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A Comparison of Leg Power and Leg Strength Within the InCHIANTI Study: Which Influences Mobility More?

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Background. In a clinical study evaluating the functioning of mobility-limited elders, muscle power accounted for more of the variation in function than strength did. There was also evidence that the power–function relationship may be described as curvilinear. However, these findings have never been confirmed in a representative population.

Methods. An analysis was conducted using data from the InCHIANTI study, a population-based cohort of 1032 adults living in Italy. To assess the relationships between impairments in power and strength and mobility performance, we created separate multivariate linear and log-transformed regression models as well as separate logistic regression models.

Results. Subjects were age $\geq$65 years, predominately female (54%), with a mean age of 74.2 years, and most had mild–moderate mobility limitations (Short Physical Performance Battery score 10.5 $\pm$ 2.1). Though leg extension power and isometric hip extension strength were closely associated, in several separate multivariate linear regression models, leg power consistently explained more of the variance than strength did in several measures of physical performance. Differences were even larger when observed in curvilinear models of power and strength. Using separate multivariate logistic regression models to examine the odds ratios for mobility limitations in persons with low muscle power versus high muscle power, and in persons with low muscle strength versus high muscle strength, we found that both factors influenced risk for mobility limitations, but low power was associated with a 2–3-fold greater likelihood than low strength.

Conclusion. These findings identified muscle power to be a more influential proximal determinant of physical performance than impairments in strength and emphasized muscle power as an important determinant of mobility skills in older adults.

LIMITATIONS in mobility affect almost 1 in 4 individuals aged 65 years or older and three quarters of those living in nursing homes (1,2). Mobility limitations with such tasks as rising from a chair, walking across a room, and maintaining standing balance are predictive of disability, institutionalization, and mortality (3,4). Impairments in muscle strength (ability to exert maximal muscular force) have long been identified as important factors leading to limitations in mobility (5). This relationship has been characterized as curvilinear in the general population of older adults (6–8), with a more linear relationship between strength and mobility performance among those who are weakest. More specifically, this refers to the concept that, after a certain threshold of strength, function improves minimally with additional increases in strength.

Muscle power reflects the ability to generate muscular work per unit of time, and is more simply understood as the product of force and velocity (power = force $\times$ velocity). Though related to muscle strength, muscle power is a separate attribute declining more precipitously after age 50 (9). Theoretically, muscle power may be related to mobility in many ways such as rapidly generating force to maintain balance following a perturbation or while performing a time-dependent task such as crossing a street before the light changes. Prior investigations have shown that impairments in muscle power are important factors limiting mobility in nursing home residents (10,11) and in community-dwelling elders (12–14). These more recent studies evaluating both muscle power and strength impairments and their relation to important mobility tasks have suggested that muscle power may be a more critical attribute than strength (12–14). In one of these investigations, evidence suggested that, like strength, the relationship between muscle power and mobility performance is best characterized as curvilinear (14). A limitation of these investigations was that they were conducted in relatively small groups of subjects limiting the scope of the analyses and the generalizability of their results.

The InCHIANTI study is a large population-based study of elders living in the Tuscany (Chianti) region of Italy. The study's purpose is to identify factors that underlie limitations in mobility among older adults living in the

Table 1. Baseline Characteristics of InCHIANTI Participants Aged 65 Years or Older

Characteristic	Mean (*SD*)	Range
Age (y)	74.2 (6.6)	65–95
Weight (kg)	69.5 (12.3)	41–120
Height (cm)	158.9 (9.4)	133–189
SPPB (0–12)	10.5 (2.1)	1–12
Gait speed (m/s)	1.08 (.26)	.09–2.80
Leg power (watts)	106.0 (63.6)	4.3–372.7
Isometric hip strength (N)	17.1 (6.9)	4.3–43.1
Isometric knee strength (N)	15.7 (5.7)	3.6–41.7

Notes: $n = 839$; 54% female.
SPPB = Short Physical Performance Battery.

community (15). This longitudinal study has over 1400 subjects ($n = 1453$) with an excellent response rate of >90%. We evaluated baseline data from the InCHIANTI study in order to investigate the respective influences of muscle power and muscle strength on mobility performance among community-dwelling older adults. We hypothesized that (a) impairments in muscle power would describe more of the variance in mobility performance than would impairments in strength; (b) that these relationships would be curvilinear; and (c) that the likelihood of having moderate-to-severe mobility limitations would be greater for persons with low muscle power than those with low muscle strength.

Methods

We performed a cross-sectional analysis of baseline data from the InCHIANTI study. Of the 1453 subjects in the study, we included those who were age ≥ 65 ($n = 1032$), and excluded any subjects who did not complete hip strength, knee strength, and leg power testing, leaving 839 subjects for the purposes of our analyses. A full description of the InCHIANTI methods are presented elsewhere (15); however, a brief description of the measures we utilized to represent muscle strength and power, mobility, and adjustment variables are described below.

Leg power, hip strength, and knee strength served as our measures of impairment. Leg power was obtained via a leg power rig as described by Bassey (17). Subjects sat in a chair and unilaterally depressed a foot lever, in the horizontal plane, attached to a flywheel. Power output was derived from the acceleration of the flywheel and was recorded in Watts. Isometric hip extensor strength and knee extensor strength were measured via a handheld isometric dynamometer. This method of strength measurement has been demonstrated to be both reliable and valid for the purposes of research (16). For all strength and power measures, the highest of 2 repetitions was utilized. Though each measurement was obtained bilaterally, the correlation coefficients between sides were considered excellent ($r = .89–.93$), so only data recorded from the right leg was used for the analyses.

Stair climb time, total Short Physical Performance Battery (SPPB) score and each of the components of the SPPB (habitual gait speed, balance, and chair rise time) served as functional measures of mobility performance. Stair climb time was measured as the fastest time of 2 trials to climb a single flight of stairs. The SPPB is a composite score of performance [0–12] based on 3 functional tasks (18). On each task, subjects can score between 0–4, with the higher values representing the best performance. To measure walking speed, 2 photocells connected with a recording chronometer were placed at the beginning and the end of 4-meter course established at the study clinic. Participants were instructed to stand with both feet touching the starting line and to begin walking at their usual pace after a verbal command. The time between the activation of the first and the second photocell was recorded. The average of 2 walks was used to compute a measure of walking speed. Use of aids (canes or walkers) was allowed for this test. Chair rise represented the time to complete 5 chair rises as quickly as possible. As a balance measure, the SPPB balance component score was used with responses ranging between 0–4. Based on their subsequent risk for disability, mobility limitations have been characterized as being mild (score ≥ 10), moderate (score 7–9), and severe (score 4–6) (18).

Age, weight, height, and gender are common covariates with the potential to influence the relationships between our independent and dependent variables, and served as our adjustment variables.

A 4-stage statistical analysis was performed. First, mean values and the distribution for all variables were determined. Second, to evaluate the relationship between our impairment (hip strength, leg strength, and leg power) and mobility measures (SPPB, stair climb time, gait speed, balance, and chair rise), 15 separate multivariate linear regression analyses were conducted utilizing each impairment measure as the independent variable and each mobility measure as the dependent variable. Third, to evaluate whether the relationship between impairment and mobility measures could be characterized as curvilinear, we created both quadratic and log-transformed multivariate regression models (15 separate models for each type of analysis). We compared the separate quadratic and log transformed models evaluating adjusted R^2 and AIC (Akaike's information criterion) values as well as visually inspecting residuals of the squared and log terms. We determined that the log-transformed models fit the data best and utilized those for our analysis. Fourth, to contrast the magnitude to which worsening impairment levels were associated with poor mobility, we performed separate logistic regression models. Using SPPB score ≤ 9 as the dependent variable and dividing each impairment variable into quartiles (with the highest quartile as the reference value), odds ratios (OR) for predicting the dependent variable were calculated using 95% confidence intervals (CI).

Results

Baseline characteristics of the participants are presented in Table 1. Subjects were in their mid-70s (mean age 74.2 years), more than one half were female (54%), had mild mobility limitations (mean SPPB 10.5, habitual gait speed 1.08 m/s), with corresponding values for hip, knee strength, and leg power being 17.1 Newtons, 15.7 Newtons, and 106 Watts, respectively. Leg power was associated with hip strength ($r = .76$; $p < .001$) and knee strength ($r = .73$;

Table 2. Separate Age-, Gender-, Height-, and Weight-Adjusted Linear Regression Models (15 Models) of Leg Power, Hip Strength, and Knee Strength Predicting Several Measures of Physical Function for Subjects Aged ≥65 Years

Functional Measure	Impairment	Coefficient	*SE*	R^2
SPPB (0–12)	Leg power (Watts)	.01	.001	.28
	Hip strength (N)	.08	.01	.27
	Knee strength (N)	.07	.02	.25
Stair climb (s)	Leg power (Watts)	−.01	.001	.38
	Hip strength (N)	−.09	.01	.36
	Knee strength (N)	−.10	.01	.35
Habitual gait (m/s)	Leg power (Watts)	.002	.0002	.38
	Hip strength (N)	.01	.001	.36
	Knee strength (N)	.01	.001	.35
Balance score (0–4)	Leg power (Watts)	.003	.0006	.27
	Hip strength (N)	.02	.005	.26
	Knee strength (N)	.02	.006	.25
Chair rise time (s)	Leg power (Watts)	–.03	.004	.22
	Hip strength (N)	–.24	.03	.23
	Knee strength (N)	–.26	.03	.21

Notes: $n = 839$ for all models except for stair climb, where $n = 779$; $p < .001$ for all models.

SPPB = Short Physical Performance Battery.

Table 3. Separate Age-, Gender-, Height-, and Weight-Adjusted Log-Transformed Regression Models (15 Models) of Leg Power, Hip Strength, and Knee Strength Predicting Function for Subjects Aged ≥65 Years

Functional Measure	Impairment	R^2
SPPB (0–12)	Leg power (Watts)	.35
	Hip strength (N)	.30
	Knee strength (N)	.28
Stair climb (s)	Leg power (Watts)	.44
	Hip strength (N)	.39
	Knee strength (N)	.38
Habitual gait (m/s)	Leg power (Watts)	.41
	Hip strength (N)	.38
	Knee strength (N)	.36
Balance	Leg power (Watts)	.29
	Hip strength (N)	.27
	Knee strength (N)	.26
Chair rise time (s)	Leg power (Watts)	.27
	Hip strength (N)	.27
	Knee strength (N)	.26

Notes: $n = 839$ for all models except for stair climb, where $n = 779$.

SPPB = Short Physical Performance Battery.

$p < .001$). Of these 839 subjects, 60 subjects did not complete the stair climb performance test.

Separate adjusted linear regression models of leg power, hip strength, and knee strength predicting several measures of mobility function are presented in Table 2. In all models, adjusted for age, height, weight, and gender, muscle power and strength were significantly associated with function. Leg power explained between 22%–38% of the total variance in the 5 functional measures, which included SPPB, stair climb time, habitual gait speed, balance, and chair stand time. In comparison with measures of strength, leg power described slightly more of the variance within the respective performance measures with the exception of chair rise.

Separate adjusted log-transformed regression models served as curvilinear models of these same impairment–function relationships and are presented in Table 3. All models were statistically significant ($p < .001$). Again, across all of the models, leg power consistently explained more of the total variance in function than leg strength, with the exception of chair rise, in which the R^2 values for leg power and hip strength were equivalent ($R^2 = .27$). Examining leg power individually, the curvilinear models consistently explained more of the variance in mobility performance as compared with the linear models. Additionally, except for chair rise time, for each mobility task, the magnitude of difference in variance between leg power and the leg strength measures was generally greater within these curvilinear models as compared with corresponding linear analyses (data not presented).

To characterize the change in slope across different levels of performance, separate linear models were generated using SPPB score ≤10 ($n = 662$) as the dependent variable in the first model and SPPB score ≤9 ($n = 177$) as the dependent variable in the second model. For all 3 impairment measures, there was an approximate twofold difference in slope of the relationship between muscle power or strength and mobility (as measured by the SPPB) among subjects with poorer mobility, compared with the subgroup with good mobility (hip strength, $\beta = .048$ vs .029; knee strength, $\beta = .045$ vs .025; leg power, $\beta = .008$ vs .004).

Logistic regression models were employed to evaluate poor physical performance (SPPB ≤9) according to quartiles of leg power, hip strength, and knee strength. As seen in Figure 1, within all 3 categories of impairment, approximately one half of all subjects with poor performance were in the lowest category (leg power 54.6%, hip strength 50.0%, and 51.7% knee strength) and approximately one quarter were in the second lowest category (leg power 27.8%, hip strength 26.7%, and knee strength 21.6%). Adjusted ORs for the separate models are presented in Figure 2. The ORs for poor performance in the lowest quartile of leg power (OR 8.9, 95% CI 4.0, 20.1) are two- to threefold higher when compared with the lowest quartile of hip strength (OR 2.9, 95% CI 1.5, 5.6) and knee strength (OR 4.5, 95% CI 2.2, 9.2). Similar data were found with regard to the second lowest quartile.

Discussion

These analyses of the InCHIANTI study underscore the importance of leg muscle power impairments as critical factors influencing the mobility of community-dwelling older adults. Our analyses demonstrate that, through both linear and curvilinear models, leg power describes more of the variance than does strength in the performance of important mobility tasks. Although low power and low strength each increased the likelihood for mobility problems, poor muscle power was associated with a 2–3-fold greater risk than poor muscle strength.

The differences between leg power and leg strength within separate linear regression models are consistent with our prior investigations in mobility-limited elders utilizing

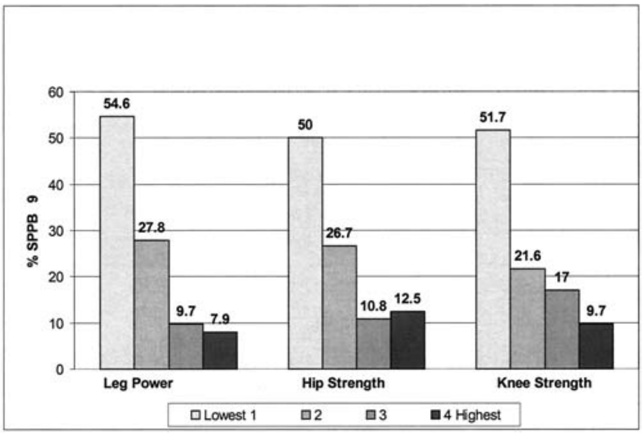

Figure 1. Quartiles of impairment. Percentages of individuals with poor physical performance (SPPB $\leq$9) according to quartiles of lower extremity muscle power and strength. SPPB $\leq$9 is consistent with moderate–severe mobility limitations. SPPB = Short Physical Performance Battery.

different methods of obtaining leg power and leg strength (pneumatic exercise equipment) (14). Consistent with prior investigations evaluating leg strength and performance of mobility tasks (6–8), the relationship between the impairment and functional measures were best characterized as curvilinear. In all cases, curvilinear models accentuated the differences between leg power and leg strength, with the exception of chair rise where the variance explained by leg power and hip strength were equivalent in both linear and curvilinear models.

There are a variety of factors that may explain the lack of difference between strength and power in their association with chair rise. These findings suggest that the performance of this task is more related to force production, the common component of power and strength, than to the rate at which that force is produced (velocity), which is represented as a component of power. Biomechanical analyses of a single chair rise may help to clarify the importance of leg strength as measured through lower extremity joint torques (19). The performance of 5 chair rises may reflect more of a strength endurance test negating the influences of shorter-term differences in rate of force production between subjects. This is supported in that similar blunting of differences between strength and power at the knee and hip has been seen with longer duration tasks such as the 6-minute walk test (20). Additionally, these findings may be related in part to our measure of leg power. In our previous report, utilizing similar statistical methodology, leg power described more of the variance in chair rise time than did strength (leg power $R^2 = .24$ vs leg strength $R^2 = .20$) (14), yet this study used measures of peak leg power measured at $\sim$70% of the 1-repetition maximum. By design, Bassey's leg rig does not provide the ability to know at which percentage of the 1-repetition maximum an individual's power is being measured. Though never formally compared with other methods of obtaining lower-extremity power in frail elders, anecdotal experience suggests that the leg rig may represent power generation at relatively lower forces, where velocity is higher, whereas chair rise may require muscle power production at higher forces with lower velocity, weakening their association. Further exploration of the relationships between different mobility tasks and muscle power generation at low versus high forces would help clarify such speculation.

In contrast to chair rise, the highest associations between functional performance and muscle power and the greatest differences between muscle power and strength were seen with habitual gait speed and stair climb time. Therefore, it is possible that, from a clinical perspective, gait speed and stair climb performance may be a surrogate means of identifying muscle power capacity, perhaps useful in an ambulatory care or home setting. Such hypotheses would be worth confirming through future clinical investigations.

There are a number of physiologic mechanisms by which declines in muscle power may occur. Age-related changes in skeletal muscle including drop-out of type 2 muscle fibers (21) and qualitative changes in skeletal muscle fiber force production properties (22,23) may contribute. Potential neurologic factors include the age-related decline in motor unit firing rate (24) and alterations in agonist/antagonist coactivation during multijoint actions (25). Though yet to be appropriately elucidated, further inquiry into the subsystems underlying declines in muscle power with aging is certainly warranted.

Potential limitations of our study exist. We conducted a cross-sectional analysis of cohort data. In the future, the respective roles of muscle power and strength impairments in predicting incident mobility limitations and disability will be more clearly defined through analyses of longitudinal data, which would more strongly support causal relationships. It should also be pointed out that, based on their SPPB score and habitual gait speed, the InCHIANTI participants are a relatively high-functioning cohort manifesting mild mobility limitations. This may reflect differences in baseline physical activity and availability of health services between community-dwelling older adults in Italy and the United States as well as the chosen methods for obtaining gait speed.

Differences between strength and power as discriminating factors for mobility performance are likely greatest at the lower level of functional performance. The fact that the cohort was at such a high functional level may have reduced our ability to discriminate larger differences between leg power and leg strength within the linear and log-transformed regression models. Given the age of the InCHIANTI participants, longitudinal data are likely to reveal greater heterogeneity due to functional decline with aging. In order to address more-specific questions regarding strength and power among those individuals with poorer mobility performance, future investigations using follow-up data or within more functionally diverse populations would be helpful. Lastly, as opposed to leg press, it has been suggested that more distal power generation at the ankle and knee may be more closely related to mobility performance as it pertains to balance and gait (20,26,27). Future investigations comparing power and strength at these sites may demonstrate that our findings are in fact conservative estimates of the differences between muscle power and strength.

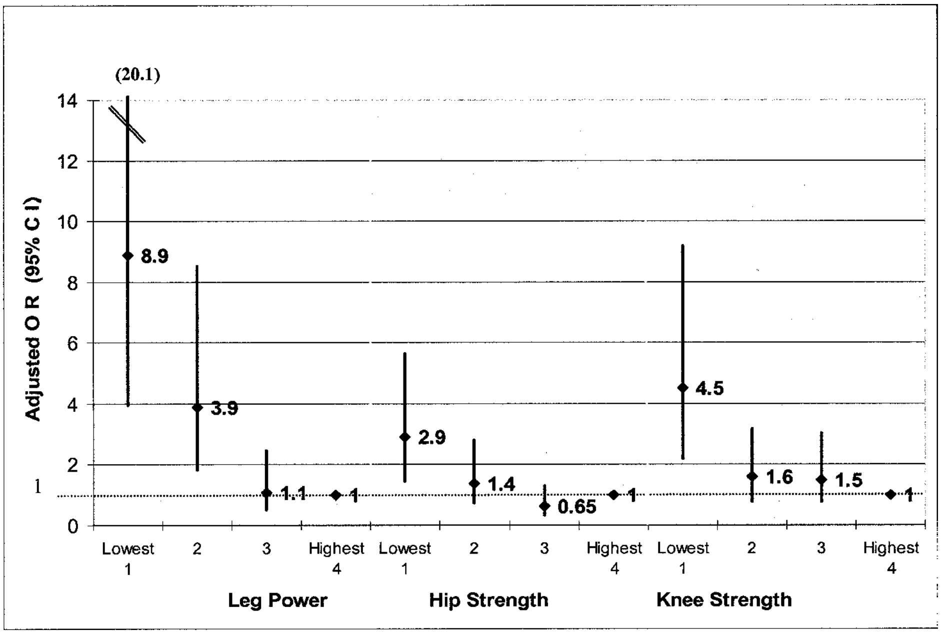

Figure 2. Quartiles of impairment. Adjusted odds ratios (OR) and 95% confidence intervals (CI) for mobility limitations (SPPB ≤9) by quartiles of muscle power and strength. (Models are adjusted for age, gender, height, and weight.) SPPB = Short Physical Performance Battery.

To our knowledge, this is the first investigation to quantify the respective influence of impairments in leg power and leg strength in their association with poor mobility performance. The SPPB is predictive of disability, institutionalization, and mortality (4,18,28). Scores of 9 or lower have been characterized as moderate-to-severe mobility limitations (18), imparting a high risk for subsequent disability. Low strength is recognized as an important impairment contributing to mobility limitations (as defined by the SPPB) and leading to subsequent disability (29,30). The recognition that low power exerts a two- to threefold greater risk for mobility limitations emphasizes muscle power impairments as important proximal factors associated with and possibly leading to disability. It underscores the importance in developing interventions for mobility-limited elders, which accentuate muscle power such as resistance training, which is conducted with a ‘‘high-velocity’’ component to the repetitions, therefore accentuating both force production and velocity of movement. Additionally, this study serves as an important rationale for investigations of the physiologic mechanisms that underlie changes in muscle power generation with aging.

Conclusion

Through linear, curvilinear, and categorical statistical models, impairments in muscle power were identified as more-influential proximal determinants of mobility performance than were impairments in strength. These findings have important implications for future physiological and disablement research addressing the needs of mobility-limited elders.

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