We compared muscle thickness, torque, normalized torque (torque/muscle thickness), and power at 1.05 rad/s and 3.14 rad/s in flexor and extensor muscles of the elbow and knee, and in ankle plantar flexors in young (n = 22, 18–31 years) and older (n = 28, 59–76 years) men. Young men had greater muscle thickness for all muscle groups (p < .01), except elbow extensors, which were similar to older men. Young men had greater torque and power at both velocities for all muscle groups (p < .01), and greater normalized torque at both velocities for the elbow extensors and knee flexors and at the fast velocity for knee extensors. Relative to young mean values, muscle thickness, and torque, normalized torque, and power in the older group were most affected for lower-body measurements, especially at the fast velocity. Torque, normalized torque, and power (especially at fast velocities), and muscle thickness in the lower body are affected more by aging than are upper body measures in men.

**METHODS**

**Participants**

Fifty healthy men (aged 18–76 years) who were not engaged in resistance-type training volunteered for the study.
followed by elbow extension, at maximal effort was repeated. A repetition of elbow flexion, separated by a 3-second pause, was performed three times. A 1-minute rest was given between repetitions. Testing was done at each velocity of 1.05 rad/s and 3.14 rad/s in random order. There was a 3-second pause between agonist and antagonist muscle contractions to help reduce stretch-reflex muscle shortening which may have influenced torque (23). The highest torque and highest average power obtained during the three repetitions at each velocity were used for analyses.

Knee flexion and extension strength and power were measured through a range of motion of 90°–170° of knee flexion (internal angle). A stabilizing belt was placed across the distal one-third of the right thigh. Torque measures were corrected for the effects of gravity on the lower leg and the dynamometer’s resistance pad. The rotational axis of the dynamometer was positioned to be coaxial with the knee axis (lateral condyle) during testing (24).

Ankle plantarflexion strength and power were measured with belts placed across the distal part of the femur and across the top of the forefoot and midfoot. The foot was positioned in the dynamometer attachment (footplate) so that the axis of rotation of the ankle was aligned with the axis of the lever arm. A pad was placed under the right distal part of the femur so that knee flexion in the exercised leg was 20° from horizontal (i.e., 160° knee extension). The knee of the non-exercised leg was flexed at 90° with the foot resting on a “t-bar” which was attached to the Biodex chair. Participants moved the ankle through a range of motion from 20° dorsiflexion to 40° plantarflexion.

Reproducibility of torque and power measurements was determined by testing 29 participants (13 young, 16 older) 1 week apart, and measuring the coefficient of variation, defined as the square root of the between-test variance (standard deviation), divided by the combined (marginal) mean of the test results for days 1 and 2, multiplied by 100 (to produce a percentage). The coefficients of variation for the young and older men are presented in Table 2.

### Muscles

#### Strength

Strength and power were measured in the elbow flexors and extensors, knee flexors and extensors, and ankle plantar flexors using an isokinetic dynamometer (Biodex System 3; Biodex Medical Systems). For all tests, participants were positioned against the backrest of the stationary seat with a hip angle of 85°, and stabilizing belts were placed across the participant’s chest and waist. The dynamometer was set in concentric mode for elbow flexion and extension, knee flexion and extension, and ankle plantarflexion at angular velocities of 1.05 rad/s and 3.14 rad/s. For elbow flexion and extension, a strap was placed across the participant’s upper right arm to keep the elbow axis of rotation in the correct position. Strength measures were corrected for gravity on the lever arm and the handle of the dynamometer, and for each participant’s individual limb weight. The elbow flexion and extension attachment on the dynamometer was set to a 100° range of motion (60°–160°) for each participant and for each testing condition, where 0° was in the farthest arm flexion (60°) and 100° was in full arm extension (160°) (22). One repetition of elbow flexion, separated by a 3-second pause, followed by elbow extension, at maximal effort was repeated three times.

#### Power

Power was measured in the elbow flexors and extensors, knee flexors and extensors, and ankle plantar flexors using an isokinetic dynamometer (Biodex System 3; Biodex Medical Systems). Power was assessed by air displacement plethysmography.

#### Muscle Thickness

Muscle thickness of the flexors and extensors of the elbow and knee, and ankle plantar flexors was measured using B-Mode ultrasound (Aloka SSD-500; Tokyo, Japan). To measure elbow flexor and extensor muscle thickness, a small

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### Table 1. Subject Characteristics of Young and Older Men

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Lean Body Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young (n = 22)</td>
<td>23.0 (0.7)</td>
<td>179 (1)</td>
<td>80.8 (3.0)</td>
<td>64.3 (1.5)*</td>
</tr>
<tr>
<td>Older (n = 28)</td>
<td>65.5 (0.9)</td>
<td>176 (2)</td>
<td>84.9 (2.6)</td>
<td>58.5 (1.2)</td>
</tr>
</tbody>
</table>

*Young men had more lean body mass compared to older men (p < .01).

### Table 2. Coefficients of Variation (%) from Duplicate Measures of Torque and Average Power in Young and Older Men

<table>
<thead>
<tr>
<th>Measure</th>
<th>Torque</th>
<th>Average Power</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.05 rad/s</td>
<td>3.14 rad/s</td>
</tr>
<tr>
<td></td>
<td>Young</td>
<td>Older</td>
</tr>
<tr>
<td>Elbow flexors</td>
<td>3.6</td>
<td>5.9</td>
</tr>
<tr>
<td>Elbow extensors</td>
<td>4.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Knee flexors</td>
<td>2.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>2.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Ankle plantar flexors</td>
<td>4.0</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>4.7</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>9.5</td>
<td>13.1</td>
</tr>
<tr>
<td></td>
<td>5.7</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>5.3</td>
<td>8.5</td>
</tr>
</tbody>
</table>

### Notes

- Values are means (SE).
- *Young men had more lean body mass compared to older men (p < .01).
mark was drawn on the lateral side of the right arm to indicate 65% of the distance down from the acromion process to the olecranon process (22). A tape measure was wrapped around the arm at the 65% mark and was used as a reference, and another mark was placed on the bulk of the biceps and triceps where the center of the ultrasound probe was placed. To measure elbow flexor muscle thickness, each participant placed his arm flat on the table with the belly of the biceps facing upwards and the forearm supinated. To measure elbow extensor muscle thickness, participants stood with their back facing the researcher and elbows relaxed and extended.

To measure knee flexor and extensor muscle thickness, a small mark was drawn on the lateral side of the right leg to indicate 70% of the distance down from the greater trochanter to the lateral epicondyle of the tibia (25). A tape measure was wrapped around the right leg at the 70% mark and was used to mark another reference point on the bulk of the vastus lateralis and biceps femoris where the center of the ultrasound was placed. To measure knee extensor muscle thickness, each participant was placed on a table in a seated position with his right leg extended and relaxed. To measure knee flexor muscle thickness, each participant was prone on the table with both legs extended and relaxed.

To measure ankle plantar flexor muscle thickness, a small mark was drawn on the lateral side of the right leg to indicate 30% of the distance down from the lateral condyle of the tibia to the lateral malleolus of the fibula (25). A tape measure was wrapped around the leg at the 30% mark and was used to mark another reference point on the bulk of the gastrocnemius where the center of the ultrasound was placed. To measure ankle plantar flexor muscle thickness, each participant was prone on the table with his right leg fully extended and relaxed.

A 5 MHz scanning transducer head was placed perpendicular to the muscle area interface. The scanning head was coated with water-soluble transmission gel to provide acoustic contact with the muscle surface. When the image produced on the screen was visible, the image on the monitor was frozen. With the image frozen, a cursor was enabled to quantify muscle thickness (cm) at three sites: the proximal, the mid, and the distal, as determined by divisions (1 cm) on the monitor. The distal and proximal sites were 6 cm apart, with the mid site located 3 cm between them. The mid site corresponded to where the reference mark was drawn over the measured muscle. Muscle thickness measurements were extrapolated from the monitor screen by measuring the distance from the bottom of the subcutaneous adipose layer to the surface of the humerus for elbow flexor and extensor muscle thickness, to the surface of the femur for knee flexor and extensor muscle thickness, and to the surface of the tibia for ankle plantar flexor muscle thickness. Three muscle thickness measurements were taken at each of the three sites. The closest two values were then taken and averaged to achieve a final muscle thickness value for that site. The values for all three sites were then averaged to achieve one global muscle thickness score for each muscle group. Reproducibility of muscle thickness measurements was determined by testing 28 participants (12 young, 16 older) 1 week apart. For each muscle thickness measurement, precise markings on the skin were taken using overhead transparency film to ensure that identical sites were measured on each occasion (22). The coefficients of variation for muscle thickness measurements in the young group were 2.6% (elbow flexors), 1.7% (elbow extensors), 3.1% (knee flexors), 0.9% (knee extensors), and 2.1% (ankle plantar flexors). The coefficients of variation for muscle thickness measurements in the older group were 2.5% (elbow flexors), 2.2% (elbow extensors), 3.6% (knee flexors), 2.1% (knee extensors), and 3.3% (ankle plantar flexors). Muscle thickness measurements for upper and lower body muscle groups have been validated with magnetic resonance imaging (MRI). Muscle thickness of the knee extensors is a significant predictor of knee extensor volume as measured by MRI ($r = 0.91$) (26), and muscle thickness of the elbow flexors and extensors are significant predictors of elbow flexors and extensors volume as measured by MRI ($r = 0.96$) (27).

**Lean Body Mass Assessment**

To assess lean body mass, air-displacement plethysmography (BOD POD; Life Measurement, Inc., Concord, CA) was used. Detailed procedures of the air-displacement plethysmography method using the BOD POD system are described elsewhere (28). Briefly, after voiding the bladder, each participant was weighed to the nearest 0.1 kg while wearing a bathing suit and swim cap. Height was measured to the nearest centimeter. Participants were then seated in the BOD POD chamber, and the chamber was sealed so that measurements of whole body volume could be made. Participants were instructed to relax, breathe normally, and sit still during the 20-second measurement. When the test was complete (2–5 minutes), body density was calculated using the equation: $\text{Density} = \frac{\text{Mass}}{\text{Volume}}$. Percent body fat (% fat) was derived using the Siri equation (29): $\% \text{ fat} = \frac{495}{\text{Density} - 450}$. Lean body mass was then determined by the equation: total body mass $- (\% \text{ fat} \times \text{ total body mass})$. Reproducibility was assessed by testing 29 participants (13 young, 16 older) 1 week apart. The coefficient of variation for lean body mass was 0.80% in the young group and 0.84% in the older group. The validity of our measurements using the BOD POD was estimated by measuring 12 young and 15 older participants in the BOD POD and by using dual-energy X-ray absorptiometry (QDR 2000; Hologic, Waltham, MA). Correlation coefficients between BOD POD and dual-energy X-ray absorptiometry measurements of lean tissue mass were 0.98 ($p < .01$) for the young group and 0.96 ($p < .01$) for the older participants.

**Physical Activity**

Physical activity was assessed by having each participant fill out a leisure time exercise questionnaire (30), in which he indicated the number of times on average per week he participated in strenuous exercise (e.g., running, jogging, bicycling), moderate exercise (e.g., fast walking, tennis, badminton), and mild exercise (e.g., yoga, gardening, housework). This questionnaire has been validated in male participants of similar ages to those in the current study against measures of metabolic equivalents by accelerometry, the four-week physical activity history from the Minnesota Leisure-Time Physical Activity Questionnaire, body fatness,
and maximal oxygen consumption (correlations ranged from 0.21 to 0.38; all \( p < .01 \)).

**Statistical Analyses**

A 2 (young vs old) \( \times \) 2 (1.05 rad/s and 3.14 rad/s) analysis of variance (ANOVA) with repeated measures on the second factor was used to determine whether there were any differences in torque, normalized torque (i.e., torque/muscle thickness), power for the elbow flexors and extensors, knee flexors and extensors, and ankle plantar flexors between young and older men. A one-factor ANOVA was used to determine differences in lean body mass and muscle thickness of the elbow flexors and extensors, knee flexors and extensors, and ankle plantar flexors between young and older men.

To determine which muscles were smallest relative to the young group, each older participant’s muscle thickness score was divided by the mean of the young group and multiplied by 100 (32). An average for each of these relative scores was then computed for each muscle group and a within-participants ANOVA was used to compare muscle groups to determine which had the greatest relative deficit compared to the young. A similar procedure was used to determine which muscles had the lowest torque, normalized torque, and average power relative to the young group, except a 5 \( \times \) 2 repeated-measures ANOVA was used to compare muscle groups and velocities.

A Tukey’s post hoc test was used to determine differences between means when interactions were significant from the ANOVAs. Chi-squared classification assessed differences in physical activity level between young and older men. All results are expressed as means (±SE). Statistical analyses were carried out using SPSS version 11.5 for Windows XP (SPSS, Chicago, IL). Significance was set at \( p < .05 \).

**RESULTS**

**Torque**

Results for torque are presented in Table 3. For all muscle groups there was a group main effect, with the young group having greater torque than the older group \( (p < .01) \) and a velocity main effect, with slow-velocity torque greater than fast-velocity torque \( (p < .01) \). The torque values for muscle groups from the older participants, expressed as a percentage of the peak torque of the young group, are presented in the last column of Table 4. Relative thickness of the elbow extensors and the plantar flexors are shown in Figure 2 for a young and an older participant. Muscle thickness measurements were significantly greater in young versus older men for all muscle groups except the elbow extensors \( (p < .01) \); Table 4). The thicknesses for muscle groups from the older participants, expressed as a percentage of the mean muscle thickness of the young group, are presented in the last column of Table 4. Relative thickness of the elbow extensors was greater than that of all other muscle groups \( (p < .05) \), and the relative thickness of the elbow flexors was greater than that of the plantar flexors \( (p < .05) \).

**Normalized Torque**

Results for normalized torque are presented in Table 5. For all muscle groups, there was a velocity main effect, with slow-velocity normalized torque greater than fast-velocity normalized torque \( (p < .01) \). For the elbow extensors and knee flexors, there was a group main effect, with the young group having greater normalized torque than the older group across velocities \( (p < .01) \). There was a group \( \times \) velocity interaction for the knee extensors, with the normalized torque at the higher velocity being greater in the young compared to the older group. The normalized torque values for muscle groups from the older participants, expressed as a percentage of the mean normalized torque of the young

**Table 3. Peak Torque (Nm) During Slow (1.05 rad/s) and Fast (3.14 rad/s) Contractions for the Elbow Flexors and Extensors, Knee Flexors and Extensors, and Ankle Plantar Flexors in Young (n = 22) and Older Men (n = 28)**

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>1.05 rad/s</th>
<th>3.14 rad/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow flexors</td>
<td>60.5 (1.5)*</td>
<td>49.6 (1.6)</td>
</tr>
<tr>
<td>Elbow extensors</td>
<td>60.2 (1.4)*</td>
<td>47.6 (1.3)</td>
</tr>
<tr>
<td>Knee flexors</td>
<td>146.0 (2.0)*</td>
<td>103.1 (2.9)</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>217.3 (4.8)*</td>
<td>162.1 (5.8)</td>
</tr>
<tr>
<td>Ankle plantar flexors</td>
<td>118.7 (3.0)*</td>
<td>86.4 (3.8)</td>
</tr>
</tbody>
</table>

Notes: Values are means (SE). *Torque is greater in young vs older men across velocities \( (p < .01) \).

Figure 1. There was a muscle group \( \times \) velocity interaction \( (p < .01) \) when comparing these percentages between muscle groups and velocities. Differences specific to each muscle group among the muscles and velocities from the older men are outlined in Figure 1. To summarize, relative torques for lower body measures at 3.14 rad/s were lower than relative torques for elbow extension at both velocities and elbow flexion at 1.05 rad/s \( (p < .05) \).

Figure 2. Ankle plantar flexor torques at 3.14 rad/s \( (p < .05) \). b = relative knee extension and plantarflexion torques at 3.14 rad/s \( < \) relative elbow flexion torque at 1.05 rad/s and relative elbow extension torque at 1.05 and 3.14 rad/s \( (p < .05) \).
Figure 2. Ultrasound images of muscles from a young (21 y) and older (61 y) individual. a) Young elbow flexors; b) older elbow flexors; c) young elbow extensors; d) older elbow extensors; e) young knee extensors; f) older knee extensors; g) young knee flexors; h) older knee flexors; i) young plantar flexors; j) older plantar flexors.
group, are presented in Figure 3. There was a muscle group × velocity interaction when comparing these percentages between muscle groups and velocities (p < .01). Specific differences between the older muscle groups and velocities are outlined in Figure 3. In general, the lowest values relative to the young group were for knee flexion at 1.05 rad/s and knee extension and flexion at 3.14 rad/s. The highest value relative to the young group was for plantarflexion at 1.05 rad/s.

**Power**

Results for average power are presented in Table 6. For elbow flexors and plantar flexors there was a group main effect with the young men having a greater average power than the older men (p < .01). There was a group × velocity interaction for the elbow extensors, knee flexors, and knee extensors (p < .01). The young group had greater power than the older group at both velocities for all these contractions (p < .01), but the differences between young and older men were greater at the higher velocity. The average power for muscle groups from the older participants, expressed as a percentage of the mean average power of the young group, is presented in Figure 4. There was a muscle group × velocity interaction (p < .01) when comparing these percentages between muscle groups and velocities in the older group. Specific differences between the older muscle groups and velocities are outlined in Figure 4. In general, the lowest values relative to the young group were for knee flexion at 3.14 rad/s and ankle plantarflexion at 3.14 rad/s.

**Physical Activity**

Young men participated more in strenuous-intensity exercise (Young = 3.1 [4.2], Older = 0.8 [1.6]; p < .05) and moderate-intensity exercise (Young = 3.5 [3.7], Older = 2.3 [3]; p < .05) on average per week compared to older men. There was no difference between young and older participants for light-intensity exercise.

Table 4. Muscle Thickness (cm) for the Elbow Flexors and Extensors, Knee Flexors and Extensors, and Ankle Plantar Flexors in Young and Older Men

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>Young (n = 22)</th>
<th>Older (n = 28)</th>
<th>Older Relative to Young, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow flexors</td>
<td>3.2 (0.1)*</td>
<td>2.8 (0.1)</td>
<td>86.6 (3.10)*</td>
</tr>
<tr>
<td>Elbow extensors</td>
<td>4.1 (0.1)</td>
<td>3.0 (0.1)</td>
<td>98.6 (2.7)*</td>
</tr>
<tr>
<td>Knee flexors</td>
<td>5.5 (0.1)*</td>
<td>4.5 (0.1)</td>
<td>82.8 (2.9)</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>4.2 (0.1)*</td>
<td>3.5 (0.1)</td>
<td>80.4 (3.8)</td>
</tr>
<tr>
<td>Ankle plantar flexors</td>
<td>4.4 (0.3)*</td>
<td>3.2 (0.2)</td>
<td>74.7 (4.2)</td>
</tr>
</tbody>
</table>

Notes: Values are means (SE).
*Young men had greater muscle thickness vs older men (p < .01).
Elbow flexors relative muscle thickness > plantar flexors relative muscle thickness (p < .05).
Elbow extensors relative muscle thickness > older (p < .05).

Table 5. Normalized Strength (Nm/cm Muscle Thickness) during Slow (1.05 rad/s) and Fast (3.14 rad/s) Contractions for the Elbow Flexors and Extensors, Knee Flexors and Extensors, and Ankle Plantar Flexors in Young (n = 22) and Older Men (n = 28)

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>1.05 rad/s</th>
<th>3.14 rad/s</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Young</td>
<td>Older</td>
<td></td>
</tr>
<tr>
<td>Elbow flexors</td>
<td>19.0 (0.6)</td>
<td>18.5 (1.1)</td>
<td>16.7 (0.7)</td>
</tr>
<tr>
<td>Elbow extensors</td>
<td>15.0 (0.5)*</td>
<td>12.1 (0.5)</td>
<td>13.7 (0.4)*</td>
</tr>
<tr>
<td>Knee flexors</td>
<td>26.7 (1.0)*</td>
<td>23.0 (0.6)</td>
<td>23.0 (0.8)*</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>52.2 (2.0)</td>
<td>48.8 (2.5)</td>
<td>39.2 (2.3)*</td>
</tr>
<tr>
<td>Ankle plantar flexors</td>
<td>29.2 (1.9)</td>
<td>28.8 (2.8)</td>
<td>17.1 (1.4)</td>
</tr>
</tbody>
</table>

Notes: Values are means (SE).
*Normalized strength is greater in young vs older men at the same velocity (p < .01).

Table 6. Average Power (Watts) During Slow (1.05 rad/s) and Fast (3.14 rad/s) Contractions for the Elbow Flexors and Extensors, Knee Flexors and Extensors, and Ankle Plantar Flexors in Young (n = 22) and Older Men (n = 28)

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>1.05 rad/s</th>
<th>3.14 rad/s</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow flexors</td>
<td>48.8 (5.9)*</td>
<td>31.8 (1.7)</td>
<td>57.9 (3.2)*</td>
</tr>
<tr>
<td>Elbow extensors</td>
<td>49.0 (1.5)*</td>
<td>34.9 (1.4)</td>
<td>92.2 (4.4)*</td>
</tr>
<tr>
<td>Knee flexors</td>
<td>90.5 (5.2)*</td>
<td>56.2 (3.2)</td>
<td>113.4 (12.1)*</td>
</tr>
<tr>
<td>Knee extensors</td>
<td>133.7 (6.8)*</td>
<td>97.8 (5.1)</td>
<td>201.7 (11.2)*</td>
</tr>
<tr>
<td>Ankle plantar flexors</td>
<td>71.3 (2.8)*</td>
<td>47.0 (4.8)</td>
<td>75.8 (5.2)*</td>
</tr>
</tbody>
</table>

Notes: Values are means (SE).
*Average power is greater in young vs older men at the same velocity (p < .01).
The difference between young and older men at the fast velocity is greater than the difference between young and older men at the slow velocity (group × velocity; p < .01).
DISCUSSION

Our results showed that muscle thickness, strength (torque), and power in the lower body are more affected with age than upper body measures. Our torque measurements are very similar to measurements for young and older participants of similar age in previous studies of the elbow flexors (33), elbow extensors (20,33), knee extensors (19,20,33), knee flexors (19,33), and plantar flexors (19,34). Our older men had lower torque values relative to young men for knee flexion and extension and ankle plantarflexion when compared to upper-body measures (Figure 1). These findings are in agreement with those of others who found lower body torque to be reduced with age while upper body torque was better maintained (4,6,9,14). Most other studies compared upper or lower body muscle groups of older to young participants, without comparing the relative deficits in strength within older participants’ muscle groups. Our study is unique in that we directly compared the deficits of torque, power, and size between muscle groups within the older participants by expressing each older participant’s torque, power, or muscle thickness relative to the young group mean (Figures 1, 3, and 4; Table 4). This allowed a statistical comparison between older muscle groups for torque, normalized torque, power, and size deficits relative to the young group.

The lowest muscle thickness measurements in the older relative to the young men were for the lower body measurements (Table 4). Our results are in agreement with those of others who found muscle mass to be significantly reduced in the lower body, but relatively well-maintained in the upper body with age (7,8,35). A limitation of our study was that ultrasound muscle thickness measurements cannot differentiate between muscle and non-muscle tissue (i.e., connective tissue and intramuscular fat). Intramuscular fat and/or connective tissue measurements are higher in older compared to young individuals for the elbow flexors and extensors (5), knee flexors and extensors (17,36), and the ankle plantarflexors (37) as assessed by MRI or computed tomography scanning. Using ultrasound, as in the current study, would overestimate the amount of muscle tissue in the older men because intramuscular fat and connective tissue would be included in this measurement. The only muscle-thickness measurement that did not differ between young and older men was for the elbow extensors (Table 4). This is in agreement with one other study that assessed muscle thickness of the elbow extensors in young and older individuals (35). It is difficult to explain why the elbow extensors would be maintained with age, while elbow flexors muscle thickness is lower (Table 4) but it may be related to changes in ability to activate the flexors and extensors with age. Jakobi and Rice (2) found that the ability to activate the elbow extensors was maintained to a greater degree than the ability to activate the elbow flexors in older versus young males.

Although loss of strength with aging is largely due to loss of muscle mass, often strength is lost to a greater degree than muscle mass (i.e., strength expressed relative to muscle mass is decreased with age). This implies that loss of strength may also be due to decreased ability to fully recruit motor units (2) or may be caused by intrinsic reduction in muscle quality (3). Our results indicated that strength expressed relative to muscle mass (i.e., normalized torque) was lowest for the elbow extensors at the slow velocity, and knee extensors and flexors at the fast velocity for the older group when expressed relative to the young group (Figure 3). Our results of decreased normalized torque, especially at fast velocities, for the knee extensors and flexors are in agreement with those of other studies that showed no difference between young and older groups at slow velocities but a decrease in normalized torque of the old at fast velocities of knee extension and flexion (13,17). It is speculated that the greater deficit at faster velocities in older groups may be related to a reduction in myosin heavy chain IIb content with age (13). Our results of reduced normalized torque for the elbow extensors, but not the elbow flexors in our older group (Table 5; Figure 3), are in contrast to those of one recent study that showed a reduction in normalized torque of the elbow flexors, but not extensors in older participants (5). As mentioned above, a limitation of the ultrasound measurements used in the current study is that noncontractile tissue (i.e., fat and connective tissue) cannot be differentiated from contractile tissue in the ultrasound images (Figure 2). The study of Klein and colleagues (5) used MRI, which can differentiate between contractile and noncontractile tissue. Torque in their study was normalized relative to contractile tissue, whereas torque in our study is normalized to contractile and noncontractile tissue. Klein and colleagues (5) found a greater amount of noncontractile tissue in the elbow extensors, compared to flexors in their older group. If this was the case in our older group, then their elbow extensors-normalized torque would be underestimated because noncontractile tissue would be included in the denominator of this measurement.

Similar to torque measurements, relative deficits for power were greatest in the lower body (specifically the knee
flexors and ankle plantar flexors at fast velocities) of the older group (Figure 4). In general, in the older group power was affected more than torque (Figure 4 vs Figure 1). This is in agreement with one other study that found greater deficits in upper and lower body power compared to strength measurements in older individuals (12). Power is important in older individuals, as it is a significant predictor of performance in functional tasks such as rising from a chair, stair climbing, and walking (38). The greater deficits in power would indicate that training programs for older individuals should emphasize power in addition to strength. Recent studies (39,40) have shown that explosive power training in older individuals can be safe and effective.

Physical activity levels could account for some of the differences between muscle groups in our study. For example, heavy- and moderate-intensity activity levels were lower in the older men. Heavy- and moderate-intensity activities such as running and jumping would involve muscle groups such as the knee flexors and extensors, and contractions at fast velocities, which were most affected in the older men (Figures 1, 3, and 4). Detailed analyses of upper versus lower body activity have not been done in older individuals; however, it is hypothesized that older individuals may supplement weaker lower body movements with upper body movements such as arm contractions, for example, when rising from a chair (10). These supplemental movements would help to maintain upper body strength and muscle mass, while lower body measures declined.

The second hypothesis that fast velocity movements would be more affected than slow velocity movements was partially supported by our results. For all muscle groups, the torque at the fast and slow velocity was lower in the older men. The absolute differences between older and young men were similar for the slow versus fast velocity torques within each muscle group (i.e., there were no age × velocity interactions; Table 3). This finding is in agreement with several studies that also showed no differences in the amount of torque reduction with age for fast versus slow velocity movements within specific muscle groups (18–20). However, when comparing different muscle groups within the older men, the torques relative to those in the young men were lower at the fast velocities for the knee flexors and extensors and ankle plantar plantar flexors when compared to the relative torques at the slow velocities for the elbow flexors and extensors (Figure 1). In other words, for the older men, the greatest torque deficits relative to the young men were for the knee flexors and extensors and ankle plantar plantar flexors at the fast velocity (Figure 1). Others have also found a greater reduction in torque at fast velocities with age for the knee flexors (17), knee extensors (11,13,17), and ankle plantar plantar flexors (16). When examining our average power measurements, we found that the effect of contraction speed is more evident, with power at the fast velocities more affected in the older group than power at slow velocities (Table 6). Power at the fast velocity was more affected than at the slow velocity for the elbow extensors, and knee extensors and flexors in the older compared to the young group (i.e., there was a group × velocity interaction). When power was expressed relative to the mean of the young group, the measurements that were most affected in the older men were the knee flexors and ankle plantar flexors at the fast velocity (Figure 4). A greater affect of age on measurements at fast velocities may be related to an age-related decline in size and number of fast-twitch fibers, whereas size and number of slow-twitch fibers are thought to be better maintained (15).

Conclusion
Lower body muscle mass, strength, and power are affected more by aging than are upper body measures. Torque and power at fast velocities, specifically in the lower body, are affected more by aging compared to measurements at slow velocities. Aging seems to have a greater effect on power than torque. Only men were included in our study. Further research is needed regarding age-related changes in older women.

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