Muscle-Power Quality:
Does Sex or Race Affect Movement Velocity in Older Adults?

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To determine sex and race differences in muscle power per unit of muscle contraction, knee-extensor muscle power normalized for knee-extensor muscle volume was measured in 79 middle-aged and older adults (30 men and 49 women, age range 50–85 years). Results revealed that women displayed a 38% faster peak movement velocity than men and African Americans had a 14% lower peak movement velocity than Whites of a similar age when expressed per unit of involved muscle ($p < .001$). As expected, men exhibited greater knee-extensor strength and peak power per unit of muscle than women, but women had a faster knee-extension movement velocity per unit of muscle than men at the same relative strength level. Moreover, African Americans had greater knee-extensor muscle volume than Whites but exhibited lower knee-extensor strength and lower movement velocity per unit of muscle when tested at the same relative strength levels.

**Key Words:** muscle quality, movement speed, sex differences, racial differences

Age-related declines in muscle mass and strength (sarcopenia), as well as interventions designed for their prevention and treatment have been widely investigated (Frontera et al., 2000; Hurley & Roth, 2000). One underlying cause of strength losses with age is thought to be declines in muscle mass, especially in the lower extremities (Lindle et al., 1997; Lynch et al., 1999). Age-related deterioration of other factors associated with strength loss has also been reported, however. Although significant age-related functional declines can be attributed to losses in strength, the product of force and velocity (muscle power) appears to be more related to losses in functional ability (Bean et al., 2002, 2003; Rantanen & Avela, 1997; Skelton,
Greig, Davies, & Young, 1994). In this regard, recent studies have reported greater age-associated losses in muscle power than in strength (Bean et al., 2002, 2003; Skelton et al., 1994). In addition, some investigators have cited deficits in the velocity of movement as the primary cause of age-related power losses (Caserotti, Aagaard, Simonsen, & Puggard, 2001; DeVito et al., 1998).

Other factors to consider when evaluating relationships among strength, muscle power, and movement velocity are muscle mass, sex differences, and racial differences. Our group has reported previously that significant age-associated losses in estimated thigh-muscle mass occurred approximately 2 decades earlier in women than in men (Lynch et al., 1999) and that analyzing strength per unit of muscle volume is important for assessing age- and sex-related differences in muscle function (Lynch et al; Tracy et al., 1999). The same is true for expressing muscle power and movement velocity, that is, normalizing for per unit volume of muscle, or muscle-power quality and movement-velocity quality take into account an intrinsic characteristic of the muscle that contributes to the performance of both.

There is a substantial amount of information available concerning maximal-force (strength) differences between sexes (Lindle et al., 1997; Samson et al., 2000; Skelton et al., 1994), but little information is available on the velocity component of power. In addition, because strength differences between sexes narrow when normalized for muscle mass (Caserotti et al., 2001), it might be of interest to determine sex differences in power and movement velocity when normalized per unit of muscle. Caserotti et al. observed lower peak-power values in women than in men and attributed much of it to deficits in movement velocity. These sex differences could, however, be explained on the basis of the greater muscle mass in the limbs being tested.

Power might be an important link to understanding racial differences in age-related deficits in muscle function. Despite having greater muscle mass than Whites (Aloia, Vaswani, Feuerman, Mikhail, & Ma, 2000; Visser et al., 2002), African Americans do not appear to have correlated greater strength (Rantanen et al., 1998) or muscle quality (Newman et al., 2003) in specific muscle groups. Because there appear to be racial differences in muscle mass and functional ability among the elderly (Means, O’Sullivan, & Rodell, 2000; Visser et al.) that could be explained by differences in muscle power, determining racial differences in these two components relative to muscle mass could have important implications. Therefore, the purpose of this study was to compare sex and racial differences in peak muscle power and peak movement velocity relative to muscle mass in middle-aged and older adults.

**Methods**

**Participants**

Seventy-nine healthy men (n = 30) and women (n = 49) between 50 and 85 years of age (range 50–83 for men and 52–85 for women) volunteered to participate in the study. Racial identification was classified by self-report of the participants. Participants qualified if they had not engaged in regular vigorous physical activity (≥1 time/wk) for at least 6 months before the study, were nonsmokers, and were free of significant cardiovascular, metabolic, or musculoskeletal disorders that would
affect their ability to safely perform heavy resistance exercise. Each participant was also asked to report all medication use, including over-the-counter supplements. For the purposes of this study, only medications reported by the participants that are known to affect muscle mass were examined as possible covariates. After all methods and procedures were explained, each participant read and signed a written consent form, which was approved by the institutional review board of the University of Maryland, College Park.

Body-Composition Assessment

Body composition was estimated by dual-energy X-ray absorptiometry (DXA) using the fan-beam technology following standard procedures to ensure consistency (model QDR 4500A, Hologic, Waltham, MA) and by computed-tomography (CT) imaging (GE Lightspeed Qxi, General Electric, Milwaukee, WI). CT was used to quantify muscle volume (MV) using MIPAV software (NIH, Bethesda, MD). Investigators were blinded to participant identification, sex, and race. Repeated-measurement coefficient of variation was calculated for each of two investigators. Average intrainvestigator CVs were 1.7% and 2.3% for Investigators 1 and 2, respectively. The average interinvestigator CV was <4.3%.

Tests of One-Repetition-Maximum Strength, Muscle Power, and Movement Velocity

One-repetition-maximum (1RM) strength was assessed unilaterally in the knee extensors using methodology previously published from our laboratory (Tracy et al., 1999). Peak knee-extensor power and angular velocity were measured on a customized Keiser pneumatic-resistance knee-extension machine (A310, Keiser Sports/Health Equip. Co., Inc., Fresno, CA) custom-equipped for muscle-power assessment. Peak power was calculated as the product of torque and angular velocity and reported in watts.

After warm-up, participants performed three power tests on each leg, alternating between right and left at 50%, 60%, and 70% of their 1RM, with a 30-s rest period between trials and a 2-min rest before each increase in resistance. To establish a more stable assessment, all power tests were repeated 48–72 hr after the initial test. Data points collected for each repetition were analyzed to determine peak power and velocity after testing. These values were also normalized for quadriceps-muscle volume for sex and race comparisons because of the sex and race differences in MV. The highest power achieved throughout all trials of all loads was reported as the peak power, and the highest velocity observed during that repetition was used as the peak-velocity measure. For both 1RM and power testing, only data for a participant’s self-reported dominant leg was used for analysis, but there was no significant difference between legs. Testing reliability was established using the test–retest method on 10 participants, allowing 48 hr between tests. The Pearson correlations between tests for the right and left legs were .973 and .972, respectively.

Statistical Analysis

All statistical analyses were conducted using SAS software (SAS version 8.2, SAS Institute Inc., Cary, NC). To determine variables that might be significantly
related to the dependent measures, multiple regression was used, with the level of significance set at \( p < .05 \). Potential confounding variables included age, height, weight, body-mass index, percentage fat, fat-free mass, and medication use. The use of medications was classified into the following categories: diuretics, ACE inhibitors, hormone-replacement therapy, and anti-inflammatory pain relievers. Once the confounding variables had been identified, analysis of covariance (ANCOVA) was performed to determine between-groups differences for each dependent variable.

Results

Physical characteristics of the participants, grouped by sex and race, are summarized in Table 1. There was no significant difference in age between men and women. Men had significantly greater height and weight than women (both \( p < .001 \), but there was no difference in body-mass index. Men also had greater fat-free mass than women (\( p < .001 \)) but significantly lower percentage body fat (\( p < .001 \)). There were no significant differences between African Americans and Whites for any physical characteristics except age; African Americans were significantly younger than Whites (\( p < .001 \)). Within these groups, 40% of the Whites were men and 60% were women, whereas 32% of the African Americans were men and 68% were women. There were 6 participants who were not included in the racial analysis because they were not categorized as either White or African American. Of the medications examined as potential confounding variables, only diuretics were used by a significant number of participants. Inclusion of diuretics did not affect any statistical analyses, however, and therefore this was not used as a covariate in the final analyses.

Table 1  Physical Characteristics of Participants Grouped by Sex and Race

<table>
<thead>
<tr>
<th></th>
<th>Sex</th>
<th>Race</th>
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<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>n</td>
<td>30</td>
<td>49</td>
</tr>
<tr>
<td>Age (years)</td>
<td>63 ± 1</td>
<td>63 ± 1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.8 ± 1.3</td>
<td>161.8 ± 1.0a</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>91.3 ± 2.7</td>
<td>75.5 ± 2.2a</td>
</tr>
<tr>
<td>Body-mass index (kg/cm²)</td>
<td>30.1 ± 0.8</td>
<td>29.0 ± 0.8</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>64.6 ± 1.8</td>
<td>45.5 ± 1.0a</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>29.0 ± 1.0</td>
<td>39.0 ± 1.0a</td>
</tr>
</tbody>
</table>

Note. Values reported are \( M ± SD \). One man and two women did not have data for weight, fat-free mass, percentage body fat, and body-mass index because of missing DXA scans. One White and one African American did not have data for weight, fat-free mass, percentage body fat, and body-mass index because of missing DXA scans.

aSignificantly different from men (\( p < .001 \)).
bSignificantly different from Whites (\( p < .001 \)).
Sex Differences

Differences in knee-extensor 1RM strength, peak power (PP), peak movement velocity (PV), and MV between sexes are presented in Table 2. The results in this table indicate that men were 84% stronger ($p < .01$), exhibited 80% higher PP ($p < .01$), and had 14% faster PV ($p < .001$) and 55% larger MV than women ($p < .001$). Diuretic use in women was the only medication category found to be significantly related to MV and was included as a confounding variable. A separate analysis was run without the women who were on diuretics, and the results indicated that exclusion of those participants did not significantly affect the difference between the groups. Men had a significantly greater PP at 50% and 60% of 1RM ($p < .01$), but there was no significant difference observed at 70% of 1RM. When PP was normalized for MV (muscle power quality), the difference narrowed, but men still showed 13% greater PP than women ($p < .001$). Figure 1 demonstrates that muscle quality in men was also 16% higher than in women ($p < .05$). Although PV was significantly greater for men at peak ($p < .05$), when normalized for MV, women exhibited a 38% faster movement velocity than men (Figure 1).

Racial Differences

Table 3 illustrates racial differences in knee-extensor 1RM strength, PP, PV, and MV. There was no significant difference in 1RM strength between races. There were no significant differences observed among racial groups for absolute PP at 50% and 60% of 1RM, but African Americans exhibited significantly greater power at 70% of 1RM ($p < .05$). African Americans had 20% greater MV ($p < .001$), but their muscle-quality values (Figure 2) were 11% less than those of Whites ($p < .01$). Adjustment for MV did not reveal any significant differences between groups for PP. There was no difference between groups for absolute PV; however, as shown by Figure 2, when movement velocity was normalized per unit of MV, African Americans had 14% lower movement-velocity quality ($p < .05$).

### Table 2  Sex Differences in One-Repetition-Maximum Knee-Extension Strength, Power, Movement Velocity, and Muscle Volume of the Knee Extensors

<table>
<thead>
<tr>
<th></th>
<th>Men, $n = 30$</th>
<th>Women, $n = 49$</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-repetition maximum (kg)</td>
<td>35 ± 2a</td>
<td>19 ± 1</td>
</tr>
<tr>
<td>Peak power (W, Nm · rad$^{-1}$ · s$^{-1}$)</td>
<td>493 ± 24a</td>
<td>274 ± 13</td>
</tr>
<tr>
<td>Velocity at peak power (rad/s)</td>
<td>5.8 ± 0.1a</td>
<td>5.1 ± 0.1</td>
</tr>
<tr>
<td>Muscle volume (cm$^3$)</td>
<td>1857 ± 72a</td>
<td>1195 ± 41</td>
</tr>
<tr>
<td>Muscle-power quality (W/cm$^3$) × 10$^{-1}$</td>
<td>2.6 ± 0.1a</td>
<td>2.3 ± 0.1</td>
</tr>
</tbody>
</table>

*Note. Values reported are overall group $M ± SD$, but *p* values are based on least-square means and consider the significant covariates. One man and two women were missing from muscle-volume measures because of errors in CT scans.

*aSignificantly greater in men than women ($p < .05$).
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Figure 1 — Differences in muscle quality and movement-velocity quality (PV/MV) between sexes. Men exhibited significantly greater muscle quality than women \( (p < .05) \). PV/MV was significantly greater in women than in men \( (p < .001) \).

Table 3  Racial Differences in One-Repetition-Maximum Knee-Extension Strength, Power, Movement Velocity, and Muscle Volume of the Knee Extensors

<table>
<thead>
<tr>
<th></th>
<th>African Americans, ( n = 28 )</th>
<th>Whites, ( n = 45 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-repetition-maximum (kg)</td>
<td>27 ± 2</td>
<td>23 ± 2</td>
</tr>
<tr>
<td>Peak power (W, Nm · rad(^{-1} ) · s(^{-1} ))</td>
<td>411 ± 28</td>
<td>328 ± 22</td>
</tr>
<tr>
<td>Velocity at peak power (rad/s)</td>
<td>5.5 ± 0.2</td>
<td>5.3 ± 0.1</td>
</tr>
<tr>
<td>Muscle volume (cm(^3))(^a)</td>
<td>1627 ± 89*</td>
<td>1355 ± 66</td>
</tr>
<tr>
<td>Muscle-power quality (W/cm(^3)) ( \times 10^{-1} )</td>
<td>2.5 ± 0.1</td>
<td>2.4 ± 0.2</td>
</tr>
</tbody>
</table>

Note. Values reported are overall group \( M \pm SE \), but \( p \) values are based on least-square means and consider the significant covariates.

\(^a\)Three White participants were missing muscle-volume measures because of errors in CT scans.

*Significantly greater than Whites \( (p < .05) \).

Discussion

The findings in this study add new perspectives to our understanding of sex and race differences in strength, power, and movement velocity in middle-aged and older adults. In this regard, a new finding is that older women exhibit significantly faster knee-extension movement velocity per volume of muscle than men. As expected,
men have significantly greater knee-extension strength and power than women of similar age, but this difference narrows when normalized for MV, expressed as muscle-power quality. Moreover, when assessed at higher relative loads (70% of 1RM), sex differences in peak muscle power disappear. Therefore, when describing the force-velocity-power relationship, the sex of the person might be an important consideration.

This study was also the first to report racial differences among these variables. African Americans show significantly greater PP at higher relative loads (70% 1RM) than Whites. When these peak values were normalized for MV, however, this difference disappeared for PP, and movement velocity became higher in Whites despite their being older than African Americans, suggesting that the greater muscle mass in African Americans was not accompanied by concomitantly faster movement velocities than those of Whites. This finding is in agreement with our original hypothesis, but the finding of no difference in strength or PP between races was unexpected and did not support our hypothesis.

Previous studies that have examined sex differences in power have concluded that men have greater absolute power than women (Lanza, Towe, Caldwell, Wigmore, & Kent-Braun, 2003; Skelton et al., 1994). This conclusion appears logical because on average men have greater absolute strength and muscle mass than women. It has been argued, however, that fair comparisons of muscle function between sexes should express values relative to the size of the muscle mass involved in the movement. Sex differences in absolute muscle strength reflect differences in muscle quantity rather than architectural characteristics or metabolic function.

Figure 2 — Differences in muscle quality and movement-velocity quality (PV/MV) between races. African Americans showed significantly lower muscle quality ($p < .01$) and PV/MV ($p < .05$) than White participants.
of the muscles in use. Previous studies that have attempted to control for body-size differences between men and women have normalized leg-extension power for total body mass and found that women still have significantly less power than men (Skelton et al., 1994). Caserotti et al. (2001) found similar results, but when power was normalized for lean body mass estimated by bioimpedance analysis, the difference between men and women disappeared. In contrast, we observed that although the difference narrowed when expressed as muscle-power quality by normalizing for the volume of the contracted muscle, men were still significantly more powerful than women. To our knowledge, no other study has examined comparisons between sexes when normalizing for the muscle directly involved in producing the movement (in our case, knee extension).

Previous investigators have attempted to explain this reduced power output in women by citing deficits in movement velocity as the primary factor. For example, Caserotti et al. (2001) concluded that men and women showed similar force values at PP but that women had less power because of reduced movement velocity. In addition, DeVito et al. (1998) reported that reductions in velocity most influenced the loss of power in women age 50–75 years. Our findings are in agreement with these previous results, in that men exhibited greater absolute movement velocity. When considering the volume of the muscle in use, however, our study revealed that women had considerably greater velocity at all relative loads, suggesting that deficits in strength are more related to the lower PP outputs observed in women.

One possible explanation for this finding is presented by Krivickas et al. (2001). They measured the maximum shortening velocity of muscle fibers in older men and women and found that men had greater age-associated losses in velocity of Type II fibers, whereas older women showed no change in velocity of Type II fibers when compared with younger women, suggesting a preferential sparing of the velocity of Type II fibers in older women. The number of Type II fibers was still lower, however, in the women in this study. Similarly, Trappe et al. (2000, 2001) reported that, at baseline, there were significant sex differences in single muscle-fiber contractile properties. They reported that myosin heavy-chain (MHC) I fibers of older women contracted 38% faster than those in older men, and MHC IIa fibers contracted 69% faster in women. Given the previous findings that older women appear to have fewer Type II fibers and are at greater risk for falls, yet have faster movement velocities per unit of muscle, there appear to be other factors affecting reduced functional ability in older women. It is possible that reduced motor-unit activation, slower reaction time, and even fat and connective-tissue infiltration into muscle might be influential and warrant further investigation.

Differences in the assessment of PP and velocity might also explain discrepancies in the values reported for power and velocity in this study and others. In this context, the two most common methods reported to assess power output have been the foot-plate/flywheel rig (Bean et al., 2003; Pearson et al., 2002; Skelton et al., 1994; Skelton, Kennedy, & Rutherford, 2002) and the standing-jump force plate (Caserotti et al., 2001; DeVito et al., 1998; Ferretti et al., 1994). Although some of the studies using the foot-plate/flywheel rig have reported peak-power measurements, they actually measured the total area under the power curve. This measurement mixes slower velocities at the beginning of the movement to overcome the inertial phase of the movement, as well as near the end of the range of movement where cocontraction of antagonist muscle groups also result in slower
velocities. These velocities are averaged in with the faster velocities that occur in the middle of the range of motion. An example of how this difference in testing can affect results comes from Macaluso et al. (2002), who found that the increased cocontraction of the knee flexors in older women compared with younger women might at least partially explain the lower knee-extension average torque seen in older women. Thus, it is conceivable that this phenomenon could explain discrepancies in the literature on sex differences in strength, power, and movement velocity. Assessing power at its peak in the range of motion eliminates the lower torque and velocities at the beginning and near the end of the range of motion and therefore might provide a more accurate description of true power differences between men and women.

Our measure of peak power might be more functionally relevant than previous reports of average power based on areas under the power curve to events such as catching oneself from a fall or quickly correcting a loss of balance, because these actions would likely be limited by the ability to instantaneously maximize both muscle strength and the speed of movement (Grabiner, Koh, Lundin, & Jahnigen, 1993; Wojcik, Thelen, Schultz, Ashton-Miller, & Alexander, 1999).

Currently, there have been very few studies examining differences in muscle-function characteristics between races. Our finding that African Americans had greater knee-extensor MV than Whites is supported by others (Aloia et al., 2000; Newman et al., 2003; Visser et al., 2002), but the present study is the only report we are aware of that has used direct measurements of MV for normalizing muscle function to allow valid comparisons between racial groups. Unlike the consensus reached for racial differences in muscle mass, reports on strength between races remain inconclusive. For example, Newman et al. showed greater knee-extension strength in African Americans using an isokinetic dynamometer, whereas Rantanen et al. (1998) reported no significant differences in knee-extension strength between races, but the validation of the instrument used to assess strength in their study is unclear. In contrast with all of the previous studies, Means et al. (2000) reported lower strength values in African American women over the age of 65 than in White women of similar age. In their study, however, strength was assessed manually by a physical therapist, who therefore did not measure the maximal force production of the participants. Thus, the differences in strength assessment might be the cause for conflicting results between our study and others. In this regard, when strength was expressed per unit of muscle (i.e., muscle quality), our results support the findings of Newman et al., who reported lower specific tension in the lower extremities of African American men and women. To our knowledge, no other study has reported racial differences in peak power and movement velocity, with which we could compare our results.

Although we did not find race differences in peak power or muscle-power quality, our finding that Whites exhibit greater movement velocity when normalized for MV might have implications for differences in functional abilities between races. There are conflicting reports on which racial group is at highest risk for losses in independence (de Rekeneire et al., 2003; Hanlon, Landerman, Fillenbaum, & Studenski, 2002; Means et al., 2000; Visser et al., 2002). It is likely that differences in MV, strength, power, and movement velocity between races influence functional abilities in performing activities of daily living, but this relationship has not been investigated. Therefore, racial differences in functional
ability should be examined in future studies, with an emphasis on determining the extent to which they can be explained by differences in MV, strength, power, and movement velocity.

The greatest limitation to our study is the cross-sectional design, which does not allow for causal conclusions to be reached. Second, the sample size of African Americans for examining racial differences was quite small, which led to sample-size and age differences between the races. Post hoc analysis revealed that MV, PP at 70% 1RM, PV, and movement-velocity quality were the only variables to reach the .8 level of statistical power. Thus, it is possible that there are differences between races among the other variables that were not observed because of a lack of statistical power. Another possible limitation is the lack of exercise history from participants. Although all participants were screened for being physically inactive for at least 6 months before the study, exercise history before that point was not considered. The fact that all data are from the dominant leg might be considered a limitation, but we found no significant difference in peak power between right and left legs in this study or for strength in our previous studies (Lindle et al., 1997; Lynch et al., 1999). Finally, although we tried to control for medication use statistically by testing for it as a covariant and comparing these results with our analysis without mediators as a covariant, we were not able to test the effects of all medications used by all participants. Thus, the lack of complete control of all medication should be considered another limitation of this study.

In conclusion, this investigation is the first to examine sex and race differences in peak power and PV when normalized for the volume of the muscles directly involved in the movement. The results indicate that men exhibit greater strength and PP per unit of muscle than women, but women have greater movement velocity per unit of muscle than men. African Americans have greater MV than Whites but exhibit poorer strength and movement velocity per unit of muscle. Although African Americans showed greater power at higher relative loads, no other power differences between races were observed. Future research should aim to examine how these variables act to influence sex and race differences in functional ability with aging.

Acknowledgment

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References


