

# Upper and Lower Limb Muscle Power Relationships in Mobility-Limited Older Adults

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**Background.** Lower limb muscle power impairments are modifiable factors underlying mobility limitations in older adults. This study examined relationships between upper and lower limb muscle power and their role in predicting mobility performance among community-dwelling older adults.

**Methods.** A cross-sectional analysis was conducted. Participants included 37 mobility-limited adults (24 women, 13 men), aged 65 to 93 years. Measures included upper (elbow extension) and lower limb (double leg press) one repetition maximum (1RM), and muscle power at both 40% and 70% one repetition maximum. Physical performance measures included stair climb time, the Short Physical Performance Battery, and 4-meter walk time. Factors commonly mediating the relationship between impairments and physical performance were analyzed as covariates.

**Results.** Participants had a mean age of 76 years, had five chronic medical conditions, and manifested moderate mobility limitations. Although the associations between the upper and lower limbs were strong ( $p < .001$ ), the magnitude of association was greater for power ( $r = .88-.89$ ) as compared to strength ( $r = .69$ ). Multivariate regression analyses revealed consistently strong relationships between limb muscle power and mobility performance measures. Substituting upper for lower limb power within these models did not materially weaken the relationships.

**Conclusion.** Muscle power appears to be a more generalized attribute between the upper and lower limbs than is muscle strength, suggesting that mechanisms underlying velocity of movement, as opposed to force production, may be important factors underlying muscle power in elderly persons. Additionally, upper limb muscle power measures may serve as a useful surrogate measure of limb power having implications for clinicians and researchers.

LIMITATIONS in basic mobility tasks, such as walking, stair climbing, and rising from a chair, affect approximately 1 in 4 older adults and predict institutionalization, mortality, and disability (1,2). A challenge for clinicians and researchers wishing to enhance and maintain the independent functioning of older adults is to identify modifiable impairments that underlie mobility limitations. For example, impairments in strength contribute to limitations in mobility and disability (3–5). Recognizing that strength impairments tend to be generalized throughout the body and the greater ease of measuring force production in the arm, epidemiological researchers have used grip strength as representative of total body strength (4–6).

More recently, impairments in muscle power have been identified as important contributors to mobility limitations (7–9). Power, which is defined as the product of force and velocity (power = force  $\times$  velocity), is a related, but different attribute than muscle strength, which generally refers to an individual's ability to exert muscular force. Muscle power declines more precipitously in late life than does leg strength (10). Muscle power measurement is infrequently used in clinical settings and in large research studies, in part, because it requires sophisticated, large, and expensive equipment. In one of the few large epidemiological studies evaluating muscle power among older adults, impairments in leg muscle power were found to impart a greater likelihood for significant mobility limitations than were impairments in leg strength (11).

This raises a number of questions regarding the measurement of limb muscle power. From a mechanistic standpoint, is muscle power capacity, with its added component of velocity of movement, as generalized as is muscle strength capacity? If so, can a suitable upper limb measure serve as a surrogate measure for overall limb muscle power? If yes, then these findings could facilitate the development of simpler and more acceptable means of muscle power measurement, making it more applicable to both clinical and research practice. Therefore, we conducted this study to examine the relationships between upper and lower limb muscle power in a cohort of mobility-limited older adults.

## METHODS

### Study Design

This study was a cross-sectional analysis of baseline data from an ongoing research study evaluating two forms of resistance training in community-dwelling older adults. Enrolled participants' lower and upper extremity strength and power were measured, and physical performance testing was completed.

### Study Population

A total of 37 participants (24 females, 13 males) met study criteria, representing 69% of the potential participants.

There were 121 inquiries solicited via advertising through local newspapers, newsletters, and direct mailings. After screening via telephone and eliminating participants who were not eligible or who were unable to commit to the study, 54 potential participants attended the in-clinic screening assessment. Of these, 14 were excluded for medical reasons, 1 chose not to commit to the study, and 2 were excluded after the second visit due to changes in the Short Physical Performance Battery (SPPB) score.

On the initial screening visit, after written informed consent was obtained, we obtained a screening physical performance test and a comprehensive history and performed a physical examination. Inclusion criteria included: age  $\geq 65$ , community-dwelling status, and mobility limitations as defined by a score of 10 or lower (out of 12) on the SPPB, which measured gait speed, standing balance, and rising from a chair (12). The SPPB is a well-established, reliable, and valid measure scored between 0 and 12, with higher scores corresponding to better mobility performance (12,13). Exclusion criteria included: unstable acute or chronic disease, a score  $< 23$  on the Folstein Mini-Mental Status Examination (14), medications that could impair muscle function (such as Parkinsonian or spasticity medications), or a neuromusculoskeletal impairment that would be aggravated by weight-bearing exercise. Participants who met these eligibility requirements returned to the laboratory to complete further baseline testing, including a repeat SPPB. Second visits were conducted within 1–3 weeks of the initial screening visit. Individuals who had a change in SPPB score  $> 2$  units, or whose score increased to 12 on the follow-up assessment, were deemed inconsistent in their performance, and were also excluded from the study. Participants completed all strength and power measurements, health questionnaires, and physical performance tests on the second visit.

#### *Physical Performance Measures (Dependent Variables)*

*Stair climb time.*—On a standard 10-stair flight, participants were instructed to ascend the stairs as quickly as possible using the handrail if necessary. The stopwatch was stopped when both feet were planted at the top of the 10th step. Time was recorded to the nearest .01 second, and the average of two trials was taken. This measure was added to the intervention study assessment only after its initiation; therefore, values for the first 13 participants were not obtained.

*SPPB.*—Testing involves an assessment of standing balance, a timed 4-meter walk, and a timed test of five repetitions of rising from a chair and sitting down. All timing was measured to the nearest .01 seconds using a stopwatch. Each of the three tests was scored between 0 and 4 and summed to a maximum score of 12. Lower scores on the SPPB have been found to predict disability over 1–6 years in several elderly populations (12,15).

*Four-meter walk time.*—The 4-meter walk time from the SPPB also was used separately in these analyses.

#### *Physiologic Measures (Independent Variables)*

Upper extremity and lower extremity strength measurements were assessed by one repetition maximum (1RM) measures of triceps press (evaluating elbow extensors) and double leg press (evaluating hip and knee extensors) using pneumatic resistance machines (Keiser Sports Health Equipment, Fresno, CA). Participants 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 one time through the full range of motion.

Following measurement of the 1RM, assessments of triceps and double leg press power muscle power at 40% and 70% of the 1RM were performed with five repetitions using the same pneumatic resistance machines. Although the repetitions were performed simultaneously on both sides, values from both the right and left side were provided in the electronic output and were summed. The maximum power (Watts) of the five repetitions generated at these two relative intensities was recorded for further analyses. These two intensities were chosen to represent muscle power production at relative high force/low velocity (70% 1RM) and low force/high velocity (40% 1RM).

#### *Covariates (Adjustment Variables)*

Measured height and body weight were obtained during the screening physical examination. The Iowa Short Form of the Center for Epidemiological Studies Depression Scale (CES-D) was administered through an interview and used as an index of depressive symptomatology (16). Scores of 16 or higher have been associated with increased risk for clinical depression. All medical diagnoses and medications were obtained via a questionnaire and subsequent interview of each participant during the history and physical examination conducted by the principal investigator. This information was confirmed through the provision of background medical information provided to the investigators by the participants' primary care physicians. Using the compiled information, the principal investigator was solely responsible for tabulating and coding all medical diagnoses and standing medications.

#### *Statistical Analysis*

We first calculated descriptive statistics for participant characteristics and double leg press strength and power. Correlations between upper limb and lower limb strength and power measures were analyzed. Separate multivariate regression analyses were conducted using each independent variable (triceps power at 40% and 70% 1RM, and double leg press power at 40% and 70% 1RM) and dependent variables (stair climb time, SPPB, and 4-meter walk time). On the basis of previous published data indicating a curvilinear relationship between strength and power measures and function and optimal fit via log transformation, all the models were log transformed (8,11). All models were adjusted for age, weight, height, sex, and chronic medical conditions. We used an alpha level of 0.05

Table 1. Baseline Characteristics of 37 Community-Dwelling Older Adults (24 Women, 13 Men)

Participant Characteristics	Mean $\pm$ SD	Range
Age, y	75.6 $\pm$ 6.6	65.0–93.0
Weight, kg	74.9 $\pm$ 19.1	30.9–129.0
Body mass index, kg/m <sup>2</sup>	27.8 $\pm$ 5.8	11.0–42.1
No. of chronic medical conditions	5.1 $\pm$ 2.0	1.0–10.0
Mini-Mental State Examination	28.8 $\pm$ 1.4	24.0–30.0
Depressive symptoms (CES-D)	14.9 $\pm$ 3.3	9.0–24.0
Short Physical Performance Battery	8.92 $\pm$ 1.6	5.0–11.0
Stair Climb Time, s	4.03 $\pm$ 1.03	2.91–7.46
4-Meter Walk Time, s	4.84 $\pm$ 0.77	3.62–7.12
Triceps 1RM (Newtons)	132.5 $\pm$ 58.4	37–300
Triceps power 40% 1RM (Watts)	286.2 $\pm$ 162.9	16–742
Triceps power 70% 1RM (Watts)	308.7 $\pm$ 165.8	107–738
Double leg press 1RM (Newtons)	930.7 $\pm$ 365.2	242–1810
Double leg press power 40% 1RM (Watts)	420.6 $\pm$ 229.2	112–1030
Double leg press power 70% 1RM (Watts)	511.2 $\pm$ 295.0	113–1343

Notes: SD = standard deviation; CES-D = The Iowa Short Form of the Center for Epidemiological Studies Depression Scale; 1RM = one repetition maximum.

to determine statistical significance, and all analyses were performed using SAS (17,18).

## RESULTS

Baseline characteristics of the participants are presented in Table 1. Participants ranged in age from 65 to 93 years with a mean age of 76 years, were mostly women (24 female, 13 male), and had a racial profile of 73% white ( $n = 27$ ), 24% African American ( $n = 9$ ), and 3% Asian ( $n = 1$ ). More than half were overweight with a body mass index  $\geq 25$ . On average, participants had five chronic medical conditions and had performance scores consistent with moderate mobility limitations. Baseline strength and power measurements are consistent with prior reports in community-dwelling older adults with mobility limitations using similar methods (8,19–21).

Correlations of strength and power between the upper and lower limbs are presented in Table 2. All correlation coefficients ( $r$ ) were statistically significant ( $p \leq .001$ ). The correlation between the upper and lower limbs was almost identical for muscle power at both 40% 1RM ( $r = .88$ ) and 70% 1RM ( $r = .89$ ) and, in comparison to muscle strength, was greater ( $r = .69$ ). Intermediate values were seen ( $r = .73$ – $.77$ ) when strength of one limb location was compared to power measured at the other location.

The relationship between muscle power measures and physical performance measures from regression analyses are presented in Table 3. The majority of the 12 models achieved statistical significance with the remaining 3 models bordering on statistical significance ( $p = .05$ – $.07$ ). For stair climb time,  $R^2$  values for triceps power was .67 for 40% 1RM and .64 for 70% 1RM, whereas values for double leg press power were .64 and .66 at these same relative intensities respectively. For the SPPB models, triceps power at 40% explained less variance ( $R^2 = .35$ ) than did the double leg press at both intensities (40% 1RM  $R^2 = .43$ ; 70% 1RM  $R^2 = .41$ ), but triceps power at 70% 1RM was greater with  $R^2 = .48$ . For the analyses modeling the 4-meter

Table 2. Associations Between Triceps and Double Leg Press Strength (Newtons) and Power (Watts) Measurements (Pearson's Correlation Coefficients)

Limb Impairment Measure	DLP 1RM	DLP Power 40% 1RM	DLP Power 70% 1RM
Triceps 1RM	.69	.73	.77
Triceps power 40% 1RM	.77	.88	.88
Triceps power 70% 1RM	.73	.87	.89

DLP = double leg press; 1RM = one repetition maximum.

Notes:  $p \leq .001$  for all values.

walk time, triceps power at both relative intensities explained greater variance (40% 1RM,  $R^2 = .31$ ; 70% 1RM  $R^2 = .45$ ) than did the models of double leg press power ( $R^2 = .26$  and  $.27$ , at 40% 1RM and 70% 1RM, respectively). In summary, when variance explained by the models ( $R^2$ ) is compared between the upper and lower limb models, differences are generally minimal, with triceps power explaining equivalent or greater amounts of variance than the models using lower extremity power.

## DISCUSSION

The major findings of this study concern the strong association between upper and lower body muscle power among mobility-limited older adults. It has long been recognized that upper and lower body strength measures are sufficiently similar to allow a measure such as grip strength to serve as a surrogate measure of total body strength. Although the association between the upper and lower limbs

Table 3. Separate Multivariate Natural Log-Transformed Regression Models (12 Models) Addressing the Associations of Upper Limb (Triceps) and Lower Limb (Double Leg Press) Muscle Power With Stair Climb Time, the Short Physical Performance Battery, and 4-Meter Walking Speed

Physical Performance Measure	Muscle Power Measure (Watts)	Coefficient $\pm$ SD	$R^{2*}$	$p$ Value
Stair Climb Time ( $n = 24$ )	Triceps power 40% 1RM	-.001 $\pm$ .0004	.67	.02
	Triceps power 70% 1RM	-.001 $\pm$ .0005	.64	.05
	Double leg press power 40% 1RM	-.0005 $\pm$ .0003	.64	.07
	Double leg press power 70% 1RM	-.0005 $\pm$ .0002	.66	.03
Short Physical Performance Battery ( $n = 37$ )	Triceps power 40% 1RM	-.0008 $\pm$ .0004	.35	.04
	Triceps power 70% 1RM	-.001 $\pm$ .0004	.48	.002
	Double leg press power 40% 1RM	-.0006 $\pm$ .0002	.43	.004
	Double leg press power 70% 1RM	-.0005 $\pm$ .0002	.41	.007
4-Meter Walk Time ( $n = 37$ )	Triceps power 40% 1RM	-.0006 $\pm$ .0002	.31	.03
	Triceps power 70% 1RM	-.001 $\pm$ .0004	.45	.002
	Double leg press power 40% 1RM	-.0004 $\pm$ .0002	.26	.06
	Double leg press power 70% 1RM	-.0003 $\pm$ .0001	.27	.04

Notes: All models were adjusted for age, height, weight, sex, and chronic medical conditions.

\* $R^2$  values are for the entire statistical model.

SD = standard deviation; 1RM = one repetition maximum.

was strong for both strength ( $r = .69$ ) and power ( $r = .88-.89$ ), the correlations were stronger for muscle power.

These findings reinforce the concept that strength and power are separate but related attributes and point toward important factors underlying the mechanisms of strength and power. Our finding that there is a substantial association between upper and lower limb power would suggest that muscle power might be dependent on a physiologic attribute that is more universal in the body than that which underlies only force production. This may be reflective of aging-vulnerable neuromuscular mechanisms that underlie velocity of movement, such as muscle fiber type and contractile properties, synchrony and timing of motor unit firing, control of agonist and antagonist muscle groups, and nerve conduction velocity (22–24). Additionally, central neurophysiologic mechanisms, which influence an individual's ability to exert a maximal effort known as central drive, may be manifested greater with maximal power production than with force production alone (25). The exact causes are not ascertainable from our investigation, but these results do underscore the importance of investigating neuromuscular mechanism, which mediates changes in velocity of movement and changes in velocity-force production relationships with aging.

Although our findings speak to the physiologic mechanisms contributing to impairments in strength and power, they also raise important points regarding the measurement of muscle power for clinicians and researchers evaluating more distal disablement relationships. We used well-established methods of deriving muscle power (8,20,21,26,27). The fact that substituting our upper limb power measure did not materially weaken the magnitude of association between muscle power and physical performance originally seen with lower limb power suggests that elbow extension power may be an appropriate surrogate for lower body muscle power. This has important implications. Muscle power is recognized as a key attribute because of its strong association with mobility performance and self-reported disability. Measurement of lower extremity muscle power impairments can be challenging for both clinical and research purposes, often involving the use of expensive, large, and immobile pieces of exercise equipment. Such measurements can also be challenging to obtain in those individuals with advanced joint problems of the hip or knee or severe mobility problems. They may not be feasible for use within a large community-based clinical practice or research study. Simple, low cost, and appropriate devices that measure muscle power are needed. Elbow extension is a relatively easy task to perform for the majority of older adults regardless of their health and mobility status and, from an engineering perspective, may facilitate the development of a simpler device than required to evaluate lower extremity muscle actions. These findings assist in guiding such efforts.

Our study should be interpreted with the recognition that potential limitations exist. There was an apparent greater magnitude of association between upper limb power and 4-meter walk speed as compared to lower limb power. As reported previously for the 6-minute walk, this is likely due the fact that walking is more dependent on power production among more distal muscle groups than that

measured through the double leg press (28). Although it is acknowledged that our study would have been enhanced with the inclusion of power measurements derived from the ankle, we feel that consideration of elbow extension power as a surrogate measure of muscle power capacity is still appropriate. It has been reported that some performance tasks such as walking may be more strongly associated with muscle power production at relatively high velocities such as that seen at 40% 1RM as compared to velocities produced at 70% 1RM (21). Our results are not fully consistent with these previous reports, but likely reflect differences in gait measurement methodology. We used the chosen methodology of gait speed measurement because of its reported relevance as a predictor for mortality and disability (12). It is possible that these alternative gait speed measures, which measure gait speed after walking is initiated (as opposed to measuring from a standing start), may be more sensitive to differences in muscle power. Additionally, this was a small, cross-sectional pilot investigation evaluating impairment and impairment-function relationships among mobility-limited older adults. Certain of our multivariate regression models bordered, but did not achieve statistical significance, likely reflecting our small sample size. Subtle differences between upper and lower body impairment measures, if they exist, would be more clearly ascertained through a larger, functionally diverse, longitudinal investigation. Nevertheless, the recognition that the relationships were statistically significant among the majority of measures with our relatively small sample size emphasizes the magnitude of the reported relationships.

### Conclusion

Our investigation among community-dwelling older adults identifies strong associations between upper and lower limb muscle power production serving as a guide for investigations exploring mechanisms underlying changes in muscle power with aging. Additionally, it supports the validity of elbow extension power as a measure of muscle power for clinicians and investigators wishing to address mobility problems of older adults.

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