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Original Study

Associations of Walking Speed, Grip Strength, and Standing Balance With Total and Cause-Specific Mortality in a General Population of Japanese Elders

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A B S T R A C T

Objectives: Walking speed, grip strength, and standing balance are key components of physical performance in older people. The present study aimed to evaluate (1) associations of these physical performance measures with cause-specific mortality, (2) independent associations of individual physical performance measures with mortality, and (3) the added value of combined use of the 3 physical performance measures in predicting all-cause and cause-specific mortality.
Design: Prospective cohort study with a follow-up of 10.5 years.
Setting: Tokyo Metropolitan Institute of Gerontology Longitudinal Interdisciplinary Study on Aging (TMIG-LISA), Japan.
Participants: A total of 1085 initially nondisabled older Japanese aged 65 to 89 years.
Measurements: Usual walking speed, grip strength, and standing balance were measured at baseline survey.
Results: During follow-up, 324 deaths occurred (122 of cardiovascular disease, 75 of cancer, 115 of other causes, and 12 of unknown causes). All 3 physical performance measures were significantly associated with all-cause, cardiovascular, and other-cause mortality, but not with cancer mortality, independent of potential confounders. When all 3 physical performance measures were simultaneously entered into the model, each was significantly independently associated with all-cause and cardiovascular mortality. The C statistics for all-cause and cardiovascular mortality were significantly increased by adding grip strength and standing balance to walking speed ($P < .01$), and the net reclassification improvement for them was estimated at 18.7% and 7.5%, respectively.
Conclusion: Slow walking speed, weak grip strength, and poor standing balance predicted all-cause, cardiovascular, and other-cause mortality, but not cancer mortality, independent of covariates. Moreover, these 3 components of physical performance were independently associated with all-cause and cardiovascular mortality and their combined use increased prognostic power.

Recent systematic reviews and meta-analyses[1,2] have confirmed that physical performance measures, including walking speed and grip strength, were useful predictors of adverse health outcomes, such as hospitalization, institutionalization, and mortality. These findings led to increased interest in physical performance in older people and the growing use of these performance measures as screening tools in clinical and research settings.

Although physical performance and mortality are clearly linked, questions remain regarding this association. First, little is known of the associations of physical performance with cause-specific mortality, as the results obtained so far are inconsistent. Several cohort studies found a significant association between lower physical

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performance and increased risk of cardiovascular death, but not cancer mortality.[3–5] However, several other studies reported a significant negative association between physical performance and cancer mortality.[6,7]

Second, although several physical performance measures are good predictors of all-cause mortality,[2] independent associations of individual physical performance measures with mortality have not been clarified because most studies assessed only one component of physical performance[3–6,8,9] or each physical performance parameter was separately included in the models.[10] Although physical performance measures are mutually correlated, if each physical performance measure independently predicts mortality it may be useful to examine whether combined use of these measures increases predictive ability. A British birth cohort study[11] examined associations of 3 physical performance measures, namely, grip strength, standing balance, and chair stand, at age 53 years with all-cause mortality by including all 3 measures in the model. Each measure was independently associated with all-cause mortality. Additionally, they showed that a model including all 3 measures had the highest predictive ability. These findings suggest that combined use of physical performance measures increases prognostic power in analyses of middle-aged populations. However, it is unclear whether the same associations are present in populations of older adults, because the specificity of motor ability decreases and correlations among factors increase in older populations.[12,13] Hence, an attempt to clarify independent associations for several physical performance measures, and the usefulness of their combined use, in older populations could complement the findings of the British birth cohort study.

To clarify these issues, we examined the independent associations of key components of mortal ability in older people (ie, walking speed, grip strength, and standing balance) with all-cause and cause-specific mortality and determined if combined use of 3 physical performance measures improved discrimination and risk stratification for mortality. Determining whether combined use of different physical performance measures increases predictive ability is important for clinicians and researchers who use physical performance measures to identify older people at increased risk of mortality.

Methods

Data Sources and Study Population

In 1991, the Tokyo Metropolitan Institute of Gerontology launched the Longitudinal Interdisciplinary Study on Aging (TMIG-LISA), a long-term project to confirm predictors of longevity and outcome and identify factors that accelerate or retard the aging process. Details of this project have been published elsewhere.[14]

The TMIG-LISA comprises 3 principal components: medical science, psychological science, and social science. For the project, 2 study areas, with different settings, were chosen for the medical science discipline: Koganei City (a suburb of Tokyo) and Nangai Village (a representative rural area in Akita Prefecture, Japan). The cohorts of the present study comprised adults aged 65 years or older living in Koganei City and Nangai Village. The baseline survey was conducted in 1991 in Koganei and 1992 in Nangai and consisted of an interview survey including a wide range of health-related variables and medical examinations comprising measurements of physical performance, body composition, blood pressure, and blood profiles. In Koganei, a random sample of one-tenth the population aged 65 to 84 years (996 men and women) was recruited. Among them, 814 residents participated in the interview survey and 405 participated in the medical examination. In Nangai, of 852 eligible residents who were confirmed to be ambulatory and living at home, 748 participated in the interview survey and 735 participated in the medical examination. Thus, a total of 1140 residents underwent medical examination. After excluding participants with disabilities in basic activities of daily living (n = 27) or missing data on such disabilities (n = 22) and those who had not completed the physical performance test battery (n = 6), 1085 individuals were enrolled. The Tokyo Metropolitan Institute of Gerontology review committee approved the study protocol, and informed consent was obtained from all participants.

Follow-up Survey

The participants were followed up prospectively for 10.5 years, from 1991 to 2000 in Koganei and from 1992 to 2001 in Nangai, through a comprehensive surveillance system that has been used successfully since the beginning of the TMIG-LISA. We ascertained all deaths by checking local registries, and linked them with Japanese National Vital Statistics. Underlying cause of death was coded according to the Ninth International Classification of Diseases (ICD-9) (through 1994) or ICD-10 (from the beginning of 1995). The respective ICD-9 and ICD-10 codes were as follows: cardiovascular disease (CVD), 390–459 (ICD-9) and I00–I99 (ICD-10); cancer, 140–208 (ICD-9) and C00–C97 (ICD-10). Use of death certificates to classify major causes of death may lead to misclassification. However, this limitation is not unique to the present study, and the use of death certificates for this purpose was reported to be accurate in Japan.[15,16]

Physical Performance Measures

Walking speed is an established indicator of overall gait performance. For the test of usual walking speed, we asked participants to walk along a straight 11-meter walkway on a flat floor, once, at their usual speed. Walking speed was measured over the 5-meter distance between markers placed at 3 meters and 8 meters from the start of the walkway. The reproducibility of this walking test is good.[17]

Grip strength is a valid indicator of overall muscle strength and is a particularly useful indicator of upper-extremity strength. Grip strength of the dominant hand was measured using a Smedley-type hand dynamometer (Yagami Co, Tokyo, Japan). The higher value from 2 trials was used in the analysis.

One-leg standing time is an indicator of static balance. In the test of 1-leg standing time, we asked participants to stand on their preferred leg with their eyes open and hands down alongside their trunk and to look straight ahead at a dot 1 meter in front of them. Duration of standing time was measured for up to 60 seconds, and the higher value from 2 trials was used in the analysis.

Other Covariates

Conventional mortality risk was evaluated as a potential confounding factor. Information on education level, history of physician-diagnosed medical conditions, psychological states, and lifestyle habits was obtained by face-to-face interview. Low education level was defined as fewer than 7 years of formal education. Body mass index (BMI) was calculated as weight in kilograms divided by the height in meters squared. A U-shaped association between BMI and mortality was previously reported in the Japanese population[18]; thus, BMI was categorized into 3 groups ($<$21, 21–26, $\geq$27 kg/m^2). History of stroke and heart disease was categorized as present or absent. Hypertension was defined as a previous hypertension diagnosis, a systolic blood pressure greater than 140 mm Hg, or a diastolic blood pressure greater than 90 mm Hg. Seated blood pressure was measured twice consecutively, using an automated sphygmomanometer (BP-103; Nippon Colin Ltd, Komaki, Japan). As a rule, the mean of the 2 measurements was used in the analysis. Diabetes mellitus was defined as a previous diabetes diagnosis or a hemoglobin A1c (HbA1c) level greater than 6.5%. Nonfasting blood samples were collected from the forearm vein and centrifuged at the examination site. The resulting serum samples were kept at 4°C and sent to a commercial laboratory (SRL, Inc, Tokyo, Japan) and measured within 24 hours. Total cholesterol, HbA1c, hemoglobin, and albumin at baseline were measured using standardized procedures. Serum cystatin C, interleukin (IL)-6, and C-reactive protein (CRP) levels were also determined at SRL, Inc, in 2006, using serum samples stored at −80°C. Depressive mood was defined as a score of 6 or more points on the Japanese version of the short-form Geriatric Depression Scale. Self-rated health was measured by the item, "How would you evaluate your present health? Is it excellent, good, fair, or poor?" The responses were combined into 2 categories: excellent/good and fair/poor. Smoking habit was classified as current/past smoker and never smoker, because we previously observed that both past and current smokers had an increased mortality rate. Drinking habit was classified as current drinker and past/never drinker. Participants who regularly engaged in walking, calisthenics, or any type of sport were classified as physically active.

Statistical Analyses

Men and women were divided into tertiles according to baseline walking speed, grip strength, and standing balance. The cutoffs were as follows: walking speed, <1.10, 1.10–1.31, ≥1.32 m/s in men, <0.94, 0.94–1.18, ≥1.19 m/s in women; grip strength, <28, 28–33, ≥34 kg in men, <17, 17–20, ≥21 kg in women; standing balance, <18, 18–59, ≥60 seconds in men, <9, 9–38, ≥39 seconds in women.

Correlations among tertiles of physical performance measures were evaluated using the Kendall tau-b correlation coefficient. Age- and sex-adjusted correlations among continuous variables of physical performance measures were evaluated using partial correlation analysis. The mean values of potential risk factors for mortality were adjusted for age and sex using analysis of covariance and were tested for trends across physical performance levels using multiple regression analysis. The frequencies of risk factors were adjusted for age and sex using the direct method, in which the overall study population was used as the standard population, and were tested for trends using a logistic regression model. The proportional hazards assumption was tested for all the physical performance measures, using log-minus-log plots and by including interaction terms between time and physical performance measures in the Cox proportional hazards models. We then used Cox proportional hazards regression to analyze associations between physical performance and mortality during follow-up, controlling for confounding factors. Model 1 was adjusted for age, sex, study area, education level, BMI (lean, obese), medical history (stroke, heart disease, hypertension, diabetes mellitus), renal function (cystatin C), inflammation (log IL-6, log CRP), nutritional status (albumin, hemoglobin, total cholesterol), psychological status (depressive mood, self-rated health), and lifestyle habits (smoking habit, drinking habit, physical activity). In model 2, the 3 physical performance measures were simultaneously added to model 1. Because cardiovascular disease, cancer, and other causes of death can be regarded as competing events, we checked our results by performing competing-risks regression, according to the method of Fine and Gray.[19] Competing risk was defined as mortality from a cause other than the cause of interest (eg, death from cancer or other-cause mortality was the competing risk in the CVD model). The hazard ratios estimated using the competing-risk model were similar to those yielded by ordinary Cox regression (data not shown), which indicates no effect of competing risks. C statistics and net reclassification improvement (NRI) were evaluated to determine how combined use of 3 physical performance measures improved discrimination and risk stratification for all-cause and cause-specific mortality. NRI cutoff point was set at 3%, 6%, and 8%.

Statistical analyses were performed using SPSS version 20 (IBM SPSS Statistics, IBM Corporation, Chicago, IL) and SAS 9.4 (SAS Institute, Inc, Cary, NC). All reported *P* values are 2-tailed, and a *P* value of less than .05 was considered to indicate statistical significance.

Results

During a median follow-up of 10.3 years, 324 deaths occurred: 122 from CVD (including 59 from heart disease and 60 from stroke), 75 from cancer, 115 from other causes (including 30 from pneumonia), and 12 from unknown causes.

The correlation coefficients among tertiles of walking speed and grip strength, walking speed and standing balance, and grip strength and standing balance were 0.33, 0.39, and 0.32, respectively ($P < .01$ for all). Age- and sex-adjusted correlation coefficients among for continuous values were 0.28, 0.33, and 0.26, respectively ($P < .01$ for all).

Table 1 shows age- and sex-adjusted mean values or frequencies of potential risk factors for mortality by tertiles of walking speed, grip strength, and standing balance at baseline. Associations of potential risk factors with mortality differed in relation to physical performance measures.

Table 2 shows the associations of baseline physical performance measures with all-cause and cause-specific mortality. Each physical performance measure was significantly negatively associated with all-cause, cardiovascular, and other-cause mortality, after covariate adjustment (model 1). No significant associations were observed between physical performance and cancer mortality.

To explore the independent association between each physical performance measure and all-cause and cause-specific mortality, the 3 performance measures were entered in the same model (model 2). Although the association was attenuated, each measure remained independently associated with all-cause and cardiovascular mortality. As compared with participants in the highest tertiles for walking speed, grip strength, and standing balance, those in the lowest respective tertiles had adjusted hazard ratios of 1.62 (95% confidence interval [CI] 1.14–2.31), 1.44 (1.03–2.02), and 1.58 (1.13–2.21) for all-cause mortality, and 2.08 (1.12–3.86), 1.84 (1.02–3.35), and 1.91 (1.07–3.42) for cardiovascular mortality.

Last, we investigated if combined use of the 3 physical performance measures significantly improved discrimination and reclassification for all-cause and cardiovascular mortality (Table 3). Here, walking speed was treated as the reference for C statistic and NRI analyses, because previous studies reported that walking speed was almost as good as the entire short physical performance battery in identifying older persons at increased risk of mortality.[20,21] Indeed, walking speed is widely used and has been recognized as the "sixth vital sign."[22] For all-cause mortality, the C statistic was slightly but significantly increased by adding the continuous grip strength value to walking speed. The C statistic was significantly increased by adding the standing balance value, and the addition of both grip strength and standing balance resulted in the largest increase in the C statistic. The addition of standing balance to walking speed, and combined use of the 3 measures, also improved risk reclassification of all-cause mortality. The NRI for the combined use of the 3 measures was estimated at 18.7%, where 64.8% of those with an event were correctly reclassified as being at higher risk for all-cause mortality when grip strength and standing balance were added to walking speed, and 3.6% of those without an event were correctly reclassified as being at lower risk. For cardiovascular mortality, the C statistic was significantly increased and risk reclassification was improved only when both grip strength and standing balance were added to walking speed. The NRI was estimated at 7.5%. The Akaike information criterion is shown in Table 3.

Table 1
Age- and Sex-Adjusted Baseline Characteristics of the Study Population by Tertiles of Physical Performance Measures

	Walking Speed				Grip Strength				Standing Balance			
	Low n = 352	Middle n = 362	High n = 371	*P* for Trend	Low n = 417	Middle n = 329	High n = 339	*P* for Trend	Low n = 348	Middle n = 319	High n = 418	*P* for Trend
Demographic and anthropometric characteristics												
Age, y	75 (0.3)	71 (0.3)	69 (0.2)	<.001*	75 (0.3)	72 (0.3)	69 (0.2)	<.001*	75 (0.3)	72 (0.3)	69 (0.2)	<.001*
Female sex, %	53.9	55.5	63.1	.49†	58.5	75.2	59.3	.927†	55.4	69.5	49.6	.062†
Education, <7 y, %	78.3	73.4	58.3	<.001	77.4	72.9	59.0	<.001	72.9	68.4	68.8	.352
BMI, kg/m^2	22.7 (0.2)	22.7 (0.2)	22.2 (0.2)	.048	22.2 (0.2)	22.5 (0.2)	22.9 (0.2)	.003	23.0 (0.2)	22.9 (0.2)	21.9 (0.2)	<.001
BMI <21 kg/m^2, %	33.6	33.3	35.3	.234	38.7	32.5	29.5	.011	33.0	31.7	40.2	.021
BMI ≥27 kg/m^2, %	11.4	9.0	7.3	.023	8.2	8.5	9.9	.451	11.2	9.6	5.0	<.001
Medical history												
Stroke, %	8.3	3.9	1.1	<.001	6.8	4.4	1.7	.004	9.0	3.2	1.5	<.001
Heart disease, %	26.8	23.4	17.9	.018	20.7	23.8	23.6	.692	27.6	23.9	21.3	.043
SBP, mm Hg	145 (1)	146 (1)	143 (1)	.464	143 (1)	143 (1)	147 (1)	.022	147 (1)	146 (1)	142 (1)	.006
DBP, mm Hg	80 (0.7)	80 (0.6)	79 (0.6)	.854	78 (0.7)	78 (0.6)	82 (0.6)	<.001	81 (0.7)	80 (0.7)	78 (0.7)	.002
Hypertension, %	66.9	71.6	64.1	.299	67.3	63.8	73.4	.048	70.5	71.6	61.6	.003
HbA1c, %	6.0 (0.05)	6.1 (0.04)	6.1 (0.04)	.169	6.1 (0.05)	6.1 (0.05)	6.0 (0.04)	.234	6.1	6.1	6.0	.149
Diabetes, %	14.8	19.4	16.0	.729	20.4	18.5	14.1	.020	17.1	19.3	16.6	.162
Renal function												
Cystatin C, ng/mL	0.94 (0.01)	0.89 (0.01)	0.90 (0.01)	.015	0.92 (0.01)	0.91 (0.01)	0.89 (0.01)	.049	0.95 (0.01)	0.91 (0.01)	0.87 (0.01)	<.001
Inflammation status												
IL-6, pg/mL	2.9 (0.2)	2.5 (0.1)	2.3 (0.1)	.009	2.7 (0.2)	2.4 (0.1)	2.5 (0.1)	.263	3.0 (0.2)	2.4 (0.1)	2.3 (0.1)	.001
CRP, μg/L	1824 (249)	1450 (226)	1152 (230)	.063	2017 (246)	1201 (238)	1216 (217)	.025	2008 (248)	1340 (242)	1117 (221)	.012
Nutritional status												
Albumin, g/L	41.2 (0.2)	41.3 (0.1)	41.4 (0.1)	.487	40.9 (0.2)	41.3 (0.1)	41.7 (0.1)	<.001	41.2 (0.2)	41.6 (0.2)	41.2 (0.1)	.911
Hemoglobin, g/L	12.9 (0.1)	12.9 (0.1)	13.1 (0.1)	.035	12.7 (0.1)	13.0 (0.1)	13.2 (0.1)	<.001	12.9 (0.1)	13.0 (0.1)	13.0 (0.1)	.962
Total cholesterol, mg/dL	192 (2)	200 (2)	201 (2)	.005	192 (2)	198 (2)	202 (2)	<.001	192 (2)	201 (2)	199 (2)	.047
Psychological status												
Depression, %	26.0	18.4	13.7	<.001	25.6	16.7	18.7	<.001	30.6	16.8	12.5	<.001
Poor self-rated health, %	38.7	24.6	14.2	<.001	35.4	24.3	20.8	<.001	39.5	22.1	20.3	<.001
Lifestyle characteristics												
Current drinking, %	40.3	36.0	40.8	.940	34.6	41.8	35.7	.416	41.1	38.1	36.9	.193
Current/past smoking, %	35.4	32.2	28.7	.104	29.8	35.6	36.3	.076	35.9	32.0	32.7	.076
Physical activity, %	44.9	56.5	70.5	<.001	56.7	58.1	56.8	.434	54.7	58.3	61.1	.325
Physical performance												
Walking speed, m/s, male	0.92 (0.01)	1.21 (0.01)	1.48 (0.01)	<.001	1.13 (0.02)	1.20 (0.02)	1.24 (0.02)	<.001	1.08 (0.02)	1.24 (0.02)	1.26 (0.02)	<.001
Walking speed, m/s, female	0.77 (0.01)	1.05 (0.01)	1.34 (0.01)	<.001	0.96 (0.02)	1.08 (0.02)	1.15 (0.02)	<.001	0.92 (0.02)	1.10 (0.02)	1.18 (0.02)	<.001
Grip strength, kg, male	29.2 (0.5)	31.0 (0.5)	33.2 (0.5)	<.001	23.0 (0.3)	30.8 (0.3)	37.7 (0.3)	<.001	28.5 (0.5)	31.3 (0.6)	32.9 (0.5)	<.001
Grip strength, kg, female	16.5 (0.3)	19.0 (0.3)	20.2 (0.3)	<.001	13.0 (0.2)	18.6 (0.2)	23.4 (0.2)	<.001	17.1 (0.3)	18.8 (0.3)	20.0 (0.3)	<.001
One-leg standing time, s, male	28 (2)	41 (2)	43 (2)	<.001	29 (2)	38 (2)	43 (2)	<.001	8 (0.5)	34 (0.6)	60 (0.4)	<.001
One-leg standing time, s, female	18 (1)	27 (1)	36 (1)	<.001	21 (1)	27 (1)	33 (1)	<.001	5 (0.4)	20 (0.4)	57 (0.4)	<.001

DBP, diastolic blood pressure; SBP, systolic blood pressure.
Age- and sex-adjusted mean (SE) or frequencies are shown.
*Sex-adjusted.
†Age-adjusted.

Table 2
Hazard Ratios for Total and Cause-Specific Mortality According to Tertiles of Walking Speed, Grip Strength, and 1-Leg Standing

	Cutpoints		No. of Events/Participants	Mortality Rate/1000 Person-Years	Model 1		Model 2	
	Men	Women			HR (95%CI)	P	HR (95%CI)	P
All-cause death								
Walking speed, m/s								
High	≥1.32	≥1.19	59/371	17.6	1.00 (reference)		1.00 (reference)	
Middle	1.10–1.31	0.94–1.18	89/362	28.4	1.16 (0.82–1.63)	.414	1.12 (0.79–1.58)	.537
Low	<1.10	<0.94	176/352	53.1	1.95 (1.39–2.73)	<.001	1.62 (1.14–2.31)	.007
Grip strength, kg								
High	≥34	≥21	70/339	28.5	1.00 (reference)		1.00 (reference)	
Middle	28–33	17–20	100/329	35.2	1.40 (1.02–1.93)	.040	1.33 (0.96–1.84)	.083
Low	<28	<17	154/417	49.5	1.66 (1.19–2.32)	.003	1.44 (1.03–2.02)	.034
Standing balance, s								
High	60	≥39	75/418	23.0	1.00 (reference)		1.00 (reference)	
Middle	18–59	9–38	74/319	30.0	1.13 (0.80–1.58)	.497	1.06 (0.75–1.49)	.751
Low	<18	<9	175/348	54.8	1.91 (1.39–2.63)	<.001	1.58 (1.13–2.21)	.007
Cardiovascular death								
Walking speed, m/s								
High	≥1.32	≥1.19	17/371	5.3	1.00 (reference)		1.00 (reference)	
Middle	1.10–1.31	0.94–1.18	26/362	8.7	1.15 (0.61–2.18)	.671	1.08 (0.57–2.06)	.813
Low	<1.10	<0.94	79/352	24.4	2.80 (1.55–5.05)	.001	2.08 (1.12–3.86)	.020
Grip strength								
High	≥34	≥21	20/339	9.1	1.00 (reference)		1.00 (reference)	
Middle	28–33	17–20	34/329	13.0	1.58 (0.89–2.81)	.122	1.40 (0.78–2.51)	.254
Low	<28	<17	68/417	21.1	2.38 (1.33–4.26)	.004	1.84 (1.02–3.35)	.045
Standing balance, s								
High	60	≥39	21/418	8.2	1.00 (reference)		1.00 (reference)	
Middle	18–59	9–38	22/319	9.4	1.06 (0.57–1.97)	.863	0.95 (0.51–1.79)	.875
Low	<18	<9	79/348	24.6	2.67 (1.54–4.62)	<.001	1.91 (1.07–3.42)	.029
Cancer death								
Walking speed, m/s								
High	≥1.32	≥1.19	22/371	6.5	1.00 (reference)		1.00 (reference)	
Middle	1.10–1.31	0.94–1.18	29/362	9.3	1.10 (0.63–2.04)	.680	1.12 (0.62–2.01)	.714
Low	<1.10	<0.94	24/352	7.0	1.01 (0.52–1.95)	.987	0.93 (0.47–1.84)	.837
High	≥34 kg	≥21	21/339	6.4	1.00 (reference)		1.00 (reference)	
Middle	28–33	17–20	29/329	10.1	1.67 (0.93–2.99)	.085	1.65 (0.92–2.96)	.095
Low	<28	<17	25/417	9.1	1.31 (0.67–2.56)	.431	1.26 (0.64–2.49)	.506
Standing balance, s								
High	60	≥39	27/418	8.8	1.00 (reference)		1.00 (reference)	
Middle	18–59	9–38	22/319	8.6	1.25 (0.68–2.36)	.475	1.21 (0.67–2.21)	.528
Low	<18	<9	26/348	9.0	1.27 (0.68–2.36)	.458	1.31 (0.69–2.50)	.413
Other-cause death								
Walking speed, m/s								
High	≥1.32	≥1.19	19/371	5.7	1.00 (reference)		1.00 (reference)	
Middle	1.10–1.31	0.94–1.18	28/362	8.4	1.01 (0.54–1.89)	.989	0.96 (0.51–1.80)	.892
Low	<1.10	<0.94	68/352	20.0	2.08 (1.14–3.77)	.016	1.67 (0.90–3.10)	.106
Grip strength, kg								
High	≥34	≥21	23/339	10.3	1.00 (reference)		1.00 (reference)	
Middle	28–33	17–20	36/329	11.8	1.43 (0.81–2.52)	.213	1.36 (0.77–2.39)	.289
Low	<28	<17	56/417	17.7	1.58 (0.88–2.82)	.123	1.34 (0.75–2.40)	.327
Standing balance, s								
High	60	≥39	20/418	4.3	1.00 (reference)		1.00 (reference)	
Middle	18–59	9–38	29/319	11.4	1.70 (0.92–3.12)	.088	1.57 (0.85–2.91)	.149
Low	<18	<9	66/348	19.8	2.60 (1.45–4.69)	.001	2.09 (1.13–3.87)	.019

HR, hazard ratio.
The mortality rate was calculated per 1000 person-years and was adjusted for age and sex by the direct method using 5-year age groups.
Model 1 is adjusted for age, sex, study area, education, body mass index, stroke, heart disease, hypertension, diabetes mellitus, cystatin C, IL-6, high-sensitivity CRP, albumin, hemoglobin, total cholesterol, self-rated health, depressive mood, smoking, alcohol, and physical activity. Model 2 is adjusted for variables in model 1 plus the other physical performance measures.

Discussion

The present study had 3 major findings. First, walking speed, grip strength, and standing balance were significant predictors of all-cause, cardiovascular, and other-cause mortality, but not cancer mortality, independent of demographics, BMI, medical history, renal function, inflammation, nutritional measures, psychological function, and lifestyle factors. Second, each of the examined physical performance measures independently predicted all-cause and cardiovascular mortality risk. Third, combined use of 3 types of physical performance measure improved risk stratification and discrimination for all-cause and cardiovascular mortality.

Regarding the first finding, several studies have examined the association between physical performance and cause-specific mortality, but the findings were inconsistent. The Three-City study, which followed 3208 participants (64.5% women, age 65–85 years) for 5.1 years, found a clear association between walking speed and cardiovascular mortality.[4] The Women's Health and Aging Study,[3] which followed 919 women (age 65–101 years) for 5 years, and the Hisayama study,[5] which followed 2527 participants (57.9% women, age ≥40 years) for 19 years, observed a clear association between grip strength and cardiovascular mortality. These 3 studies did not show a significant association between physical performance and risk of cancer death, which is largely consistent with the present findings.

Table 3
Added Value of 3 Types of Physical Performance Measurement

Model	C Statistic (95% CI)	AIC	NRI, %
All-cause death			
Walking speed	0.60 (0.55–0.65)	4328	Reference
Walking speed + grip strength	0.61 (0.56–0.65)*	4328	2.4
Walking speed + standing balance	0.64 (0.59–0.69)*	4305	21.9
Walking speed + grip strength + standing balance	0.66 (0.61–0.70)*	4299	18.7
Cardiovascular death			
Walking speed	0.66 (0.60–0.73)	1580	Reference
Walking speed + grip strength	0.66 (0.60–0.72)	1582	0.8
Walking speed + standing balance	0.69 (0.62–0.75)	1569	10.0
Walking speed + grip strength + standing balance	0.69 (0.63–0.75)*	1569	7.5

AIC, Akaike information criterion.
*$P < .01$ vs waking speed.

However, several other studies reported a significant association between physical performance and cancer mortality.[6,7] The Ruiz et al study followed 8762 men (age 20-80 years) for 18.9 years and found an association between muscle strength and cancer mortality.[7] This discrepancy regarding cancer mortality may be due to differences among studies in sex distribution and/or cancer type. Because the findings regarding cardiovascular mortality are more consistent (to our knowledge, 5 of 6 studies[3–6] [including the present study] found a clear association), physical performance may be a stronger risk factor for cardiovascular mortality than for other major causes of death. Past and present evidence suggests that maintaining physical fitness is an effective means of preventing cardiovascular mortality. Low nutrition,[23,24] physical activity,[25] depressive symptom,[23] smoking, and histories of arthritis and diabetes[24] are determinant of change in physical performance. Hence, a healthy lifestyle, including good nutrition, physical activity, tobacco avoidance, and effective prevention and/or management of common diseases such as arthritis and diabetes, is a promising target for primary prevention of cardiovascular mortality. However, the present findings suggest that maintaining physical fitness is not effective in preventing cancer mortality. A different health strategy is required.

In the present study, physical performance measures predicted other-cause mortality, as was the case for cardiovascular mortality. Because one-third of other-cause deaths were due to death from pneumonia, we suspect that the same mechanism underlies poor physical performance, CVD, and pneumonia death. One plausible explanation is that frailty mediates the association between poor physical performance and increased risk of death from these diseases. Although different definitions have been proposed for capturing frailty status,[26,27] there is overall agreement that poor physical performance is a characteristic of frailty. Because frail elders are more vulnerable to psychological and physiological stresses, it may be that they are more likely to develop CVD and pneumonia and that these acute illnesses lead to death. Although there is limited evidence of an association between frailty and increased risk of CVD incidence or death, frailty was found to be associated with clinical CVD and underlying CVD measured by carotid ultrasound and the ankle-arm index.[28] These findings appear to support our hypothesis.

Regarding our second finding, this study is the first to show that each of the examined physical performance measures independently predicted all-cause and cardiovascular mortality in older populations. Participants with a poor score for any measure had an increased hazard of mortality, independent of performance on the other two measures. Although it is understandable to assume that the 3 physical performance measures are highly correlated with each other, the strength of the correlations was low to moderate. Additionally, the associations with potential risk factors for mortality varied by physical performance measure (Table 1). These findings clearly indicate that walking speed, grip strength, and standing balance reflect different abilities and that the combined use of these 3 simple tests is useful in identifying a wide range of mortality risks.

Regarding the third finding, although our results are consistent with the findings from the British birth cohort study,[11] previous studies that examined the added value of using 3 tasks (walking speed, standing balance, and repeated chair stands) in older populations reported that combined use of the physical performance measures only marginally increased predictive ability.[19,20] Additionally, those studies showed that walking speed is almost as good as the full battery of performance tests in identifying older persons at increased risk of adverse health outcomes. In most of these studies, however, only a Cox proportional hazards model or the area under the receiver operating curve was used to evaluate discrimination. No study evaluated the added value of different physical performance measures using an NRI, a relatively new metric for evaluating the predictive ability of new biomarkers. Moreover, no study evaluated the added value of the combined use of walking speed, grip strength, and standing balance. In the present study, combined use of these 3 physical performance measures improved discrimination and resulted in the largest increase in the C statistic, as compared with use of walking speed alone. Additionally, we found that adding standing balance to walking speed is almost as good as the combined use of all 3 measures. Because standing balance does not require substantial space or time, it may be more informative to collect data on standing balance along with walking speed, when practicable.

This study has several strengths, particularly its use of a population-based sample of the TMIG-LISA cohort and the 10-year follow-up period. The availability of comprehensive information from the TMIG-LISA database allowed us to adjust for important covariates, especially renal function and inflammation measures, which might have confounded the relationship between physical performance and mortality. The study participants were all initially nondisabled older adults; thus, the results are generalizable to general community-dwelling elders.

Several potential limitations of the present study should be noted. First, history of medical conditions was self-reported. Additionally, we were unable to obtain precise information on cancer history, and we did not adjust for cancer history. These limitations might lead to overestimation of the importance of physical performance. Second, the present study examined a high-functioning population, which might have resulted in underestimation of the associations of poor physical performance measure with all-cause and cause-specific mortality. Third, the study was used as a derivation cohort and no validation cohort was available to confirm the results. Finally, we could not further subdivide the study participant groups because of the small sample size. Hence, we may have missed nonlinear associations between physical performances and mortality that might have been detectable by further classification of the study participants. Additionally, we were unable to use a clinically meaningful cutpoint because no such cutpoint has been determined for Japanese elders. Thus, our findings may not be applicable to clinical settings, and our ability to compare findings across studies is limited. A larger study with a clinically meaningful cutpoint for Japanese elders is required.

Conclusions

Slow walking speed, weak grip strength, and poor standing balance predicted all-cause, cardiovascular, and other-cause mortality but not cancer mortality in community-dwelling Japanese elders, independent of covariates. Moreover, these 3 components of physical performance were independently associated with all-cause and cardiovascular mortality and their combined use increased prognostic power.

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