Impact of Muscle Power and Force on Gait Speed in Disabled Older Men and Women

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Background. The purpose of this study was to explore the relationship between muscle power output at different external resistances and performance of functional tasks. The authors hypothesized that power at 40% skeletal muscle 1 repetition maximum (1RM), in which contraction velocity is high, would explain more of the variability in tasks such as level walking than would peak power or 1RM strength, in which contraction velocity is lower.

Methods. Participants were men and women (n = 48; ages 65–91 years) with physical disability as evidenced by 2 or more deficits on the Medical Outcomes Study Short Form physical function subscale or a score of 9 or less on the Established Populations for the Epidemiologic Studies of the Elderly short physical performance battery. Muscle strength (1RM) was measured using a bilateral leg press exercise, and power output was determined by selecting the highest power output from 6 different contraction velocities: 40%, 50%, 60%, 70%, 80%, and 90% 1RM. Functional performance tasks consisted of habitual gait velocity (HGV) and stair climb (SC) and chair rise (CR) performance. Separate linear regression models were fit for each of the 3 dependent variables (SC, CR, HGV) using 1RM strength, power at 70% 1RM, and power at 40% 1RM as independent variables. All models were adjusted for age, body mass, and sex.

Results. Lower extremity power at 70% and 40% 1RM demonstrated greater associations with SC and HGV than did 1RM strength, whereas power at 40% 1RM demonstrated similar or stronger associations with all functional tasks compared with 1RM strength. Power at 40% 1RM explained the same or more of the variability in SC (R² = .42 [regression coefficient = −.169 ± .06] vs .43 [−.206 ± .071]), CR (R² = .28 [−.154 ± .057] vs .24 [−.152 ± .070]), and HGV (R² = .59 [.214 ± .37] vs .51 [.223 ± .049]) compared with power at 70% 1RM. Power at 40% 1RM explained more of the variability in the lower intensity (HGV) compared with the higher intensity (SC or CR) functions.

Conclusions. Power output at 40% of 1RM explained more of the variability in HGV than did power at 70% 1RM, suggesting that measures such as HGV that require a lower percentage of maximal strength to perform might be more sensitive to differences in contraction velocity. Because HGV is highly predictive of subsequent disability, future studies should evaluate the determinants of muscle power output at low external resistances.

Traditionally, muscle strength (maximum force-generating capacity) has been viewed as a key impairment measure on the pathway to age-associated disability (1). Specifically, skeletal muscle 1 repetition maximum (1RM), in which load is high and velocity is low, is often significantly related to tasks representing high-intensity functions such as the stair climb and chair rise (2–4). Although studies have shown a relationship between 1RM strength and lower intensity functions such as habitual walking in older adults (5,6), other studies have not documented this relationship (3,7,8). Skeletal muscle peak power (force × velocity of shortening) decreases earlier and more precipitously with advancing age than does muscle strength (9). More recently, we observed in a series of studies that skeletal muscle peak power explained more of the variability in function and disability than did strength in older persons, particularly during lower intensity tasks such as walking compared with higher intensity functions such as climbing stairs or rising from a chair (10,11). During dynamic concentric contractions, power output can vary based on the magnitude of force generated and the velocity of muscle shortening. We hypothesized that functions such as level walking that require a lower percentage of maximum force to perform might be more sensitive to differences in power output at low external resistances than differences in peak power or strength in older persons because of differences in the velocity of shortening during these tests.

The purpose of the current study was to explore the relationship between muscle power and functional performance by evaluating power output at low and high external resistances during bilateral leg press exercise in community-dwelling older persons. Because, during the performance of some functional tasks, such as level walking, the necessary force generated is low and the velocity of shortening is higher, we hypothesized that power at 40% 1RM (when shortening velocity is higher) would explain more of the variability in functional performance (chair rise, stair climb,
habitus in elderly persons, with higher scores indicating

is a valid and reliable instrument for assessing physical

and leisure physical activity was estimated using the
dwelling older persons. Habitual occupational, household,
increasing severity of clinical depression in community-
the previous week (15). A score greater than 9 indicates the
Geriatric Depression Scale is a questionnaire containing 30
scores ranging from 0 (severe dementia) to 30 (normal). The

Folstein Mini-Mental State Examination, an instrument with
assessed. Global cognitive function was assessed using the

in regular, strenuous exercise sessions (more often than once
shortening velocity is lower). In addition, to confirm our
previous observations, we evaluated the relationship between
lower extremity functional performance and 1RM strength.

METHODS

Study Design

This study had a cross-sectional design to determine the
relationship between low- and high-velocity power outputs,
strength, and functional performance. Lower extremity
power and strength were assessed using bilateral leg press
in community-dwelling older adults.

Study Population

Participants were recruited from the Boston area through
advertisements in local senior citizens publications, visits to
senior residences, and through the Harvard Research
Cooperative on Aging volunteer database. Eligible persons
had to be older than 65 years, living in the community, able
to walk with or without an assistive device, and report 2 or
more deficits on the physical function subscale of the
Medical Outcomes Study Short Form (MOS SF-36) (12) or
score 9 or fewer points on the Established Populations for
the Epidemiologic Studies of the Elderly short physical
performance battery (13). Eligible participants completed
a medical history questionnaire and underwent a physical
examination and medical screening by the study physician.
Participants were excluded from participation if they had
acute or terminal illness, myocardial infarction in the past 6
months, unstable cardiovascular disease or other medical
conditions as assessed during the screening history and
physical examination, upper or lower extremity fracture in
the past 6 months, upper or lower extremity amputation,
cognitive impairment according to the Folstein Mini-Mental
State Examination (score ≤ 23) (14), or current participation
in regular, strenuous exercise sessions (more often than once
a week). All participants gave written informed consent. The
Boston University Institutional Review Board approved the
study.

Participant Characteristics

Body mass was recorded on a standard platform scale to
the nearest 0.1 kg with the participant fully clothed. Height
was measured to the nearest 0.5 cm with a scale stadiometer.
Psychosocial variables, including measures of cognition,
depressive symptoms, and physical activity, were also
assessed. Global cognitive function was assessed using the
Folstein Mini-Mental State Examination, an instrument with
scores ranging from 0 (severe dementia) to 30 (normal). The
Geriatric Depression Scale is a questionnaire containing 30
yes/no questions administered to assess depression during
the previous week (15). A score greater than 9 indicates the
increasing severity of clinical depression in community-
dwelling older persons. Habitual occupational, household,
and leisure physical activity was estimated using the
Physical Activity Scale for the Elderly (16,17). This scale
is a valid and reliable instrument for assessing physical
activity in elderly persons, with higher scores indicating
higher levels of participation in physical activities (11). The
numbers of medical diagnoses and daily medications were
assessed via medical history questionnaires and the physical
examination.

Outcome Measures

Muscle strength.—Muscle strength of the lower extremities
was quantitatively assessed by the 1RM measure of
bilateral leg press using Keiser pneumatic resistance training
equipment (Keiser Sports Health Equipment, Fresno, CA).
The 1RM is defined as the maximum load that can be
moved 1 time only throughout the full range of motion
while maintaining proper form (18). The recumbent leg
press apparatus was adjusted to provide support to the spinal
column during 1RM assessments. In the starting position,
the seat was positioned to place the knee joint between 90
and 100° of flexion. In this position, the hips were in
a similar degree of flexion. Participants were instructed to
extend both legs fully but without locking the knee joint.
They performed the concentric phase, maintained full
extension, and performed the eccentric phase of each
repetition over 2, 1, and 2 seconds, respectively. The
examiner progressively increased the resistance for each
repetition until the participant could no longer move the
lever arm 1 time through the full range of motion. The
reliability of this measure was excellent as calculated using
the intraclass correlation coefficient (ICC) (0.98).

Muscle power.—After the 1RM was measured, bilateral
leg press peak muscle power was measured using the same
pneumatic resistance machines used for 1RM testing.
Measurement of muscle power tests using the pneumatic
resistance machines has previously been described and
validated by our laboratory and has excellent reliability in
this population (19,20). Power was assessed at several
percentages (40%, 50%, 60%, 70%, 80%, and 90%) of the
1RM. Beginning at 40%, participants performed the lift at
each established percentage of 1RM as fast as possible
through the full range of motion. Only 1 maximal attempt
was made at each resistance level, with 30 to 45 seconds of
rest given between each repetition. The software engineered
for the testing equipment calculated work and power during
the concentric phase of each repetition by sampling the
system pressure (equivalent to force [piston area is
constant]) and position 400 times per second. To eliminate
noisy data generated at the start and end of the motion, data
obtained between 5% and 95% of the concentric phase were
used to calculate velocity and power. After each repetition,
work, velocity, and power data were stored and then
displayed on the output screen. The highest power achieved
was recorded as the peak power. Because of changes in our
technical capabilities, we were able to simultaneously
measure both power output and velocity of movement from
the computerized output in a subset of participants (n = 17)
assessed in the latter part of the study, and those data are
also reported. We selected power at 40% of 1RM and 70%
of 1RM as outcome variables because they represented the
external resistance at which the velocity was highest and the
external resistance at which power output tended to peak,
respectively. The measured power outputs at 40% and 70% of the 1RM were both excellent (ICCs = 0.85 and 0.88, respectively).

**Functional Performance Measures**

*Stair climb.*—A standard 8-stair flight (stair height = 19 cm), with handrails on both sides, was used for this test. The participant was instructed to ascend the stairs as quickly and safely as possible. If necessary, the handrails could be used on either (preferred) side. The stopwatch was started when the participant moved his or her feet to begin climbing the stairs and was stopped when both feet landed on the top (eighth) step. Time was recorded to the nearest 0.01 second, and left/right handrail use was also noted. Two trials were attempted on the same day and the average was recorded. The reliability for this test is excellent (ICC = 0.97).

*Chair rise time.*—A chair with arms and a seat height of 0.43 meters from the floor was placed against a wall for support and safety purposes. Each participant was instructed to sit in the chair with his or her back against the chair back, provided that both feet remained flat on the floor. Each was asked to place his or her arms across the chest. One completed chair rise was defined as moving from a starting seated position to standing fully upright and returning to the seated position. The participant was then instructed to perform 10 repetitions. The elapsed time to the nearest 0.01 second was recorded, as was whether the arms were used at any time during completion. As a result of participant fatigue, a single test was performed.

*Habitual gait velocity.*—Habitual gait velocity was measured using an Ultra timer (DCPB Electronics, Glasgow, Scotland). Participants were fitted with an emitting device, with the examiner standing immediately behind them. They were instructed to walk away from the examiner at their normal walking velocity, “as if you were walking down the street to go to the store.” Velocity was measured with a sonar transducer after the participant had walked 2 meters to avoid bias from acceleration and deceleration. These tests were each performed twice, and the average of two trials was used for analysis. The reliability for this test is excellent (ICC = 0.96).

**Statistical Analyses**

Descriptive statistics were calculated for all participants. Differences in power and velocity across varying external resistances were assessed using a one-way analysis of variance for repeated measures. When significance was found, post hoc comparisons were made with power and velocity at 70% 1RM. Significance was set at $p < .05$, with a Bonferroni adjustment for 5 multiple comparisons to $p < .01$. In the first part of the regression analyses, we fit 3 unadjusted linear regression models for each of the 3 dependent variables (stair climb time, chair rise time, and habitual gait velocity): 1 using 1RM as the independent variable, 1 using power at 70% 1RM as the independent variable, and 1 using power at 40% 1RM as the independent variable to confirm the relationships between impairment and functional performance. Next, we fit 2 unadjusted regression models for each of the 3 dependent variables: 1 using power at 70% 1RM as the independent variable and 1 using power at 40% 1RM as the independent variable. Each model was fit with a logarithmic curve to describe the nature of the relationship between impairment and function. Finally, we fit 2 final multivariate linear models for each of the 3 dependent variables, adjusting for the variables of age, body mass, and sex: 1 using power at 70% 1RM as the independent variable and 1 using power at 40% 1RM as the independent variable. Age, body mass, and sex were chosen as adjustment variables from a pool of variables including the Folstein Mini-Mental State Examination, the Physical Activity Scale for the Elderly, and medications per day due to their association ($p < .15$) with each of the functional performance measures. Because the impairment and function data were positively skewed, log transformations were performed on each dependent variable to obtain a normal distribution about the regression line, and then the independent variable was transformed to achieve linearity. Statistical significance for all regression models was accepted at $p < .05$. All data were analyzed using SPSS statistical software (Chicago, IL).

**RESULTS**

**Participant Characteristics**

Forty-seven men ($n = 6$) and women ($n = 41$) were enrolled in this study. Table 1 shows descriptive statistics and participant characteristics. The power at 40% 1RM data for 2 women were not obtained, and thus all analyses comparing power at 70% 1RM and power at 40% 1RM were restricted to 45 participants. Table 1 also shows results from all outcome measures (lower extremity 1RM strength, power at 70% 1RM, power at 40% 1RM) and functional performance tests (stair climb time, chair rise time, and habitual gait velocity).

### Table 1. Descriptive Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Range</th>
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<tbody>
<tr>
<td>Age (y)</td>
<td>72.7 (0.8)</td>
<td>65–91</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>160 (0.01)</td>
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<tr>
<td>Weight (kg)</td>
<td>77.2 (2.7)</td>
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<td>Physical functioning (0–100)</td>
<td>75.4 (3.1)</td>
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</tr>
<tr>
<td>Physical Activity†</td>
<td>107 (8.9)</td>
<td>26–282</td>
</tr>
<tr>
<td>Cognitive score (0–30)‡</td>
<td>29.1 (0.2)</td>
<td>26–30</td>
</tr>
<tr>
<td>Depression score§</td>
<td>4.3 (0.6)</td>
<td>0–15</td>
</tr>
<tr>
<td>Medications per day (no.)</td>
<td>2.9 (0.3)</td>
<td>0–7</td>
</tr>
<tr>
<td>1RM (N)</td>
<td>1089 (75.6)</td>
<td>450–2852</td>
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<tr>
<td>Power at 70% 1RM (W)</td>
<td>216 (15.6)</td>
<td>46–563</td>
</tr>
<tr>
<td>Power at 40% 1RM (W)</td>
<td>177 (15.6)</td>
<td>21–462</td>
</tr>
<tr>
<td>Stair climb time (s)</td>
<td>5.8 (0.3)</td>
<td>3.4–12.9</td>
</tr>
<tr>
<td>Chair rise time (s)</td>
<td>27.9 (1.0)</td>
<td>16.1–47.6</td>
</tr>
<tr>
<td>Habitual gait (m/s)</td>
<td>1.12 (0.03)</td>
<td>0.53–1.5</td>
</tr>
</tbody>
</table>

Notes: Data represent means (standard error).
†Physical Activity Scale for the Elderly (16).
‡Folstein Mini-Mental State Examination (14).
§Geriatric Depression Scale (15).
RM = repetition maximum.
Muscle strength, power, and velocity.—Figure 1 illustrates the relationship among the external resistance (expressed as a percentage of the 1RM, during the double leg press), power output, and contraction velocity. As the external resistance increased, power output increased, peaking at 70% of the 1RM (p < .01). Velocity was highest at 40% of the 1RM and subsequently declined thereafter (p < .0001) (n = 17).

Linear associations of strength and power with functional performance.—Table 2 shows the bivariate relationships between our outcome measures and tests of functional performance. To confirm our previous findings on the relationships among strength, power, and functional performance, unadjusted bivariate linear associations among strength and functional performance and power (70% and 40% 1RM) and functional performance were performed and are shown in Table 3. Linear associations of leg strength, power at 70% 1RM, and power at 40% 1RM with stair climb time and chair rise time were all significant (p < .05). Linear associations of power at 70% 1RM and power at 40% 1RM with habitual gait velocity were also significant (p < .05), but the association between leg strength and habitual gait velocity was not (p < .07). Lower extremity muscle power, both power at 70% 1RM and power at 40% 1RM, explained a greater proportion of the variability in stair climb time, chair rise time, and habitual gait velocity than did 1RM strength. Furthermore, power at 40% 1RM explained a greater proportion of the variability in habitual gait velocity than did power at 70% 1RM.

Curvilinear relationship between power and functional performance.—Because previous studies had indicated a curvilinear relationship between impairment measures and function (1,21), unadjusted bivariate linear and curvilinear associations between power (70% 1RM and 40% 1RM) and functional performance were performed, and the results are shown in Table 4. Curvilinear associations of power at 70% 1RM and power at 40% 1RM (using a logarithmic model) with stair climb time, chair rise time, and habitual gait velocity were all significant (p < .05). The logarithmic model for both power at 70% 1RM and power at 40% 1RM explained a greater proportion of the variability in stair climb time, chair rise time, and habitual gait velocity than did the linear models.

Table 4 also shows which of the power measures (power at 70% 1RM or power at 40% 1RM) explains the greatest proportion of the variability in functional performance. There is little difference in the relationship of power at 70% 1RM and power at 40% 1RM with stair climb time using the logarithmic model ($R^2 = .30$ vs .28) or with chair rising time using the logarithmic model ($R^2 = .18$ vs .22). However, power at 40% 1RM explained a greater proportion of the variability in habitual gait velocity compared with power at 70% 1RM when the logarithmic model ($R^2 = .50$ vs .39) (Figure 2) was used.

Multivariate linear associations between power and functional performance.—To include other established covariates of functional performance, a final multivariate linear regression model was run adjusting for age, body mass, and sex to determine the relationship of power at 70% 1RM and power at 40% 1RM with functional performance.
Similar to the unadjusted bivariate linear model, power at 70% 1RM and power at 40% 1RM were significantly associated with stair climb time, chair rise time, and habitual gait velocity (all $p < .05$). Although the associations of power at 70% 1RM and power at 40% 1RM with stair climb time ($R^2 = .43$ vs .42) and chair rise time ($R^2 = .24$ vs .28) were similar, power at 40% 1RM explained more of the variability in habitual gait velocity than did peak power ($R^2 = .59$ vs .51). Furthermore, power at 40% 1RM explained a greater proportion of the variability in habitual gait velocity (59%) compared with the variability in stair climb time (42%) or chair rise time (28%).

**DISCUSSION**

The major finding in the current study was that lower extremity skeletal muscle power obtained at high velocities (40% 1RM) explained as much, or more, of the variability in functional performance than did muscle power at 70% 1RM. Furthermore, lower extremity power at 40% 1RM explained a greater proportion of the variance in habitual gait velocity compared with either stair climb time or chair rise time. In addition, these results continue to support earlier findings that lower extremity power demonstrated stronger associations with functional performance than did muscular strength and that the nature of this relationship was curvilinear (22,23).

We hypothesized that both skeletal muscle power at 70% 1RM and power at 40% 1RM would explain more of the variability in functional performance than would 1RM strength. In all unadjusted bivariate linear models run in the current study, leg power (both 70% and 40% 1RM) demonstrated a stronger relationship with stair climb time, chair rise time, and habitual gait velocity than did muscular strength. In the final adjusted model (age, body mass, and sex), leg power had a stronger relationship with stair climb time and gait velocity than did 1RM strength. Power output at the highest velocity of shortening that we measured (40% 1RM) showed similar or stronger associations with all functional tasks compared with 1RM strength. Although skeletal muscle strength has been shown to improve functional performance (5,24,25), the findings in the current study and others from our laboratory underscore the potentially greater influence of skeletal muscle power on functional performance than strength (22,23).

In addition, the relationship between skeletal muscle power and functional performance is best described as curvilinear. Both quadratic and logarithmic models explained a greater proportion of the variance in the 3 dependent variables (chair rise, stair climb, and gait velocity) than did the linear model. This finding is consistent

<table>
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<tr>
<th>Physical Performance</th>
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<tr>
<td>Stair climb (n = 45)</td>
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<tr>
<td>Power (70% 1RM)</td>
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<td>Linear model</td>
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<td>Logarithmic model</td>
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<td>Chair rise (n = 45)</td>
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<tr>
<td>Habitual gait velocity (n = 45)</td>
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<tr>
<td>Power (70% 1RM)</td>
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<tr>
<td>Linear model</td>
<td>.26</td>
<td>Linear model</td>
<td>.35</td>
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<tr>
<td>Logarithmic model</td>
<td>.39</td>
<td>Logarithmic model</td>
<td>.50</td>
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*Note: RM = repetition maximum.*

The findings in the current study and others from our laboratory underscore the potentially greater influence of skeletal muscle power on functional performance than strength (22,23).
with those of previous studies that have reported a curvilinear association of impairments such as strength (1,21,26) and peak power (22) with functional performance. The significance of the curvilinear relationship between muscle power and gait speed may be related to the concept of functional threshold (21). Functional threshold suggests that there is some level of function above which differences in a particular impairment (e.g., lower extremity power) have little effect on functional performance. In our study, power had a functional threshold in relation to gait speed. Beyond this threshold, persons with higher levels of power apparently do not walk incrementally faster.

Our second hypothesis was that power at 40% 1RM would explain more of the variability in tasks such as walking than would power at 70% 1RM. Unadjusted quadratic and logarithmic models and adjusted multivariate linear models showed that lower extremity power at 40% 1RM was a better predictor of functional performance than power at 70% 1RM, especially for the habitual gait velocity measure. This finding is interesting because of the highly predictive value of gait velocity on future disability. Guralnik and colleagues (27) found that gait speed alone, based on the Established Populations for the Epidemiologic Studies of the Elderly short physical performance battery, was a significant predictor of mobility-related disability and activities of daily living disability in community-dwelling older adults at both 1 and 4 years of follow-up. Strength and functional performance have been shown to be significantly related to some functional tasks, such as stair climb and chair rise performance (2–4), but not all, such as walking tasks (3,7,8). Our findings suggest that if skeletal muscle power at 40% 1RM is the best predictor of walking performance, then the velocity component (highest at 40% 1RM compared with power at 70% 1RM and 1RM) may be a more critical determinant than other impairment measures that are traditionally more related to strength. Thus, activities such as level walking that require a much lower percentage of maximal strength to perform compared with stair climb or chair rise might be more sensitive to reductions in velocity or power output at low external resistances with advancing age.

Potential limitations in the current study also must be considered. First, measures of 1RM and power were obtained using leg press, but associations between these measures and gait speed might have been greater had measures of ankle strength and power been included in the analysis. Second, the sample size was relatively small. A larger and more functionally diverse sample would have allowed further evaluation of the impairment–mobility relationships across varying magnitudes of the different measures of strength and power. Future studies could include measures of leg and ankle power as well as function in a larger cohort to examine these relationships.

**Conclusion**

Lower extremity skeletal muscle power obtained at high velocities (40% 1RM) explained as much, or more, of the variability in functional performance than did skeletal muscle power at 70% 1RM. Furthermore, lower extremity power at 40% 1RM explained a greater proportion of the variance in habitual gait velocity compared with either stair climb time or chair rise time. Future studies should address the effect of training at higher velocities on impairment measures such as strength and peak power and how these relate to various functional performance measures.

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