

Association of Muscle Power With Functional Status in Community-Dwelling Elderly Women

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Background. Identification of the physiologic factors most relevant to functional independence in the elderly population is critical for the design of effective interventions. It has been suggested that muscle power may be more directly related to impaired physical performance than muscle strength in elderly persons. We tested the hypothesis that peak muscle power is closely associated with self-reported functional status in sedentary elderly community-dwelling women.

Methods. We used baseline data that were collected as part of a 1-year randomized controlled clinical trial of a combined program of strength, power, and endurance training in 80 elderly women (mean age 74.8 ± 5.0 years) with 3.2 ± 1.9 chronic diseases, selected for baseline functional impairment and/or falls.

Results. Functional status at baseline was related in univariate analyses to physiologic capacity, habitual physical activity level, neuropsychological status, and medical diagnoses. Leg power had the strongest univariate correlation to self-reported functional status ($r = -.47, p < .0001$) of any of the physiologic factors we tested. In a forward stepwise regression model, leg press power and habitual physical activity level were the only two factors that contributed independently to functional status ($r = .64, p < .0001$), accounting for 40% of the variance in functional status.

Conclusions. Leg power is a strong predictor of self-reported functional status in elderly women.

THE proportion of older individuals in the United States continues to grow and more significantly, this group is experiencing greater longevity, especially women. Although women are living longer than men are, they are spending more time in a disabled state and most often while still living in the community. The National Center for Health Statistics estimates that 84% of persons aged 65 and older who are dependent in basic or instrumental activities of daily living reside in the community (1). As functional dependency becomes more prevalent, an associated increase in utilization of health care services, admission to nursing homes, and excess mortality may occur (2-4). Therefore, understanding the etiology of functional dependency and potential for reversibility assumes critical importance.

Functional independence requires the complex interaction of many factors spanning physiologic, psychological, social, environmental, and health status domains (4). In the physiologic domain, age-associated declines in Vo_2 peak and muscle strength have been well-documented (5-8). However, more limited research has been conducted to determine the relationship between decreases in Vo_2 peak (9,10) and muscle strength and self-report of functional status (9,11,12). Although studies which show some relationship between muscle strength and performance-based tests

of mobility tasks are more prevalent (13-17), there are clearly discrepancies between performance testing in the laboratory and real world functional independence which cannot be addressed by such research.

An emerging area of interest to researchers is the possible role that peak muscle power (work per unit time) may play in functional independence in elderly persons. Many basic activities in daily life such as walking, climbing stairs, or simply standing from a seated position, require leg muscle power. Muscle power output is a product of the force and the velocity of muscle shortening (18). It has been suggested that muscle power may be more directly related to impaired physical performance than strength in the elderly (19-22). Along with decreases in muscle strength (the force of muscle contraction) which take place with advancing age, the other component of power, the velocity with which muscle force can be generated, declines in old age as well (23). Therefore, power declines to an even greater degree than strength (21,22,24-27), making it a potentially major etiologic factor in age-related functional decline.

Identification of the physiologic factors most relevant to functional independence is critical for the design of effective, targeted interventions to prevent or delay dependency. We chose to study women exclusively because of their

lower absolute power and power normalized with respect to body mass than men of the same age, and their increased risk for falls and functional dependency. Our hypothesis was that peak muscle power would be more closely associated with self-reported functional status than other physiologic attributes in sedentary community-dwelling elderly women selected for baseline functional impairment and/or falls. We further hypothesized that additional explanatory power would be contributed by neuropsychological state (higher self-efficacy and cognition, fewer depressive symptoms), lower burden of disease, and higher overall physical activity level.

METHODS

Study Design

The data were collected as part of a 1-year randomized controlled clinical trial of a combined program of strength, power, and endurance training in elderly women with pre-existing impairments of functional status. Subjects were randomly assigned to either the combined exercise group or the control group after acceptance into the study and after completing all of the baseline testing. Only baseline data are presented in the analyses below.

Study Population

Identification and recruitment of human subjects were performed in accordance with a protocol approved by the Tufts University Human Investigation Review Committee at New England Medical Center. Subjects were recruited from the Boston area community for this study from March 1994 to January 1997. All subjects gave written informed consent prior to participation in the research study, as required and approved by the Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University (HNRCA).

To be eligible for the study in terms of functional status, one deficit on either the IADL (28) or the physical function subscale of the Medical Outcomes Study Short Form (MOS SF-36) Health Status Survey (29) was required *and/or* one or more falls within the previous 12 months. A fall was defined as unintentionally coming to rest on the ground, floor, or other lower level, whether or not an injury occurred (30). Excluded were falls where the respondent came to rest on a chair or bed. In addition, the 80 women selected for this study fulfilled the following entry criteria: age 70 or above, community-dwelling, ambulatory, with or without an assistive device, and independence in the basic activities of daily living (with the exception of incontinence). Exclusion criteria included: (i) acute or terminal illness; (ii) moderate or severe cognitive impairment (inability to understand and provide written informed consent and/or follow instructions); (iii) unstable cardiovascular or other medical condition as assessed during the screening history and physical examination; (iv) upper or lower extremity amputation; (v) significant abnormal response to the screening exercise tolerance test, including ventricular arrhythmias, angina during test, heart block, sustained atrial arrhythmias, hypotension or bradycardia during test, and >3 mm horizontal or downsloping ST segment depression (asymptomatic ST depression or minor arrhythmias were not exclusions); (vi) myocardial in-

fraction within the past 6 months; (vii) upper or lower extremity fracture within the past 6 months; (viii) current involvement in regular sessions of aerobic or resistance exercise (1 time/week or more); and (ix) unwillingness to be randomized to a control group or complete study requirements. Interested potential volunteers were administered a screening questionnaire by telephone by the study coordinator. This questionnaire included the IADL scale and the physical function component of the MOS SF-36 as well as other questions relevant to the eligibility criteria. If the entrance criteria were fulfilled, subjects were invited to the HNRCA for further screening with a history and physical examination, blood chemistries and hematology, and submaximal and maximal exercise testing with electrocardiographic (EKG) monitoring. If there were no exclusionary abnormalities on these tests, the subject came back to the center on another day to complete the remainder of the baseline testing.

Outcome Measures

The primary dependent variable of this study was functional status as assessed by self-report (NHANES I questionnaire) (31). Independent variables included demographic variables; the physiologic measurements of dynamic muscle strength, muscle power, muscle endurance, Vo_2 peak, and body mass index; the neuropsychological measures of depression, self-efficacy, and cognitive status; and health status as evaluated by the total number of chronic medical diagnoses, total number of medications and nutritional supplements, and habitual physical activity level.

Functional Status

The functional status questionnaire used was Part C (Activities of Daily Living) (ADLs) of the NHANES I Epidemiological Follow-up Study, 1986 (31). This self-report questionnaire assesses both basic and instrumental activities of daily living, as well as mobility, and thus is ideal to identify subjects with deficits which may be helped by an exercise intervention. Moreover, this scale includes information on degree as well as presence of difficulty and whether an assistive device or person is needed for each activity. Individuals were asked how much difficulty they have in doing 23 activities of daily living. Response choices for each question are: no difficulty = 0; some difficulty = 1; much difficulty = 2; or unable to do without assistance = 3. The 23 questions are grouped into eight functional categories: dress/groom, arise, eat, walk, grip, hygiene, reach, or errands/chores. Each functional category was assigned a numerical score from 0 to 3 (from no difficulty, some difficulty, much difficulty, to unable to do without assistance) by taking the highest reported score of the questions in a category. A total functional status score (FSS), also ranging from 0 to 3, was then calculated by averaging the eight functional category scores.

Physiologic Measures

The dynamic concentric strength of the upper and lower body was measured as the bilateral one repetition maximum (1RM) obtained on the chest press, upper back, leg press, and hip abductor computer-interfaced pneumatic resistance

machines (Keiser Sports Health Equipment Inc., Fresno, CA). The 1RM is defined as the maximum load that can be moved one time only throughout the full range of motion (ROM) using proper form (32). ROM was determined visually by the assessor, by comparing the excursion of a lighted bar on the output screen in unloaded (defined as full ROM) and loaded extensions. This testing was performed by each subject at least 1 hour after a meal, on a day when no other resistance exercises had been performed, and with the verbal coaching of the tester to elicit a maximal effort after the subject had become familiarized with the equipment. Beginning with minimal resistance, each new weight was lifted once to full extension in proper form until no more resistance could be successfully applied. Each repetition took 2 seconds to complete the concentric phase and 4 seconds to complete the eccentric phase. A rest interval of 1 minute was allowed between trials. Incremental resistance was tailored to the tester's perceived strength of the subject to achieve the 1RM in approximately 8 to 10 lifts. Baseline 1RM testing was repeated once by the same tester between 2 and 7 days apart from the initial test. The best of the two baseline measures of strength was used as the baseline 1RM. The correlation of repeated 1RM testing of the leg press in this population was $r = .90, p < .0001$.

Muscle power testing was conducted using the same four machines used for the 1RM testing. These computer-interfaced pneumatic resistance machines were specifically modified for this study. We have previously validated this method of power testing against standard laboratory and field tests of muscle power (33). Following the measurement of the baseline 1RM, the percentages of the 1RM from 40% to 90%, in increments of 10% up to 80%, and then for 85% and 90%, were calculated for each of the four machines. Starting at 40%, the subject performed the lift at each established percentage of her 1RM as fast as possible through her full range of motion. The power test was performed once at each force setting with a 45-second to 1-minute rest between each repetition. For each repetition performed, the computer interface calculated work and power by sampling the system pressure (force) at the cylinder 400 times per second during the movement and recorded the distance traveled by the piston. The algorithm used calculated work and power based only on the outgoing stroke which was determined as the distance between the minimum and maximum position in the stroke. All data between these points were used to calculate work. For the calculation of mean power of a single stroke, the data between 5% and 95% of the stroke were used to avoid the noise and discrepancies that occur at the very end and beginning of the exercise. This method produces more repeatable data and much more reliable start and stop points in the exercise. The highest mean power achieved of all of the repetitions performed was recorded as the peak power. The machines were calibrated at the factory and the same equipment was utilized throughout the entire study.

Muscle endurance was determined on each of the four pneumatic resistance machines by the maximum number of repetitions that could be performed in correct form at a fixed load of 90% of the baseline 1RM. Subjects performed at a slow, self-determined but continuous pace and failure

occurred when either two consecutive lifts could not be completed correctly or 25 repetitions had been achieved. Subjects who were stopped by the examiner at 25 repetitions were assigned a score of 26 repetitions for that muscle group. Muscle endurance was assessed at least 24 hours apart from a 1RM or power test.

Vo_2 peak was measured on a motorized treadmill (Desmo CE-25, Woodway USA, Waukesha, WI) by a graded exercise tolerance test with continuous on-line analysis of expired gases. The subject's expired gases were obtained through a Hans Rudolph face mask (series 8930 #5, Hans Rudolph Inc., Kansas City, MO) fitted around the face with a custom-fitted thin compliant sealant (Elastogel, Southwest Technologies, Inc., Kansas City, MO) to prevent air leakage (34). Expired gases were continuously analyzed by a Beckman LB-2 CO_2 analyzer (Sensormedics, Schiller Park, IL) and an Applied Electrochemistry S-3A O_2 analyzer (Applied Electrochemistry, Inc., Sunnyvale, CA), both calibrated daily with previously analyzed gas mixtures. Analyzers were interfaced with a Zenith-PC minicomputer programmed for a 0.5-minute output of minute ventilation, CO_2 production, Vo_2 peak, and respiratory exchange ratio.

The treadmill speed was set at a rate of 0.1–3.0 mph, based on the habitual gait speed of the individual. Habitual gait speed was measured to the nearest 0.01 second as the mean of two trials by an ultrasonic gait speed monitor (Ultratimer, DCPB Electronics, Glasgow, Scotland). The test was set initially at 80% of habitual gait speed, then adjusted as needed for tolerance during treadmill walking. The test was standardized with all subjects keeping two hands lightly on the handrails for balance at all times. The first two minutes of the test were performed at 0% grade and the grade was increased by 2% every minute beginning at the end of minute 2 and continuing until the subject reached her maximal effort and requested to stop. All exercise stress testing took place under physician supervision with the subject in a rested condition, with no consumption of caffeine during the previous 12 hours, and not less than 1 hour following a meal. Subjects had a maximal exercise test as above at screening and at baseline assessment, within a period of 2 to 16 weeks. The highest oxygen consumption value during maximal effort from these two tests was recorded as Vo_2 peak at baseline. The correlation between the screening and baseline Vo_2 peak tests in this population was $r = .90, p < .0001$.

The body weight of each subject (wearing a preweighed johnny and robe) was measured to the nearest 0.1 kg with a digital platform scale. A naked weight was determined by subtracting the weight of the johnny and robe. Height was measured to the nearest 0.5 cm with a wall-mounted stadiometer (Seca, Germany). These measurements were taken in the morning following a 12–14-hour fast. Body mass index was calculated as the weight in kilograms divided by the square of the height in meters.

Neuropsychological Measures

Depression was measured by the Geriatric Depression Scale (GDS) (35), a questionnaire containing 30 yes/no questions including a variety of nonphysical symptoms related to depression which may have been present over the

past week. Scores greater than 9 are associated with clinical depression of increasing severity in community dwelling elderly.

Ewart's Self Efficacy Scales (score 0–100, with higher scores indicating higher self-efficacy) were used to measure self-perceived ability to walk various distances, jog, climb stairs, lift objects of various weights, and do push-ups (36). Self-efficacy scores were used in univariate analyses, and then averaged to provide a single score for entry into multivariate regression models.

Global cognitive function was assessed by the Mini-Mental State Examination (37), a screening tool with scores ranging from 0 (severe dementia) to 30 (normal).

Health Status

A tabulation of all medical diagnoses was obtained via questionnaire of each subject and during the history and physical examination performed by a physician or nurse practitioner. All diagnoses were coded by extraction of these records by the same study physician. Both over-the-counter and prescribed medications were recorded from medical records, subject interview, and inspection of pill bottles they were asked to provide at assessment visits.

Leisure, household, and occupational activity levels were estimated by the Physical Activity Scale for the Elderly questionnaire (PASE), with higher scores reflecting higher physical activity levels (38). The PASE is a brief, reliable, and valid instrument for the assessment of physical activity in studies of older people.

All of the testing for this project was carried out prior to randomization at the HNRCA in the Human Physiology Laboratory, Boston, MA, and 1000 Southern Artery, a senior housing community in Quincy, MA. All of the strength, power, and endurance measurements were done by exercise physiologists experienced in working with the elderly. These testers were rigorously trained by the principal investigator (M.A.F.S.) and were well-conversant with the testing protocols. All questionnaires were interviewer-administered.

Statistical Analysis

All data were analyzed with Statview 5.0 (Abacus Concepts, Berkeley, CA) or Systat statistical software (Systat Inc., Evanston, IL). All data were first examined visually and statistically for normality of distribution. Because of its nonparametric distribution, a logarithm (log) transformation was applied to the FSS. A constant (0.05) was added to each raw score and then each score was logged. The log-transformed data were used for all of the analyses. However, the results are presented in the original units for comparability with other studies. Continuous data are described as the mean (standard deviation) or median and range as appropriate. Univariate regression analyses were performed to determine if significant relationships existed between the FSS and other variables of interest. The variables with a univariate association with the FSS at the level of $p < .15$ were then entered into appropriate multiple and forward stepwise regression models. To test for a nonlinear relationship between leg press power and FSS, leg press strength and FSS, and Vo_2 peak and FSS, regression analyses using leg press

power squared, leg press strength squared, and Vo_2 peak squared (quadratic transformations) were performed. A p value of $< .05$ was accepted as indicative of statistical significance.

RESULTS

Recruitment

One hundred and ninety-seven women responded to broad advertising via newspaper, talks, and newsletters and had a telephone screening. One hundred and one or 51% met the study eligibility criteria of having functional impairment and/or one or more falls in the past 12 months and were invited to a screening assessment at the HNRCA. Of the 96 who were ineligible, 46 did not meet study eligibility and 50 met the criteria but could not commit to the study requirements. Following the screening assessment, 12 were no longer eligible and 9 were eligible but could not commit to study requirements. Therefore, 80 subjects were eligible and randomized, which was 41% of the original respondents.

Subject Characteristics

The participants' demographic characteristics are presented in Table 1. The median age for the group was 73 (range from 70 to 95) and all but one of the women were Caucasian. Physiologic characteristics are presented in Table 2.

Table 3 contains information on the health and functional status of the group. The mean number of total diseases for the group was 3.15. The most common medical diagnoses in this sample were osteoarthritis (71%), hypertension (55%), musculoskeletal (20%), peripheral vascular (19%), gastrointestinal (16%), coronary disease (15%), respiratory (15%), osteoporosis (14%), thyroid (14%), cancer (12.5%), and psychiatric (11%). The total medications category included all regular and as-needed medications (e.g., arthritis medications), whereas the medications plus supplements category included the regular and as-needed medications

Table 1. Baseline Subject Characteristics

Age (years)	74.8 ± 5.0*
Height (cm)	159.0 ± 6.1*
Weight (kg)	71.4 ± 14.8*
Body mass index (kg/m ²)	28.2 ± 5.2*
Education	
High School	71.25%
College	22.5%
Marital status	
Married	31.25%
Widowed	45.0%
Divorced/separated	15.0%
Never married	8.75%
Residence	
House	48.75%
Apartment	13.75%
Retirement home	30.0%
Others	7.5%
Lives	
Alone	62.5%
With other(s)	37.5%

*Mean ± SD.

Table 2. Baseline Physiologic Characteristics

Variable	N	Mean	SD	Range
Vo ₂ peak (mL/kg/min)	75	17.34	3.47	9.05–25.85
Maximal treadmill time (min)	80	7.39	2.85	1.40–14.02
Muscle strength (Newtons)				
Chest press	73	251	41	144–344
Leg press	78	1994	433	1122–3376
Upper back	76	138	24	92–206
Hip abductor	78	152	52	60–264
Muscle power (Watts)				
Chest press	70	69	29	16–144
Leg press	73	272	150	10–712
Upper back	75	133	58	30–272
Hip abductor	73	48	24	6–108
Percent 1RM where peak power occurs				
Chest press	70	76	9	51–92
Leg press	73	65	13	40–89
Upper back	75	79	12	53–127
Hip abductor	73	80	11	51–100
Muscle endurance (no. repetitions)				
Chest press	63	6	3	0–16
Leg press	72	16	8	0–26
Upper back	71	10	5	2–26
Hip abductor	68	11	6	3–26

plus nutritional supplements. Sixty-six percent of the women were taking nutritional supplements, primarily self-prescribed multivitamin and mineral preparations.

Twenty-five percent of the 80 subjects had experienced at least one fall in the previous 12 months. All but one of the 80 women had functional or mobility impairment on the IADL or physical function scale of the MOS SF-36.

Univariate Predictors of Functional Status

Better functional status at baseline was related in univariate analyses to independent variables in all of the domains assessed, and is shown in Table 4. The strongest univariate associations were found between FSS and leg press power, physical activity level, and self-efficacy. Variables that were not significantly related to functional status in univariate analyses were body mass index, education level, upper back and hip abductor strength and endurance measurements, and chest press and leg press endurance measurements. The quadratic transformations to test for nonlinear relationships between leg press power and FSS, leg press strength and FSS, and Vo₂ peak and FSS were not significant.

In addition to functional status, advancing age was negatively associated with power measurements in all muscle groups ($r = -.25$ to $-.33$, $p = .036$ – $.005$), chest press, leg press, and upper back strength measurements ($r = -.28$ to $-.36$, $p < .02$ – $.001$), and Vo₂ peak ($r = -.20$, $p = .08$). Advancing age was not significantly associated with any of the endurance measurements.

Multivariable Analysis of Factors Related to Functional Status

A multiple regression model was constructed with all variables having univariate associations to FSS, and the variables entered were age, cognitive score, depression score, average self-efficacy, habitual physical activity level, total number of diagnoses and medications, Vo₂ peak, chest

Table 3. Health, Neurological State, and Functional Status of Study Participants

Variable	N	Mean	SD	Range
No. of medications	80	3.0	2.3	0–11
Medications plus supplements	80	5.4	2.9	0–14
No. of chronic diseases	80	3.2	1.9	0–9
Functional status score* (total)	80	.45	.45	0–1.75
Dressing and grooming	80	.18	.44	0–2
Arising	80	.39	.63	0–2
Eating	80	.33	.71	0–3
Walking	80	.31	.61	0–3
Personal hygiene	80	.66	1.1	0–3
Gripping	80	.14	.35	0–1
Reaching	80	.51	.87	0–3
Errands and chores	80	1.1	1.2	0–3
Instrumental activities of daily living†	80	.41	.90	0–4
Depression score‡ (0–30)	79	4.5	3.9	0–17
Cognitive function score§ (0–30)	80	28.7	1.2	24–30
Physical activity scale for the elderly	78	94.5	45.5	2.2–206.8
Quality of life¶				
Physical functioning	80	73.8	20.5	25–100
Role physical	77	76.0	35.5	0–100
Bodily pain	77	69.1	23.1	22–100
General health	77	69.7	12.6	20–85
Vitality	77	61.1	21.5	5–100
Social functioning	77	90.1	17.5	12.5–100
Role emotional	77	87.9	27.5	0–100
Mental health	77	84.1	14.5	36–100
Self-efficacy# (%)				
Lifting	78	41.1	12.7	7–70
Walking	78	46.9	24.7	0–100
Jogging	78	7.6	13.6	0–81
Climbing	78	46.4	22.3	0–89
Push-ups	78	12.1	14.8	0–62

* NHANES I Functional Status questionnaire (31).

† Lawton and Brody IADL (28).

‡ Geriatric Depression Scale (36).

§ Mini-Mental State Examination (38).

|| PASE (39).

¶ Medical Outcomes Study Short Form Health Survey (SF-36) (29).

Ewart's Scale of Self-Efficacy (37).

press and leg press strength and power measurements. In the complete multiple regression model, the combination of these factors accounted for 52% of the variance in FSS ($r = .72$, $p = .0002$). These same variables were then entered into a forward stepwise multiple regression model and leg press power and habitual physical activity level were the only two factors that contributed independently to FSS ($r = .64$, $p < .0001$), accounting for 40% of the variance in FSS.

In order to look more closely at the relationships among contributing factors to functional decline, three smaller forward stepwise multiple regression models were constructed that separated the variables into three different domains: physiologic, neuropsychological, and health status, each adjusted for age as well. The physiologic model included Vo₂ peak, chest press power and strength, leg press power and strength, and age. In this model, leg press power and Vo₂ peak were the only physiologic variables that contributed independently to FSS ($r = .57$, $p < .0001$), accounting for 32% of the variance in FSS. Although Vo₂ peak and leg press power were related to each other ($r = .28$, $p = .02$), an interaction term between Vo₂ peak and leg press power was

Table 4. Univariate Relations Between Independent Variables and FSS as Dependent Variable

Variable	<i>r</i>	<i>p</i>
Average sum of self-efficacy scales	-.51	<.0001
Physical activity	-.49	<.0001
Leg press power	-.47	<.0001
Leg press strength	-.43	.0001
Depression score	.41	.0002
Vo ₂ peak	-.40	.0003
Chest press power	-.35	.0027
Total number of diagnoses	.28	.0110
Total regular medications	.28	.0704
Chest press strength	-.27	.0223
Upper back power	-.26	.0270
Cognitive function score	-.22	.0514
Age	.19	.0940
Hip abductor power	-.18	.1353

examined and was not significant. The neuropsychological model included cognitive score, depressive symptoms, self-efficacy, and age. Depressive symptoms and self-efficacy contributed independently to FSS ($r = .56, p < .0001$), accounting for 31% of the variance. An interaction between depressive symptoms and self-efficacy was examined and found to be not significant. The health status model included total number of medications, total number of diagnoses, physical activity level, and age. Total number of diagnoses and physical activity level remained in the model, and accounted for 29% of the variance ($r = .54, p < .0001$). An interaction between total number of diagnoses and physical activity level was examined and found to be not significant.

DISCUSSION

The major findings of this study were that peak leg press power and habitual physical activity level were independent predictors of self-reported functional status in community-dwelling older women. This is the first study to measure and demonstrate the relationship between peak muscle power and self-reported functional status. Peak leg press power had the highest univariate correlation of any of the factors in the physiologic domain. Peak power for the chest press, upper back, and hip abductor were also correlated with functional status, whereas only the strength for the leg press and chest press were significantly related to functional status. The findings of earlier studies showing leg power related to performance-based tests (39) are thus confirmed and extended by our findings.

The curvilinear relationship which has been discussed by Buchner and deLateur (11) between strength and function was not evident in our data for either power or strength measurements. It is possible that the range of performance in these women lay primarily below the threshold at which function would be impaired by physiologic decrements, and thus the relationships we saw were linear. Because our women were targeted for functional impairment and falls were entry criteria for this study, we would have likely screened out those on the nonlinear portion of the curve by design.

We postulate that there are several reasons why power emerged as the strongest predictor of function in the present

study. Leg press power had a negative correlation with age in our population across a 25-year span, which is consistent with the relative decrements in power found in other cross-sectional studies. Bosco and Komi (27) assessed explosive power in a maximal vertical jump from a force plate. They reported that healthy men and women in their early 70s produced an average power output of 70 to 75% less than healthy men and women in their early 20s. Interestingly, the decrease in average force was only about 50%, demonstrating the preferential loss of power with age. Similarly, two studies that evaluated leg extension power in elderly men and women using a specially designed rig both found that the elderly subjects had about 20% of the power found in nonathletic young adults (21,22). These losses in power far exceed what has been reported for declines in strength with age, which range from 20 to 40% in various studies. A cross-sectional study has shown that across the age range of 65 to 89 years in healthy men and women, losses in handgrip and quadriceps strength average 1.5% per year, whereas the decline of explosive leg extensor power is about 3.5% per year (20). Results from a survey of 2000 men and women aged 16 to 75 years showed that leg extensor power declines with age more rapidly than isometric quadriceps strength (40). These very large losses in power with age may explain its dominant role in relation to function which we have described for the first time in this population.

In addition to these age-related decrements, gender plays a strong role in the determination of muscle power. In women over 65, power decreases at a faster rate than strength (20). Women have been shown to reach their levels of peak power sooner than men do and to decline earlier (27). In addition, women have lower power standardized for body weight than do men of the same age (20,21). Therefore, women may be closer to the threshold at which low power begins to impair function, and this factor thus assumes great importance in the functionally impaired women targeted for this study.

Upper body muscle power was not found to be a significant independent predictor of functional status. However, 17 out of the 23 questions on the NHANES I questionnaire are related to lower body movement, and sensitivity to upper body contribution may have been low. In addition, lower extremity function deteriorates more rapidly with age than upper body function (41), and the age range of our subjects may have been lower than that required to see upper extremity physiology/function relationships.

Habitual physical activity level was the only other factor identified which contributed independently to functional status in these women. The lack of interaction with leg press power suggests that activity may influence function via nonphysiologic pathways, such as psychological health or disease modification, for example, and underscores the multifactorial effects of exercise on independence and quality of life in old age. Sedentariness itself is thus a risk for functional dependency, independent of disease state or other characteristics in these individuals, just as it is in heart disease, and should therefore be screened for in vulnerable populations. It remains to be definitively demonstrated that changing physical activity levels will significantly improve functional independence in these individuals.

A paucity of information exists concerning the contribution of Vo_2 peak to functional status in elderly persons. Our findings of a modest relationship are consistent with those of Morey (9) and Posner (10) and their colleagues, the only previously published studies relating Vo_2 peak to self-reported function. In the first study by Posner and colleagues (10), self-reported ability to perform ADLs was significantly predicted by Vo_2 peak ($r^2 = .41$, $p < .001$) in 61 women (mean age 69 years). In more recent work by Morey and colleagues (9), cardiorespiratory fitness was directly associated with functional limitations ($p < .05$) as assessed by four self-reports of physical functioning and one performance-based test in 161 community-dwelling older adults (72.5 ± 5.1 years).

It has been suggested that a Vo_2 peak of 13 mL/kg/min is required for functional independence (42). Although we did show that functional status was significantly predicted by Vo_2 peak, a threshold was not evident. However, only 10 of our subjects had Vo_2 peaks below 13 mL/kg/min and perhaps there were too few subjects in this range to detect a threshold. Posner and colleagues (10), by contrast, were able to identify the minimum level of Vo_2 peak associated with ability to perform activities of daily living necessary for functional independence. They determined that for subjects whose Vo_2 peak values were in the lower range for the cohort, Vo_2 peak correlated positively with self-reported ability to perform ADLs, whereas for subjects whose Vo_2 peaks exceeded this level, ADL scores leveled off to within 10% of the maximum possible score.

This study is limited in that only women were studied and it is important to see if the relationships identified hold true for men as well. In addition, we intentionally excluded moderately to severely cognitively impaired, institutionalized, and acutely ill individuals, in whom these conditions overwhelm other causes for functional impairment which may be more amenable to intervention. These models therefore apply to medically stable community-dwelling older women with a variety of chronic medical conditions and disabilities.

In conclusion, functional dependency in the elderly is clearly multifactorial, but the strongest predictors are muscle power and habitual physical activity level in older women, both potentially treatable contributors. Future research needs to address whether targeted interventions can substantially modify these two factors and if such modifications lead to sustained, clinically important improvements in functional status.

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