Our findings indicate that in nonobese, healthy community-dwelling seniors there are marked gender differences in strength and limits of stability, although the latter can be eliminated by normalizing to body height. Torque values are primarily explained by gender and to a lesser extent by weight and activity level. Exploring factors relating to lower limb torque production for men and women independently revealed weight to be the strongest predictor for women, and activity level, for men. Although the predictive validity of these factors remains to be determined, the findings suggest that in older adults, factors that determine strength might be gender specific. The implication is that strength-training programs for seniors could potentially be enhanced if designed specifically for older men or women.

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References


