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Correlates of Performance-Based Measures of Muscle Function in the Elderly: The Cardiovascular Health Study

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Background. It is unknown how much age-related changes in muscle performance represent normal aging versus the effects of chronic disease and life style. We examined the correlates of four performance measures — gait speed, timed chair stands (TCS), grip strength, and maximal inspiratory pressure (MIP) — using baseline data from the Cardiovascular Health Study (CHS), a population-based study of risk factors for heart disease and stroke in persons ≥ age 65.

Methods. We analyzed data from the 5,201 CHS participants. Variables were arranged into nine categories: Personal Characteristics, Anthropometry, Physical Condition, Reported Functional Status, Subjective Health, Psychological Factors, Symptoms, Cognitive Status, Habits and Lifestyle, and Prevalent Disease. Independent correlates were identified using stepwise linear regression.

Results. The regression models explained 17.7–25.4% of the observed variability. Although age significantly correlated with each measure, it explained little of the variability (≤ 5.7%). Anthropometric features plus physical condition explained 14.0–17.4% of the variability for grip strength and MIP, but 2.8–12.9% of the variability for gait speed and the log of TCS. Subjective health and psychological factors explained 1.8–9.4% of the variability in gait speed and the log of TCS, but ≤ 1.2% of the variability in grip strength and MIP. Variables for prevalent disease explained ≤ 1.3% of the variability in each measure.

Conclusions. After age 64, age explained little of the variability in muscle performance in a large sample of mostly functionally intact, community-dwelling older persons. Complex measures such as gait speed were more associated with subjective factors than were direct measures of strength. Prevalent disease contributed surprisingly little to muscle performance.

WEAKNESS constitutes one of the principal determinants of physical frailty, contributing to reduced activity, falls, and loss of independence. Strength declines progressively after age 50 (1,2), resulting in a net loss of 30–40% of peak strength during the remainder of an average lifetime (2). However, the decline of muscle performance may not be inexorable. Muscle mass, strength, and performance measures such as gait and balance have been shown to improve in weight-trained older individuals (3–5). The etiology of the age-associated decline in various measures of muscular performance is poorly understood. Loss of strength has been attributed to decreased muscle mass (1,6), to selective atrophy of type II (fast-twitch) muscle fibers (2), and to reduced numbers of functioning motor units (7). It remains unclear how much these changes represent normal aging, the cumulative effects of chronic disease, and changes in life style.

The goal of this study was to examine the independent correlates of several performance-based measures of muscle function obtained during the baseline examination of subjects enrolled in the Cardiovascular Health Study: grip strength, gait speed, timed chair stands (TCS), and maximal inspiratory pressure (MIP). We sought to answer two principal questions:

1. How much do these measures change with age after age 64, and how much of the variability is explained by age alone?
2. To what extent is performance on these measures associated with prevalent disease, psychological factors and subjective health, body habitus and composition, functional status, and life style?

The four performance tests vary in their specificity as measures of muscle strength. Gait velocity correlates with lower-extremity strength in the elderly (3,5,8,9), and its slowing has been attributed to reduced stride length (10). However, gait speed also may be affected by the interaction of conditions such as arthritis, foot abnormalities, low vision, impaired balance, stooped posture, and heterogeneous neurological conditions. The time required for five chair stands depends on balance and endurance as well as quadriceps strength, and likely it is affected by pain or dysfunction in the hips and knees. In contrast to gait speed and chair stands, grip strength and MIP more specifically measure muscular contractile force. Grip strength reflects the strength of the forearm musculature. MIP primarily measures the strength of the diaphragm and is not affected by obstructive or interstitial lung disease except in states of severe hyperinflation (11–13) or the concomitant use of corticosteroids, which may lead to a myopathy (11). We hypothesized that gait speed and timed chair stands would correlate more strongly with subjective health and reported functional status than either grip strength or MIP. Conversely, we hypothesized that grip strength and MIP would be relatively more influenced by anthropometric features and physical condition than gait speed or timed chair stands.

Methods

Study Population

The data for this study were derived from baseline data collected as part of the Cardiovascular Health Study (CHS), a population-based, longitudinal study of risk factors for coronary artery disease and stroke in persons aged 65 and older. A total of 5,201 subjects were recruited between 1989 and 1990 from Medicare eligibility lists in four communities in the United States: Sacramento County, California; Washington County, Maryland; Forsyth County, North Carolina; and Allegheny County, Pennsylvania. To be eligible to participate, subjects could not be institutionalized, wheelchair-bound, or under treatment for cancer. For details of the study design, the reader is referred to Fried et al. (12).

Baseline Data Collection

Participants in the CHS were interviewed in their homes, where they answered standardized questionnaires covering their medical history, psychosocial status, activities, and physical functioning. Information on the use of prescription medication was obtained directly from the labels of medication bottles. Within 2 weeks of the home interview, participants came to the field center for a 4-hour standardized examination that included the following tests of physical performance which comprise the outcome measures for this analysis:

1. *Grip strength.* Forearm muscle strength was measured by a hand-held Jamar A dynamometer, which recorded the force in kilograms of three maximal attempts with the subject's dominant and nondominant hands. The variable chosen for analysis was the best of three attempts in the dominant hand.
2. *Maximal inspiratory pressure.* MIP was measured in cm H_2O through a mouthpiece connected to an electronic pressure transducer. The highest MIP was deemed acceptable and recorded if a second value of at least 90% of the highest MIP was obtained during three to five attempts.
3. *Timed walk.* The time (to 0.1 sec) required for a participant to walk a 15-foot course at his or her usual pace after starting from a standstill was recorded by stopwatch. We converted the results into speed (meters per second) to facilitate comparison to other studies.
4. *Timed chair stands.* This test recorded how quickly the subject could perform five consecutive chair stands (timed to 0.1 sec). The test required the subject to stand up from a seated position on a 45-cm-tall chair with arms folded across the chest.

Selection of Independent Variables

Independent variables for this analysis were selected or derived from variables assessed at the baseline examination of the CHS participants. Variables were initially chosen because of a scientific or logical basis for potentially correlating with one or more of the performance measures. In order to avoid spurious effects in our multivariate analyses, we separated variables that consisted of ratios (e.g., the ankle-arm index) into their respective components, which were treated as independent variables (13). From this list of variables, 56 had a significant univariate association ($p \leq .01$) with at least one of the performance measures and were retained. These variables were then entered into a correlation matrix. One of each pair of variables having a correlation of ≥ 0.5 was dropped as redundant, unless both variables in the pair were considered to be clinically relevant. In this manner, seven variables were eliminated. We subsumed the 49 remaining variables under nine conceptual categories: *personal characteristics* (age, race), *anthropometric features* (e.g., weight), *physical condition* (e.g., grip strength), *reported functional status, subjective (self-reported) health, psychological factors* (e.g., depression), *symptoms, cognition, habits and lifestyle* (e.g., smoking), and *prevalent disease* (see Appendix).

Analytic Procedures

All data were analyzed using the SPSS/PC+ statistical package (14). To assess the independent relationship of the variables with the respective performance measures, we employed three iterations of forward stepwise linear regression stratified by gender. The first iteration included in the analysis only those subjects without missing variables. All 49 potential correlates were entered into the models without restriction, using a significance to enter of $p = .01$ and a significance to remove of $p = .05$. For the second iteration, the main effects of each model were entered first, then interaction terms for age and the main effects, followed by a quadratic age term (AGE^2) to detect a nonlinear contribution of age to the performance measures. The smaller number of variables entered into the second set of regressions resulted in fewer subjects with missing variables, thereby maximizing the sample sizes. Significantly associated variables from the second iteration were entered into a third and final iteration, with age terms forced in last in order to assess their independent contribution to the variability above and beyond the other variables. Residual analysis tested the assumption of normality for the dependent variable. In the case of the regression model for timed chair stands, attainment of a normal distribution of the standardized predicted values required logarithmic transformation of the dependent variable, "seconds." Gender differences in the age-associated rate of decline for each performance measure were assessed by combining significant covariates for either gender and entering them into a model for all 5,201 subjects. Gender was included with the covariates, and an age-gender interaction term was forced into each model at the end. A significant age-gender interaction suggested a differential rate of decline for men and women after adjustment for other covariates.

Results

Demographic and baseline health characteristics of the 5,201 CHS participants performing or missing the four performance measures are presented in Table 1. Persons missing the timed chair stands, grip strength, and timed walk (women) tended to be older. Subjects missing any test other than MIP tended to have slightly greater dependence in self-care. Few subjects missed the timed walk, and those doing so had similar prevalences of chronic illness and self-reported health to those performing the test. Those missing chair stands were more likely to have major chronic illness, poorer self-reported health, and cognitive impairment. Those missing the test of grip strength were older on average and had a greater burden of comorbidity, but were not more cognitively impaired. Although more subjects missed MIP than any of the other performance tests, the health characteristics and mean age of those missing the measure were statistically similar to those undergoing the test. All four physical performance measures declined slightly but significantly with increasing age ($p < .0001$).

The final regression models are presented in Table 2 with the independent correlates grouped according to the categories defined in the Appendix. Age was a significant independent correlate of each performance measure. Significant age–main effect interactions were found with ADL for gait speed (women), grip strength for the log of timed chair stands (women), and FEV_1 for MIP (women). The age interaction term indicates that the influence of the variable on the performance measure varied as a function of age. The quadratic age term (AGE^2) was significant for gait speed and MIP in men only, suggesting that after age 64, an acceleration of decline in these measures occurs with increasing age. For the remaining two measures in men, and all four measures in women, the relationship between age and the measure was linear. All correlates were significant at $p \le .05$.

Table 1. Selected Characteristics and Comparison of CHS Subjects Performing or Missing the Four Performance Tests

Men (*n* = 2239)	Gait Speed (Missing = 29)	Chair Stands (Missing = 250)	Grip Strength (Missing = 147)	MIP‡ (Missing = 285)
Characteristic	Performing / Missing	Performing / Missing	Performing / Missing	Performing / Missing
Mean age	73.3 / 74.6	73.0 / 76.3†	73.2 / 74.5**	73.2 / 73.9
Prior stroke (%)	6.7 / 13.8	5.5 / 17.2†	6.5 / 10.9	7.1 / 4.9
Prior MI (%)	20.5 / 17.2	19.7 / 26.4*	19.9 / 27.2	20.5 / 19.6
CHF (%)	3.4 / 0	3.2 / 4.4	3.4 / 2.7	3.6 / 1.8
Angina (%)	15.3 / 17.2	14.7 / 20.4†	14.7 / 25.2†	15.2 / 16.5
Arthritis (%)	44.0 / 31.0	41.9 / 58.8†	43.0 / 55.8**	44.2 / 41.4
Hypertension (%)	38.8 / 41.4	37.7 / 47.4*	38.7 / 40.4	38.8 / 38.9
Glucose intolerance (%)	51.1 / 44.8	50.2 / 58.0**	50.5 / 59.2	51.4 / 48.4
Fair-poor health (%)	22.1 / 31.0	20.3 / 37.5†	21.9 / 27.2**	22.4 / 21.1
MMSE§ <24 (%)	6.8 / 20.7*	5.5 / 18.4†	6.7 / 10.2	7.0 / 6.7
ADL score‖	0.07 / 0.55†	0.04 / 0.39†	0.07 / 0.27†	0.08 / 0.12

Women (*n* = 2962)	Gait Speed (Missing = 44)	Chair Stands (Missing = 389)	Grip Strength (Missing = 229)	MIP‡ (Missing = 379)
Characteristic	Performing / Missing	Performing / Missing	Performing / Missing	Performing / Missing
Mean age	72.3 / 75.5†	71.9 / 75.6†	72.3 / 73.3**	72.3 / 72.7
Prior stroke (%)	3.2 / 0	2.5 / 7.7†	3.1 / 3.5	2.9 / 4.7
Prior MI (%)	11.3 / 18.2	10.0 / 20.1†	10.8 / 17.5**	11.6 / 9.5
CHF (%)	2.2 / 2.3	1.3 / 8.0†	1.9 / 5.7**	2.1 / 2.6
Angina (%)	9.8 / 13.6	8.6 / 18.0†	9.5 / 14.0**	9.6 / 11.3
Arthritis (%)	56.0 / 63.6	53.3 / 75.1†	54.7 / 73.8†	55.8 / 58.6
Hypertension (%)	43.1 / 42.5	41.4 / 54.2†	43.2 / 41.4	42.5 / 46.9
Glucose intolerance (%)	49.2 / 63.6*	47.5 / 62.2†	49.0 / 55.0*	49.3 / 50.4
Fair-poor health (%)	24.1 / 34.1	21.2 / 44.3†	23.7 / 29.8	24.0 / 25.6
MMSE§ <24 (%)	4.5 / 13.6**	3.8 / 9.8†	4.6 / 5.2	4.3 / 7.1*
ADL score‖	0.13 / 0.61†	0.07 / 0.59†	0.12 / 0.31†	0.14 / 0.14

‡Maximal inspiratory pressure.
§Folstein Mini-Mental State score; scored 0 (very impaired) to 30 (cognitively intact).
‖Score 0 (no impairment) to 6 (completely dependent).
*$p < .05$; **$p < .01$; †$p < .0001$.

Table 2. Stepwise Linear Regression Models for Gait Speed, the Log of The Time Required for 5 Chair Stands, Grip Strength, and Maximal Inspiratory Pressure

Dependent Variable	Associated Independent Variables: Category*	Associated Independent Variables: Name	R^2†	CATEG. R^2‡	CUMUL. R^2§	BETA¶	*p*-value
Gait speed — men	Anthropometric features	Waist circumference	0.006			–0.260	<.0001
		Weight	0.022	0.028		0.187	<.0001
	Subjective health	Subjective health	0.080	0.080		–0.185	<.0001
	Symptoms	Dizzy in past 2 weeks	0.005			–0.066	.0008
		Weak in past 2 weeks	0.004	0.009		–0.056	.005
	Cognition	Mini-Mental State score	0.049	0.049		0.143	<.0001
	Habits and life style	Estimated kilocalories consumed in physical activity in past week	0.016	0.016		0.086	<.0001
	Age	Age in years	0.030			0.967	.014
		(Quadratic age term)	0.003	0.033	0.215	–1.162	.003
Gait speed — women	Anthropometric features	Waist circumference	0.014	0.014		–0.153	<.0001
	Physical condition	Forced expiratory volume (1 second)	0.051			0.114	<.0001
		Grip strength	0.012	0.063		0.074	<.0001
	Functional status	Activities of daily living (ADL) score	0.006			0.471	.043
		(Age-ADL interaction term)	0.031	0.037		–0.610	.009
	Subjective health	Subjective health	0.093	0.093		–0.174	<.0001
	Psychological factors	Nervous or emotional disorder	0.001	0.001		–0.046	.009
	Cognition	Mini-Mental State score	0.021	0.021		0.103	<.0001
	Prevalent disease	Hematocrit	0.004	0.004		0.057	.0009
	Age	Age in years	0.021	0.021	0.254	–0.171	<.0001
Log of timed chair stands — men	Anthropometric features	Waist circumference	0.013			0.214	<.0001
		Weight	0.004			–0.142	.003
		Height	0.022	0.039		0.197	<.0001
	Physical condition	Grip strength	0.062			0.7	.009
		(Age-grip strength interaction term)	0.028	0.090		–0.830	.0009
	Subjective health	Subjective health	0.040	0.040		0.153	<.0001
	Symptoms	Dyspnea score	0.007	0.007		0.077	.0005
	Cognition	Mini-Mental State score	0.006	0.006		–0.076	.0005
	Habits and life style	Estimated kilocalories consumed in physical activity in past week	0.005	0.005		–0.064	.002
	Age	Age in years	0.013	0.013	0.2	0.464	<.0001
Log of timed chair stands — women	Anthropometric features	Waist circumference	0.025			0.137	<.0001
		Height	0.012	0.037		0.153	<.0001
	Physical condition	Grip strength	0.039	0.039		–0.183	<.0001
	Functional status	Instrumental activities of daily living score	0.058			0.119	<.0001
		Difficulty walking	0.012	0.070		0.092	<.0001
	Subjective health	Subjective health	0.017	0.017		0.121	<.0001
	Psychological factors	CES–D score	0.001	0.001		0.053	.006
	Habits and life style	Current smoking	0.001	0.001		0.058	.001
	Age	Age in years	0.046	0.046	0.211	0.230	<.0001
Grip strength — men	Anthropometric features	Waist circumference	0.040			–0.321	<.0001
		Weight	0.022			0.420	<.0001
		Height	0.112	0.174		0.139	<.0001
	Psychological factors	CES–D score	0.005	0.005		–0.063	.001
	Prevalent disease	Arthritis	0.010	0.010		–0.072	.0002
	Age	Age in years	0.057	0.057	0.246	–0.253	<.0001
Grip strength —women	Anthropometric features	Waist circumference	0.015			–0.161	<.0001
		Weight	0.022			0.279	<.0001
		Height	0.091			0.137	<.0001
		Serum creatinine	0.001	0.129		0.053	.0007
	Physical condition	Forced expiratory volume (1 second)	0.023	0.023		0.086	<.0001
	Psychological factors	CES–D score	0.003	0.003		–0.06	.0007
	Prevalent disease	Arthritis	0.013	0.013		–0.092	<.0001
	Age	Age in years	0.031	0.031	0.199	–0.196	<.0001

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Table 2. Stepwise Linear Regression Models for Gait Speed, the Log of The Time Required for 5 Chair Stands, Grip Strength, and Maximal Inspiratory Pressure *(Continued)*

Dependent Variable	Associated Independent Variables: Category*	Name	R^2†	CATEG. R^2‡	CUMUL. R^2§	BETA¶	*p*-value
MIP — men	Physical condition	Forced expiratory volume (1 second)	0.096			0.196	<.0001
		Grip strength	0.044	0.140		0.160	<.0001
	Subjective health	Subjective health	0.012	0.012		−0.099	<.0001
	Symptoms	Dizzy when stand up quickly	0.006	0.006		−0.074	.0006
	Habits and life style	Current smoking	0.003	0.003		−0.071	.001
	Age	Age in years	0.020			1.565	.0004
		(Quadratic age term)	0.007	0.027	0.188	−1.722	.0001
MIP — women	Anthropometric features	Weight	0.010			0.134	<.0001
		Height	0.007	0.017		−0.089	<.0001
	Physical condition	Forced expiratory volume (1 second)	0.082			−0.571	.03
		(Age-forced expiratory volume interaction term)	0.004			0.702	.005
		Grip strength	0.037	0.123		.152	<.0001
	Subjective health	Subjective health	0.008	0.008		−0.078	.0002
	Symptoms	Dyspnea score	0.003	0.003		−0.064	.002
	Cognition	Mini-Mental State score	0.017	0.017		0.103	<.0001
	Habits and life style	Current smoking	0.003	0.003		−0.065	.0009
	Age	Age in years	0.006	0.006	0.177	−0.297	<.0001

Note: Age terms were forced into the equations last to assess the independent contribution of age above and beyond the other covariates.
*Category under which the adjacent variables have been grouped.
†R^2 = the amount of variability explained by the individual variable.
‡CATEG. R^2 = categorical R^2, the amount of variability explained by the category of variables.
§CUMUL. R^2 = the total variability explained by the model.
¶BETA (beta coefficient) = standardized regression coefficient.

Overall, the regression models explained between 17.7% and 25.4% of the observed variability, with age terms independently explaining between 0.6 and 5.7% of the variability. Subjective health plus psychological factors independently explained between 1.8 and 9.4% of the total variability for gait speed and the log of timed chair rises, but explained just 0.3–1.2% of the variability for MIP and grip strength. Although assessed and reported prevalent disease was associated with all four measures, it explained ≤ 1.3% of the variability. The positive association of forced expiratory volume in one second with gait speed (women) and grip strength (women) in addition to MIP suggests that it reflected physical condition rather than pulmonary disease. Creatinine similarly was positively associated with grip strength in women, suggesting that it reflected muscle mass, not renal function. Figure 1 shows the means for each performance measure before and after adjustment for covariates. Age–gender interactions were significant for grip strength ($p < .0001$) and marginally significant for gait speed ($p = .02$). Based on the Beta values for age for these measures, the slope of decline for grip strength appears significantly greater in men after age 64, and may be steeper for gait speed in men, as well.

Discussion

For the assessment of correlates of performance-based measures of muscle function, the CHS offers advantages over other population-based studies of older persons. The Established Populations for Epidemiologic Studies of the Elderly (EPESE) was designed to examine the prevalence and incidence of chronic conditions, impairments, and disabilities, as well as to determine risk factors for mortality and institutionalization. Although approximately 14,000 persons were enrolled, the number of chronic conditions assessed was limited and data were collected primarily by interview. Several direct measures of physical functioning were performed only at the time of the third household interview (15). The objective of the third National Health and Nutrition Examination Survey (NHANES III) was to estimate the prevalence of chronic conditions and associated risk factors in a representative sample of the U.S. population, including 5,721 persons aged 50 and older. In Phase I, NHANES III assessed a broad array of health topics through self-report and direct measurements, and conducted a limited physical performance examination (16). Compared to NHANES III, the scope of health-related variables in the CHS is likewise extensive, and the CHS offers greater detail in many of its measures, particularly with regard to the cardiovascular system.

Our analysis of data from the Cardiovascular Health Study confirms previous research showing an age-related decline in grip strength (1,17), gait velocity (18,19), and MIP (20,21). Not surprisingly, anthropometric variables emerged as significant correlates of all four measures: persons with more muscle mass are likely to be stronger. The combination of variables for anthropometric features and physical condition explained more of the variability for the tests specifically measuring contractile force (MIP and grip strength) than for those measuring complex muscle function and sensorimotor integration (gait speed and log timed

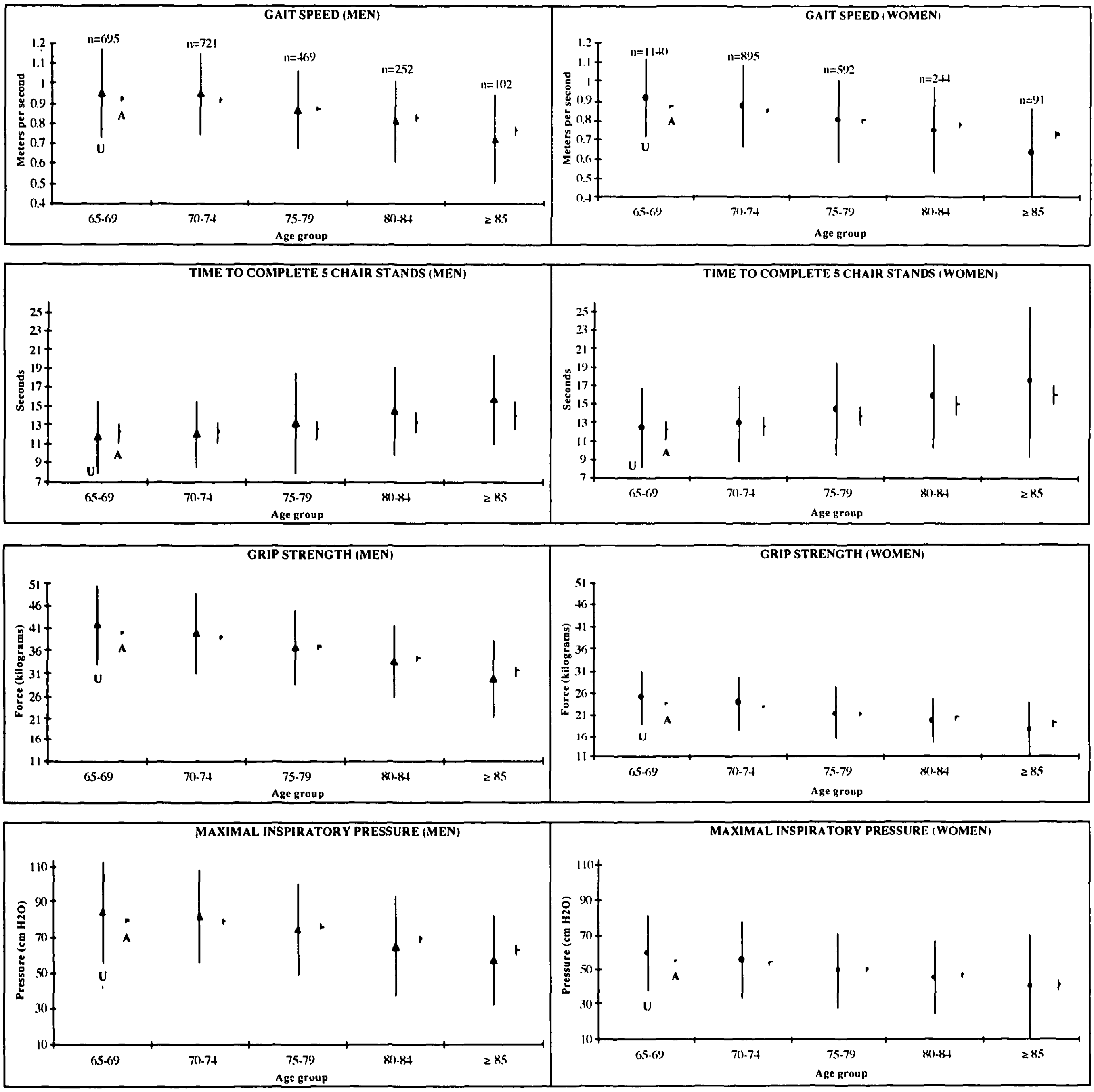

Figure 1. Physical performance measures by age group. U = unadjusted means (± standard deviation). A = adjusted means (± standard error) derived from regression models.

chair stands). Variables representing psychological factors and perceived health explained more of the variability for gait speed and log timed chair stands than for MIP and grip strength. Variables for reported functional status emerged as significant independent correlates of gait speed and log timed chair stands in women but not men, possibly reflecting the greater prevalence of functional impairment among women in the CHS cohort. The contribution of symptoms and subjective health to the models may reflect the failure of our collection of health-related variables to tap the pathophysiologic processes leading to reduced performance, with symptoms and subjective health serving as proxies for these unidentified variables.

The absolute cross-sectional decline in mean performance for the CHS cohort was small for all four measures. Although age remained a significant independent correlate of each performance measure, its unique contribution to the explained variability, after controlling for covariates, was minor, ranging from 0.6% for MIP in women to 5.7% for grip strength in men. By contrast, in the Baltimore Longitudinal Study of Aging (BLSA), Kallman et al. (1) found that age explained 38% of the total variability in summed grip strength (the sum of grip strength in both hands), while summed forearm circumference explained an additional 16%. The comparatively narrow age range of the CHS (spanning ages 65–100) compared to the BLSA (spanning ages 20–100) may account for some of this large difference in explained variability. The numerous variables reflecting personal and health-related characteristics that were entered into our stepwise regressions also may have reduced the contribution of age to the explained variability. The small independent contribution of age to all four performance measures supports the concept that the age-related decline in some domains of muscle function can be slowed if not reversed (3–6). However, because of the cross-sectional nature of this analysis, a cohort bias cannot be excluded, with physically fit older persons more likely to enroll in the study than frailer individuals.

Data on longitudinal changes in grip strength from two population-based studies of normative aging suggest that the rate of decline in muscle strength increases as a function of age (1,17). In our cross-sectional analysis, the quadratic age term was significant only in the models for gait speed and MIP in men, suggesting that the acceleration of decline after age 64 may vary according to gender and muscle group. Bassey and Harries (17) observed a greater decline in grip strength among women compared to men after four years of follow-up of 620 elderly subjects. However, our cross-sectional analysis across age groups suggests the opposite: men's grip strength declines more rapidly than women's, at least after age 64.

Lean body mass has been shown to account for much of the difference in strength between young and old individuals (22,23). In the CHS, lean body mass was measured indirectly through bioelectrical impedance (24), but this variable was eliminated from the analyses because of its colinearity with weight. Creatinine, originally entered as a measure of renal function, correlated positively with grip strength in women, suggesting that it was reflecting muscle mass more than renal function. Depending on the performance measure, one or more of the anthropometric variables — weight, waist circumference, height, and serum creatinine — was positively correlated with superior performance, in keeping with being a proxy for muscle mass. Consistent with our hypothesis, anthropometric features explained more of the variability for grip strength (12.9–17.4%) than for either gait speed (1.4–2.8%) or the log of timed chair stands (3.7–3.9%). However, anthropometric features explained just 1.7% of the variability for MIP in women and none of the variability for MIP in men, suggesting that lean body mass may not be an important correlate of diaphragmatic strength. Muscular atrophy resulting from underuse also has been postulated as an important cause of age-associated weakness (1). The significant independent association of kilocalories consumed per week, an indirect measure of physical activity, with gait speed and the log of timed chair stands in men supports this hypothesis.

Important strengths of this study include the measurement of physical performance in several domains, the multiplicity of health-related variables, and the large size of the study sample. As a community-based population study, the CHS protocol excluded only persons with cancer under treatment. Subjects missing at least one performance test tended to be older, more dependent in self-care, and to have a greater likelihood of cognitive impairment. Those missing grip strength and chair stands suffered from more comorbidities and reported poorer health compared to subjects performing the tests. In contrast, those missing gait speed and MIP were largely similar to subjects performing these tests with respect to prevalent illness and subjective health.

Consequently, the results for gait speed and MIP may be more generalizable than those for chair stands and grip strength. Due to the cross-sectional nature of this study, the results must be interpreted cautiously until they can be confirmed with prospective data currently being collected by the CHS. It is possible that some of the differences in performance between age groups reflect a cohort or survival bias. For example, very old persons volunteering for the study may have been healthier than average individuals from their peer group, resulting in unrepresentatively good performances.

In conclusion, our analysis of cross-sectional data gathered during the baseline evaluation of participants in the Cardiovascular Health Study revealed an age-associated decline in physical performance among men and women in four different domains: gait speed, grip strength, maximal inspiratory pressure, and timed chair stands. After controlling for health-related variables, age explained little of the variability in the measures, suggesting that other age-associated factors accounted for the changes in performance. Although variables reflecting prevalent illness — as assessed by the CHS — independently and significantly correlated with the performance measures, their contribution to the explained variability was minor. This finding was unexpected and may reflect the limited ability of an individual's report of chronic disease or even objective measures of disease severity to capture those disease-related factors that affect muscle performance. It also may reflect in part the lack of data in the CHS on musculoskeletal impairments or prior trauma which could have affected physical performance. Further research is needed to clarify the influence of chronic disease and its treatment. Our observations based on cross-sectional analysis also need to be confirmed by prospective data.

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REFERENCES

1. Kallman DA, Plato CC, Tobin JD. The role of muscle loss in the age-related decline of grip strength: cross-sectional and longitudinal perspectives. J Gerontol Med Sci 1990;45:M82–8.
2. Larsson K, Grimby G, Karlsson J. Muscle strength and speed of movement in relation to age and muscle morphology. J Appl Physiol 1979;451–6.

3. Fiatarone MA, Marks EC, Ryan DT, Meredith CN, Lipsitz LA, Evans WJ. High-intensity strength training in nonogenarians. JAMA 1990; 263:3029–34.
4. Fiatarone MA, O'Neill EF, Ryan ND, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 1994;330:1769–75.
5. Judge JO, Underwood M, Gennosa T. Exercise to improve gait velocity in older persons. Arch Phys Med Rehabil 1993;74:400–6.
6. Klitgaard H, Mantoni M, Schiaffino A, et al. Function, morphology and protein expression of ageing skeletal muscle: a cross-sectional study of elderly men with different training backgrounds. Acta Physiol Scand 1990;140:41–54.
7. Campbell MJ, McComas AJ, Petito F. Physiological changes in ageing muscles. J Neurol Neurosurg Psychiatry 1973;36:174–82.
8. Aniansson A, Rundgren A, Sperling L. Evaluation of functional capacity in activities of daily living in 70-year-old men and women. Scand J Rehab Med 1980;12:145–54.
9. Ito H, Nagasaki H, Maruyama H, Hashizume K, Nakamura R. Age related changes in the walking cycle during fastest walking in healthy male subjects. Nippon Ronen Igakkai Zasshi 1989;26:347–52.
10. Elbe RJ, Thomas SS, Higgins C, Colliver J. Stride-dependent changes in gait of older people. J Neurol 1991;238:1–5.
11. Decramer M, Lacquet LM, Fagard R, Rogiers P. Corticosteroids contribute to muscle weakness in chronic airflow obstruction. Am J Respir Crit Care Med 1994;150:11–16.
12. Fried LP, Borhani NO, Enright P, et al. The cardiovascular health study: design and rationale. Ann Epidemiol 1991;1:263–76.
13. Kronmal RA. Spurious correlation and the fallacy of the ratio standard revisited. J Roy Stat Soc (A) 1993;156(Part III):379–92.
14. Norusis NJ. SPSS/PC+™ 4.0, 444 N. Michigan Ave., Chicago, IL 60611, SPSS Inc., 1990.
15. Cornoni-Huntley J, Ostfeld AM, Taylor JO, et al. Established Populations for Epidemiologic Studies of the Elderly: study design and methodology. Aging Clin Exp Res 1993;5:27–37.
16. Burt VL, Harris T. The third National Health and Nutrition Examination Survey: contributing data on aging and health. Gerontologist 1994;34:486–90.
17. Bassey EJ, Harries UJ. Normal values for handgrip strength in 920 men and women over age 65 years, and longitudinal changes over 4 years in 620 survivors. Clin Sci 1993;84:331–7.
18. Hageman PA, Blanke DJ. Comparison of gait of young and elderly women. Phys Ther 1986;66:1382–7.
19. Imms FJ, Edholm OG. Studies of gait mobility in the elderly. Age Ageing 1981;10:147–56.
20. Chen HI, Kuo CS. Relationship between respiratory muscle function and age, sex, and other factors. J Appl Physiol 1989;66:943–8.
21. Enright PL, Kronmal RA, Manolio TA, Schenker MB, Hyatt RE. Respiratory muscle strength in the elderly: correlates and reference values. Am J Respir Crit Care Med 1994;149:430–8.
22. Young A, Stokes M, Crowe M. The size and strength of the quadriceps muscles of old and young women. Eur J Clin Invest 1984;14:282–7.
23. Young A, Stokes M, Crowe M. The size and strength of the quadriceps muscles of old and young men. Clin Physiol 1985;5:145–54.
24. Stewart SP, Bramley PN, Heighton R, Green JH, Horsman A, Losowsky MS, Smith MA. Estimation of body composition from bioelectrical impedance of body segments: comparison with dual-energy X-ray absorptiometry. Br J Nutr 1993;69:645–55.
25. Radloff LS. The CES–D scale: a self-report depression scale for research in the general population. Appl Psychol Measure 1977;1:385–401.
26. House JS. Chronic life situations and life change events: content discussion. In: Ostfeld AM, Eaker ED, eds. Measuring psychosocial variables in epidemiologic studies of cardiovascular disease: proceedings of a workshop. NIH pub. no. 85-2270. Bethesda, MD: National Institutes of Health, 1985:129–135.
27. Wells JA. Chronic life situations and life change events. In: Ostfeld AM, Eaker ED, eds. Measuring psychosocial variables in epidemiologic studies of cardiovascular disease: proceedings of a workshop. NIA pub. no. 85-2270. Bethesda, MD: National Institutes of Health, 1985:105–128.
28. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state": a practical method for grading the cognitive state of patients for the clinician. J Psychiatric Res 1975:12:189–98.
29. Ferris BG. Epidemiology Standardization Project (American Thoracic Society). Am Rev Respir Dis 1978;118:1–120.

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Appendix

Variables Entered Into Stepwise Regression Models for the Physical Performance Measures

Category	Variable	Category	Variable
Personal characteristics	Subject's age Gender Race	Cognition	Cognition (Folstein Mini-Mental Score; 28)
Anthropometric Features	Standing height Weight Waist circumference Serum creatinine*	Habits and life style	Reported packs of cigarettes smoked per day multiplied by number of years smoked Former smoker Current smoker Estimate of total kilocalories consumed in physical activity in past week Amount of alcohol consumed in past week
Physical condition	Grip strength in dominant hand Forced expiratory volume in 1 sec		
Subjective health Symptoms	Perception of general health (excellent, good, fair, poor) Fatigue in past 2 weeks Weakness in past 2 weeks Dizziness in past 2 weeks Lightheaded or dizzy when stand up quickly History of frequent falls History of blackouts or fainting Exertional dyspnea†	Reported functional status	Activities of daily living score Instrumental activities of daily living score Reported difficulty walking
Psychological factors	CES–D score (25) Stressful Life Events score (26,27) Reported presence of a nervous or emotional disorder	Prevalent disease (Reported disease)	History of myocardial infarction Congestive heart failure Angina pectoris Chronic bronchitis, asthma, or emphysema History of transient ischemic attacks History of cerebrovascular accident Definite hypertension Borderline hypertension Arthritis

(Continues next page)

Appendix *(Continued)*

Category	Variable	Category	Variable
Prevalent disease			Brachial blood pressure
(Assessed disease)	Left ventricular mass derived from electrocardiogram		The lower of the right and left tibial blood pressures
	Any major electrocardiographic abnormality‡		Presence of diabetes mellitus
			Glucose intolerance
	Qualitative echocardiographic left ventricular ejection fraction		Serum cholesterol
			Serum albumin
	Average of the common carotid near- and far-wall maximal thicknesses, for left and right side (average of 4 measurements)		Hematocrit
		(Medication use)	Total number of medications currently prescribed or taken
	Average of internal carotid near- and far-wall maximal thicknesses; right and left (average of 12 measurements)		Current use of a benzodiazepine, tricyclic, or major tranquilizer

*Here creatinine is used as a measure of lean body mass.

†Four-point ordinal scale derived from American Thoracic Society questionnaire (29).

‡One or more of the following: ventricular conduction defect, major Q-wave abnormality, minor Q-wave or QS waves, ST-T abnormalities, left ventricular hypertrophy, isolated ST-T wave abnormalities, atrial fibrillation, first-degree AV block.