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National Institute for Longevity Sciences - Longitudinal Study of Aging (NILS-LSA)における運動能力調査

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Physical Function Tests in the National Institute for Longevity Sciences Longitudinal Study of Aging (NILS-LSA).

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The purpose of the present study was to report the contents and results of physical function tests in the National Institute for Longevity Sciences Longitudinal Study of Aging (NILS-LSA).

The NILS-LSA is a multidisciplinary longitudinal project conducted by the Department of Epidemiology, the National Institute for Longevity Sciences. The subjects of the NILS-LSA are 2400 male and female residents of 40 to 79 years old, who are stratified by both age and gender, and randomly selected from resident registrations around the institute. They will be followed up every two years. The variables examined in the NILS-LSA include various areas of gerontology and geriatrics such as medical examinations, anthropometry, body composition, physical functions, psychological assessments, nutritional analysis and molecular epidemiology.

Physical function tests included 1) Exercise test system : Foot balance with eye closed, Reaction time, Sitting trunk flexion, Grip power, Leg extension power, Static leg strength, Sit ups, 2)Walking test (10 m walking test system using four cameras and two force plates), 3) Balance test (stabilometer), and 4) Physical activity (Electric pedometer).

The recent major outcomes of physical function tests between November, 1997 and March, 1999 were as follows. Foot balance with eye closed, grip power, leg extension power, static leg strength and sit ups inversely correlated with age, and reaction time was prolonged with aging. Sitting trunk flexion showed no relationship with age. Pitch, step length and velocity in 10 m walking test showed negative correlation with age. There were significant positive relationship between leg extension power with pitch, stride and speed.

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Ⅰ．はじめに

高齢者の日常生活動作（ADL）の低下を防ぎ，寝たきりを予防するには，日常生活における身体諸活動の遂行能力を主とした運動能力を総合的に評価し，その維持増進を図ることが重要である．高齢者の運動能力を総合的に評価するには，運動能力の加齢による変化を明らかにすることが必要だが，この加齢変化に関する研究は十分に完成されているとは言えない[1]．そこで，長寿医療研究センター疫学研究部では，老化に関する長期縦断疫学研究 （National Institute for Longevity Sciences-Longitudinal Study of Aging ; NILS-LSA）において，運動能力の加齢に伴う変化に関する縦断的な検討を開始した．

NILS-LSA は，老化の進行について観察を行い，老化に関する基礎データを蓄積し，老化や老年病の成因を疫学的に解明することを目的とした学際的な縦断的疫学調査である．対象者は，研究センター周辺の 40-79 歳の地域住民から年齢・性別層化無作為抽出で選定した 2,400 名で，この対象集団を 2 年ごとに追跡調査する．調査項目は，医学・形態学・運動生理学・心理学・栄養学・分子疫学など多分野にわたり，1997 年 11 月より第 1 回調査が開始された．このプロジェクトの詳細については，他文献を参照されたい[2-4]．

論文では，NILS-LSA における運動能力調査について，その調査内容を説明するとともに，1997 年 11 月から 1999 年 3 月までの第 1 回調査結果の一部をまとめた．

Ⅱ．方法

1．調査対象

対象は，1997 年 11 月から 1999 年 3 月までに NILS-LSA の第 1 回調査に参加した 1,137 名（男性 582 名，女性 555 名）である．対象者には，事前に説明会を開催し，調査の目的，内容について詳しい説明を行い，文書による同意を得た．

2．調査項目

運動能力調査の項目は以下の通りであった．これらは，中高年者における運動能力の総合的評価を主な目的として，既存の研究[1,5]を参考に選ばれたものである．なお，調査当日の医師による問診，あるいは，本人の希望に基づき，運動能力調査の一部もしくは全部が実施されない場合があった．

①体力計測：平衡能，敏捷性，柔軟性，筋力を評価するため，閉眼片足立ち，全身反応時間，長座位体前屈，握力，脚伸展パワー，脚筋力，上体起こしの各項目を，タケイ体力診断システムを用いて測定した．

②平衡能検査：重心動揺計 NEC 平衡機能計測 98Ⅱを用いて平衡能を評価した．

③歩行分析：ヤガミ 10m 歩行測定器 YM3 を用いて，通常歩と速歩における歩行因子（歩幅，歩調，速度）を調べた．また，Oxford Metrics 社製 VICON140 により，歩行動作の 3 次元解析を行った．

④身体活動量測定：スズケンカロリーカウンターSelect2 を 1 週間装着して歩数を測定した．

3．分析方法

男女別に，40 代，50 代，60 代，70 代の各年代の平均値を求めた．そして，統計パッケージ SAS の GLM プロシジャにおける contrast コマンドを用いて，年代が上がるにつれ，平均値が増加，あるいは減少する傾向（トレンド）があるかを検討した．

Ⅲ．結果

1．体力計測

閉眼片足立ち，全身反応時間，長座位体前屈，握力，脚伸展パワー，脚筋力，上体起こしの性・年代別結果（平均値）を表 1 に示した．閉眼片足立ち時間，握力，脚伸展パワー，脚筋力，上体おこし回数については，高齢になるほど短縮，減少するトレンドが認められた．全身反応時間は，高齢になるにつれ延長していた．長座位体前屈は年齢による差異を認めなかった．

表1　体力計測の結果

		40代			50代			60代			70代			
		mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	n	Trend
閉眼片足立ち（秒）	男性	33.7	32.3	153	15.4	15.6	148	9.8	15.2	134	5.5	6.4	133	＊＊
	女性	27.2	27.5	145	16.8	27.4	134	6.8	7.5	135	4.0	4.0	121	＊＊
全身反応時間（秒）	男性	0.423	0.066	153	0.441	0.074	147	0.464	0.096	134	0.537	0.133	133	＊＊
	女性	0.463	0.072	143	0.489	0.083	134	0.515	0.100	134	0.630	0.151	117	＊＊
長坐位体前屈（cm）	男性	3.3	8.7	153	3.4	8.9	146	2.7	9.2	133	2.7	8.1	131	ns
	女性	10.0	6.8	145	9.8	7.8	134	10.5	6.6	137	9.3	7.3	126	ns
握力（右）（kg）	男性	48.1	7.2	152	43.2	7.2	148	39.7	6.4	133	35.3	5.9	134	＊＊
	女性	28.0	5.1	145	25.6	4.6	134	24.1	4.7	135	21.1	3.9	129	＊＊
脚伸展パワー（ワット）	男性	707.0	192.7	152	585.9	150.4	145	487.0	129.5	130	386.1	123.6	125	＊＊
	女性	360.0	115.9	144	333.6	94.0	129	298.5	83.6	126	219.3	79.5	108	＊＊
脚筋力（右）（kg）	男性	43.0	9.8	64	42.6	10.5	66	34.1	7.4	57	29.4	6.2	52	＊＊
	女性	26.4	6.8	73	26.0	6.0	49	23.9	6.8	53	19.6	5.7	56	＊＊
上体起こし（回）	男性	16.1	4.6	152	13.5	3.7	143	11.2	3.9	128	8.8	4.3	122	＊＊
	女性	10.2	4.2	138	6.3	5.1	122	4.3	4.6	120	3.6	4.0	103	＊＊

＊＊：p<0.01
ns : not significant

表2　平衡能検査の結果

		40代			50代			60代			70代			
		mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	n	Trend
開眼時重心動揺面積（cm^2）	男性	1.93	0.91	66	2.18	0.91	67	2.71	1.43	58	2.95	2.06	61	＊＊
	女性	1.66	0.76	75	2.14	0.93	48	2.48	1.30	57	2.80	1.47	59	＊＊
開眼時重心動揺距離（cm）	男性	72.26	13.68	66	76.26	12.39	67	81.13	13.86	58	89.36	25.71	61	＊＊
	女性	67.47	10.39	75	72.44	16.30	48	76.08	13.76	57	81.02	21.54	59	＊＊
閉眼時重心動揺面積（cm^2）	男性	3.68	2.13	66	4.06	2.57	67	4.47	2.77	58	4.79	3.03	61	＊＊
	女性	3.13	2.26	75	3.35	1.81	48	4.30	2.92	57	4.47	5.39	59	＊＊
閉眼時重心動揺距離（cm）	男性	101.47	34.96	67	108.08	33.96	66	117.18	34.77	58	127.72	46.43	61	＊＊
	女性	91.64	19.22	75	93.59	25.00	48	104.86	28.63	57	108.35	46.53	59	＊＊

＊＊：p<0.01
ns : not significant

表3 歩行分析の結果

			40代			50代			60代			70代			
			mean	SD	n	mean	SD	n	mean	SD	n	mean	SD	n	Trend
通常歩	歩幅	男性	71.4	7.0	151	70.2	8.4	146	68.2	8.9	131	64.9	8.8	131	**
		女性	67.0	6.1	143	66.6	7.5	128	63.1	6.5	134	57.8	7.4	126	**
通常歩	歩調	男性	115.9	9.5	151	116.6	11.5	146	117.8	10.0	131	115.0	13.6	131	ns
		女性	123.9	12.5	143	124.2	14.2	128	125.5	12.9	134	118.5	11.8	126	**
通常歩	歩速	男性	82.8	10.8	151	81.8	12.1	146	80.4	12.5	131	74.8	13.4	131	**
		女性	83.1	11.6	143	82.6	11.9	128	79.5	10.5	134	68.7	12.1	126	**
速歩	歩幅	男性	83.0	8.6	151	82.0	8.7	146	79.0	9.3	131	74.1	8.6	130	**
		女性	74.2	7.3	143	73.9	8.8	128	69.2	7.4	133	64.5	10.7	126	**
速歩	歩調	男性	140.0	15.7	151	136.0	15.3	146	136.9	15.4	131	134.0	13.3	130	**
		女性	146.5	16.9	143	143.7	18.7	128	144.7	17.4	133	135.5	15.8	126	**
速歩	歩速	男性	115.8	13.9	151	111.6	15.3	146	108.1	16.6	131	99.3	14.3	130	**
		女性	108.2	12.4	143	105.7	13.4	128	99.8	12.6	133	86.4	14.2	126	**

** : $p<0.01$
ns : not significant

2．平衡能検査

開眼時と閉眼時の重心動揺面積，重心動揺距離の性・年代別平均値を表 2 に示した．いずれの場合も，距離，面積共に年代が上がるにつれ大きくなる有意なトレンドが認められた．

3．歩行分析

通常歩と速歩における歩幅，歩調，速度の性年代別平均値を求めた（表 3)．通常歩における男性の歩調を除き，年代が上昇するにつれて測定値が減少するトレンドが認められた．

4．身体活動量測定

1 日の平均歩数の性年代別結果を図 1 に示した．高齢になるに従い，歩数は有意に減少していた．

Ⅳ．考察

NILS-LSA における運動能力調査結果を年齢別に概観したところ，柔軟性を除いた，筋力，敏捷性，平衡能，歩行機能，身体活動量の各能力が，高齢になるにつれ低下する傾向を男女共に認めた．運動能力は，身長や体重など形態に関係するためその影響を考慮する必要がある．そこで，一部の運動能力について，形態を補正して年代変化をみたが，やはり年代が上がると低下する傾向があった（図 2)．

運動能力は，一般に加齢により低下するとされており[6-9]，今回の結果もこれをよく支持するものと考えられる．

この調査の主目的の一つは，中高年者の運動能力を総合的に評価し，その加齢変化を検討することである．そのため，過去の研究[1,5]を参考に，各運動能力を反映する多数の項目からなるテストバッテリーを構築した．ただし，衣笠らの研究と比較した場合，手指巧緻性と全身持久力に関する項目が含まれていない．これは，運動能力のみではなく，多分野の詳細な検査・調査を一日で実施するという時間的制約，および，40 代から 70 代までの人を同条件で調査する際の安全面の確保という点から実施困難だったためである．今後，第 2 回目以降の調査において，可能ならば，これらの項目についても調査を行いたい．

また，運動能力の加齢変化を調べる場合は，運動能力の低下傾向は直線的か，年齢と最も強く関連する能力は何か，各運動能力相互の関係はどうか，などといった問題についても検討する必要がある．しかし，今回は，

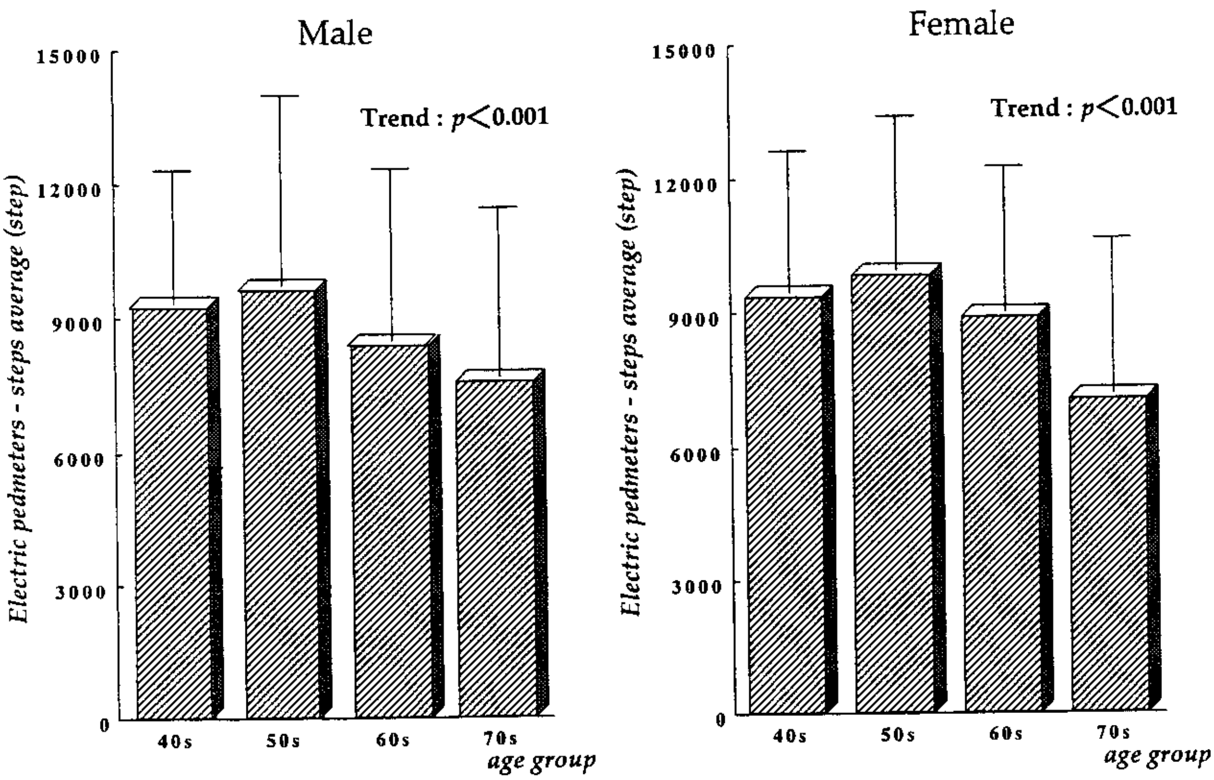

図1　身体活動量　(mean ± SD)

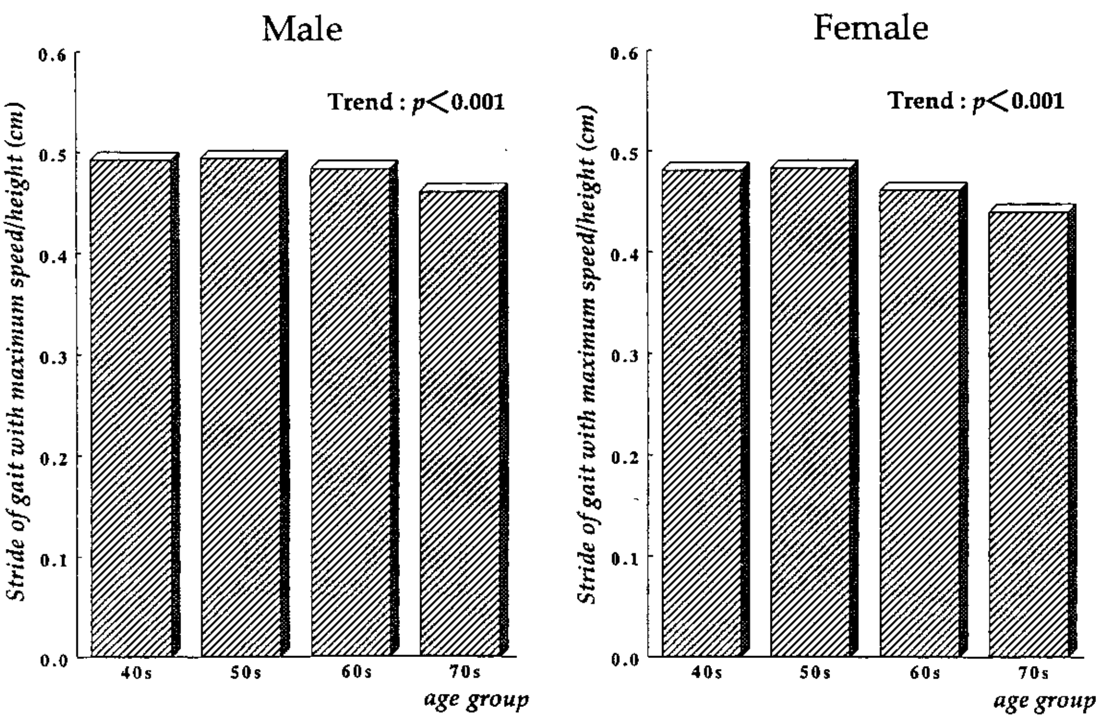

図2　身長で補正した速歩時の歩幅

NILS-LSAにおいて反復調査する予定となっている全対象者中，約半数の人についてのみの結果分析であった．そのため，それらの問題に関する詳細な検討は行わなかった．今後，全対象者の調査結果がそろった時点で，前述の問題に関する検討も含めた解析を実施する予定である．なお，他分野の調査結果との関連，そして縦断的な解析なども，今後，データが整った時点で，順次実施していく計画である．

以上，1997年11月から1999年3月までのNILS-LSAにおける運動能力調査結果を分析したところ，筋力，敏捷性，平衡能，歩行機能，身体活動量の各能力が，高齢になるにつれ低下する傾向が認められた．柔軟性には年齢による影響が認められなかった．

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Calcified Tissue International

Calcaneus Bone Mineral Density is Lower Among Men and Women with Lower Physical Performance

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Abstract. Fracture risk is influenced by both bone strength and by falls. Measures of physical function and performance are predictors of falls. However, the interrelationships among bone mineral density (BMD), regular physical activity, and measures of physical performance are not well known. We studied 447 community-dwelling Japanese people aged 40 years and over (96 men and 351 women) to examine the association of calcaneus BMD with measures of physical performance (grip strength, walking speed, chair stand, and functional reach) and regular physical activity. Calcaneus BMD decreased with age by approximately 25% in men and 42% in women. Measures of physical performance decreased with age by approximately 30% in both genders, however, performance on the chair stand test declined by approximately 60%. There were only minimal differences in performance measures and calcaneus BMD between people with and those without regular physical activity in both genders, and most differences were not significant. However, there were significant BMD increases of 3–6% per standard deviation (SD) increase in all performance measures for women and a 7% increase in BMD per SD increase in grip strength for men, after adjusting for age. These associations remained after additional adjustment for body mass index and regular physical activity. These findings suggest that bone density and physical function decline markedly in both men and women with age, and that low BMD and poor function tend to occur together, which would increase fracture risk more than either risk factor alone.

Key words: Bone density — Physical activity — Physical performance — Physical function.

Fracture risk is influenced by both bone strength and falls. Measures of physical function and performance are predictors of falls, and both BMD and physical performance are independent predictors of fracture risk [1–3]. However, the interrelationships among bone mineral density (BMD), regular physical activity, and measures of physical performance are not well known.

Previous studies demonstrated that regular physical activity was associated with better measures of physical performance, compared with less activity [4–6]. As such, measures of performance may provide some indication of habitual activity levels. However, performance may also vary independently of physical activity. To explore how BMD and performance are related, we examined the associations of calcaneus BMD with regular physical activity and measures of physical performance (grip strength, walking speed, chair stand, and functional reach) among Japanese men and women aged 40 years and over.

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Subjects and Methods

The Mitsugi Bone and Joint Study (MBJS) was conducted between 1994 and 1995 on community-dwelling people aged 40–85 in Mitsugi town, Hiroshima, Japan. A total of 447 people (96 men and 351 women) participated in the study. All subjects gave informed consent prior to the examination.

BMD was measured at the calcaneus using a single-energy X-ray densitometer (Osteoanalyzer, Dove Medical, CA, USA) [7]. This measure is a consistent predictor of vertebral and nonvertebral fracture risk [8–11]. Height and weight were measured, and body mass index (BMI) was calculated as weight (kg)/height $(m)^2$. Information on regular physical activity (yes/no) was collected by questionnaire; participants were asked whether they do any physical activity (e.g., walking, jogging, or bicycling) long enough to work up a sweat at least once a week.

Measures of physical performance [6] included grip strength of the dominant hand, measured by hydraulic dynamometer and calculated as the average of two trials. Chair stand time was measured as the time it took (average of two trials) to stand up from a standard chair five times; the subjects were asked, if possible, not to use their arms for assistance. Walking speed was calculated from the time required for subjects to walk a 6 m course at their usual pace (usual walking speed; average of two trials), and at a rapid but safe pace (rapid walking speed, single trial). Functional reach was calculated as the difference between two measurements (average of three trials). The subjects first stood comfortably upright, facing forward, hand in a fist, with their arm extended next to a yardstick mounted on a wall; subsequently, they reached forward as far as possible without stepping or losing their balance.

Statistical Analysis

Statistical analyses were performed using SAS version 6.12 software (SAS Institute, Cary, NC, USA). Student's t-tests were used to compare the characteristics between men and women subjects for continuous variables; the Chi-square statistic was used for categorical variables. Age-specific means of calcaneus BMD and measures of physical performance [analysis of variance

Table 1. Characteristics of subjects

Characteristic	Men	Women	P-value
Mean (SD)			
Age (years)	66.2 (9.4)	61.2 (10.0)	<0.001
Height (cm)	161.3 (5.7)	150.3 (5.9)	<0.001
Weight (kg)	59.7 (8.7)	51.6 (7.7)	<0.001
Body mass index (kg/m^2)	22.9 (2.7)	22.8 (2.9)	0.79
Percentage			
Regular physical activity	42.7	35.0	0.17

(ANOVA)], and age-adjusted means between people with and those without regular physical activity [analysis of covariance (ANCOVA)] were performed using general linear modeling methods. Multiple linear regression analysis was used to explore the associations of measures of physical performance with calcaneus BMD after adjustment for age and other covariates. Characteristics of subjects are shown in Table 1.

Results

Calcaneus BMD decreased significantly with age, especially in women (Table 2). The BMD values among ages ≥80 were 25% lower for men and 42% lower for women, compared with ages 40–49. Physical performance also decreased with age: grip strength, walking speed (both usual and rapid), and functional reach decreased and chair stand time increased (the longer time required to complete the test represents a decline in function). In contrast to BMD, the declines were similar (approximately 30%) for both men and women; differences in chair stand time were greater (56–65%) than for the other measures.

There were no significant differences in calcaneus BMD between men and women with and those without regular physical activity (Table 3). Walking speed (both usual and rapid) of men who were physically active was significantly faster than that of men who were not. Women with regular physical activity had shorter chair stand time compared with the nonphysically active women.

Better performance was associated with higher BMD for all variables. The magnitudes of age-adjusted associations with BMD were generally smaller among men than among women, and were not significant among men, except for grip strength (Table 4). For example, each SD increase in chair stand, grip strength, and walking speed was associated with a 3–6% increase in BMD. Associations with grip strength were greater in magnitude than for other performance variables in both genders. Additional adjustment for BMI and regular physical activity were also explored, but had little effect on most associations, as evidenced by the similarity of values across each row in Table 4. Adjustment for weight and height instead of BMI did not affect the associations except for functional reach among women; the association was no longer significant.

Discussion

We found that grip strength, chair stand time, walking speed, and functional reach declined with age in both genders, in accordance with previous studies [5, 12–14]. Poor performance on these neuromuscular tests was significantly associated with an increased risk of falls [15, 16]. Calcaneus BMD also decreased dramatically with age, more so in women, similar to reports by others [17, 18]. Poor physical performance and low BMD were independent, complimentary predictors of increased risk of hip fracture in a separate study, suggesting that both the declines in BMD and physical performance may contribute to increased fracture risk with age [1–3].

There were no significant differences in calcaneus BMD between those with and those without regular physical activity. In contrast, measures of physical performance were associated with BMD, especially in women. Some of the performance measures were also associated with physical activity; both performance and physical activity may reflect general health. However, adjustment for regular physical activity had little effect on associations of physical performance measures with BMD. Each SD difference in measures of physical performance was associated with 3–6% difference in BMD. Thus, women with 1 SD above average performance would have 6–12% greater BMD compared with those with 1 SD below average performance. A 6% difference in calcaneus BMD corresponds to a 27% difference in vertebral fracture risk; a 12% difference in BMD corresponds to a 60% difference in fracture risk [9].

Increased stress on bone during physical activity could stimulate bone to maintain or increase bone density [19–21]. There is substantial evidence that the magnitude of loading is more important than the frequency of loading. In support of this, the highest bone densities have been found in bones subjected to high-impact or high-loading activities such as weight lifting [19], football [20], and squash [21]. However, the role of customary physical activity, such as walking, has remained inconclusive. Krall and Dawson-Hughs [22] reported a possible association of customary physical activity with bone density, but Uusi-Rasi et al. [23] did not. In this study, we defined regular physical activity as current activity at least once a week, performed long enough to work up a sweat, such as walking, jogging, or bicycling. This definition may include, but is not limited to high-impact or high-loading activities.

Thus, our failure to detect an association between BMD and physical activity may have been due to the fact that the average loading involved in these activities was insufficient to influence the rate of bone loss [23]. It is also difficult to accurately assess physical activity by self-report; in particular, our questionnaire has important limitations (see below). These factors may partly explain the variability in results between studies regarding the influence of regular physical activity on BMD [22, 24]. Furthermore, there is evidence that mechanical stimulation may be insufficient to maintain skeletal mass, especially among postmenopausal women [25]. Antiresorptive treatments may reverse this blunting, resulting in an increase in bone mass in response to mechanical demands [26].

We demonstrated that grip strength was significantly associated with calcaneus BMD in both genders. One study [27] reported that grip strength was significantly associated with BMD at the sites of wrist, lumbar spine, and hip, but another study [28] found no association with hip BMD. Although grip strength does not directly reflect forces on the heel, calcaneus BMD correlates with the radius, spine, and hip BMD [8], and greater grip strength is associated with more strenuous activities of daily living [6]. These findings suggest that grip strength may be indirectly associated with bone density because it is an indicator of general health and activity. Since this study was cross-sectional, we also can-

Table 2. Age-specific means (SD) of calcaneus BMD and performance measures

Age group	N	Calcaneus BMD (mg/cm^2)	Grip strength (kg)	Chair stand time (sec)	Usual walking speed (m/sec)	Rapid walking speed (m/sex)	Functional reach (cm)
Men							
40–49	7	481.6 (55.3)	48.9 (7.4)	5.2 (0.6)	1.26 (0.18)	1.73 (0.15)	38.5 (6.0)
50–59	10	443.3 (57.3)	41.5 (6.3)	6.5 (1.2)	1.10 (0.14)	1.59 (0.37)	32.5 (5.8)
60–69	41	415.1 (88.8)	38.0 (7.4)	7.5 (1.6)	1.14 (0.17)	1.51 (0.22)	29.0 (6.8)
70–79	32	392.0 (88.2)	35.0 (4.8)	7.9 (1.5)	1.00 (0.17)	1.42 (0.21)	27.5 (5.4)
80–	6	362.5 (90.3)	34.0 (5.5)	8.6 (1.5)	0.93 (0.11)	1.25 (0.25)	24.6 (6.0)
Total	96	411.9 (86.9)	38.0 (7.3)	7.4 (1.6)	1.08 (0.19)	1.49 (0.25)	29.3 (6.8)
Change		24.7 %	30.5 %	65.4 %	26.2 %	27.7 %	36.1 %
Trend[a]		$P = 0.046$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P = 0.002$	$P < 0.001$
Women							
40–49	57	409.5 (62.6)	32.5 (6.1)	5.7 (1.3)	1.26 (0.18)	1.66 (0.23)	33.7 (5.7)
50–59	76	352.5 (73.7)	28.9 (5.5)	6.3 (1.6)	1.24 (0.17)	1.56 (0.21)	30.6 (5.5)
60–69	146	293.1 (56.6)	26.4 (4.6)	7.8 (2.0)	1.12 (0.17)	1.43 (0.23)	28.0 (5.5)
70–79	63	247.9 (62.1)	23.1 (4.9)	9.0 (2.7)	0.97 (0.17)	1.24 (0.23)	25.7 (6.3)
80–	9	238.3 (38.7)	21.4 (4.5)	8.9 (1.9)	0.84 (0.24)	1.15 (0.34)	23.0 (5.8)
Total	351	315.4 (82.2)	27.2 (5.9)	7.4 (2.3)	1.13 (0.21)	1.45 (0.27)	29.0 (6.3)
Change		41.8 %	34.2 %	56.1 %	33.3 %	30.7 %	31.8 %
Trend[a]		$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$

[a] P values relate to a test for trend versus age group

Table 3. Comparison of age-adjusted means[a] (SE) of calcaneus BMD and performance measures between people with and without regular physical activity

	Regular physical activity		
	With	Without	P value
Men	n = 41	n = 55	
Calcaneus BMD (mg/cm^2)	411.4 (13.0)	412.2 (11.2)	0.96
Grip strength (kg)	38.7 (1.0)	37.4 (0.9)	0.30
Chair stand time (s)	7.4 (0.2)	7.4 (0.2)	0.86
Usual walking speed (m/s)	1.13 (0.03)	1.05 (0.02)	0.03
Rapid walking speed (m/s)	1.55 (0.04)	1.44 (0.03)	0.02
Functional reach (cm)	29.5 (1.0)	29.2 (0.8)	0.81
Women	n = 123	n = 228	
Calcaneus BMD (mg/cm^2)	319.5 (5.6)	313.1 (4.1)	0.36
Grip strength (kg)	27.4 (0.5)	27.1 (0.3)	0.61
Chair stand time (s)	7.0 (0.2)	7.6 (0.1)	0.01
Usual walking speed (m/s)	1.15 (0.02)	1.13 (0.01)	0.17
Rapid walking speed (m/s)	1.47 (0.02)	1.45 (0.01)	0.45
Functional reach (cm)	29.6 (0.5)	28.6 (0.4)	0.14

[a] Means adjusted by general linear modeling (analysis of covariance) methods

not rule out a possible genetic basis for the observed associations: both BMD and measures of physical performance may be influenced by heredity.

Another possibility is that muscle mass is associated with both performance and BMD. Some studies have reported that higher values of muscle mass, lean body mass (which is correlated with muscle mass), and muscle strength were associated with increased BMD [29–31]. However, other studies did not find associations [28, 32, 33], and some have reported that hip fracture risk and BMD at certain skeletal sites were more strongly associated with fat mass than with lean mass [2, 29]. Increased muscle mass would be associated with greater skeletal loading, both from weight bearing and from muscular forces exerted on the skeleton. Consequently, the associations of muscle mass with BMD may be stronger for some skeletal sites than others [29, 34].

Our findings suggest that measures of physical performance may be better indicators of physical function than the physical activity question used in this study. Muscle strength may partly reflect customary physical activity. Both chair stand time and walking speed are associated with lower extremity muscle strength [13, 35]. Physical activity also has been reported to be associated with increased grip strength [4, 27]. Higher levels of physical activity may help maintain general muscle strength and independent activities of daily living in old age.

One limitation of this study is that only one measure of physical activity was available, and this measure may not be optimal for exploring associations. Although walking was found to be as effective as vigorous exercise for preventing cardiovascular disease [36], the magnitude of skeletal loading may be more important for bone health than the energy-expending or aerobic qualities of physical activity. Also,

Table 4. The percent difference[a] in calcaneus BMD per standard deviation[b] of performance measures

	Age adjusted	Age and BMI adjusted	Age, BMI, and physical activity adjusted
Men			
Grip strength (kg)	7.0 (P = 0.003)	6.0 (P = 0.006)	5.9 (P = 0.007)
Chair stand time (sec)	−1.5 (P = 0.52)	−1.4 (P = 0.51)	−1.4 (P = 0.52)
Usual walking speed (m/sec)	3.6 (P = 0.12)	2.4 (P = 0.26)	2.3 (P = 0.31)
Rapid walking speed (m/sec)	3.3 (P = 0.15)	2.1 (P = 0.33)	1.9 (P = 0.38)
Functional reach (cm)	2.2 (P = 0.36)	0.8 (P = 0.70)	0.8 (P = 0.72)
Women			
Grip strength (kg)	6.3 ($P < 0.001$)	5.9 ($P < 0.001$)	5.9 ($P < 0.001$)
Chair stand time (sec)	−3.0 (P = 0.02)	−3.7 (P = 0.002)	−3.6 (P = 0.003)
Usual walking speed (m/sec)	4.7 ($P < 0.001$)	4.5 ($P < 0.001$)	4.4 ($P < 0.001$)
Rapid walking speed (m/sec)	5.4 ($P < 0.001$)	5.4 ($P < 0.001$)	5.4 ($P < 0.001$)
Functional reach (cm)	2.8 (P = 0.02)	2.5 (P = 0.03)	2.4 (P = 0.04)

[a] The difference was divided by the mean of BMD for all people in each gender: 411.9 mg/cm^2 in men and 315.4 mg/cm^2 in women (see Table 2)
[b] For example, the standard deviation for grip strength among men was 7.3 kg (see Table 2)

only one BMD site was examined; the findings reported here may not apply to other skeletal sites. Furthermore, cross-sectional studies such as this one can detect associations between variables, but cannot demonstrate causality; prospective studies are less susceptible to bias and would provide more reliable information regarding the extent to which physical activity, physical performance, and the rate of bone loss are intertwined.

We conclude that women with poor physical performance tend to have low BMD and vice versa. Similar associations were observed among men, but were weaker and not significant, except for grip strength. These associations may represent joint effects of general health on both BMD and performance. Poor physical performance is a risk factor for falls; this combined with low BMD would compound the risk of fractures, as has already been reported by others [1–3].

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