Muscle Power of the Ankle Flexors Predicts Functional Performance in Community-Dwelling Older Women

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OBJECTIVES: To test the hypothesis that peak power of the ankle flexors is related to physical functioning in older women with functional limitations.

DESIGN: A cross-sectional study.

SETTING: University-based human physiology laboratory.

PARTICIPANTS: Thirty-four older women (75.4 ± 5.1 years, 67.8 ± 11.3 kg, body mass index 27.4 ± 4.5) with self-reported functional limitations.

MEASUREMENTS: Plantarflexion (PF) and dorsiflexion (DF) peak power and isometric strength with physical performance (stair climb time, repeated chair rise time, maximal and habitual gait velocity) were determined. An isokinetic dynamometer was used to measure isometric strength, isokinetic peak torque and power of PF and DF at five angular velocities (30°, 60°, 90°, 120°, and 180°·sec^{-1}), and isometric strength.

RESULTS: Peak torque for both PF and DF declined with increasing velocity of movement (PF: $P < .0001$; DF: $P < .0001$), whereas peak power increased with increasing velocity up to 120°·sec^{-1}. The strongest univariate associations were found between chair rise time and DF peak power ($r = 0.50$; $P < .002$), stair climb time and DF peak power ($r = 0.49$; $P < .003$), habitual gait velocity and PF isometric strength ($r = 0.53$; $P < .001$), and maximal gait and PF isometric strength ($r = 0.47$; $P < .005$). Multivariate regression analysis revealed that DF and PF peak power along with the physical functioning and general health scores from the Medical Outcomes Study Short Form were independent predictors of chair and stair climb performance.

CONCLUSION: These data suggest that ankle muscle power together with self-reported measures of health and physical functioning are essential components of functional mobility in older women with functional limitations. J Am Geriatr Soc 49:1161–1167, 2001.

Key words: strength; exercise; disability; aging

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This work was partially supported by a grant from the American Federation of Aging Research. Roger A. Fielding is a Brookdale National Fellow at Boston University.

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Advancing age is associated with a progressive decline in skeletal muscle mass.[1] Concomitant with this decline in skeletal muscle mass have been observed changes in exercise capacity, including declines in cardiorespiratory fitness,[2] muscle strength, and peak power.[3]

The projected increase in the older population, especially women, together with the observation that women are more likely to become disabled as they age, have made understanding age-associated functional limitations in women an important public health issue.[4,5] Several studies have established the role of lower extremity muscle strength (maximum force generating capacity) as a predictor of functional limitations in disabled and nondisabled older people.[6,7] It has been proposed that peak muscle power or the maximum capacity to perform muscular work per unit time is a more critical variable than strength in helping to understand the relationship between muscle impairments, functional limitations, and subsequent disability. Peak muscle power has been shown to decline earlier and more precipitously with advancing age.[3] Peak lower extremity power has also been associated with functional limitations and falling risk in institutionalized older people.[8,9] Recently, peak power of the leg extensor muscles was identified as an independent predictor of self-reported disability using the Functional Status Survey in community-dwelling frail older women.[10]

The plantarflexor (PF) and dorsiflexor (DF) muscles of the ankle play an important role in functional activities, including generation of torque during gait and chair rising.[7,11,12] In addition, low peak torque of the PF muscle has been linked to falling risk in institutionalized older individuals.[8] However, no studies have examined the relationships between PF and DF strength and peak power and performance-based functional tasks in older individuals.

Therefore, the primary objective of the present study was to establish the predictors of performance-based func-

0002-8614/01/$15.00

tional tasks among independent, community-dwelling older women with self-reported functional limitations. We specifically tested the hypotheses that strength and power of the ankle PF and DF muscle groups would be independent predictors of performance-based functional tasks—stair climb time, chair rise time, and maximal gait velocity.

MATERIALS AND METHODS

All testing was completed at the Human Physiology Laboratory at Boston University. Participants were evaluated twice separated by at least 1 week (T1 and T2). During the first visit, the subjects completed a series of questionnaires and underwent body composition measurements and the physical performance and ankle function tests were administered. During the second visit, the physical performance and ankle function tests were repeated to test the reliability of these measurements. Each visit took approximately 2 hours and was administered by the same individual.

Study Participants

Thirty-four community-dwelling women between the ages of 65 and 84 were recruited by telephone screening for this study. If a subject was determined to be suitable for the study during the telephone screening, they were invited to the laboratory for further evaluation. During this first visit, all potential participants completed a standardized medical history questionnaire, the Medical Outcomes Study Short Form (MOS SF-36) Health Status Survey,[13] the Folstein Mini-Mental State Examination (MMSE),[14] the Physical Activity Scale for the Elderly (PASE),[15] and the Geriatric Depression Scale[16] and signed an informed consent. Tabulation of medical diagnoses and number of daily prescription medications were obtained from review of each subject's medical history questionnaire. Subjects were excluded from the study if they scored less than 23 on the MMSE or reported fewer than two limitations on the physical component section of the MOS-SF36. The Institutional Review Board at Sargent College, Boston University, approved this study.

Ankle Function Tests

A Cybex II isokinetic dynamometer (Ronkonkoma, NY) was used to measure the isometric strength and isokinetic peak torque and power of the PF and DF muscles of the ankle. The subjects were positioned lying prone and attached to the dynamometer with their hip and knee extended fully. Each subject was secured to the table with a 15-cm-wide belt to stabilize the body and minimize body movement during the testing. The foot was attached to a footplate and fixed with two belts. The ankle joint was aligned with the axis of the dynamometer. The reference angle (0°) corresponded to the ankle in a neutral position. For all subjects, the right foot was tested first through all of the angular velocities, followed by the left.

All tests consisted of six reciprocal cycles of plantardorsiflexion at six angular velocities and were performed in the following order: 30°, 60°, 90°, 120°, 180°, and 0° (isometric)·sec^{-1}. The participants were allowed to rest approximately 1 minute between trials, then were tested at a new velocity. Before testing, each person performed a warm-up exercise of five submaximal repetitions to familiarize them with the equipment. For the isokinetic test, the subjects were instructed to push the foot away from them and then to pull it toward them at maximum velocity through the full available range of motion (ROM) for each repetition. The isometric test was done with the ankle positioned at neutral (0°). For the test at 0°/second (isometric), each participant was instructed to push down (PF) on an immovable plate for 5 seconds as forcefully as possible. Following a rest period, subjects then pulled the same foot toward them (DF) for 5 seconds.

Peak torque at each specific velocity was determined as the highest torque generated throughout each individual's full ROM from the six trials. The isometric strength was determined as the maximum force generated during each 5-second contraction. Isokinetic power was calculated as a product of the peak torque (Nm) and angular velocity (°/sec). Torque and power data were normalized per kilogram of body weight for all regression analyses.

Balance

Dynamic balance was determined using the forward and backward tandem walk time measured over 10 meters. Each participant was instructed to walk as fast as and as carefully as possible. An assistant followed the individual during this test for safety. This test was performed twice, and the average of two trials was used for analysis. The forward and backward tandem walk time was summed for all regression analyses.

Chair Rise Time

A chair with arms and a seat height of 0.43 meter from the floor was placed against a wall for support and safety purposes. Participants were instructed to sit in the chair with their backs against the chair back, provided that both feet remained flat on the floor. They were asked to place their arms across their 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 subject was then instructed to perform 10 repetitions. The elapsed time to the nearest .01 second was recorded as was whether or not the arms were used at any time during completion. Only two subjects performed this test by using the chair handrails for support, and their data were included in all analyses. The average of the two trials was calculated.

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 stopped when both feet landed on the top (8th) step. Time was recorded to the nearest .01 second; left/right handrail use was also noted. Two trials were attempted on the same day.

Habitual and Maximal Gait Velocities

Habitual and maximal gait velocities were measured using an Ultra timer (DCPB Electronics, Glasgow, Scotland). Participants were instructed to walk 10 meters at their normal and maximal velocity. The velocity was recorded at between 3 and 8 meters to avoid bias from acceleration and deceleration. These tests were each performed twice, and the average of two trials was used for analysis.

Body Composition

Anthropometrics were recorded including height, weight, and body mass index. In addition, bioelectrical impedance to determine total body water was measured (RJL, Clinton Township, MI). Total body water and fat free mass were calculated using equations derived for older individuals.[17]

Data Analysis

All data are presented as mean ± standard error. The reliability of the ankle function tests and the physical function tests was assessed by calculating the intraclass correlation coefficients (ICC). Reliability was classified as poor (0.00 to 0.40), fair to good (0.41 to 0.75), and excellent (>0.75) based on criteria established by Fleiss et al.[18]

Differences in peak torque and power at each velocity were assessed using analysis of variance. Univariate regression analyses for muscle strength, power, other variables of interest, and physical functioning were performed using Pearson's correlation coefficients. All variables with a univariate association with functional performance at the level of $P < .15$ were then entered into appropriate multiple and forward stepwise regression models. All statistical analyses were performed using StatView on a personal computer (Macintosh, Cupertino, CA).

Table 1. Physical, Clinical, and Demographic Characteristics (n = 34)

	Mean	±SD
Physical characteristics		
Age (years)	75.4	5.1
Body weight (kg)	67.8	11.3
Height (cm)	157.4	6.6
Body mass index (kg/m²)	27.4	4.5
Fat free mass (kg)	38.2	4.0
Physical activity (PASE)	102.5	55.7
Clinical characteristics		
Number of medical diagnoses	3.0	2.8
Number of daily prescription medications	1.8	2.1
Geriatric Depression Scale (total = 30)	24.9	3.5
Falls reported in past year (%)	20.7	
		Percent
Demographics		
Ethnicity		
Caucasian		79.3
African American		10.3
Native American		3.4
Marital status		
Married		19.2
Widowed		38.5
Separated/divorced		26.9
Never married		15.4
Residence		
House		14.3
Apartment/condominium		85.7
Living situation		
Alone		72.4
With spouse		13.8
With children		10.3
With nonfamily members		3.4
Education		
High school graduate or less		34.5
Some college/college graduate		37.9
Postgraduate degree		27.6

SD = standard deviation; PASE = Physical Activity Scale for the Elderly.

RESULTS

Subject Characteristics

The participants' demographic, physical, and clinical characteristics are presented in Table 1. All participants performed all of the study procedures without complication with the exception of six subjects who refused to complete portions of the psychosocial questionnaires because of anxiety. All 34 women who were recruited had some degree of functional limitation on the physical function subscale of the MOS SF-36. The percentile scores for the various domains of the MOS SF-36 (physical functioning, role physical, bodily pain, general health, vitality, social functioning, role emotional, and mental health) are presented in Table 2. Consistent with these findings are the number of major medical diagnoses reported (3.0 ± 2.8) and daily use of prescription medications (1.80 ± 2.08 per day).

Ankle Function

The descriptive statistics for the peak torque measurements are presented in Table 3. The calculated ICCs indicate that the isokinetic tests on both PF and DF were reliable. The reliability of the PF and DF isometric strength and PF torque measures were classified as good to excellent. The reliability of the DF torque measurements were more diverse, with one of the speeds being classified as poor, two being fair, and the remainder being good to excellent. The results of PF and DF torques from the left leg were used for all further analyses because of the slightly better reliability at selected velocities (0° and 120°sec^{-1}). We chose to use the isometric torque measurement as our representative measure of ankle strength because the highest torques (forces) were generated at this velocity and because isometric strength has been used previously in studies examining functional performance in older people.[22] Our index of ankle peak power was chosen as the peak

Table 2. Medical Outcomes Study Short Form Health Status Survey

Variables	N	Mean	±SE
Physical functioning	30	73.7	3.9
Role physical	30	73.3	6.2
Bodily pain	29	75.2	4.3
General health	29	68.4	2.0
Vitality	29	62.5	4.0
Social functioning	29	92.7	2.8
Role emotional	28	82.1	6.2
Mental health	29	81.9	2.3

SE = standard error.

power at 120°sec^{-1} for both PF and DF because the highest power generated was typically observed at 120°sec^{-1} and the reliability of the measurement at this velocity was good to excellent (Table 4).

The torque-velocity curves for the left ankle PF and DF are presented in Figure 1. As expected, both PF and DF torque decreased with increasing velocity of movement (PF, $P < .0001$; DF, $P < .0001$). The calculated peak power measurements for these velocities are presented in Figure 2. PF and DF power increased with increasing velocity, with the highest values occurring at 120°sec^{-1}.

Physical Performance

The descriptive statistics and reliability for all the physical performance tests are presented in Table 5. All measurements were categorized as excellent (ICC > 0.75), with the exception of the repeated chair rise test, which was categorized as good (> 0.41).

Univariate Predictors of Physical Performance

Univariate regression analyses were performed to determine whether significant relationships existed between physical performance measures, ankle strength and peak power, balance, and behavioral and psychosocial measures. The strongest univariate associations were found between chair rise time and DF peak power ($r = 0.50$; $P < .002$), stair climb time and DF peak power ($r = 0.49$; $P < .003$), habitual gait velocity and PF isometric strength ($r = 0.53$; $P < .001$), and maximal gait and PF isometric strength ($r = 0.47$; $P < .005$). The strongest univariate associations between function and the psychosocial variables were between the physical functioning subscale of the MOS SF-36 and chair rise time ($r = 0.58$; $P < .01$) and stair climb time ($r = 0.48$; $P < .01$).

Multivariate Predictors of Physical Performance

A multiple regression model was constructed with all variables having univariate associations to each physical performance measure ($P \leq 0.15$). Each of the four physical performance variables was analyzed separately and is listed in Table 6.

Chair Rise Time

PF isometric strength, PF peak power, DF peak power, balance, physical functioning, general health, vitality, and the mental health score explained 53% of the variance in

Table 3. Isometric Strength and Peak Torque

	Force (T1) (N)	Force (T2) (N)	Mean (N)	±SE	ICC
Isometric strength					
PF right	43.1	44.2	43.6	2.5	0.89
PF left	41.3	42.3	41.8	2.5	0.79
DF right	15.5	15.1	15.3	0.8	0.61
DF left	15.9	16.7	16.3	0.9	0.68
Velocity (°/sec)	**Torque (T1) (Nm)**	**Torque (T2) (Nm)**	**Mean (Nm)**	**±SE**	**ICC**
Peak torque					
PF right					
30	28.0	34.1	31.0	2.2	0.70
60	20.8	24.2	22.5	1.8	0.80
90	17.7	19.5	18.6	1.5	0.73
120	15.4	15.8	15.6	1.2	0.68
180	10.2	10.5	10.3	1.0	0.77
PF left					
30	28.4	31.3	29.8	2.0	0.83
60	23.3	24.5	23.9	1.5	0.66
90	18.7	18.5	18.6	1.4	0.77
120	15.1	15.6	15.4	1.2	0.85
180	9.5	9.9	9.7	0.9	0.78
DF right					
30	14.7	16.3	15.5	0.6	0.60
60	11.3	12.6	12.0	0.6	0.52
90	8.8	9.5	9.1	0.5	0.61
120	7.2	7.1	7.2	0.5	0.75
180	4.5	4.3	4.4	0.4	0.83
DF left					
30	16.8	15.9	16.1	0.8	0.62
60	13.8	12.3	13.1	0.8	0.56
90	9.8	10.3	10.0	0.7	0.34
120	7.4	7.5	7.4	0.5	0.78
180	4.5	4.5	4.5	0.3	0.80

PF = plantarflexor; DF = dorsiflexor; SE = standard error; ICC = intraclass correlation coefficients; T_1 = time one; T_2 = time two; N = Newtons of force; Nm = Newton Meters of work.

Table 4. Peak Power

Velocity (°/sec)	Watts (mean)	±SE
PF Right		
30	16.1	1.1
60	23.5	1.9
90	29.2	2.3
120	32.7	2.6
180	32.4	3.0
PF left		
30	15.5	1.0
60	25.0	1.6
90	29.2	2.1
120	32.3	2.5
180	30.5	2.7
DF right		
30	8.1	0.3
60	12.5	0.6
90	14.3	0.8
120	15.0	1.0
180	13.8	1.2
DF left		
30	8.4	0.4
60	13.7	0.8
90	15.7	1.1
120	15.6	0.9
180	14.2	1.1

PF = plantarflexor; DF = dorsiflexor; SE = standard error.

chair rise time (r = 0.73; $P < .048$). Forward stepwise regression revealed that PF peak power and the physical functioning score were the only two factors that contributed independently to chair rise time (r = 0.69; $P < .0005$), explaining 47% of the variance.

Stair Climb Time

DF isometric strength, DF peak power, PF isometric strength, PF peak power, PASE score, physical functioning, general health, and the mental health score explained

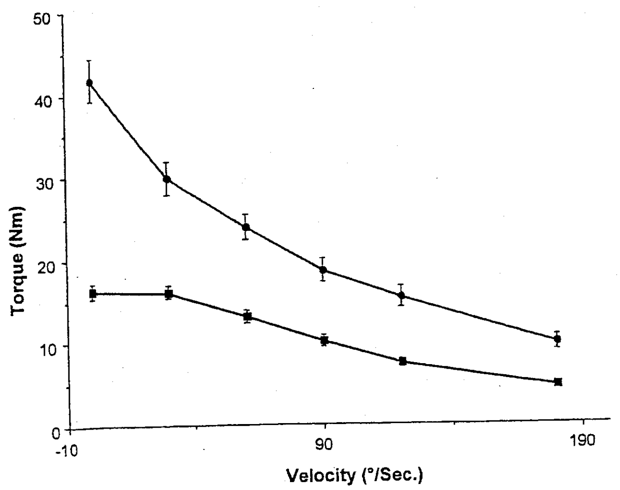

Figure 1. Plot of plantarflexor (filled circles) and dorsiflexor (filled squares) peak torque at selected angular velocities (n = 34).

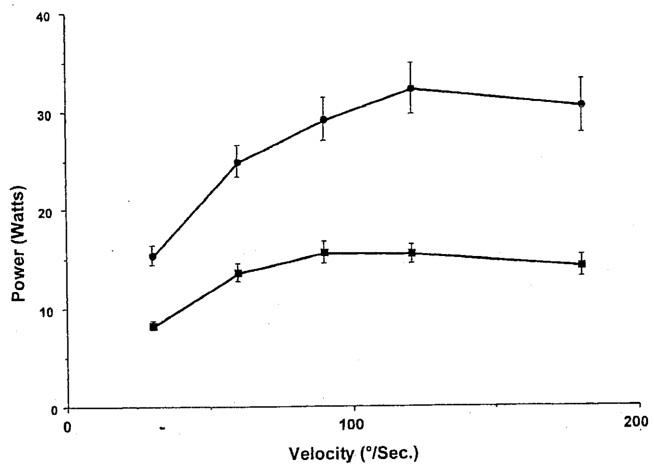

Figure 2. Plot of plantarflexor (filled circles) and dorsiflexor (filled squares) peak power at selected angular velocities (n = 34).

56% of the variance in stair climb time (r = 0.74; $P <$ .03). Forward stepwise regression revealed that DF peak power, physical functioning, and the general health score were the only independent predictors of stair climb time (r = 0.73; $P < .0004$), explaining 54% of the variance.

Habitual Gait Velocity

DF isometric strength, DF peak power, PF isometric strength, PF peak power, balance, PASE score, and the general health score explained 62% of the variance in habitual gait velocity (r = 0.79; $P < .006$). Forward stepwise regression revealed that PF isometric strength, balance, and the general health score contributed independently to habitual gait velocity (r = 0.72; $P < .0009$), accounting for 52% of the variance.

Maximal Gait Velocity

PF isometric strength, PF peak power, PASE score, physical functioning score, PF isometric strength, and PF isometric power explained only 29% of the variance in maximal gait velocity ($P < .07$). Forward stepwise regression revealed that PF isometric strength contributed independently to maximal gait velocity (r = 0.48; $P < .01$), accounting for 23% of the variance.

DISCUSSION

The main findings of the present study were that PF power was an independent predictor of chair rise performance, and DF power was an independent predictor of stair climb

Table 5. Physical Performance Measures

	T1	T2	Mean	±SE	ICC
Repeated chair rises (sec.)	25.5	23.3	24.4	0.9	0.71
Stair climb (sec.)	5.1	44.0	5.0	0.4	0.96
Habitual gait speed (m/sec)	1.1	1.1	1.1	0.1	0.76
Maximal gait speed (m/sec)	1.6	1.6	1.6	0.1	0.87

T1 = time one; T2 = time two; SE = standard error; ICC = intraclass correlation coefficients.

Table 6. Multiple Regression Model

Physical Performance	Variables entered into multivariate analysis	Coefficient	±SE	*r*	*P*-value
Repeated chair rises	Physical functioning	−0.127	0.034	0.58	<.01
	DF peak power	−61.655	18.698	0.50	<.01
	PF peak power	−18.161	7.793	0.38	.03
	Vitality	−0.083	0.040	0.37	.05
	DF isometric strength	−17.294	9.199	0.32	.07
	Mental health	−0.121	0.070	0.32	.10
	Balance	0.063	0.043	0.26	.15
Stair climb	DF peak power	−30.293	9.477	0.49	<.01
	Physical functioning	−0.061	0.021	0.48	<.01
	PF peak power	−10.598	3.803	0.44	<.01
	General health	−0.113	0.045	0.44	.02
	PF isometric strength	−4.936	2.011	0.40	.02
	DF isometric strength	−10.232	4.528	0.37	.03
	Mental health	−0.068	0.040	0.31	.10
	PASE	−0.015	0.009	0.30	.12
Habitual gait	PF isometric strength	0.530	0.149	0.53	<.01
	DF peak power	2.303	0.773	0.47	<.01
	PASE	0.002	0.001	0.44	.02
	Balance	−0.004	0.002	0.43	.01
	General health	0.008	0.004	0.40	.03
	PF peak power	0.689	0.318	0.36	.04
	DF isometric strength	0.795	0.365	0.36	.04
Maximal gait	PF peak power	1.143	0.375	0.47	<.01
	DF peak power	2.705	0.984	0.44	.01
	PF isometric strength	0.528	0.200	0.42	.01
	DF isometric strength	1.145	0.446	0.41	.02
	PASE	0.001	0.001	0.28	.14
	Physical functioning	−0.003	0.002	0.28	.14

SE = standard error; PF = plantarflexor; DF = dorsiflexor; PASE = Physical Activity Scale for the Elderly.

performance. Interestingly, neither PF nor DF strength was an independent predictor of chair rise or stair climb performance, but PF strength was an independent predictor of both measures of gait quality (habitual and maximal gait velocity). In addition, both the physical functioning and general health subscales of the MOS SF36 were equally strong independent predictors of function.

DF peak power had the highest degree of univariate association of any of the factors with the functional performance measures. Stepwise regression models revealed that PF peak power was a significant independent predictor of chair rise time and DF peak power was a significant independent predictor of stair climb time. Both of these observed relationships are consistent with the biomechanical involvement of the PF in chair rising functions[7] and the DF in stair climbing.[19] Reduced PF and DF power has been linked to an increased risk of falling in institutionalized older individuals.[8] Interestingly, when entered into the same regression model, neither PF strength nor DF strength was identified as an independent predictor of stair climb and chair rising functions. This suggests that both the force and velocity-generating components of ankle movement are important factors related to stair climbing and chair rising performance. Peak power of the leg extensor muscles has previously been shown to correlate with chair rising, stair climbing, and gait functions in frail institutionalized men and women.[9] Furthermore, we have recently noted that peak power of the leg extensors is an independent predictor of functional status in community-dwelling frail older women.[10] Peak muscle power may be a more critical variable than muscle strength in explaining decrements in physical function in older people because of its well-described rapid decline with advancing age.[3,20] The present study extends this work by demonstrating that peak power of the ankle flexors is correlated to function and is an important independent predictor of performance of specific functional tasks (e.g., stair climbing and chair rising).

PF isometric strength and balance were independent predictors of habitual gait velocity, whereas PF strength was the sole independent predictor of maximal gait velocity. These results are consistent with reports on the relationship between knee extensor strength, balance, and gait speed in older women with severe walking disability.[6] Gait speed alone has also recently been shown to be a good predictor of subsequent disability in two large cohorts of older individuals.[21] The present data suggest that peak power of the ankle flexors is not predictive of gait velocity and this may be explained by the relatively slow velocity of movement achieved even during maximal gait in our study population.

Self-reported measures of functional limitations were also related to our measures of functional performance. Specifically, the physical functioning and general health subscales were independent predictors of physical performance in our study population. These data are consistent with previous reports on the relationships between impairments, function, and disability in older people.[22,23] Other psychosocial variables may in fact have been related to function in older women with self-reported disability. However, our analysis of these relationships is limited by our relatively small sample size.

Linear associations were observed between measures of ankle power and strength and several of the tests of functional performance we employed. Although previous studies have observed a curvilinear relationship between impairment and function,[22,24] this apparent inconsistency may be a result of the relatively small sample size employed in the present study. In addition, the specific measures of impairment and function utilized, and the relatively narrow range of age and level of functional limitations among participants in the present study, may have also accounted for these differences.

The absolute peak torques and the declines in peak torque observed with increasing velocity were similar to previous studies on older individuals.[25,26] In addition to observations regarding the relationships between ankle power and function, the reliability of isokinetic and isometric measures of ankle torque and power was consistent with previous reports in young and older individuals and ranged from good to excellent.[27-29] Furthermore, the reliability of our physical performance measures was also good to excellent, confirming a previous report on the suitability of performance-based measures in older individuals.[30]

In summary, the results of this study support the concept that muscle power generated by the ankle DFs and PFs are important predictors of stair climb and chair rise performance. These data suggest that ankle muscle power is an essential component of functional mobility in older women with functional limitations. In addition, for specific functional tasks such as gait, isometric strength of the ankle PFs is a strong independent predictor. Furthermore, self-reported measures of general health status and physical functioning were also predictors of functional performance. In addition to strategies aimed at improving general health, function, and strength, interventions targeted at improving function in older people should include exercises designed to increase peak power of the ankle PFs and DFs.

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