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Association between muscle strength and physical performance in Japanese elderly: The Fujiwara-kyo Study

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ABSTRACT

Background/Purpose: Muscle strength, which affects physical activity and performance, can be used to evaluate physical function. This study aimed to investigate the association between muscle strength and physical performance in community-dwelling Japanese elderly individuals.

Methods: Subjects were 249 men and 340 women aged over 65 years who had valid anthropometric data, muscle strength data and physical performance data.

Results: Greater muscle strength was significantly associated with better physical performance (10-meter gait time, timed up and go test, chair rise time, floor stand up time, one-leg standing time with opened eyes and maximum one-step length) in women after adjusting for age, height and weight. In addition, greater hand grip strength was significantly associated with better physical performance in men. Moreover, greater knee extension strength was significantly associated with shorter chair rise time and floor stand up time, and greater knee flexion strength was significantly associated with better physical performance (except for 10-meter gait time), in men after adjusting for age, height and weight.

Conclusion: Physical performance was affected by muscle strength in women, but only partially in men, although higher muscle strength was associated with better physical performance in both sexes. Our results suggest that muscle strength can be used as a predictor of low physical performance (locomotion, anti-gravity activity and balance) in elderly men and women.

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INTRODUCTION

Physical function decreases with age. Age-related muscle atrophy is considered one of the causes of low physical function in the elderly. In one study, Lexell et al. reported that age-related atrophy of skeletal muscle begins at around the mid-twenties and accelerates thereafter, and that the main cause of atrophy is a reduction in muscle fiber size and numbers, with muscle area reduced by 40% from 20 to 80 years of age.[1] Goodpaster et al. reported that the annual rate of decline in leg strength (2.6%-4.1%) was approximately three times greater than the rate of leg muscle mass loss (1%) in white and black elderly men and women in their 70s.[2] They also suggested that muscle quantity and quality might be an important determinant of strength loss with aging.[2] Although loss of muscle mass is required for the diagnosis of sarcopenia,[3] it also is responsible for the decline in muscle strength among the elderly. Sarcopenia is a syndrome characterized by progressive and generalized loss of skeletal muscle mass and strength and correlates with physical disability, poor quality of life and death.[3] The prevalence of sarcopenia was 1-29%, up to 30% in women, for community-dwelling older adults;[4] in Japan, the prevalence is >20% among community-dwelling Japanese elderly men and women.[5] Sarcopenia is commonly observed in the elderly, with loss of muscle mass associated with disabilities in instrumental activities of daily living (IADL),[6] and an increased risk of falls among community-dwelling elderly in Japan.[7] It is also a major cause of disability and frailty in the elderly,[8] the latter of which in turn results in disability and limitations on physical function.

Many factors can contribute to reduced physical function, such as decreased physiological and psychological functions, insufficient nutrition and chronic diseases, in addition to loss of muscle mass and decline of muscle strength. Moreover, in addition to muscle mass and strength, muscle power and endurance are related to physical function, both functions of which are affected by neuromuscular activation, movement velocity, muscular capability and other factors.[9,10] Unlike muscle mass and activation measurements, muscle strength can be measured easily without computed tomography, magnetic resonance imaging and electromyograms. Some studies have reported that muscle strength is related to physical performance measures, such as walking speed, timed up & go test (TUG),[11] impaired physical activity and ADL disabilities,[12] and can serve as a predictor of ADL disability.[13] Moreover, Woods et al. reported that hip strength, but not muscle mass or indices of sarcopenia, predicted both TUG and walking speed in elderly women.[14]

Physical performance is related to and predicts ADL and mobility-related disabilities.[15-17] Short physical performance battery (SPPB) can be used to assess sarcopenia,[3] and has been shown to be valid and reliable in assessments of physical performance.[18,19] Physical performance, using proxies such as SPPB, has been shown to be related to disabilities of ADL and mobility and frailty. However, Clark and Manini proposed that dynapenia, the age-related loss of muscle strength, and sarcopenia, the age-related loss of muscle mass, are different indices, and that muscle strength is an independent factor that influences physical performance.[20] Thus, it may be informative to investigate the association between muscle strength and physical performance and gain an understanding of how muscle strength affects disabilities in mobility and frailty. As discussed above, muscle strength can be easily measured at low cost, and is an easy index of physical function for the elderly to understand.

In this study, we assessed the association between muscle strength and physical performance in Japanese elderly individuals. To this end, we assessed certain measures, including six types of lower extremity functions (to assess locomotion, anti-gravity activity and balance) and three types of muscle strength, and compared our results with those of previous studies.

MATERIALS AND METHODS

Subjects

Subjects were elderly men and women aged ≥65 years who participated in a cohort study (Fujiwara-kyo study).[21,22] The administrative center of the Fujiwara-kyo study recruited subjects with the cooperation of local residents' associations and elderly people's clubs organized in four cities in Nara, Japan. A total of 4,427 elderly provided written informed consent and underwent a baseline examination in 2007 or 2008. We selected 249 men and 340 women for whom data were available for height, weight, three types of muscle strength and six types of physical performance at the baseline examination. Subjects were able to walk either with or without walking sticks, and were able to communicate. This study was approved by the Ethics Committee for Human Subjects of Nara Medical University.

Body size measurement

Height (cm) and weight (kg) were measured with an automatic scale.

Muscle strength measurements

Hand grip strength (HGS; kg), and knee extension and flexion strength (KES and KFS; kg·m) were assessed as measures of muscle strength. All muscle strength measurements were performed twice and mean values were used for analysis.

HGS of the dominant hand was measured in the sitting position with the elbow joint extended using a digital hand grip dynamometer (TKK5401, Takei Scientific Instruments Co., Ltd. Niigata, Japan). Isometric muscle strength of knee extension and flexion was measured in the sitting position on a chair with the knee joint flexed at 90 degrees using an isometric muscle strength dynamometer (μTasMF-01, ANIMA Corporation, Japan). Arm length was determined as the distance between knee joint space and the center of the measuring dynamometer. KES and KFS were calculated by isometric muscle strength of knee extension and flexion multiplied by arm length, respectively.

Physical performance measurements

Ten-meter gait time (10MGT; sec), timed up & go test (TUG; sec), chair rise time (CRT; sec), floor standing up time (FST), one leg standing time with opened eyes (OLST; sec) and maximum one step length to height ratio (MSL) were assessed as measures of physical performance. All measurements were performed twice and mean values were used for analysis.

10MGT was measured using a 2-channel display timer (Takei Scientific Instruments Co., Ltd. Niigata, Japan), which records time when subjects pass by the sensor system. Subjects walked straight for 14 m with maximum effort, and 10MGT was used in the middle of 10 m for 14 m to reduce the effects of acceleration and deceleration. TUG was measured using a multi-timer (TKK5801, Takei Scientific Instruments Co., Ltd. Niigata, Japan) as the time it took subjects to stand up from a chair, walk a distance of 3 m, turn, walk back and sit down on a chair. CRT was measured using a multi-timer (TKK5801, Takei Scientific Instruments Co., Ltd. Niigata, Japan) as the time required to stand up and sit down on a chair repeatedly 5 times. FST was measured using a stopwatch (SEIKO Watch Corporation, Tokyo, Japan) as the time it took subjects to stand up from the floor in a supine position to a straight standing position. OLST was measured using a stopwatch (SEIKO Watch Corporation, Tokyo, Japan) as the time subjects were able to maintain one leg standing with both hands on the waist and one leg raised forward. MSL was calculated by maximum one step length divided by height. The starting and finishing positions of both feet were side by side. Subjects stepped forward with one leg (to which a string of yarn was tied), and the other leg then was brought alongside the first leg. Maximum one step length was measured as the length of yarn stretched by the legs (TKK5082a, Takei Scientific Instruments Co., Ltd. Niigata, Japan).

Statistical analysis

Measured values are expressed as mean and SD. Differences in height, weight, muscle strength and physical performance between men and women were analyzed with the unpaired t-test. Linear regression analyses were used to identify associations between muscle strength and physical performance. Model 1 was adjusted for age, and Model 2 was additionally adjusted for height and weight. In addition, multiple regression analyses with muscle strength and physical performance as dependent variables, and age, sex and age*sex product terms as independent variables, were performed to determine associations of age, sex and these interactions with muscle strength and physical performance. Moreover, multiple regression analyses with physical performance as the dependent variable, and age, sex, muscle strength and sex*muscle strength product terms as independent variables, were performed to determine associations of age, sex, muscle strength and these interactions with physical performance. P <0.05 was considered statistically significant. All statistical analyses were performed using SPSS software (SPSS version 17.0 for Windows, SPSS Japan Inc., Tokyo, Japan).

RESULTS

Height, weight and all muscle strength measures were significantly greater in men than in women. 10MGT, TUG and FST were significantly shorter in men than in women, and MSL was significantly higher in men than in women (Table 1).

Table 2 shows the associations between muscle strength and physical performance. Men with higher HGS performed significantly better in 10MGT, TUG, CRT and OLST after adjusting for age, and additionally in FST and MLS after adjusting for height and weight. A higher KES was associated with shorter CRT after adjusting for age, and additionally with shorter FST after adjusting for height and weight. A higher KFS was associated with shorter 10MGT, TUG and CRT after adjusting for age, and additionally with shorter FST, higher OLST and MLS, but not with 10MGT, after adjusting for height and weight. In women, higher muscle strength was significantly associated with better performance in all measures.

In multiple linear regression analyses, age and sex were significantly associated with all types of muscle strength (HGS, KES, and KFS), and age was significantly associated with all types of physical performance. Interactions of age*sex were significant for all types of muscle strength (Table 3). These associations and interactions remained significant after adjusting for height and weight. In addition, sex was significantly associated with FST and MSL for all types of muscle strength, i.e., 10GMT and TUG for KES, and 10MGT and OLST for KFS, respectively. HGS was significantly associated with 10MGT, TUG, CRT and OLST; KES was significantly associated with CRT and KFS was significantly associated with 10MGT, TUG and CRT independently of age and sex. Interactions of sex*muscle strength were significant for FST, OLST and MSL in HGS; all types of physical performance except for CRT and

Table 1. Anthropometric characteristics, muscle strength and physical performance in both sex

	Men	Women
	n=249	n=340
Anthropometric characteristics		
age (year)	73.7±5.3	73.0±5.2
Height (cm)	162.6±5.6	149.7±5.3*
Weight (kg)	61.2±8.6	51.2±7.8*
Muscle strength		
Hand grip strength (kg)	34.6±6.0	21.4±4.1*
Knee extension strength (kgm)	6.49±2.00	4.42±1.43*
Knee flexion strength (kgm)	4.09±1.13	2.53±0.75*
Physical performance		
10 meter gait time (sec)	5.74±1.27	6.20±1.29*
Timed up & go test (sec)	6.65±1.33	6.95±1.38*
Chair rise time (sec)	9.76±3.22	9.42±2.87
Floor stand up time (sec)	4.12±1.27	5.16±1.76*
One-leg standing time with opened eyes (sec)	32.3±20.5	30.3±20.9
Maximum one-step length to height ratio	0.659±0.130	0.615±0.120*

*Significant difference vs. men (p <0.01). mean±SD

Table 2. Associations between muscle strength and physical performance

	Men						Women					
	Hand Grip Strength		Knee Extension Strength		Knee Flexion Strength		Hand Grip Strength		Knee Extension Strength		Knee Flexion Strength	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Unadjusted model												
10-meter gait time (sec)	-0.070*	-0.094, -0.045	-0.135*	-0.212, -0.057	-0.372*	-0.505, -0.239	-0.113*	-0.145, -0.082	-0.310*	-0.401, -0.219	-0.652*	-0.822, -0.482
Timed up & go test (sec)	-0.079*	-0.104, -0.053	-0.167*	-0.247, -0.086	-0.444*	-0.581, -0.306	-0.114*	-0.148, -0.080	-0.367*	-0.463, -0.272	-0.671*	-0.854, -0.489
Chair rise time (sec)	-0.160*	-0.224, -0.096	-0.425*	-0.619, -0.231	-0.857*	-1.199, -0.515	-0.176*	-0.248, -0.103	-0.512*	-0.720, -0.304	-1.128*	-1.518, -0.738
Floor stand up time (sec)	-0.063*	-0.088, -0.033	-0.175*	-0.251, -0.098	-0.328*	-0.463, -0.193	-0.137*	-0.180, -0.093	-0.454*	-0.577, -0.332	-0.647*	-0.888, -0.407
One-leg standing time with opened eyes (sec)	1.044*	0.638, 1.451	1.618*	0.350, 2.885	4.317*	2.091, 6.533	1.848*	1.338, 2.358	3.210*	1.678, 4.742	9.662*	6.870, 12.454
Maximum one-step length to height ratio	0.004*	0.002, 0.007	0.008	-0.001, 0.016	0.023*	0.009, 0.038	0.009*	0.006, 0.012	0.023*	0.014, 0.032	0.044*	0.028, 0.061
Model 1 (adjusted for age)												
10-meter gait time (sec)	-0.039*	-0.065, -0.014	-0.045	-0.121, 0.030	-0.190*	-0.331, -0.050	-0.074*	-0.106, -0.042	-0.229*	-0.316, -0.142	-0.479*	-0.645, -0.312
Timed up & go test (sec)	-0.040*	-0.065, -0.014	-0.057	-0.133, 0.019	-0.215*	-0.356, -0.075	-0.070*	-0.105, -0.036	-0.284*	-0.375, -0.192	-0.484*	-0.662, -0.306
Chair rise time (sec)	-0.103*	-0.170, -0.035	-0.265*	-0.464, -0.067	-0.516*	-0.888, -0.144	-0.118*	-0.195, -0.042	-0.397*	-0.605, -0.188	-0.887*	-1.286, -0.489
Floor stand up time (sec)	-0.021	-0.045, 0.003	-0.064	-0.135, 0.006	-0.067	-0.199, 0.066	-0.089*	-0.134, -0.045	-0.363*	-0.483, -0.243	-0.428*	-0.666, -0.190
One-leg standing time with opened eyes (sec)	0.555*	0.137, 0.972	0.144	-1.098, 1.385	1.048	-1.274, 3.370	1.152*	0.641, 1.664	1.701*	0.266, 3.135	6.562*	3.872, 9.252
Maximum one-step length to height ratio	0.001	-0.002, 0.004	-0.001	-0.009, 0.007	0.005	-0.001, 0.020	0.007*	0.004, 0.010	0.018*	0.009, 0.026	0.033*	0.016, 0.049
Model 2 (adjusted for age, height and weight)												
10-meter gait time (sec)	-0.029*	-0.056, -0.001	-0.031	-0.111, 0.048	-0.131	-0.293, 0.031	-0.063*	-0.099, -0.033	-0.251*	-0.336, -0.167	-0.455*	-0.631, -0.279
Timed up & go test (sec)	-0.041*	-0.069, -0.013	-0.069	-0.150, 0.011	-0.263*	-0.426, -0.101	-0.187*	-0.099, -0.027	-0.311*	-0.399, -0.222	-0.466*	-0.654, -0.278
Chair rise time (sec)	-0.111*	-0.185, -0.037	-0.285*	-0.497, -0.073	-0.619*	-1.053, -0.186	-0.130*	-0.211, -0.050	-0.448*	-0.655, -0.240	-1.014*	-1.439, -0.588
Floor stand up time (sec)	-0.039*	-0.064, -0.014	-0.120*	-0.192, -0.048	-0.224*	-0.372, -0.075	-0.114*	-0.158, -0.069	-0.430*	-0.541, -0.320	-0.572*	-0.811, -0.332
One-leg standing time with opened eyes (sec)	0.875*	0.434, 1.315	0.901	-0.395, 2.197	3.478*	0.853, 6.104	1.332*	0.810, 1.854	2.263*	0.877, 3.648	7.795*	5.020, 10.570
Maximum one-step length to height ratio	0.003*	0.000, 0.006	0.002	-0.007, 0.010	0.019*	0.002, 0.036	0.007*	0.003, 0.010	0.019*	0.010, 0.027	0.032*	0.014, 0.050

b=partial regression coefficient; 95% CI=95% confidence interval; *p <0.05 for linear regression analyses.

Table 3. Associations of age and sex with muscle strength and physical performance

	Age		Sex		Age*Sex		
	b	SE	b	SE	b	SE	adjusted R^2
Muscle strength							
Hand grip strength	-0.460*	0.056	-25.864*	5.404	0.170*	0.073	0.683
Knee extension strength	-0.131*	0.019	-6.863*	1.892	0.064*	0.026	0.334
Knee flexion strength	-0.096*	0.010	-5.586*	0.999	0.054*	0.014	0.500
Physical performance							
10-meter gait time (sec)	0.104*	0.014	0.401	1.357	0.002	0.018	0.207
Timed up & go test (sec)	0.129*	0.015	1.532	1.414	-0.016	0.019	0.220
Chair rise time (sec)	0.211*	0.035	3.796	3.365	-0.055	0.046	0.097
Floor stand up time (sec)	0.130*	0.017	1.382	1.663	-0.003	0.023	0.259
One-leg standing time with opened eyes (sec)	-1.646*	0.225	9.102	21.872	-0.167	0.297	0.191
Maximum one-step length to height ratio	-0.009*	0.001	-0.207	0.137	0.002	0.002	0.138

b=partial regression coefficient; SE=standard error; R^2=coefficient of determination; *p <0.01.

OLST in KES and all types of physical performance except for CRT in KFS (Table 4).

DISCUSSION

In the present study, muscle strength and physical performance were found to decline with increasing age in both sexes. Low muscle strength was associated with low physical performance, and this association was stronger in women than in men.

We found that low HGS was associated with low physical performance after adjusting for age, height and weight in both sexes. Consistent with this, Hardy et al. analyzed eight cohort studies and showed that higher HGS was associated with better performance in chair rise performance, walking speed and balance in older men and women after adjusting for age and height.[23] Similarly, Visser et al. suggested that low HGS, but not low leg muscle mass, was associated with poor lower extremity performance (chair stand test and 6m walking test) in older men and women after adjusting for all potential confounders.[24] Legrand et al. classified the level of physical performance using the SPPB, which included standing balance, gait speed and CRT, and found that low physical performance remained associated with low HGS even after considering other risk factors for sarcopenia in the oldest old.[25] In yet another study, Baron and Guidon investigated the association between HGS and four balance measures including TUG and OLST.[26] They found that total HGS was significantly correlated with each of the four measures (TUG, r=-0.38; OLST, r=0.49), although the association between HGS and balance was not sufficiently robust to use HGS as a screening tool for balance impairment in older people, given that HGS accounted for 14-16% of the variance (r^2 values) in older women.[26] In the present study, the influence of HGS on OLST (standardized partial regression coefficient) was strong for both sexes. Moreover, the association between HGS and physical performance, including locomotion (10MGT and TUG), anti-gravity activity (TUG, CRT and FST) and balance (TUG, OLST and MSL) were evaluated, and our findings were consistent with those of the previous studies.[23-26] HGS is one of the diagnostic criteria for sarcopenia,[3] and was reported to be associated with lower limb muscle strength and a better predictor of clinical outcomes in older people.[27] In addition, sex differences in HGS reportedly diminished with increasing age,[28] and HGS decreased similarly in elderly men and women with aging.[29,30] Taken together, these data suggest that HGS reflects physical performance in both sexes and can help in ADL evaluations.

A lower KES was associated with longer CRT and FST after adjusting for age, height, and weight in men, whereas KES was associated with all physical performance measures in women. It was previously reported that KES is associated with walking speed and TUG.[11] Moreover, Kim et al. reported that muscle mass was associated with SPPB in older adults with high muscle strength (knee extensor peak torque), but not in older adults with low muscle strength.[31] In contrast, muscle strength was found to correlate with SPPB to a significantly higher degree in older adults with low muscle strength than in older adults with high muscle strength.[31] The present study showed the supported and non-supported result in men for the previous studies in men.[11,31] The former is the association with CRT in SPPB, and the latter is the non-association with walking speed, TUG and balance. Knee extensor muscles are important against-gravity muscles. Thus, lower KES is associated with slower CRT and FST. However, the influence of KES on FST and TUG was strong in women, and this was reflected in the association of KES with all physical performance measures, among which TUG consists of standing up, gait, and turning around. Decreases in KES with aging differed between men and women. According to previous studies, the relative reduction in KES or the thigh muscle area of individuals in their 80's compared with those in their 60's

Table 4. Associations of physical performance with age, sex and muscle strength

	Age		Sex		Muscle Strength		Sex*Muscle Strength	
	b	95% CI	b	95% CI	b	95% CI	b	95% CI
Hand grip strength								
10-meter gait time (sec)	0.085*	0.066, 0.104	0.731	-0.314, 1.775	-0.039*	-0.064, -0.015	-0.034	-0.072, 0.004
Timed up & go test (sec)	0.100*	0.081, 0.120	0.307	-0.786, 1.399	-0.043*	-0.069, -0.018	-0.024	-0.063, 0.016
Chair rise time (sec)	0.140*	0.092, 0.187	-1.725	-4.341, 0.891	-0.111*	-0.172, -0.050	0.001	-0.093, 0.096
Floor stand up time (sec)	0.109*	0.086, 0.132	2.083*	0.793, 3.372	-0.025	-0.055, 0.005	-0.061*	-0.107, -0.014
One-leg standing time with opened eyes (sec)	-1.442*	-1.748, -1.135	-9.428	-26.311, 7.454	0.537*	0.143, 0.930	0.633*	0.023, 1.242
Maximum one-step length to height ratio	-0.007*	-0.009, -0.005	-0.111*	-0.218, -0.004	0.002	-0.001, 0.004	0.004*	0.000, 0.008
Knee extension strength								
10-meter gait time (sec)	0.094*	0.076, 0.112	1.212*	0.590, 1.834	-0.049	-0.122, 0.023	-0.177*	-0.288, -0.067
Timed up & go test (sec)	0.106*	0.087, 0.124	1.123*	0.481, 1.766	-0.071	-0.146, 0.004	-0.203*	-0.316, -0.089
Chair rise time (sec)	0.149*	0.103, 0.195	-0.441	-1.994, 1.113	-0.290*	-0.471, -0.109	-0.089	-0.365, 0.186
Floor stand up time (sec)	0.110*	0.088, 0.133	2.205*	1.455, 2.956	-0.074	-0.162, 0.013	-0.282*	-0.415, -0.149
One-leg standing time with opened eyes (sec)	-1.670*	-1.970, -1.369	-10.036	-20.252, 0.179	0.105	-1.084, 1.295	1.622	-0.188, 3.432
Maximum one-step length to height ratio	-0.007*	-0.009, -0.005	-0.116*	-0.179, -0.052	0.001	-0.007, 0.008	0.016*	0.004, 0.027
Knee flexion strength								
10-meter gait time (sec)	0.086*	0.067, 0.105	0.957*	0.278, 1.635	-0.190*	-0.321, -0.060	-0.288*	-0.490, -0.086
Timed up & go test (sec)	0.099*	0.079, 0.118	0.603	-0.105, 1.311	-0.235*	-0.371, -0.099	-0.237*	-0.448, -0.026
Chair rise time (sec)	0.136*	0.089, 0.138	-0.416	-2.118, 1.286	-0.570*	-0.897, -0.243	-0.284	-0.791, 0.223
Floor stand up time (sec)	0.115*	0.091, 0.138	1.816*	0.969, 2.664	-0.086	-0.249, 0.077	-0.330*	-0.582, -0.078
One-leg standing time with opened eyes (sec)	-1.540*	-1.845, -1.235	-15.237*	-26.316, -4.159	1.058	-1.073, 3.189	5.498*	2.199, 8.797
Maximum one-step length to height ratio	-0.007*	-0.009, -0.005	-0.089*	-0.159, -0.019	0.009	-0.005, 0.022	0.022*	0.001, 0.042

b=partial regression coefficient; 95% CI=95% confidence interval; *p <0.05 for linear regression analyses.

was higher in men than in women.[29,32] In addition, body mass and composition differed between men and women. As mentioned above, CRT and FRT are anti-gravity actions, and need more strength than locomotion or balance actions. In fact, KES showed the strongest association with FST in both sexes, suggesting that KES affects lower extremity performance, in particular, anti-gravity activity.

A higher KFS was associated with better physical performance after adjusting for age, height and weight in both sexes, except for 10MGT in men. KFS was reported to associate with walking speed and CRT,[33,34] although there are fewer reports on KFS than on KES. In the present study, like KES in men, KFS did not associate with 10MGT after adjusting for age, height and weight. In a previous study, gait speed was better accounted for by leg strength in the non-linear model (quadratic and inverse) than in the linear model, suggesting that small changes in physiological capacity might have large effects on physical performance in frail adults, while large changes in physiological capacity have little or no effect on physical performance in healthy adults.[35] In addition, gait characteristics such as cadence, step length and head and pelvic movement were reported to differ between men and women.[36] 10MGT is thus likely not affected by KES and KFS, because subjects in this study were able to walk with or without walking aids, regardless of sex.

In this study, we found that higher muscle strength was significantly associated with better performance in all assessed measures in women, but not in men. In particular, muscle strength, power, mass and flexibility, body composition and characteristic actions like gait differed by sex. These changes with aging also differed between men and women. For example, sites, degree or composition of reduction of muscle strength and mass with aging has been reported to differ between men and women.[29,32] In addition, we found that FST and MSL were affected by sex for all types of muscle strength and interactions (sex*muscle strength), and all types of muscle strength were affected by sex. This suggests that more muscle strength was needed to shift and maintain weight in FST and MSL compared with other physical performance parameters. These finding collectively support the possibility of sex-based differences in associations between muscle strength and physical performance.

This study has some limitations. First, the subjects were all recruited in a certain area in Japan. However, mean HGS, 10MGT and OLST values in the present study were similar to those reported in a previous study.[37] Second, we did not measure muscle mass. Recently, Clark et al. proposed that loss of muscle strength and muscle mass are different indices.[20] Moreover, muscle strength is independently associated with lower-extremity performance.[24,31] Kim et al. concluded that measures of muscle strength might be more important clinically than measures of muscle mass in weak older adults.[31] In addition, muscle strength, but not muscle mass, is associated with mortality.[38] Third, it will be necessary to consider potential confounding factors, although subjects of our study could walk independently, communicate and perform all measurements. Future studies should assess muscle mass as a way to examine the association between loss of muscle strength and physical performance in the healthy and frail elderly.

In conclusion, higher muscle strength was associated with better physical performance in both sexes. Although HGS, KET and KFS were associated with all physical performance measures in women, HGS and KFS were associated with all physical performance measures except for 10MGT in men. In addition, KES was strongly associated with anti-gravity activity such as CRT and FST. Physical performance was affected by muscle strength, and a site-specific association between lower extremity muscle strength and lower extremity performance was found in both men and women. Our results suggest that muscle strength can be used to predict low physical performance, especially with regard to locomotion, anti-gravity activity and balance, in older men and women.

CONFLICTS OF INTEREST STATEMENT

All contributing authors declare no conflicts of interest.

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