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Lower Extremity Physical Performance and Hip Bone Mineral Density in Elderly Black and White Men and Women: Cross-Sectional Associations in the Health ABC Study

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Background. Aging is characterized by declines in physical capacity and bone mineral density (BMD), both of which contribute to increased risk for fracture. However, it is unclear if these factors coexist or are independent in elderly people, and if a relationship does exist, whether it varies by sex and/or race.

Methods. Data are from 847 white women, 723 black women, 927 white men, and 544 black men aged 70–79 years participating in the Health Aging and Body Composition (ABC) Study, a cohort of well-functioning community-dwelling elders. BMD (g/cm^2) of the hip (femoral neck and trochanter) was determined by dual X-ray absorptiometry. Physical capacity measures included knee extensor strength, repeated chair-stands, gait speed (6 m), walking endurance (400 m), and standing balance.

Results. In analyses of BMD as a continuous measure, BMD and physical performance were most consistently related at the trochanter in black women, even after adjusting for body size and several covariates including physical activity. For each performance measure, black women in the bottom quartile(s) had lower BMD than those in the top quartile(s). For the femoral neck, there was a significant association with performance tasks, except for the 400-m walk. In comparison, only chair-rise performance was related to BMD at the femoral neck, and knee extensor strength, chair-rise performance, and balance with the trochanter in white women. For white and black men, trends existed only for lower BMD in those with poorer knee extensor strength.

Conclusions. In this cohort of well-functioning young-old seniors, physical capacity is only modestly related to BMD at the hip. The association was strongest in black women, who as a group exhibited the poorest functional capacity in the cohort. Our data show that, although both poorer physical performance and low BMD are risk factors for fracture, they remain largely independent in the well-functioning young-old, except in black women. This independence suggests that interventions to reduce fracture incidence should be targeted at improving both physical performance and bone density.

POOR physical function and low bone density are significant risk factors for fracture in older men and women (1–3). Physical function and performance predict falls (4,5), and bone density accounts for 50%–80% of the variance in bone strength (6). In the Study of Osteoporotic Fractures, low calcaneal bone density and inability to rise from a chair were risk factors for hip fracture (2), as was neuromuscular impairment and femoral neck bone mineral density (BMD) in the EPIDOS (EPIDemiology of Osteoporosis) study (3). Hip fracture in elderly people has devastating consequences resulting in substantial mortality, morbidity, use of institutionalized care, and reduced quality of life (7,8).

This analysis was undertaken to determine whether lower functional capacity and reduced bone density coexist or are independent factors in well-functioning older persons. To date, only limited data are available to investigate this relationship. Existing studies primarily have examined the relationship between bone density and muscle strength. In general, strength is associated with and is an independent predictor of BMD in older men and women (9–12), although not all studies found this (13). Moreover, the association of muscle strength and hip bone density may differ by sex, being greater in men than in women (14). Recently, Aoyagi and colleagues (15) reported that, in Japanese men and women aged 40 years and older, those with superior grip strength and lower body function, determined by walking speed and chair-stand ability, had higher calcaneal BMD. However, only 38 men and 72 women were aged 70 years or older, the population at greatest risk for osteoporotic fracture (16) and functional decline (17).

Thus it remains uncertain the degree to which physical performance is related to bone density in community-dwelling elderly people, and whether this association is independent of body size and other factors that impact bone such as medications, physical activity, smoking status, sex, and race. Specifically, does good physical performance necessarily imply high bone density, and does poor physical performance imply low bone density?

The purpose of the present analysis was to examine the cross-sectional association between several measures of physical capacity (quadriceps strength, chair-rise ability, gait speed, endurance, and standing balance) that capture different dimensions of lower extremity function and BMD of the hip in the well-functioning young-old. We hypothesized that those with superior physical performance will also have higher BMD, independent of age, body size, medications affecting bone, smoking, and physical activity, and that the relationships would be consistent across sex and race.

Methods

Subjects

Data are from 3041 well-functioning white and black men and women, aged 70–79 years, participating in the Health Aging and Body Composition (Health ABC) Study; a prospective cohort study investigating changes in body composition, health conditions, and social and behavioral factors in association with functional decline. The cohort included 847 white women, 723 black women, 927 white men, and 544 black men, from two field centers located at the University of Pittsburgh and the University of Tennessee at Memphis. The full Health ABC cohort consists of 3075 individuals; however, 34 individuals did not undergo a bone density scan of the hip and were therefore excluded from this article. Health ABC was established by recruitment of a population-based cohort based on Medicare records. The goal of recruitment was not to have a representative sample for generalizability to the base community but rather enrollment of a high-functioning cohort to examine early onset of functional limitations. All black age-eligible persons in selected zip codes and a random sample of whites were sent an information letter. Those who did not indicate unwillingness to participate were called and received a telephone screen for inclusion/exclusion criteria including functional status, and so forth. Because enrollment of black persons lagged, we also instituted recruitment in the selected areas through community centers and churches, enrolled cohort members, and private medical practices used by black persons. For this reason, an absolute response rate is difficult to estimate, but would be similar to that for Medicare beneficiaries (approximately 55% of those eligible). To be eligible for Health ABC, participants had to report no difficulty walking a quarter of a mile, climbing 10 steps without resting, or undertaking activities of daily living. Participants provided informed consent after the study's approval by the Institutional Review Boards of the University of Pittsburgh and the University of Tennessee at Memphis. Data presented are from the baseline examination that took place between April 1997 and June 1998.

Physical Performance

Several lower-body physical performance measures were assessed including knee extensor strength, chair-stands, gait speed over 6 meters, walking endurance, and balance. Dynamic knee extensor strength was measured at an angular velocity of 60°/s on a Kin-Com 125 AP isokinetic dynamometer (Chattanooga, TN). Participants were familiarized to the testing procedure, and then completed a maximum of 6 trials with the average maximum torque determined from 3 reproducible and acceptable trials. The chair-rise test involved the time required to rise on command from a standard chair to a full standing position 5 times with arms folded across their chest. For gait speed, participants were instructed to walk 6 m at their usual speed. For the test of walking endurance, participants were required to walk 400 meters, which consisted of 10 laps out and back over a 20-meter course, as quickly as they could at a pace they could maintain over the distance. Heart rate was monitored prior to and throughout the 400-m walk using a Polar Pacer (model no. 61190, Polar Electro Oy, Finland). Three balance maneuvers comprised the balance test: a semitandem stand, tandem stand, and one-leg stand. For each maneuver, participants were asked to maintain the position for 30 seconds, with 90 seconds being the maximal score possible. Good reliability for these physical performance measures has been reported in elderly persons (18–20).

Not all participants undertook or completed each performance test. Three hundred ninety-six participants did not do the knee extensor strength test, due to elevated resting systolic blood pressure (BP), while 386 were ineligible (primarily due to worsening of cardiac symptoms, elevated standing BP, or a pretest heart rate [HR] >120 beats per minute [bpm]), and 371 were unable to complete the 400-meter walk (due to obtaining an HR >135 bpm or other symptoms). Due to the stringent eligibility and completion criteria for these two performance measures, we were unable to conclude whether their performance in these measures would be necessarily poorer than those that completed these tests. When analyzed by sex and race, there was no difference for bone density between those that completed these tests versus those that did not. Therefore, only participants completing the strength and 400-meter walk tests are included in the respective analyses. For the chair-rise test, 91 tried but were unable to stand 5 times; these subjects were given the highest time-to-complete value and were included in the poorest performance quartile. In addition, 26 participants attempted but were unsuccessful in completing the standing balance maneuvers. These individuals were allocated a score of zero and were included in the standing balance analyses.

Bone Mineral Density

BMD (g/cm^2) of the hip (proximal femur) was assessed by dual X-ray absorptiometry (DXA) (Hologic 4500A, version 8.20a, Waltham, MA). The femoral neck and trochanter were the hip sites assessed due to their

Table 1. Subject Characteristics

Characteristic*	Women		Men		p Value	Comparison
	White [1] (N = 847)	Black [2] (N = 723)	White [3] (N = 927)	Black [4] (N = 544)		
Age (y)	73.6 ± 2.8	73.4 ± 2.9	73.9 ± 2.9	73.5 ± 2.8	.001	2 and 4 < 3
Height (cm)	159.5 ± 5.9	159.6 ± 6.3	173.5 ± 6.4	173.0 ± 7.0	<.001	1 and 2 < 3 and 4
Body weight (kg)	66.3 ± 12.3	75.7 ± 16.5	81.4 ± 12.4	81.4 ± 14.4	<.001	1 < 2 < 3 and 4
BMI (kg/m^2)	26.0 ± 4.6	29.7 ± 6.1	27.0 ± 3.7	27.1 ± 4.3	<.001	1 < 3 and 4 < 2
Lifestyle factors						
Smoking (pack-years)	12.5 ± 24.2	11.3 ± 21.1	27.7 ± 33.8	22.7 ± 26.3	<.001	1 and 2 < 4 < 3
Physical activity (% low)	74.0	83.3	51.9	73.5	<.001	
Medications						
Thiazides (%)	17.4	27.1	9.8	17.5	<.001	
Corticosteroids (%)	7.4	4.7	6.6	4.0	.022	
Estrogen (%)	25.5	10.8			<.001	

Notes: *Mean ± *SD* (standard deviation).
BMI = body mass index.

significance for fracture (21). DXA quality assurance measurements were performed at both study sites to ensure that scanner reliability and identical patient scan protocols were employed for all participants.

Other Measurements

Height and weight were obtained using a Harpenden stadiometer (Holtain, Wales, UK) and a standard balance beam scale, respectively, and body mass index (BMI) was calculated as weight divided by height squared (kg/m^2). Smoking history (pack-years), physical activity, and medication usage were determined by an interviewer-administered questionnaire. Physical activity and exercise were ascertained by a standardized instrument derived from the Leisure Time Physical Activity Questionnaire (22). Approximate metabolic equivalent unit (MET) values were assigned to each activity and intensity level reported to derive a caloric expenditure estimate in kcal/kg/hour (23). Total kilocalories expended in stair climbing, walking, and exercise activity per week, analogous to the physical activity measure used in the Harvard University alumni studies (24), was constructed by multiplying the participant's weight in kilograms with kcal/kg/hour expended. Three activity levels were calculated based on kcals/week expended on walking, stair climbing, and moderate and vigorous physical activity. The levels were: low, less than 1000 kcal/week; moderate, more than 1000 but less than 2000 kcal/week; and high, greater than 2000 kcals/week. Current thiazide, oral and inhaled corticosteroid, and estrogen usage was determined from drug data coded using the Iowa Drug Information System (IDIS) ingredient codes (25).

Statistical Analyses

Data were analyzed using SPSS statistical software (SPSS, Inc., Chicago, IL). Descriptive characteristics were analyzed by analysis of variance for continuous variables and chi-square for categorical variables. The association among performance measures was determined by partial correlation, controlling for age, study site, height, and weight. To examine the association between physical performance and BMD, race and sex stratified analysis of covariance (ANCOVA) was performed for quartiles of performance and adjusted for age, study site, height, weight, medications, smoking (pack-years), and physical activity. Race and sex stratification was performed due to known differences in BMD and physical capacity between men and women and blacks and whites (26–30). Where appropriate, the Bonferroni post hoc procedure for multiple comparisons was used to locate the source of significant differences in means. Trend analysis was performed using linear regression and entering quartiles of performance as an ordinal variable. All tests were two-tailed, and an alpha level of 0.05 was considered statistically significant.

To further examine the association between performance and BMD, subjects were classified as osteoporotic, based on a sex-specific femoral neck T score of more than 2.5 *SD* (standard deviation) below that of the young adult mean for American whites (31), according to World Health Organization guidelines (32), or nonosteoporotic. This resulted in 194 white women and 72 white men being classified as osteoporotic but only 53 black women and 11 black men. Sex-specific logistic regression for whites was then performed with bone density (osteoporotic/nonosteoporotic) as the outcome variable, adjusted for age, body size, study site, medications, smoking history, and physical activity. This analysis was not performed in blacks due to the low prevalence of osteoporosis based on the above criteria. At present, it is unclear what the appropriate cutoff values for osteoporosis classification should be in black men and black women.

Results

Subject characteristics are shown in Table 1 and physical performance and BMD measures adjusted for body size are displayed in Table 2. Knee extensor strength was greater in men than women with no difference by race. For the chair-rise test, measures of walking speed, and balance, white men performed best and black women the poorest. Bone density at the hip, after adjustment for body size, medications, smoking history, and physical activity, was greater in men than women and in blacks than whites. Low-to-moderate interrelationships ($p < .001$) existed among the performance

Table 2. Physical Performance and Bone Mineral Density Measures

	Women		Men			
	White [1]	Black [2]	White [3]	Black [4]	*p* Value	Comparison
*Physical performance**						
Knee ext. strength (N/m)‡	87.4 ± 1.2	89.1 ± 1.2	123.9 ± 1.1	127.1 ± 1.4	<.001	1 and 2 < 3 and 4
Chair-rise (s)‡	15.0 ± 0.2	15.9 ± 0.2	12.4 ± 0.2	14.3 ± 0.2	<.001	3 < 4 and 1 < 2
6-m walk time (s)‡	5.2 ± 0.04	5.9 ± 0.04	4.8 ± 0.04	5.5 ± 0.04	<.001	3 < 1 < 4 < 2
400-m walk time (s)‡	330 ± 2	369 ± 3	307 ± 2	338 ± 3	<.001	3 < 1 and 4 < 2
Standing balance (s)‡	64.3 ± 0.9	60.0 ± 1.0	74.7 ± 0.9	69.9 ± 1.1	<.001	2 < 1 < 4 < 3
Bone mineral density (g/cm^2)†						
Femoral neck	0.679 ± 0.005	0.751 ± 0.005	0.749 ± 0.005	0.831 ± 0.005	<.001	1 < 2 and 3 < 4
Trochanter	0.613 ± 0.005	0.649 ± 0.005	0.729 ± 0.005	0.770 ± 0.005	<.001	1 < 2 < 3 < 4

Notes: Mean ± *SE* (standard error).

*Adjusted for age, study site, height, and weight by ANCOVA (analysis of covariance).

†Adjusted for age, study site, height, weight, thiazides, corticosteroids, estrogen (women), smoking, and physical activity by ANCOVA.

‡Subject numbers: Knee extensor strength = 2658; Chair-rise = 2928; 6-meter walk = 3016; 400-meter walk = 2298; Balance = 3028.

measures, indicating that a broad range of lower body function was assessed (Table 3). The associations were substantially unchanged when analyzed separately by race and sex.

There was no independent association observed between femoral neck BMD and physical performance (Table 4) except in black women, in whom there was a moderately strong trend for knee extensor strength, chair-rise capacity, usual gait speed, and balance, and in white women for chair-rise capacity. The association between physical performance and bone density was stronger at the trochanteric site than at the femoral neck (Table 5). A graded association was found between knee extensor strength and chair-stand performance and trochanter BMD in all race and sex groups. For black women, there was a strong relationship between walking and balance capacity with a trend in white women for standing balance. Removing physical activity from the models had little impact on the findings.

When osteoporotic and nonosteoporotic categories for femoral neck BMD were constructed, white women in the lowest performance quartile for chair-stands were twice as likely as those in the top quartile to be osteoporotic (odds ratio [OR] 2.05; 95% confidence interval [CI] 1.19–3.54), while white men with the poorest endurance were 2.78 times (CI 1.13–6.84) more likely to be osteoporotic at the hip (Table 6).

Discussion

A modest association was found between several physical performance measures that target different aspects of lower extremity function and bone density at the hip. This relationship was sex and race dependent, being strongest in black women, especially at the trochanter. A coexistence of low function and BMD may exist, as poor physical function reduces mechanical loading at the hip leading to a loss of bone mineral. Nevertheless, physical function and BMD remained largely independent in this young-old biracial cohort suggesting that both factors need to be targeted for intervention if fracture risk is to be reduced.

Across sex and race, the association between performance and hip BMD was stronger in black women, possibly because they are further along the disablement pathway (33). This was evidenced by their slower gait speed, chair-rise time, and poorer balance performance than the other groups. Several studies indicate that older blacks have a higher risk and earlier onset of functional disability than whites (34,35). A result of poorer function may be reduced mechanical strain on bone resulting from reduced physical activity and consequently a reduction in BMD. In this regard, the association between performance and BMD may be similar to that between strength and functional limitation, where the association is only readily apparent below a given threshold in strength (36,37). Further, blacks had a lower level of physical activity than whites, which has been previously reported (37,38); however, we controlled for physical activity in our analyses. Moreover, the associations between physical performance and BMD were not significantly altered when physical activity was not included in the model, indicating that physical activity is not an intermediate between performance and bone density in the present cohort.

Although we adjusted for physical activity in our models, the effect of current or past physical activity on BMD is inconsistent (39). Cross-sectional studies of athletes and nonathletes indicate substantial increases in bone mass and density, up to 30% or more in athletes (40), whereas exercise interventions in adults are less impressive, with bone loss arrested or modest gains in the order of 1%–3% (41). However, the gains to bone health may be greater than that reported by DXA, as the integrity of bone is dependent not only on bone mass but also bone architecture and

Table 3. Associations Among Physical Performance Measures

Measures*	Knee Strength	Chair-Rise	6-Meter Walk	400-Meter Walk
Chair-rise	– 0.264†			
6-m walk	– 0.236	0.358		
400-m walk	– 0.292	0.351	0.595	
Standing balance	0.197	– 0.164	– 0.249	– 0.254

Notes: *Partial correlations controlling for age, study site, race, sex, height, and weight.

†All correlations are significant at $p < .001$.

Table 4. Association of Femoral Neck Bone Mineral Density to Physical Performance by Sex and Race*

	Women		Men	
Performance Measure[†]	White (g/cm^2)	Black (g/cm^2)	White (g/cm^2)	Black (g/cm^2)
Knee extensor strength quartiles				
4	0.654 ± 0.007	0.769 ± 0.009	0.775 ± 0.009	0.843 ± 0.012
3	0.651 ± 0.007	0.758 ± 0.009	0.769 ± 0.008	0.866 ± 0.012
2	0.653 ± 0.007	0.743 ± 0.009	0.764 ± 0.008	0.843 ± 0.012
1	0.643 ± 0.007	0.739 ± 0.009	0.754 ± 0.009	0.832 ± 0.012
ANCOVA	p = .700	p = .099	p = .410	p = .217
Trend	p = .350	p = **.014**	p = .096	p = .322
Chair-rise quartiles				
4	0.654 ± 0.007	0.765 ± 0.009	0.779 ± 0.008	0.845 ± 0.011
3	0.660 ± 0.006	0.768 ± 0.009	0.769 ± 0.008	0.856 ± 0.012
2	0.645 ± 0.007	0.741 ± 0.008	0.758 ± 0.008	0.846 ± 0.010
1	0.640 ± 0.007	0.733 ± 0.009	0.759 ± 0.008	0.838 ± 0.011
ANCOVA	p = .122	p = **.011; 1 < 3**[‡]	p = .215	p = .754
Trend	p = **.048**	p = **.002**	p = .053	p = .572
6-m walk quartiles				
4	0.651 ± 0.007	0.766 ± 0.009	0.768 ± 0.008	0.858 ± 0.011
3	0.650 ± 0.007	0.759 ± 0.009	0.766 ± 0.008	0.844 ± 0.011
2	0.650 ± 0.007	0.748 ± 0.009	0.772 ± 0.008	0.845 ± 0.011
1	0.650 ± 0.007	0.734 ± 0.009	0.760 ± 0.008	0.837 ± 0.011
ANCOVA	p = .998	p = .079	p = .782	p = .591
Trend	p = .911	p = **.010**	p = .661	p = .196
400-m walk quartiles				
4	0.648 ± 0.008	0.752 ± 0.011	0.770 ± 0.009	0.848 ± 0.013
3	0.659 ± 0.007	0.771 ± 0.011	0.768 ± 0.009	0.859 ± 0.013
2	0.651 ± 0.008	0.742 ± 0.011	0.769 ± 0.009	0.850 ± 0.013
1	0.650 ± 0.008	0.735 ± 0.011	0.754 ± 0.009	0.830 ± 0.013
ANCOVA	p = .778	p = .111	p = .549	p = .450
Trend	p = .947	p = .113	p = .278	p = .276
Standing balance quartiles				
4	0.657 ± 0.007	0.745 ± 0.009	0.767 ± 0.007	0.839 ± 0.009
3	0.651 ± 0.007	0.770 ± 0.009	0.758 ± 0.012	0.847 ± 0.014
2	0.651 ± 0.007	0.756 ± 0.009	0.760 ± 0.008	0.846 ± 0.011
1	0.641 ± 0.007	0.731 ± 0.009	0.774 ± 0.008	0.854 ± 0.011
ANCOVA	p = .420	p = **.013; 1 < 3**	p = .535	p = .815
Trend	p = .114	p = .163	p = .669	p = .353

Notes: In mean ± *SE* (standard error).

*Adjusted for age, study site, height, weight, use of thiazides, corticosteroids, estrogen (women), smoking pack-years, and physical activity.

[†]Performance improves with higher quartiles, 1 = low and 4 = high.

[‡]Post hoc analysis; numerals refer to quartiles being compared.

ANCOVA = analysis of covariance.

quality. Recently, Vuillemin and colleagues (39) reported that sports participation in the teenage years is a predictor of lumbar spine but not femoral neck or total body BMD in later life, whereas lifetime participation in sport was a predictor at the femoral neck. Interestingly, sporting activity within the past 20 years was associated with lower femoral neck BMD in their cohort of older men and women. Beneficial results of current and lifelong exercise on hip BMD have been reported in the Rancho Bernardo study (42), however, similar results were not found for a Swedish population (43). What appears crucial is the type of physical activity with increased mechanical loading conferring skeletal benefits with the effects being site specific (44,45). Apart from the magnitude of loading, the hormonal and nutritional environment, as well as when the activity is initiated (46) are important determinants of the effectiveness on BMD.

When considering both hip sites, the associations with performance measures were stronger at the trochanter. The associations may be stronger at the trochanter, as this site has a greater percentage of metabolically active trabecular bone than the femoral neck (47) and is more responsive to mechanical loading (44). Further, the trochanter has direct muscle attachment by the vastus lateralis, gluteus medius, and gluteus minimus, compared to the femoral neck, which is intracapsular with no direct muscle attachment. Consequently, muscle pull at the trochanter resulting from locomotion and movement or unloading resulting from reduced activity may result in a closer association between measures of performance and bone mineral.

Table 5. Association of Trochanter Bone Mineral Density to Physical Performance by Sex and Race*

Performance Measure[†]	Women		Men	
	White (g/cm^2)	Black (g/cm^2)	White (g/cm^2)	Black (g/cm^2)
Knee extensor strength quartiles				
4	0.595 ± 0.007	0.680 ± 0.009	0.764 ± 0.009	0.809 ± 0.012
3	0.591 ± 0.007	0.656 ± 0.009	0.752 ± 0.008	0.800 ± 0.012
2	0.587 ± 0.007	0.640 ± 0.009	0.740 ± 0.008	0.787 ± 0.012
1	0.569 ± 0.007	0.628 ± 0.009	0.724 ± 0.009	0.762 ± 0.012
ANCOVA	$p = .075$	$p =$ **.001; 1, 2 < 4**[‡]	$p =$ **.016; 1 < 4**	$p = .052$
Trend	$p =$ **.018**	$p <$ **.001**	$p =$ **.001**	$p =$ **.007**
Chair-rise quartiles				
4	0.596 ± 0.007	0.668 ± 0.009	0.753 ± 0.008	0.797 ± 0.011
3	0.593 ± 0.006	0.662 ± 0.009	0.753 ± 0.008	0.794 ± 0.012
2	0.584 ± 0.007	0.641 ± 0.009	0.743 ± 0.008	0.793 ± 0.010
1	0.568 ± 0.007	0.622 ± 0.009	0.731 ± 0.008	0.761 ± 0.011
ANCOVA	$p =$ **.022; 1 < 4**	$p =$ **.001; 1 < 3, 4**	$p = .173$	$p = .088$
Trend	$p =$ **.003**	$p <$ **.001**	**p = .034**	**p = .041**
6-m walk quartiles				
4	0.590 ± 0.007	0.671 ± 0.009	0.757 ± 0.008	0.794 ± 0.011
3	0.588 ± 0.007	0.655 ± 0.008	0.743 ± 0.008	0.794 ± 0.011
2	0.585 ± 0.007	0.652 ± 0.008	0.747 ± 0.008	0.792 ± 0.011
1	0.579 ± 0.007	0.619 ± 0.009	0.733 ± 0.008	0.771 ± 0.011
ANCOVA	$p = .654$	$p <$ **.001; 1, 2, 3 < 4**	$p = .235$	$p = .404$
Trend	$p = .219$	$p <$ **.001**	$p = .069$	$p = .163$
400-m walk quartiles				
4	0.597 ± 0.008	0.674 ± 0.011	0.749 ± 0.009	0.805 ± 0.013
3	0.595 ± 0.007	0.677 ± 0.010	0.752 ± 0.009	0.794 ± 0.013
2	0.585 ± 0.007	0.631 ± 0.010	0.750 ± 0.009	0.783 ± 0.013
1	0.579 ± 0.008	0.624 ± 0.011	0.731 ± 0.009	0.771 ± 0.014
ANCOVA	$p = .358$	$p <$ **.001; 1, 2 < 3, 4**	$p = .319$	$p = .319$
Trend	$p = .082$	$p <$ **.001**	$p = .203$	$p = .061$
Standing balance quartiles				
4	0.596 ± 0.007	0.658 ± 0.009	0.750 ± 0.007	0.787 ± 0.010
3	0.583 ± 0.007	0.664 ± 0.008	0.743 ± 0.012	0.784 ± 0.015
2	0.588 ± 0.007	0.645 ± 0.009	0.741 ± 0.008	0.786 ± 0.011
1	0.573 ± 0.007	0.627 ± 0.009	0.740 ± 0.008	0.785 ± 0.011
ANCOVA	$p = .132$	$p =$ **.015; 1 < 3**	$p = .818$	$p = .997$
Trend	$p =$ **.044**	$p =$ **.004**	$p = .429$	$p = .911$

Notes: Mean ± *SE* (standard error).

*Adjusted for age, study site, height, weight, use of thiazides, corticosteroids, estrogen (women), smoking pack-years, and physical activity.

[†]Performance improves with higher quartiles, 1 = low and 4 = high.

[‡]Post hoc analysis; numerals refer to quartiles being compared.

ANCOVA = analysis of covariance.

In a cross-sectional analysis of elderly women in the EPIDOS study (48), total body BMD was inversely associated with instrumental activities of daily living (IADL) disability. It is possible that IADL disability may reduce skeletal loading leading to a loss of bone mineral. Similarly, in black women, those with poorer physical performance had lower hip BMD. As muscle strength and physical function are related to falls, those with poorer performance attributes may be at a greater risk of falls, and if BMD were compromised would be at an increased risk of fracture once a fall had taken place. A targeted intervention aimed at improving physical function in black women may therefore have beneficial effects on skeletal loading and BMD.

Although a number of therapeutic strategies target skeletal tissue, such as bisphosphonates and hormone replacement therapy (49), two forms of physical activity, resistance training and increased weight-bearing activity, appear to have complimentary effects on targeting both BMD and physical performance. High-intensity resistance training has a dramatic effect on muscle strength in elderly individuals, resulting in improvement in indices of physical performance (50,51), and results in the maintenance or modest improvement in bone density (45,52). Recently, Snow and colleagues (53) found that a long-term lower-body exercise program in postmenopausal women with a weighted vest, which included jumps, not only improved neuromuscular performance (54) but also maintained hip BMD over a 5-year period. The improved physical performance following both exercise modes would reduce fall risk while maintenance of hip BMD aids in the preservation of bone strength and resistance to fracture following a fall. Further, once a hip fracture has occurred

Table 6. Logistic Regression Models for the Association Between Physical Performance and Hip Osteoporosis in White Women and Men

	White Women*†		White Men†	
Measure‡	Values	OR (95% CI)	Values	OR (95% CI)
Knee extensor strength (N/m)				
4	≥90.8	Reference	≥151.2	Reference
3	79.0–90.7	1.37 (0.71–2.64)	129.4–151.1	0.84 (0.28–2.52)
2	66.3–78.9	1.61 (0.84–3.08)	109.2–129.3	1.15 (0.43–3.12)
1	≤66.2	1.77 (0.92–3.41)	≤109.1	2.47 (0.96–6.32)
Trend		***p* = .026**		***p* = .003**
Chair stands (s)				
4	≤11.87	Reference	≤10.98	Reference
3	11.88–13.71	1.02 (0.60–1.73)	10.99–12.72	0.89 (0.40–1.97)
2	13.72–16.37	1.53 (0.91–2.58)	12.73–14.97	0.85 (0.39–1.87)
1	≥16.38	**2.05 (1.19–3.54)**	≥14.98	1.85 (0.92–3.72)
Trend		***p* = .002**		*p* = .062
6-m walk (s)				
4	≤4.58	Reference	≤4.16	Reference
3	4.59–5.03	0.83 (0.50–1.37)	4.17–4.71	0.69 (0.31–1.56)
2	5.04–5.69	0.79 (0.47–1.33)	4.72–5.25	0.56 (0.24–1.30)
1	≥5.70	0.92 (0.54–1.57)	≥5.26	1.73 (0.85–3.51)
Trend		*p* = .929		*p* = .085
400-m walk (s)				
4	≤294.1	Reference	≤273.3	Reference
3	294.2–323.2	0.90 (0.50–1.63)	273.4–299.6	1.47 (0.61–3.58)
2	323.3–352.8	1.38 (0.76–2.51)	299.7–333.2	1.57 (0.64–3.88)
1	≥352.9	1.61 (0.87–2.99)	≥333.3	**2.78 (1.13–6.84)**
Trend		***p* = .019**		***p* = .011**
Balance (s)				
4	≥88.5	Reference	= 90.0	Reference
3	69.5–88.4	0.96 (0.57–1.62)	79.1–89.9	1.49 (0.62–3.62)
2	57.1–69.4	1.04 (0.60–1.80)	65.5–79.0	1.70 (0.85–3.41)
1	≤57.0	1.53 (0.90–2.61)	≤65.4	1.81 (0.91–3.60)
Trend		*p* = .182		***p* = .049**

Notes: *Osteoporotic: women 22.9%, men 7.8%.

†Adjusted for age, study site, height, weight, use of thiazides, corticosteroids, estrogen (women), smoking pack-years, and physical activity.

‡Performance improves with higher quartiles, 1 = low and 4 = high.

OR = odds ratio; CI = confidence interval.

and medical management has taken place, appropriate programs to improve muscle strength and aspects of neuromuscular performance would aid in the recovery of mobility and independence (55).

Although BMD and physical performance have an underlying genetic basis, other factors contribute such as physical activity, nutritional patterns, and hormonal status. In the absence of neurological and degenerative disorders, it is likely that poor physical performance in elderly people results from reduced physical activity, and a consequence of the reduced mechanical loading would be a reduced bone mass and density. Therefore, a relationship may exist between bone and physical performance, as both reflect, to varying degrees, the underlying health of the individual and physical activity. Indeed, in black women, physical activity was related to chair-rise performance (p for trend = .029) and the 6-meter and 400-meter walk ($p < .001$), with those in the lowest category for physical activity having poorer performance, although there was no association between physical activity and BMD.

Participants in this study were well functioning and free of lower-extremity functional limitations, and thus are not representative of all black and white elderly adults. Indeed, it is possible that the associations may have been stronger and consistent across race and sex had we included participants representative of all stages of functional ability, including the disabled. Further, due to the cross-sectional nature of this study, we were not able to determine the causal pathway involved in the associations. Nevertheless, it has been proposed that forces resulting from muscle contraction have a strong influence on skeletal tissue (56,57).

In summary, physical performance was modestly related to hip BMD in healthy young-old seniors, with the association strongest and most consistent in black women. As poor physical performance predicts falls, and both falls and low BMD are risk factors for fracture, our data shows that they remain largely independent in the well-functioning young-old, except in black women. This independence suggests that, to reduce fracture incidence, targeted interventions that improve both physical performance and bone density, either via separate focused treatments or by a combined strategy such as resistance training, require implementation.

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