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対象の内訳		ヒト	動物	地 域	欧米	研究の種類	縦断研究
	対象	一般健常者	空白		( )		コホート研究
	性別	男女混合	( )		( )		( )
	年齢	72.8歳			( )		前向き研究
	対象数	1000～5000	空白		( )		( )
調査の方法	実測	( )					
アウトカム	予 防	なし	なし	なし	なし	(死亡)	( )
	維持・改善	なし	なし	なし	なし	( )	( )
図 表							
図表掲載箇所							
概 要 (800字まで)	目的:メキシコ人、アメリカ人の高齢男女における握力と死亡率との関係を調査すること。デザイン:5年間のプロスペクティブ(前向き)コホート研究。設定:5つの南西の州:テキサス、ニューメキシコ、コロラド、アリゾナ、およびカリフォルニア。参加者:2488人の65歳以上のメキシコおよびアメリカ人の高齢男女。測定項目:最大握力、歩行時間、およびBMIは1993～94年の間、ベースライン時において評価された。機能的障害、様々な医学的状態、および追跡時における状態に関する自己報告が得られた。結果:完全なデータのベースライン時のサンプルにおいて、507名が死亡した5年後に確認された。握力の平均値(平均値±標準偏差)は女性(18.2±6.5 kg)より男性(28.4±9.5kg)で有意に高かった。握力が22.01kg未満であった男性と14kg未満であった女性では、それぞれ38.2%と41.5%は5年後に死亡していた。男性に関しては、最も低い握力の4段階における者では、最も高い握力の4段階におけるそれらと比べて、ベースライン時における社会人口統計、機能障害、歩行時間、医学的状態、BMIおよび喫煙状況制御後の死亡リスクは、2.10[1.31-3.38](95%信頼区間)であった。女性に関しては握力の4段階におけるそれらと比べて、死亡リスクは1.76[1.05-2.93](95%信頼区間)であった。顕著に劣る歩行時間や糖尿病、高血圧、およびガンの存在は5年後の死亡率において重大な予測因子となった。結論:握力の強さは、関連する危険因子制御後の、高齢メキシコ人およびアメリカ人に対して死亡率の強い予測因子となりえる。						
結 論 (200字まで)	握力はリスク補正後のメキシカンアメリカン高齢者男女の死亡率の強い予測因子となる。						
エキスパートによるコメント (200字まで)	特に高齢者では、筋力が死亡リスクの予測因子であるようだ。						

担当者 宮地 劉

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Physical Performance and Risk of Hip Fractures in Older Men

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ABSTRACT: The aim of these analyses was to describe the association between physical performance and risk of hip fractures in older men. Performance on five physical function exams (leg power, grip strength, usual walking pace, narrow walk balance test, and five repeated chair stands) was assessed in 5902 men ≥65 yr of age. Performance (time to complete or strength) was analyzed as quartiles, with an additional category for unable to complete the measure, in proportional hazards models. Follow-up averaged 5.3 yr; 77 incident hip fractures were confirmed by physician review of radiology reports. Poor physical performance was associated with an increased risk of hip fracture. In particular, repeated chair stand performance was strongly related to hip fracture risk. Men unable to complete this exam were much more likely to experience a hip fracture than men in the fastest quartile of this test (multivariate hazard ratio [MHR]: 8.15; 95% CI: 2.65, 25.03). Men with the worst performance (weakest/slowest quartile or unable) on at least three exams had an increased risk of hip fracture compared with men with higher functioning (MHR: 3.14, 95% CI: 1.46, 6.73). Nearly two thirds of the hip fractures (N = 49, 64%) occurred in men with poor performance on at least three exams. Poor physical function is independently associated with an increased risk of hip fracture in older men. The repeated chair stands exam should be considered in clinical settings for evaluation of hip fracture risk. Concurrent poor performance on multiple physical function exams is associated with an increased risk of hip fractures.
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Key words: epidemiology, hip fracture, strength, physical performance, walking

INTRODUCTION

Osteoporosis and fracture are multifactorial events, and no single risk factor can account for these conditions.[(1)] However, most hip fractures are the direct result of a fall,[(2)] and risk factors for falling are complex. Poor neuromuscular function (such as performance on measures such as grip strength and walking tests) increases fall risk in older adults,[(3–6)] and poor physical performance may improve with intervention.[(7–14)] Despite the link between fall and fracture risk, few studies in women, and very few in men, have evaluated the association between physical performance and fracture risk. In the Study of Osteoporotic Fractures (SOF), women who were unable to rise from a chair five consecutive times were about twice as likely to suffer a hip fracture as women able to complete this test.[(15)] A previous report from the Osteoporotic Fractures in Men (MrOS) Study,[(16)] a large cohort of community-dwelling older men, screened a large number of variables for association with incident non-spine fracture risk and found that, among the physical performance measures analyzed (simple exams that included ability to rise from a chair once, ability to complete a walking balance test, and grip strength), only inability to complete the walking balance test was associated with incident non-spine fracture risk after multivariate adjustment. Analyses evaluating physical performance and risk of hip fractures in older men are lacking.

The aim of these analyses was to describe the association between performance on various tests of physical performance and subsequent risk of hip fractures in the MrOS study cohort.

MATERIALS AND METHODS

Study participants

Men ≥65 yr of age living in six communities in the United States (Birmingham, AL; Minneapolis, MN; Palo Alto, CA; Monongahela Valley near Pittsburgh, PA; Portland, OR; and San Diego, CA) were recruited to participate in the MrOS study. To be eligible to participate, men must have been ambulatory (able to walk without assistance of an-

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other person or aide); must not have had bilateral hip replacements; and must have provided written informed consent. Participants completed a battery of clinical exams and a self-administered questionnaire during the baseline visit between March 2000 and April 2002. Institutional review boards at all clinic centers and the San Francisco Coordinating Center (University of California, San Francisco, and California Pacific Medical Center Research Institute) approved this study.

Descriptions of the study design and recruitment strategies for this cohort of 5995 men have been published elsewhere.[17,18] To be included in the analysis dataset for this report, MrOS participants must have had nonmissing values for the narrow walk balance test, usual pace, chair stands and grip strength measures, and a valid femoral neck BMD measure. Ninety-three participants were missing data for at least one of the tests or the BMD measure, leaving 5902 men with adequate data for inclusion in the analysis set. Data were missing because of participant refusal to complete the exam, equipment failure, or incorrect protocol administration. Men unable to complete an exam for physical or health reasons were included in the analysis dataset. Because of equipment failure, 509 participants (8.5% of total cohort) were also missing data for the leg power measure; the analysis dataset for this measure was smaller (N = 5393).

Physical performance

Physical performance was assessed during the baseline examination during a single baseline visit. Rigorous centralized training, examiner certification in protocol administration, and periodic protocol review during the course of the study were used to ensure consistency in the measures of physical performance.

Time to complete a walking course (s) was determined from the better of two attempts of usual walking pace over 6 m. The walking attempts were completed consecutively without a rest between attempts. To test balance, men were asked to stay within a narrow walking path (20 cm) over 6 m. Men with two or fewer deviations from the path were considered to have successfully completed the trial, and a time for completion was recorded. A deviation occurred when a participant stepped outside the path or relied on a wall or the test administrator to maintain balance. If a participant had three or more deviations, the trial was considered unsuccessful. Participants were allowed up to three attempts to complete two successful narrow walk trials. The fastest time (s) of the successful trial(s) was analyzed, and a participant was considered unable to complete this measure if he had no successful trials after three attempts.

Leg power (W) was ascertained using the Nottingham Power Rig (Nottingham University, Nottingham, UK).[19,20] Participants completed up to nine measurements on each leg separately; the overall maximal leg power from both legs was analyzed. Additionally, each participant was asked to rise from a standard chair once without using his arms to stand. If he was unable to do this, he was considered unable to complete a single chair stand. If he was able to rise one time successfully, he was asked to rise from a chair five times without using his arms; time to complete the five chair stands was recorded. Men unable to complete the single measure or the repeated stand test were considered unable to complete the repeated chair stands exam. In analysis of a small subsample of the MrOS participants (N = 55), the test–retest reliability of the Nottingham Power Rig was estimated (unpublished data). CVs for between-examiner consistency ranged from 2.6% to 3.5%, and the CVs representing the combination of within-examiner variance, within-participant variance, and machine variance were <11%.

Grip strength was measured using Jamar dynamometers[21] (Sammons Preston Rolyan, Bolingbrook, IL, USA). The maximum effort from two trials of both hands was analyzed. Men with a recent injury or new weakness in the hands or wrists could elect to skip this assessment, in which case they were considered unable to complete the grip strength assessment.

Fracture outcomes

Every 4 mo, study participants were contacted by a mailed questionnaire and asked to report recent fractures. When a participant did not return a mailed questionnaire in a timely fashion, clinic staff contacted the participant's next of kin. Clinical staff were usually notified of a participant's death through these contacts for missing questionnaires. Death certificates were reviewed by physician adjudicators to validate cause and date of death. Response to the mailed questionnaires exceeded 99%. Fractures were adjudicated by centralized physician review of radiology reports. Follow-up time for these analyses averaged 5.3 yr.

Other measures

Race was by self-reported. Smoking status, alcohol use, history of falls in the previous year, and fractures since age 50 were collected in interviews and questionnaires. Alcohol use was classified as none, intermittent use (<14 drinks/wk), and ≥14 drinks/wk. Height was measured on wall-mounted Harpenden stadiometers (Holtain, Dyved, UK) and weight on balance beam scales (except at the Portland site, which used digital scales) according to standardized protocols. Body mass index (BMI) was calculated as weight (kg) divided by square height (m^2). Activity level was determined from the Physical Activity Scale for the Elderly (PASE)[22]; a higher score indicated a higher activity level. Self-rated health was classified as excellent/good (compared with fair/poor/very poor) in response to the question, "Compared to other people your own age, how would you rate your overall health?" Participants were asked to bring all prescriptions (any use within last 4 wk) and nonprescription medications. Interviewers completed a medication history for each participant, including name of medication and frequency of use. All medications recorded by the clinics were stored in an electronic medications inventory database (San Francisco Coordinating Center, San Francisco, CA, USA). Each medication was matched to its ingredient(s) based on the Iowa Drug Information Service (IDIS) Drug Vocabulary (College of Pharmacy, University of Iowa, Iowa City, IA, USA). Use of antidepressants (selective serotonin reuptake inhibitors [SSRIs] and/or tricyclic antidepressants [TCAs]) was determined. A surrogate measure of depression was collected. Participants were asked, "How much of the time during the past 4 weeks have you felt downhearted or blue?" Participants who responded "All of the time," "Most of the time," "A good bit of the time," or "Some of the time" were classified as having a depressed mood; participants who responded "A little of the time" or "None of the time" were classified as not having a depressed mood. Participants also reported a history of a physician diagnosis of the following medical conditions: stroke, diabetes, hyperthyroidism, hypothyroidism, Parkinson's disease, heart attack, congestive heart failure, chronic obstructive pulmonary disease (COPD), and cancer (non-skin). Femoral neck BMD was measured using Hologic 4500 DXA machines; the maximum percent difference between scanners was 1.2%. DXA scans were analyzed at each clinical center, with a centralized review of a random subset of scans and all problematic scans identified by technicians at the clinics.

Statistical analysis

Participant characteristics were compared by level of performance for each physical performance exam separately. ANOVA was used for continuous variables and χ^2 tests for categorical variables. χ^2 tests for categorical variables and *t*-tests for continuous variables were used to compare men excluded from analyses (because of missing data) to the analysis subset. Age-adjusted hip fracture rates were calculated by ability to complete the repeated chair stands, narrow walk, or grip strength measures. Spearman's correlation coefficients (for the continuous measures of physical performance) were calculated to estimate the correlation between each of the physical performance variables.

Cox proportional hazard models were used to model risk of first hip fracture associated with poor performance on the physical performance exams. Grip strength, narrow walk, and chair stands performance were analyzed as quartiles, with an additional category for those unable to complete the measure. The main analysis variable for the chair stands protocol was the ability or time to rise from a chair five times without the use of the arms. Walking pace and leg power were analyzed as quartiles; inability to complete a measure was not assessed for leg power and was not applicable to walking speed, because ability to walk without assistance was an entrance criterion for the study. Race/ethnic status was analyzed in three groups: white non-Hispanic, black non-Hispanic, and a third group that included men of other races or ethnic backgrounds. For all physical performance exams, the best performance quartile was defined as the referent category. For chair stands, a subanalysis was completed. To determine the association of inability to complete a single chair stand and hip fracture risk, the rates of hip fracture were determined for this definition (ability to stand once versus unable to stand once). Additionally, hazard ratios to estimate risk of hip fracture for inability to stand once (compared with ability to rise one time without the use of the arms) were calculated.

For each physical performance exam, age- and clinical center–adjusted models were performed. Multivariate models were constructed using backward selection, with a covariate retention threshold of $p < 0.10$. Covariates considered for inclusion in the multivariate models were associated with a majority of the physical performance variables at the $p < 0.10$ level and were known to be associated with the outcome (hip fractures) in this cohort. Clinical center was forced into the models to account for intersite differences in measures.

To determine the independent effects of each physical performance measure, all five measures (as four- or five-level categorical variables) were added to the same age- and clinical center–adjusted model. Variance inflation factors (VIFs) were calculated for the physical performance variables in a single model. All VIFs were <2, signifying that the variables were not collinear and could be included in the same model.

Finally, to determine the effects of concurrent poor performance in several physical performance tests, a summary score for the measures was created. The possible values of the summary score ranged from 0 to 5, with 0 indicating the ability to perform all tests and 5 indicating poor performance on all five tests. For each test with poor performance (defined as in the worst performance quartile or unable to complete the measure), one point was added to the score. Next, the risk of hip fracture by category of the summary score (0, 1–2, 3 or more) was estimated in both the age- and clinical center–adjusted model and the multiply adjusted model.

RESULTS

During 5.3 yr of follow-up, 77 men (1.3%) experienced at least one hip fracture. Men who were excluded from the main analysis dataset ($N = 93$) because of missing data were older, had worse self-rated health, had more comorbidities, and had less physical activity than the men included in the analysis data set ($p < 0.05$ for all).

Men with the best performance on the repeated chair stands exam tended to be healthier, report fewer comorbidities, and have better health habits than men with worse performance (Table 1). Comparisons of participant characteristics by category of performance for the other neuromuscular exams were performed, and results tended to be similar (data not shown).

Inability to complete a test of physical performance was rare, because only 2.3% were unable to complete the repeated chair stands; 8.0% were unable to complete the narrow walk and 1.6% were unable to complete the grip strength measure. Men unable to complete a physical performance measure had higher rates of hip fractures than men who completed the measure (Table 2). For example, the age-adjusted rate of hip fractures was 11.2 per 1000 person-years (95% CI: 2.1–20.3) for men unable to complete the repeated chair stands and only 2.3 (95% CI: 1.7–2.8) for men able to do the measure. Similarly, the age-adjusted rate of hip fracture for men unable to stand once ($N = 104$) was 6.9 (95% CI: 0.2, 13.7) per 1000 person-years; for men able to stand once, the rate of hip fractures was 2.3 (95% CI: 1.8, 2.9) per 1000 person-years.

Lower performance on most exams was associated with an increased risk of hip fracture. The association between

TABLE 1. CHARACTERISTICS OF PARTICIPANTS IN THE MROS STUDY, BY CATEGORY OF PERFORMANCE ON THE REPEATED CHAIR STANDS EXAM

		Quartile of time to complete five chair stands				
Characteristic, N (%) or mean	*Unable (N = 135)*	*Slowest quartile: 12.6–56.8 s (N = 1442)*	*Quartile 3: 10.5–12.6 s (N = 1450)*	*Quartile 2: 9.0–10.5 s (N = 1423)*	*Fastest quartile: 3.5 to <9.0 s (N = 1435)*	*p*
White, non-Hispanic	108 (80.0%)	1326 (92.0%)	1285 (88.6%)	1278 (89.8%)	1264 (88.1%)	<0.001
Excellent/good health status	71 (52.6%)	1120 (77.7%)	1279 (88.2%)	1267 (89.0%)	1332 (92.8%)	<0.001
Smoking status: current	5 (3.7%)	54 (3.7%)	53 (3.7%)	50 (3.5%)	40 (2.8%)	0.050
Smoking status: past	84 (62.2%)	894 (62.0%)	866 (59.7%)	812 (57.1%)	819 (57.1%)	
Smoking status: never	46 (34.1%)	494 (34.3%)	531 (36.6%)	560 (39.4%)	576 (40.1%)	
Any nontrauma fracture since age 50	48 (35.6%)	293 (20.3%)	218 (15.0%)	231 (16.2%)	216 (15.1%)	<0.001
One or more medical conditions	100 (74.1%)	893 (61.9%)	729 (50.3%)	663 (46.6%)	601 (41.9%)	<0.001
Stroke	20 (14.8%)	112 (7.8%)	78 (5.4%)	72 (5.1%)	49 (3.4%)	<0.001
Diabetes	28 (20.7%)	212 (14.7%)	154 (10.6%)	124 (8.7%)	108 (7.5%)	<0.001
High thyroid	2 (1.5%)	33 (2.3%)	27 (1.9%)	18 (1.3%)	15 (1.1%)	0.069
Low thyroid	13 (9.6%)	124 (8.6%)	96 (6.6%)	93 (6.5%)	78 (5.4%)	0.010
Parkinson's disease	6 (4.4%)	17 (1.2%)	13 (0.9%)	8 (0.6%)	4 (0.3%)	<0.001
Heart attack	20 (14.8%)	275 (19.1%)	202 (13.9%)	158 (11.1%)	155 (10.8%)	<0.001
Congestive heart failure	17 (12.6%)	117 (8.1%)	66 (4.6%)	57 (4.0%)	48 (3.3%)	<0.001
COPD	23 (17.0%)	198 (13.7%)	152 (10.5%)	142 (10.0%)	113 (7.9%)	<0.001
Non-skin cancer	33 (24.4%)	303 (21.0%)	272 (18.8%)	236 (16.6%)	225 (15.7%)	0.001
Antidepressant use	5 (3.9%)	78 (5.7%)	94 (6.9%)	90 (6.7%)	80 (5.8%)	0.447
Depressed mood	36 (26.7%)	273 (18.9%)	214 (14.8%)	195 (13.7%)	169 (11.8%)	<0.001
Fall in past year	67 (49.6%)	355 (24.6%)	296 (20.4%)	251 (17.6%)	260 (18.1%)	<0.001
Alcohol use: none	69 (51.1%)	563 (39.1%)	508 (35.1%)	466 (32.8%)	468 (32.6%)	<0.001
Alcohol use: intermittent to <14 drinks/wk	56 (41.5%)	709 (49.2%)	764 (52.8%)	790 (55.6%)	798 (55.7%)	
Alcohol use: ≥14 drinks/wk	10 (7.4%)	168 (11.7%)	175 (12.1%)	166 (11.7%)	168 (11.7%)	
Femoral neck BMD (g/cm^2)	0.744	0.778	0.790	0.782	0.792	<0.001
Age (yr)	77.2	75.5	73.7	72.8	71.9	<0.001
Body mass index (kg/m^2)	28.0	27.9	27.5	27.2	26.8	<0.001
Height (cm)	174.1	174.9	174.6	173.7	173.3	<0.001
Weight (kg)	84.9	85.4	84.1	82.3	80.5	<0.001
PASE score	100.8	131.1	145.7	153.8	162.9	<0.001

Data were missing for 17 participants that were able to complete five chair stands but did not have a valid time. Data were also missing for the following measures and number of participants: health status ($n = 1$), smoking status ($n = 1$), fracture history ($n = 1$), alcohol intake ($n = 7$), BMI ($n = 2$), height ($n = 2$), and PASE ($n = 3$).

COPD, chronic obstructive pulmonary disease; PASE, Physical Activity Scale for the Elderly (higher score indicates higher activity level).

TABLE 2. RATES OF HIP FRACTURE BY ABILITY TO COMPLETE TEST OF PHYSICAL PERFORMANCE

Test of physical performance	*Number of fractures*	*Age-adjusted rate per 1000 person-years (95% CI)*
Repeat chair stands		
Unable ($N = 135$)	9	11.2 (2.1, 20.3)
Able ($N = 5767$)	68	2.3 (1.7, 2.8)
Narrow walk		
Unable ($N = 471$)	16	4.5 (1.2, 7.8)
Able ($N = 5431$)	61	2.3 (1.7, 2.9)
Grip strength		
Unable ($N = 95$)	5	12.0 (1.0, 23.0)
Able ($N = 5807$)	72	2.3 (1.8, 2.9)

poor performance and hip fracture risk tended to be modest. Risk of fracture was more pronounced for a few measurements. The strongest associations were seen for the repeated chair stands test; the narrow walk balance test; and inability to do the grip strength test. Men who were unable to rise from a chair five times without the use of their arms were approximately eight times more likely to experience a hip fracture than men who completed the chair stands test in the fastest quartile after multivariate adjustment (hazard ration[HR]: 8.15; 95% CI: 2.65, 25.03; Table 3). Men in the slowest quartiles of time to complete the repeated chair stands test also had an increased risk of hip fracture (multivariate HR: 3.60; 95% CI: 1.39, 9.37). In additional subanalyses, we evaluated the risk of hip fracture in men who were unable to complete the chair stands compared with men who were able to complete the measure (referent group). For the main analyses, the referent group was men who completed the chair stands in the fastest quartile; in these subanalyses, the referent group was men who were able to complete the chair stand tests. Men who were unable to stand once had an increased risk of hip fracture (multivariate HR: 3.19; 95% CI: 1.56, 6.50) compared with men who could rise once. Similarly, men who could not stand five times repeatedly were also more likely to experience a hip fracture (multivariate HR: 2.42; 95% CI: 1.04, 5.67) compared with men who could complete the repeated chair stands task.

TABLE 3. HAZARD RATIO (95% CI) OF HIP FRACTURE BY CATEGORY OF PHYSICAL PERFORMANCE

Test of physical performance	*Age- and clinical site–adjusted*	*Multiple-adjusted**
Repeated chair stands		
Unable	12.59 (4.08, 38.85)	8.15 (2.65, 25.03)
Quartile 4 (worst time, ≥12.6 s)	4.73 (1.82, 12.28)	3.60 (1.39, 9.37)
Quartile 3 (≥10.5 to <12.6 s)	3.02 (1.12, 8.16)	2.70 (1.00, 7.33)
Quartile 2 (≥9.0 to <10.5 s)	1.85 (0.63, 5.42)	1.61 (0.55, 4.72)
Quartile 1 (best time, <9.0 s)	1.00 (referent)	1.00 (referent)
p for trend	<0.001	<0.001
N	5885	5883
Per SD increase in time to complete test (3.30 s)	1.32 (1.16, 1.50)	1.31 (1.13, 1.51)
N	5750	5748
Leg power		
Quartile 1 (worst power, <164.7 W)	2.20 (0.78, 6.25)	1.21 (0.41, 3.53)
Quartile 2 (≥164.7 to <206.4 W)	1.20 (0.41, 3.51)	0.78 (0.26, 2.31)
Quartile 3 (≥206.4 to <247.8 W)	0.97 (0.31, 3.09)	0.78 (0.24, 2.51)
Quartile 4 (best power, ≥247.8 W)	1.00 (referent)	1.00 (referent)
p for trend	0.035	0.383
N	5393	5391
Per SD decrease in maximal leg power (62.9 W)	1.75 (1.23, 2.50)	1.46 (1.01, 2.11)
N	5393	5391
Narrow walk		
Unable	4.70 (1.50, 14.76)	3.53 (1.11, 11.23)
Quartile 4 (worst time, ≥6.2 s)	4.71 (1.63, 13.59)	3.70 (1.27, 10.83)
Quartile 3 (≥5.2 to <6.2 s)	2.50 (0.82, 7.60)	2.24 (0.73, 6.85)
Quartile 2 (≥4.5 to <5.2 s)	1.42 (0.41, 4.86)	1.39 (0.41, 4.77)
Quartile 1 (best time, <4.5 s)	1.00 (referent)	1.00 (referent)
p for trend	<0.001	0.003
N	5901	5899
Per SD increase in time to complete test (1.98 s)	1.15 (1.07, 1.24)	1.14 (1.05, 1.25)
N	5430	5429
Walking speed		
Quartile 4 (worst time, ≥5.4 s)	3.04 (1.38, 6.68)	2.41 (1.09, 5.35)
Quartile 3 (≥4.8 to <5.4 s)	1.42 (0.60, 3.34)	1.30 (0.55, 3.06)
Quartile 2 (≥4.3 to <4.8 s)	0.92 (0.34, 2.45)	0.86 (0.32, 2.30)
Quartile 1 (best time, <4.3 s)	1.00 (referent)	1.00 (referent)
p for trend	<0.001	0.003
N	5902	5900
Per SD increase in time to complete test (1.22 s)	1.24 (1.15, 1.33)	1.28 (1.17, 1.40)
N	5902	5900
Grip strength		
Unable	6.50 (1.94, 21.77)	4.50 (1.32, 15.35)
Quartile 1 (worst strength, <36 kg)	2.44 (0.97, 6.15)	1.63 (0.65, 4.14)
Quartile 2 (≥36 to <42.0 kg)	1.44 (0.55, 3.75)	1.03 (0.39, 2.69)
Quartile 3 (≥42.0 to <48.0 kg)	2.02 (0.79, 5.16)	1.83 (0.72, 4.70)
Quartile 4 (best strength, ≥48 kg)	1.00 (referent)	1.00 (referent)
p for trend	0.017	0.184
N	5902	5900
Per SD decrease in strength (8.48 kg)	1.27 (0.97, 1.66)	1.08 (0.82, 1.43)
N	5807	5805

* Adjusted for age, clinical center, femoral neck bone mineral density, body mass index, history of heart attack and history of stroke.

Generally, measures of leg power and grip strength were modestly associated with hip fracture risk. (Table 3) However, men unable to complete the grip strength measure had an increased risk of hip fracture compared with men with the best grip strength (multivariate HR: 4.50; 95% CI: 1.32, 15.35). Performance on the narrow walk and usual pace were also associated with modestly increased hip fracture risk.

Among men able to complete the tests, poorer performance time or lower strength was associated with an increased risk of hip fracture. For example, each SD increase in time to complete the usual pace walk (1.22 s) was associated with a modest increase in risk of hip fracture (HR: 1.28; 95% CI: 1.17, 1.40) in multivariate models.

Correlations between all the physical performance variables were statistically significant and tended to be low to moderate in magnitude. The highest correlations were seen between time to complete the usual pace walking test and time to complete the narrow walk ($r = 0.64$); leg power and grip strength ($r = 0.54$); and time to complete the repeated

TABLE 4. SPEARMAN CORRELATION COEFFICIENTS FOR CONTINUOUS MEASURES OF PHYSICAL PERFORMANCE IN OLDER MEN

	Leg power	*Narrow walk time*	*Repeated chair stand time*	*Walking time*
Grip strength	0.54 (N=5315)	−0.28 (N = 5350)	−0.21 (N=5661)	−0.29 (N=5807)
Walking time	−0.36 (N=5393)	0.64 (N = 5430)	0.42 (N=5750)	
Chair stand time	−0.30 (N=5290)	0.34 (N = 5328)		
Narrow walk time	−0.33 (N=5017)			

All correlations significant at $p < 0.001$.

chair stands and usual pace walking test ($r = 0.42$; Table 4). When all five measures of physical performance (as four- or five-level categorical variables) were added to the same model, only repeated chair stands remained independently associated with hip fracture risk ($p < 0.05$) for both age and clinical center models, and multivariate models.

Men with poor performance (poorest performing quartile or unable to complete the measure) on three or more of the exams had more than three times the risk of hip fracture (multivariate HR: 3.14; 95% CI: 1.46, 6.73; Table 5) compared with the highest functioning group. In addition, of the 77 incident hip fractures, nearly two thirds (N = 49, 64%) occurred in men with poor performance on three or more measures. Men with intermediate performance (poor performance on one to two of the tests) had an intermediate but nonsignificant increased risk of hip fracture compared with men with high performance on all exams (age- and clinical center–adjusted HR for hip fractures: 1.25; 95% CI: 0.57, 2.74).

DISCUSSION

Poor performance on physical performance tests was associated with an increased risk of hip fracture over 5 yr of follow-up in this cohort of older, community-dwelling men. Inability to complete an exam, or performance in the worst quartile for an exam, tended to be associated with an increased risk of hip fractures. The inability to complete the repeated chair stand examination was strongly related to hip fracture risk. Results from multivariate analyses showed that men who were unable to complete five consecutive chair stands were much more likely to suffer a hip fracture than men who completed the measure in the fastest time. Coexisting poor performance on several exams was also associated with an increased risk of hip fracture, because men with poor performance on three or more physical performance tests (inability or performance in the worst quartile) had a 3-fold greater risk of hip fracture than men who did not have poor performance in any of the measures.

Inability to rise from a chair repeatedly is also an independent risk factor for hip fracture in older white women and remained significant after multivariate adjustment.[15] Several factors may explain the especially strong association between repeated chair stand performance and hip fracture risk. For example, the ability to complete repeated chair stands may be a more complex measure than the other physical performance exams, because repeated chair stands require strong legs, good agility, coordination, and balance. Ability to complete a repeated chair stand examination may be easy to assess in a clinical setting. Clinicians would simply ask an older male patient to attempt to rise five times consecutively without using his arms. If the patient was unable to rise all five times, it is likely that he would be at high risk for subsequent hip fracture compared with men who could easily complete the measure.

Walking speed and the narrow walk exam (a test of balance) were weakly associated with risk of hip fracture. Ability to walk without assistance was an entrance criterion for the study. Therefore, MrOS participants do not represent the full spectrum of walking difficulties; those who require assistance with walking are likely to walk more slowly than those who do not need assistance to walk. The association between walking speed and hip fracture risk may be different in a cohort with walking difficulties.

Inability to complete the grip strength test, which is likely a marker for significant muscle weakness, was associated with hip fracture risk. Performance on the grip strength measure (analyzed by quartiles of strength or by SD decrease in strength) was not associated with hip fracture risk after multivariate adjustment. Grip strength performance may be more strongly related to fractures at other skeletal locations, such as wrist fractures. However, upper extremity strength does not seem to be strongly related to hip fracture risk. After multivariate adjustment, leg power (when analyzed as quartiles) was not associated with hip fracture risk. However, when leg power was analyzed as a continuous variable in multivariate models, each SD decrease in leg power was associated with a 46% increased risk of hip fracture. From these results, we conclude that poor leg power is weakly associated with increased hip fracture risk. Results from these analyses are similar to previous reports in MrOS that showed that men with greater leg power and grip strength had a decreased risk of falls.[23]

Multivariate adjustment somewhat attenuated the association between poor physical performance and risk of hip fracture; however, the association between poor performance and hip fracture risk tended to be independent of femoral neck BMD, which is a strong risk factor for fracture in older men.[24,25] This implies that poor physical performance is associated with increased hip fracture risk through pathways that do not influence BMD, such as through increased fall risk.

Exercise interventions for frail and healthy older adults, including home-based prescriptions and group exercise classes, have proven effective for improving physical performance, including lower extremity strength[7–14] and power,[26,27] static and dynamic balance,[9,11,12,29,30] gait velocity,[8,10,28,30] and overall fall risk.[31,32] It is hypothesized that such improvements in physical performance may translate into reduced fracture risk, but to date, there has been

TABLE 5. SUMMARY SCORE FOR POOR PERFORMANCE ON PHYSICAL PERFORMANCE EXAMS AND RISK OF HIP FRACTURE

			Hazard ratio (95% CI)	
	N	*Fractures (N)*	*Age- and clinical site–adjusted*	*Multiple-adjusted**
Summary score 3–5 (worst functioning)	1171	49	4.75 (2.24, 10.07)	3.14 (1.46, 6.73)
Summary score 1–2	2404	18	1.25 (0.57, 2.74)	1.03 (0.47, 2.27)
Summary score 0 (best functioning)	2327	10	1.00 (referent)	1.00 (referent)

* Adjusted for age, clinical center, femoral neck BMD, body mass index, history of heart attack, and history of stroke.

little evidence available to test this thesis. The results of this study show that physical performance is an important determinant of hip fracture risk in older men, and they suggest that the largest reductions in fracture risk would likely be realized by exercise interventions that could effectively retrain older men to complete physical performance tasks that they were unable to complete at trial entry. These data also suggest that physical performance tests, particularly repeated chair stands, are an important functional outcome to evaluate in exercise intervention trials with older men.

These analyses have many strengths. The participants in this large, well-characterized cohort had multiple measures of physical performance and excellent response rates during the follow-up period. However, some limitations should be noted. All participants in MrOS must have been able to walk without assistance of another person or aide at the baseline examination and were generally in good health and well educated compared with the population-based samples such as the NHANES cohort (National Health and Nutrition Examination Survey).[18] Generalizability of these findings to less mobile populations, less healthy or institutionalized groups, and to women may be limited. Missing data for some measures was fairly high, especially the leg power measure, which may have limited our ability to detect modest or weak associations. Only hip fracture outcomes were analyzed in this paper; the relationship between physical performance and other fracture outcomes, such as vertebral, wrist, or rib fractures, may be different.

In conclusion, poor performance on objective tests of physical performance, especially inability to complete repeated chair stands, is associated with an increased risk of hip fracture in older men. This association was independent of femoral neck BMD. Ability to complete a simple repeated chair stands exam might be of value in clinical settings when evaluating hip fracture risk and as an endpoint in exercise intervention studies.

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対象の内訳		ヒト	動物	地 域	欧米	研究の種類	縦断研究
	対象	一般健常者	空白		( )		コホート研究
	性別	男性	( )		( )		( )
	年齢	65歳以上			( )		前向き研究
	対象数	5000～10000			( )		( )
調査の方法	実測	( )					
アウトカム	予 防	な し	な し	な し	転倒・骨折予防	( )	( )
	維持・改善	な し	な し	な し	な し	( )	( )

図 表

TABLE 3. HAZARD RATIO (95% CI) OF HIP FRACTURE BY CATEGORY OF PHYSICAL PERFORMANCE

Test of physical performance	Age- and clinical site-adjusted	Multiple-adjusted*
Repeated chair stands		
Unable	12.59 (4.08, 38.85)	8.15 (2.65, 25.03)
Quartile 4 (worst time, ≥12.6 s)	4.73 (1.82, 12.28)	3.60 (1.39, 9.37)
Quartile 3 (≥10.5 to <12.6 s)	3.02 (1.12, 8.16)	2.70 (1.00, 7.33)
Quartile 2 (≥9.0 to <10.5 s)	1.85 (0.63, 5.42)	1.61 (0.55, 4.72)
Quartile 1 (best time, <9.0 s)	1.00 (referent)	1.00 (referent)
p for trend	<0.001	<0.001
N	5885	5883
Per SD increase in time to complete test (3.30 s)	1.32 (1.16, 1.50)	1.31 (1.13, 1.51)
N	5750	5748
Leg power		
Quartile 1 (worst power, <164.7 W)	2.20 (0.78, 6.25)	1.21 (0.41, 3.53)
Quartile 2 (≥164.7 to <206.4 W)	1.20 (0.41, 3.51)	0.78 (0.26, 2.31)
Quartile 3 (≥206.4 to <247.8 W)	0.97 (0.31, 3.00)	0.78 (0.24, 2.51)
Quartile 4 (best power, ≥247.8 W)	1.00 (referent)	1.00 (referent)
p for trend	0.035	0.383
N	5393	5391
Per SD decrease in maximal leg power (62.9 W)	1.75 (1.23, 2.50)	1.46 (1.01, 2.11)
N	5393	5391
Narrow walk		
Unable	4.76 (1.50, 14.76)	3.53 (1.11, 11.23)
Quartile 4 (worst time, ≥6.2 s)	4.71 (1.63, 13.59)	3.70 (1.27, 10.83)
Quartile 3 (≥5.2 to <6.2 s)	2.50 (0.82, 7.60)	2.24 (0.73, 6.85)
Quartile 2 (≥4.5 to <5.2 s)	1.42 (0.41, 4.86)	1.39 (0.41, 4.77)
Quartile 1 (best time, <4.5 s)	1.00 (referent)	1.00 (referent)
p for trend	<0.001	0.003
N	5901	5899
Per SD increase in time to complete test (1.98 s)	1.15 (1.07, 1.24)	1.14 (1.05, 1.25)
N	5430	5429
Walking speed		
Quartile 4 (worst time, ≥5.4 s)	3.04 (1.38, 6.68)	2.41 (1.09, 5.35)
Quartile 3 (≥4.8 to <5.4 s)	1.42 (0.60, 3.34)	1.30 (0.55, 3.06)
Quartile 2 (≥4.3 to <4.8 s)	0.92 (0.34, 2.45)	0.86 (0.32, 2.30)
Quartile 1 (best time, <4.3 s)	1.00 (referent)	1.00 (referent)
p for trend	<0.001	0.003
N	5902	5900
Per SD increase in time to complete test (1.22 s)	1.24 (1.15, 1.33)	1.28 (1.17, 1.40)
N	5902	5900
Grip strength		
Unable	6.50 (1.94, 21.77)	4.50 (1.32, 15.35)
Quartile 1 (worst strength, <36 kg)	2.44 (0.97, 6.15)	1.63 (0.65, 4.14)
Quartile 2 (≥36 to <42.0 kg)	1.44 (0.55, 3.75)	1.03 (0.39, 2.69)
Quartile 3 (≥42.0 to <48.0 kg)	2.02 (0.78, 5.16)	1.83 (0.72, 4.70)
Quartile 4 (best strength, ≥48 kg)	1.00 (referent)	1.00 (referent)
p for trend	0.017	0.164
N	5902	5900
Per SD decrease in strength (8.48 kg)	1.27 (0.97, 1.66)	1.08 (0.82, 1.43)
N	5807	5805

* Adjusted for age, clinical center, femoral neck bone mineral density, body mass index, history of heart attack and history of stroke.

図表掲載箇所	P1041, Table3
概 要 (800字まで)	本研究は、アメリカのThe Osteoporotic Fractures in Men (MrOS) Studyに参加した65歳以上の男性5,902名を対象に平均5.3年間の追跡調査を行い、身体機能と腰部骨折との関連を検討したものである。6メートル歩行速度、20cm幅×6mのバランス歩行に費やす時間、最大脚力、椅子座り立ち5回に費やす時間、握力を測定した。それぞれの項目に応じて、測定値を4群に分類した。さらに、5つの項目で最下分位もしくは完遂できなかったに分類された回数を合計し、0-5の身体機能スコアで評価した。椅子座り立ちに費やす時間が9.0秒未満の集団(Q1)と比較すると、12.6秒以上費やした集団(Q4)と完遂できなかった集団で、腰部骨折リスクがそれぞれ3.60(95%信頼区間:1.39-9.37)、8.15(2.65-25.03)と有意に上昇し、バランス歩行に費やす時間が4.5秒未満の集団(Q1)と比較すると、6.2秒以上費やした集団(Q4)と完遂できなかった集団でそれぞれ3.70(1.27-10.83)、3.53(1.11-11.23)と有意なリスク上昇がみられた。歩行速度では、4.3秒未満(Q1)と比較すると、5.4秒以上(Q4)で2.41(1.09-5.35)のリスク上昇がみられた。握力では、48kg以上と比較すると、完遂できなかった集団で4.50(1.32-15.35)のリスク上昇がみられた。最大脚力に関しては、有意な差はみられなかった。身体機能スコアが0の集団と比較すると、3-5の集団で腰部骨折リスクが3.14(1.46-6.73)と有意に上昇した。
結 論 (200字まで)	高齢男性コホートの5年間の追跡調査において、身体機能の低下は腰部骨折リスクを上昇させることが明らかとなった。特に椅子座り立ちテストを完遂できない場合の腰部骨折リスク上昇が強力であった。
エキスパートによるコメント (200字まで)	筋力やバランス能力などの体力が、骨折のリスクと関連することを、男性の集団で示した貴重な研究である。骨折は高齢女性の問題であると考えられてきたが、低体力男性でもリスクが高くなることを示し点に意義がある。

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Added Value of Physical Performance Measures in Predicting Adverse Health-Related Events: Results from the Health, Aging, and Body Composition Study

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Abstract

Objectives—To determine how three different physical performance measures (PPM) combine for added utility in predicting adverse health events in elders.

Design—Prospective cohort study.

Setting—Health, Aging, and Body Composition Study.

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Marjolein Visser: interpretation of data, critical review of the manuscript.
Marco Pahor: study concept and design; analysis and interpretation of data; critical review of the manuscript; preparation of manuscript.

Participants—3,024 well-functioning older persons (mean age 73.6 years).

Measurements—Timed gait, repeated chair stands and balance (semi- and full-tandem, and single leg stands each held for 30 seconds) tests were administered at baseline. Usual gait speed was categorized to distinguish high and low risk participants using the previously established 1 m/sec cut-point. The same population-percentile (21.3%) was used to identify cut-points for repeated chair stands (17.05 sec) and balance (53 sec) tests. Cox proportional hazard analyses were performed to evaluate the added value of PPM in predicting mortality, hospitalization, and (severe) mobility limitation events over 6.9 years of follow-up.

Results—Risk estimates for developing adverse health-related events were similarly large for each of the three high risk groups considered separately. A greater number of PPM scores at the high risk level was associated with a greater risk of developing adverse health-related events. When all three PPMs were considered, having only one poor performance was sufficient to indicate a highly significant higher risk of (severe) lower extremity and mortality events.

Conclusion—Although gait speed is considered the most important predictor of adverse health events, these findings demonstrate that poor performance on other tests of lower extremity function are equally prognostic. This suggests that chair stand and standing balance performance may be adequate substitutes when gait speed is unavailable.

Keywords

Short Physical Performance Battery; Functional limitation; Death; Hospitalization; Usual gait speed

INTRODUCTION

During the last decade, physical performance measures have gained increased acceptance in the evaluation of functional status of older persons. One of the most commonly used measures of physical performance is the Short Physical Performance Battery (SPPB)[1–3]. This measure evaluates lower extremity function through tests of gait speed, standing balance, and time to rise from a chair five times. The SPPB not only provides information about physical function, but also predicts major adverse health-related events in the elderly, such as disability[1–3], nursing home admission[1], and mortality[1]. This measure also has been associated with several physiological factors, such as inflammation[4] and body composition changes[5], believed to be involved in the disablement process and which may underlie specific health-related events.

A study by Guralnik and colleagues[3] has suggested that timed usual gait, one of the three tasks, provides a predictive value for the onset of disability similar to that obtained for the complete SPPB. However, in that study, the predictive value of usual gait speed was compared with that of the total SPPB for the onset of disability, considering each physical performance measure as a continuous variable. The use of continuous measurements may have limited applicability in clinical settings, where biological markers are typically dichotomized or treated as threshold markers for providing meaningful information.

The present study aims to evaluate the added value of the three tasks included in the SPPB (i.e. usual gait speed, chair stands, and balance tests) for predicting incident adverse health-related events. Analyses will be conducted using dichotomized assessments of physical performance to mirror their potential clinical application.

METHODS

This study uses data from the Health, Aging and Body Composition (Health ABC) study, a prospective cohort study designed to investigate the impact of body composition changes and weight-related health conditions on the functional status of older adults. Participants (n=3,075), aged between 70 and 79 years, were recruited between April 1997 through June 1998, from a list of Medicare beneficiaries residing in the areas surrounding Pittsburgh, PA, and Memphis, TN. Eligibility criteria included: 1) No reported difficulty walking ¼ mile, climbing 10 steps, or performing basic activities of daily living, 2) No life-threatening illness, and 3) No plans to permanently leave the area for three years. Participants were contacted by telephone every 6 months and had annual clinic visits during which health status was assessed and data on interim hospitalizations and major outpatient procedures were collected.

The present study is based on 3,024 participants, after exclusion of 51 participants who had missing baseline values on the physical performance measures. All participants provided written informed consent. The Institutional Review Boards of the clinical sites approved the study protocol.

Physical performance measures

Three physical performance measures were considered in this analysis: usual gait speed, repeated chair stands, and standing balance tests. These measures, easy and quick to administer, have shown good reliability in elders6. The SPPB, based on similar tests, has shown to be predictive of adverse health-related outcomes in older persons1.

Usual gait speed—Participants were asked to stand stationary with their feet behind a starting line marked with tape, then, following the examiner's command of "Go!", to walk at their usual pace over a 6-meter course and to stop just past the finish line. Timing was started with the first foot fall and stopped when participant's first foot completely crossed the 6-meter end line. The faster of two trials (in meters/second) was used for the present analyses.

Repeated chair stands—Participants were asked to stand up five times in a row as quickly as possible from a chair without stopping, keeping arms folded across the chest. Participants had to come to a full standing position each time they stood up, and to sit all the way down each time. Timing was started when examiner said "Go!", and stopped when the participant sat down for the fifth time. Time (in seconds) or inability to perform the test were used for the present analyses.

Standing balance—Participants were asked to stand in the following three increasingly challenging positions for 30 seconds each: 1) semi-tandem stand, in which participants stand with the side of the heel of one foot touching the big toe of the other foot; 2) tandem stand, in which participants stand with the heel of one foot in front of and touching the toes of the other foot; and 3) single-leg stand, in which participants stand on one leg. The test was stopped when the participant could not hold a stand without support after two attempts. The total amount of time each stand was held, ranging from 0 to 90 seconds, was used for the present analyses.

Outcomes

During the study follow-up, participants were contacted by telephone every 6 months and had a clinical visit every year, during which vital/health status was assessed and data about interim hospitalizations or major outpatient procedures were collected. When an overnight hospitalization or major outpatient procedure was reported, hospital records were collected and the event verified by a Health ABC Disease Adjudicator at each site.

For the present analyses, we explored the additive value of physical performance measures in predicting each of the following outcomes:

- *Persistent lower extremity limitation.* Defined as two consecutive semi-annual reports of having any difficulty either walking ¼ mile or climbing up 10 steps without resting;
- *Persistent severe lower extremity limitation.* Defined as two consecutive semi-annual reports of having a lot of difficulty or not being able to walk ¼ mile or to climb up 10 steps without resting;
- *Death.* Date of death taken from the death certificate;
- *Hospitalization.* Any hospitalization in an acute care unit that occurred during the first year of follow-up.

Physical performance measure cut-points

In a previous paper7, we demonstrated that a usual gait speed (over a 6-meter course) slower than 1 m/sec identified older persons at high risk of health-related events. This gait speed cut-point was identified on the basis of the rates of incident persistent lower extremity limitation events in a random subsample of Health ABC participants. The remaining participants were then used to evaluate the predictive value of the identified cut-point for major health-related events. This cut-point was found to consistently predict health-related events across gender and race (Whites, Blacks) groups7. In the present analyses, we used the 1 m/sec cut-point to dichotomize usual gait speed into high and low risk performance. The balance and chair stand tests were dichotomized using the same percentile (21.3%) as the chosen usual gait speed cut-point. By choosing this same threshold to identify individuals at increased risk of health-related events, we determined equal distributions of the three physical performance measures of interest, consequently allowing fair comparisons.

An alternative approach using ROC curves analysis was also considered to categorize the physical performance measures (*results available on request*). In the ROC curve analysis, the true-positive rate (sensitivity) is plotted against the false-positive rate (1-specificity) across a range of values from a diagnostic test. Cut-points of 1.175 m/sec for usual gait speed, 77.0 sec for balance test, and 14.5 sec for chair stand test were identified by maximizing the sum of sensitivity and specificity derived on the basis of the persistent lower extremity limitation outcome.

Covariates

Covariates included sociodemographic variables (age, sex, race, study site, smoking, alcohol consumption, education), health indicators (Body Mass Index -BMI, defined as body weight divided height squared), Modified Mini-Mental State (3MS) examination score8, and physical activity -calculated using the Harvard Alumni study9 variable based on walking and exercise expenditure in kcal/week), and comorbidity (adjudicated presence of coronary heart disease, congestive heart failure, diabetes, hypertension, osteoarthritis, peripheral artery disease, cerebrovascular disease, depression, and pulmonary disease). The presence of clinical conditions at baseline was ascertained using algorithms mirroring those adopted in the Cardiovascular Health Study10 and based on self-report of physician diagnoses, current medications, and measures obtained in the clinical examination.

Statistical analyses

Unadjusted and adjusted Cox proportional hazards analyses were performed to assess hazard rate ratios (HR) and 95% confidence intervals (95%CI) for incident outcome events according to the defined risk groups for each physical performance measure (low risk groups considered as reference groups). Analyses also considering continuous variables for the physical performance measures, rescaled as previously described11, were also performed. Then, analyses were repeated to evaluate HR (and 95%CI) for incident outcome events according to the number of physical performance measures in the high risk category (participants with no physical performance measure in the high risk group served as the reference group). Analyses were adjusted for age, sex, race and those variables showing a significant ($p<0.10$) correlation with physical performance measures and/or outcome variables. The proportional hazard assumption was tested for all the variables of interest 1) using log minus log plots (to verify whether they were approximately parallel for all levels of each categorical explanatory variable), and 2) including interaction terms between time and the variables under consideration (to verify the statistical significance) as part of the Cox proportional models.

To evaluate the predictive value of categorized physical performance measures for health-related events, sensitivity, specificity, predictive values and likelihood ratios were also calculated.

For the persistent (severe) lower extremity limitation outcome, days to event were determined from the baseline assessment visit date to the date of the first of two successive reports of difficulty. For those participants who did not develop functional limitation, follow-up time was censored to the last contact or death date. For the mortality outcome, days to event were determined from the baseline assessment visit date to the date of death. For the hospitalization outcome, follow-up time was defined as the time from the baseline visit to the first hospitalization date (for those who had one) or was censored at one year of follow-up or death date if occurred within the first year (for those with no hospitalizations).

RESULTS

Mean age of the sample population (n=3,024) was 73.6 years (SD ± 2.9), 51.6% were women, and 41.2% were Black. Median follow-up duration was 6.9 years. Main sociodemographic characteristics of the sample population are described in Table 1.

Spearman's analyses were performed to evaluate the correlations among the continuous variables of the physical performance measures. Usual gait speed and chair stand tests showed the strongest correlation ($r=-0.413$; $p<0.001$). Significant, but weaker correlations were reported between the balance and usual gait speed tests ($r=0.310$; $p<0.001$), and between the balance and chair stand tests ($r=-0.271$; $p<0.001$).

In the sample population the 1 m/sec cut-point for usual gait speed corresponded to the 21.3 percentile. The same percentile was used to identify the cut-points to categorize chair stand (high risk group: ≥17.1 sec) and standing balance test (high risk group: ≤53.0 sec). Cross-tabulations and unadjusted odds ratios of dichotomous physical performance measures are reported in Table 2.

The predictive values for adverse health-related events using the identified cut-points for each physical performance measure were evaluated (Table 3). Unadjusted and adjusted Cox proportional hazard analyses showed that participants in the high risk group for usual gait speed, repeated chair stands, or standing balance were more likely to experience persistent (severe) lower extremity limitation, death and hospitalization events. The risk estimates for developing adverse health-related events were rather similar across the three physical performance measures evaluated (e.g. persistent lower extremity limitation - high risk group for usual gait speed HR 1.53, 95%CI 1.35–1.74; high risk group for standing balance test HR 1.58, 95%CI 1.40–1.78; high risk group for repeated chair stands test HR 1.59, 95%CI 1.41–1.78; all p values <0.001). The chair stand test was less strongly associated with new hospitalizations than the other two performance measures after adjustment for potential confounders (HR 1.20, 95%CI 0.97–1.49; p=0.09).

Significant race interactions (both p values for interaction terms <0.01) were found for the relationship between number of high risk physical performance measures and onset of mobility limitation outcomes. The hazard ratios associated with number of high physical performance measures were highly significant in both race groups (p values for trend <0.001), but lower in Blacks (e.g. persistent lower extremity limitation - one physical performance measure: HR 1.32, 95%CI 1.09–1.59; two physical performance measures: HR 1.66, 95%CI 1.33–2.07; three physical performance measures: HR 2.18, 95%CI 1.67–2.85) compared to Whites (one physical performance measure: HR 1.81, 95%CI 1.52–2.14; two physical performance measures: HR 2.56, 95%CI 2.02–3.24; three physical performance measures: HR 3.92, 95%CI 2.60–5.92). No race interaction was detected for the other outcomes. No significant sex interaction was found between number of high risk physical performance tests and onset of any outcome evaluated.

The added value of each additional physical performance measure to the prediction of adverse health-related events was also investigated using Cox proportional hazard models (Figure 1). For each outcome there was a monotonic increase in the event rate with an increasing number of functional criteria. Any single criterion was associated with a significantly higher risk of all outcomes except for hospitalization. In this case, two or more criteria predicted a new hospitalization in the following year.

In Table 4 (and Supplemental Table), we also presented sensitivity, specificity, predictive values and likelihood ratios for different combinations of physical performance measures at high risk for health-related events. Each single measure of physical performance was characterized by a high specificity (higher than 80%) and low sensitivity (lower than 30%).

When analyses were repeated considering physical performance measures categorized according to cut-points derived from ROC curves analysis, similar findings were obtained *(data available on request)*. However, in this alternative approach, the predictive value of the chair stand test was consistently lower than the other physical performance measures.

DISCUSSION

To our knowledge, this is the first study to systematically evaluate the added value of using up to three dichotomized physical performance measures in the prediction of several adverse health-related events. The present analyses were specifically aimed at evaluating whether differences in the predictive value for events were present among the three components of the SPPB (i.e. timed usual gait speed, repeated chair stands and standing balance). Our findings demonstrate that poor performance on any one of these three commonly administered performance tests present similar predictive values for major events, although slow usual gait speed and balance test showed the most consistent results. When the three physical performance measures were considered together, a direct association between the number of impaired tests and risk of events was reported. However, having only a single physical performance measure at high risk was significantly and strongly associated with risk of persistent (severe) lower extremity limitation and mortality outcomes. When all three measures were considered together, a significant prediction of hospitalization events could only be reached when all tests showed poor results. No combination of physical performance tests was clearly superior in the prediction of events, and different results were reported for different outcomes. Interestingly, each single physical performance test was characterized by a high specificity for all the study outcomes. This finding clearly confirm the importance of all these measures in the screening process of older persons by 1) correctly identifying negative cases, and 2) consequently avoiding further (and sometime burdensome) investigations in low risk individuals.

It has been suggested that timed gait alone predicts disability nearly as well as the full SPPB[3] when the physical performance measures are considered as continuous variables, a rare practice in a clinical setting. Whether this observation would hold when performances on tests were examined as dichotomous variables as it is frequently done in clinical settings with most biological markers, was unknown. The present analyses evaluated the added value of physical performance measures for the prediction of health-related events after categorization into high and low risk groups. Our findings showed that timed usual gait speed, standing balance and repeated chair stand tests have similar utility in identifying subjects who will develop events.

However, the combination of the three measures leads to only a marginal gain in the prediction of physical disability and mortality outcomes. These results confirm that the timed usual gait speed (but also the balance and chair stand tests) is almost as good as the complete SPPB in identifying older persons at risk of physical disability events[3]. Therefore, even though gait speed is considered the most important predictor of several adverse health events, these findings demonstrate that poor performance on other tests of lower extremity function are equally prognostic. Therefore, chair stand and standing balance performance may be adequate substitutes when gait speed is unavailable. This is particularly valuable and applicable to studies that do not or can not include gait testing due to lack of space.

Our findings from Cox proportional hazard models show that single measures of physical performance are less predictive of hospitalization events compared to physical disability and mortality outcomes, though the simultaneous evaluation of all three physical performance tests does provide significant risk prediction. This finding may be explained in two different ways. First, physical performance measures were originally developed with physical disability as the "gold standard" outcome. Therefore, the stronger association with incident physical disability (and mortality as correlate of overall health status) compared to hospitalization is not unexpected. Second, even if our hospitalization outcome was defined on the basis of overnight hospital stays, it is likely to be an heterogenous outcome, composed of severe as well as mild clinical cases, and clinical events that might not be function related (e.g. plastic surgery).

Despite strong evidence that physical performance measures play an important role in the evaluation of older persons, their clinical use is still very limited[12,13]. Several problems may inhibit wider usage. Some physical performance measures are time consuming and need special equipment and/or training. This study explored three physical performance tests that are quick and easy to perform and do not require special equipment or training. A second major issue limiting clinical use of physical performance measures concerns the hard to remember and often population-based cut-points currently available in literature[2,14–19]. Previously[7], we identified a cut-point for the 6-meter walking speed (1 m/sec) for a study sample aged 70–79 years based on subsequent risk of functional limitation. The delineation of an easy to remember cut-point for gait speed will hopefully encourage systematic assessment of gait speed in older persons. In the present study, we dichotomized performance on the balance and chair stand tests on the basis of the population-percentile corresponding to the newly established usual gait speed cut-point, to allow a fair comparison across the different tests.

Using this approach[7], we found that inability to complete the chair stand test within 17 seconds identified participants at high risk of functional limitation. This cut-point is very similar to those suggested by previous papers in which 16.3[20], 16.5[21], or 16.7[2,3,6] seconds cut-points were used to identify participants scoring one point (on a scale ranging from 0 to 4, whereas higher result is indicative of better performance) in the SPPB score.

The standing balance test in the SPPB consists of three 10-second long tasks: the side-by-side, the semi-tandem, and the full tandem position[2]. The 30 seconds that participants were asked to hold each progressively more difficult stand and the final one-leg stand evaluation make the version used here more challenging for older persons. The original balance test is a relatively easy task of physical performance and it is often successfully completed by a high percentage of older persons[22]. The cut-point we identified approximately corresponds to the inability to hold a one-leg stand. Thus, it might be easy to remember and may facilitate the implementation of this measure. This means that, instead of the three tasks evaluating the standing balance, it may be sufficient only to ask the subject attempt only the one-leg stand to identify persons at high risk of adverse health-related events.

All cut-points identified have been shown to predict several adverse health-related events, such as (severe) mobility limitation, hospitalization, and death. These findings confirm results from previous studies[1,15,23] and strengthen the recommendation to consider these measures as indicators of age-related body changes and/or markers of (sub)clinical disease.

In our analyses we found significant race interactions in the relationships between number of high risk physical performance tests and onset of persistent (severe) lower extremity limitation. Interestingly, these race differences were observed for the mobility limitation outcomes, only. These findings, consistent with a previous study[7], may suggest that the relationship between the SPPB and onset of mobility limitation is more affected by the presence of potential confounders compared to the mortality and hospitalization outcomes. The use of additional measures may be particularly desirable in Black older adults to obtain a better evaluation of risk of mobility disability events.

The Health ABC population consists of well-functioning non-disabled persons, aged 70 to 79 years. Thus, the cut-points identified for usual gait speed, chair stands, and standing balance tests likely represent normative values. These values may also serve as targets for interventions aimed toward improving physical performance and provide useful parameters to evaluate intervention efficacy in reducing risk of health-related events. Most studies evaluating change over time in functional performance have only described improvements in physical performance[16,24–26], and not whether meaningful thresholds have been obtained. It is also noteworthy that our results may be useful for evaluating older persons in which a disabling process is not yet clinically evident, providing basis for the development of a "real" preventive program.

Some limitations of the present study should be mentioned. Although a loss of information may occur when continuous variables are dichotomized, the provision of cut-points is essential for promoting the use of physical performance measures for the screening and evaluation of older persons. The three components of the SPPB administered to the Health ABC study participants were slightly modified from the original version[1] to provide more challenging tests to a well-functioning and selected older population. It might be argued that these modifications may limit the applicability of the present results to the original version of the SPPB. However, given the similar nature of the Health ABC subtasks compared to the original ones, we believe that this potential issue may not significantly limit the export of our results. Further studies should expand our findings to different age groups and evaluate whether interventions aimed at improving physical performance measures24–26 are able to prevent adverse health-related outcomes. Our choice to define the cut-points for the considered physical performance measures on the basis of a previously validated cut-point7 and the population distribution might be arguable. However, alternative analyses *(available on request)* using cut-points based on specificity and sensitivity of the physical performance measures for predicting persistent lower extremity limitation were performed and led to similar results.

In conclusion, our findings demonstrate that dichotomized physical performance measures (i.e. usual gait speed, chair stand, and balance tests), which may facilitate use of these measures in clinical practice, provide similar predictive values for adverse health-related events when considered separately. Participants with poor results for all three measures had a higher risk of incident functional limitation, hospitalization and death compared to those with normal values on all of them. Estimating risk for incident physical disability and mortality may not require administration of all three physical performance tests, since a single measure provides significant prediction. However, the predictive value does increase with an increasing number of tests. The value of this increasing predictive ability may be offset by increasing the complexity of administering and interpreting multiple tests in a clinical setting.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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