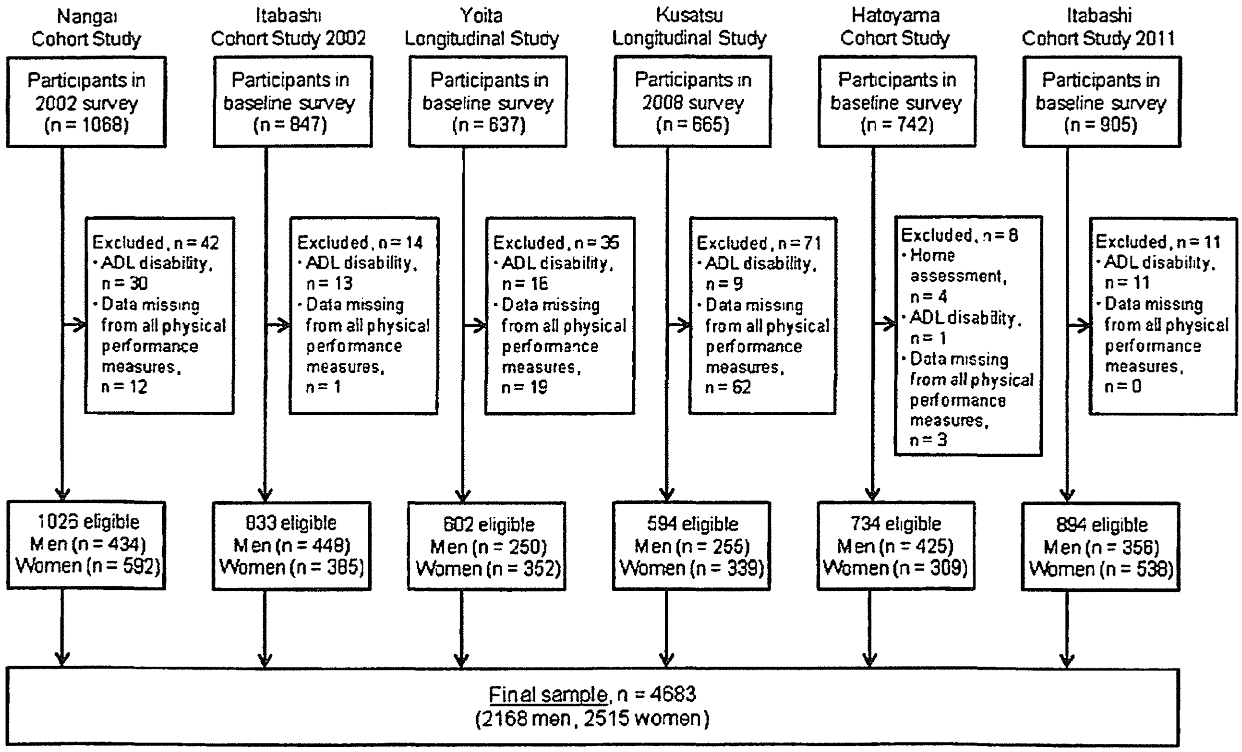

Figure 1. Schematic of participant selection processes in each included study.
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Assessment of health-related information

Age, body height and weight, history of chronic disease (hypertension, stroke, heart disease, and diabetes mellitus), self-rated health, alcohol drinking and smoking status, and Tokyo Metropolitan Institute of Gerontology Index of Competence (TMIG-IC) [34] were assessed in all cohorts. Body mass index (BMI) was defined as body weight divided by the height squared (kg/m^2). History of chronic disease was determined through face-to-face interviews by physicians. Participants were asked whether a physician had diagnosed the specific condition (yes or no). Self-rated health (excellent, good, fair, or poor), alcohol drinking and smoking status (current, past, or never), and TMIG-IC were determined on the basis of questionnaire responses. The TMIG-IC was developed to assess levels of functional competence greater than those required for ADLs. The response to each item in this multidimensional 13-item index of competence is either 'yes' (able to perform) for 1 point or 'no' (unable to perform) for 0 points. The total score ranges from 0 to 13; lower scores indicate lower functional capacity [34].

Assessment of PPMs

Well-trained staff measured hand-grip strength, one-legged stance with eyes open, and gait speed and step length at both usual and maximum paces. Participants wore the same type of shoe that had been prepared for them during the initial assessment.

Hand-grip strength. Hand-grip strength was assessed in all cohorts using common Smedley-type hand dynamometers [7,29]. Participants stood with their arms hanging naturally at their sides holding the dynamometer with the grip size adjusted to a comfortable level. They were instructed and verbally encouraged to squeeze the hand-grip as hard as possible. In the YOITA, KUSATSU, and HATOYAMA studies, participants performed two trials with the dominant hand, and the best result (to the nearest 0.1 kg) was used. In all other cohorts, participants performed one trial with the dominant hand.

One-legged stance with eyes open. One-legged stance with eyes open was assessed using a participant's preferred leg in the NANGAI, KUSATSU, HATOYAMA, and ITABASHI11 studies. Participants were asked to place their hands at their waists while staring at a mark on the wall, raise one leg, and stand as long as possible. They were timed until they lost their balance or reached the maximum of 60 s [7]. Participants performed two trials, and the better time (to the nearest 0.1 s) was used.

Usual and maximum gait speeds. Usual and maximum gait speeds were measured over 5 m, with acceleration and deceleration phases of 3 m each, in all cohorts excepting ITABASHI11, in which participants were measured over a distance of 10 m, with acceleration and deceleration phases of 3 m each. Wang et al [35] reported that usual and maximum gait speeds measured over different distances are comparable only if acceleration and deceleration phases are used. We combined the 5 m and 10 m gait speeds because the acceleration and deceleration phases were identical for both measurement distances and because 3 m is considered sufficient to maintain steady usual and maximum gait speeds [35,36].

Participants stood with their feet behind but just touching a starting line marked with tape at 0 m. Upon receiving the tester's command, they started walking at their normal and maximum paces along an 11-m (16-m in the ITABASHI11) course. The actual walking time was measured over 5 m, starting with the body trunk past the 3-m mark and ending with the body trunk after the 8-m (13-m in the ITABASHI11) mark [7,29]. We calculated gait speed as distance divided by walking time (m/s). Usual gait speed was measured once. Maximum gait speed was measured twice, and the better of the two results (to the nearest 0.01 m/s) was used.

Usual and maximum gait step length. Step length is a component of gait speed and an independent predictor of cognitive decline [32]. Step length at both usual and maximum paces was assessed in the NANGAI, YOITA, KUSATSU, and HATOYAMA studies, in conjunction with usual and maximum gait speeds. Two other staff members measured mean step length by marking the heel points near the tape at 3 and 8 m and dividing the distance between the two heel points by the number of steps required [32]. Usual gait step length was measured once. Maximum gait step length was measured twice, and the better of the two results (to the nearest 0.1 cm) was used.

Statistical analyses

We used descriptive statistics to characterize the study population. Differences in characteristics between men and women were analyzed using the unpaired t test, chi-square test, and Mann-Whitney U test. The means and standard deviations (SDs) of all PPMs were tabulated per 5-year age group (65–69, 70–74, 75–79, 80–84, and 85 years or older) for each sex. We also calculated gait speed and step length at both usual and maximum paces normalized for height (computed as speed or length divided by height in meters) because height is a predictor of gait speed [12]. Similarly, we normalized hand-grip strength for weight (computed as strength in kg divided by weight in kg). Furthermore, we performed a random effects meta-analysis using a Microsoft Excel spreadsheet developed by Neyeloff et al. [37] to obtain weighted means of PPMs and tested heterogeneity across studies using Q and I^2 statistics [38].

To evaluate linear trends in the means of PPMs between the age groups, we used weighted one-way analyses of variance by sex. Furthermore, we visualized univariate regression lines between age and PPMs in both sexes. To examine whether sex differences in PPMs changed with age (due to statistical interactions between age and sex), we performed multiple linear regression analyses with six PPMs as dependent variables, and age, sex (men = 1, women = 2), and the age × sex product terms as independent variables. In these analyses, we used the mean deviations of the independent variables to avoid issues related to multicolinearity [39]. In addition, one-legged stance with eyes open was log transformed.

Quintiles of each physical performance measure were used to construct appraisal standards according to sex and age group. We used an alpha level of 0.05 to identify statistical significance and performed all statistical analyses using IBM SPSS Statistics Version 20.

Results

Table 1 shows the numbers of participants who provided complete data for each variable. Among the six PPMs, hand-grip strength and usual and maximum gait speed were assessed in all cohorts. The rates of missing data were 2.8% (n = 132) for hand-grip strength, 0.6% (n = 19) for one-legged stance with eyes open, 0.5% (n = 23) for usual gait speed, 0.7% (n = 22) for usual gait step length, 4.1% (n = 194) for maximum gait speed, and 3.9% (n = 111) for maximum gait step length. The lowest and highest rates of missing data were for usual and maximum gait speeds, respectively. The numbers of participants with complete data for each variable, by cohort, are available as (Table S1 in File S1).

Table 2 summarizes the characteristics of the study participants. There was no significant difference in age distribution between sexes. All PPM values were significantly higher in men than in women. The descriptive details of the study participants, by cohort (Tables S2 [men] and S3 [women] in File S1) and age group (Tables S4 [men] and S5 [women] in File S1), are available.

Tables 3 and 4 present unweighted simple means and SDs for PPMs according to age group in men and women, respectively. In both sexes, the sample size was small for the age group 85 years or older, and all PPMs showed significant decreasing trends with advancing age (all $P<0.001$ for trend). Unweighted simple means for PPMs according to age group were very similar to and only slightly lower than weighted means (Table S6 in File S1). The Q statistics for all age strata had probability levels exceeding 0.05 ($I^2 = 0.0$–29.2%), indicating that studies were homogeneous within strata.

Univariate linear regression analysis also showed significant associations between age and all PPMs in both sexes (all $P<0.001$; Figure 2). In multiple linear regression analyses, age and sex were significantly associated with hand-grip strength (standardized regression coefficient [β] = -0.30 and -0.70, respectively), one-legged stance with eyes open ($\beta = -0.39$ and -0.06, respectively), usual gait speed ($\beta = -0.40$ and -0.09, respectively) and step length ($\beta = -0.42$ and -0.31, respectively), and maximum gait speed ($\beta = -0.39$ and -0.27, respectively) and step length ($\beta = -0.38$ and -0.48, respectively) (all $P<0.001$). Age × sex interactions were small but significant in hand-grip strength ($\beta = 0.05$, $P<0.001$), one-legged stance with eyes open ($\beta = -0.08$, $P<0.001$), usual gait speed ($\beta = -0.08$, $P<0.001$) and step length ($\beta = -0.03$, $P = 0.030$), and maximum gait speed ($\beta = -0.04$, $P = 0.002$). However, the age × sex interaction was not significant for maximum gait step length ($\beta = -0.01$, $P = 0.527$). These associations and interactions remained significant after adjusting for chronic diseases, alcohol intake and smoking status.

Finally, Tables 5 and 6 show quintiles of PPMs according to age group in men and women, respectively. Although ceiling effects were seen in both sexes in the age group 65–74 years on the one-legged stance with eyes open test, all other PPMs had an approximately symmetrical distribution. The quintiles of weight-adjusted hand-grip strength and height-adjusted gait speed and step length at both usual and maximum paces are included as (Tables S7 [men] and S8 [women] in File S1).

Discussion

Main findings

Our pooled analysis established age- and sex-specific unweighted simple mean values for six PPMs among nondisabled, community-dwelling, older Japanese adults. Our study populations from six cohort studies were homogeneous. In addition, unweighted simple means for PPMs from a pooled analysis were very similar to weighted means from a random effects meta-analysis model, and their 95% confidence intervals largely overlapped. Therefore, we used unweighted simple means as the reference values and also constructed age- and sex-specific appraisal standards according to quintiles. These reference values and appraisal standards can be used in comparative assessments of healthy Japanese of the same sex and age group.

Sex difference in hand-grip strength significantly decreased with increasing age. In contrast, sex differences significantly increased for one-legged stance with eyes open, usual gait speed and step length, and maximum gait speed. These results suggest there are sex differences in the age-related decline of PPMs.

Comments on our results

Reference values. The present study is the first to report age- and sex-specific values for both gait speed and step length at

Table 1. Numbers of participants with complete data for each variable.

Variables	Sample with complete data, n		
	Overall	Men	Women
	(n = 4683)	(n = 2168)	(n = 2515)
Age	4683	2168	2515
Height	4680	2165	2515
Weight	4681	2166	2515
Body mass index	4680	2165	2515
Chronic disease			
Hypertension	4674	2164	2510
Stroke	4674	2164	2510
Heart disease	4659	2158	2501
Diabetes mellitus	4677	2164	2513
Self-rated health	4681	2166	2515
Alcohol drinking status	4679	2165	2514
Smoking status	4677	2164	2513
TMIG-IC	4682	2167	2515
Physical performance measures			
Hand-grip strength	4551	2097	2454
One-legged stance with eyes open	3229	1463	1766
Usual gait speed	4660[a]	2154[c]	2506[e]
Usual gait step length	2934	1352	1582
Maximum gait speed	4489[b]	2075[d]	2414[f]
Maximum gait step length	2845	1326	1519

TMIG-IC = Tokyo Metropolitan Institute of Gerontology Index of Competence.
[a]n = 3767 (5 m usual gait speed)+893 (10 m usual gait speed) = 4660.
[b]n = 3613 (5 m maximum gait speed)+876 (10 m maximum gait speed) = 4489.
[c]n = 1799 (5 m usual gait speed)+355 (10 m usual gait speed) = 2154.
[d]n = 1728 (5 m maximum gait speed)+347 (10 m maximum gait speed) = 2075.
[e]n = 1968 (5 m usual gait speed)+538 (10 m usual gait speed) = 2506.
[f]n = 1885 (5 m maximum gait speed)+529 (10 m maximum gait speed) = 2414.
doi:10.1371/journal.pone.0099487.t001

usual and maximum paces in older Japanese adults. Usual gait speed and hand-grip strength are the most commonly examined measures worldwide [5], and individual normative and reference data have been published, most commonly usual gait speed [12,16,17,19,40,41]. However, several studies [7,32,42,43] reported that maximum gait speed and step length at both usual and maximum paces were also valid for predicting adverse health outcomes. Shinkai et al. [7] reported that usual gait speed was more sensitive in predicting onset of ADL disability among people aged 75 years or older, whereas maximum gait speed was more sensitive among people aged 65–74 years. Fitzpatrick et al. [42] reported that maximum gait speed was most sensitive in predicting early cognitive decline in a healthy cohort. Furthermore, Taniguchi et al. [32] showed that usual gait step length in women and maximum gait step length in men were better than either usual or maximum gait speed at predicting future cognitive decline. These results indicate that measuring gait performance at both usual and maximum paces is important because the ability to voluntarily increase gait performance, i.e. gait speed and step length, may better reflect individual reserves in overall health status. Moreover, measuring gait parameters such as step length, cadence, and variability during maximum walking may optimize detection of early cognitive dysfunction among healthy older people [32,44]. Unfortunately, reference values for these measures were not previously available. This study is of great significance as it provides inclusive reference values for the PPMs considered to be the best indicators of overall well-being.

Compared with previous study results from Western populations [6,40,41,45], the mean values in the present study tend to be somewhat lower for hand-grip strength and higher in gait speed and step length. The measurement protocol for hand-grip strength recommended by The American Society of Hand Therapists (ASHT) [46] has been widely used in Western countries. That protocol calls for participants to be seated, shoulders adducted and neutrally rotated, elbow flexed at 90°, forearm in a neutral position, and the wrist between 0 and 30° of dorsiflexion. However, the protocol of standing with fully extended elbows has been used throughout Japan [7], and the standing protocol produced higher values than the ASHT recommended position [21]. Nevertheless, hand-grip strength was higher in older Westerners [45] than in the older Japanese included in the present study, which suggests that differences in body type (older Japanese are thinner and have less muscle mass than Westerners [47]) have a stronger effect than differences in measuring protocols.

Regarding the difference in gait performance between Western and Japanese adults, a component of the traditional Japanese lifestyle, i.e. lifelong squatting behaviors, may have a long-term

Table 2. Characteristics of the study participants (n = 4683).

Variables	Mean ± standard deviation or n (%)		*P* value
	Men (n = 2168)	Women (n = 2515)	
Age, years	74.0±5.3	73.9±5.5	0.800
Age group, n (%)			0.398
65–69	481(22.2)	588(23.4)	
70–74	727(33.5)	847(33.7)	
75–79	615(28.4)	658(26.2)	
80–84	297(13.7)	354(14.1)	
85 or over	48(2.2)	68(2.7)	
Geographic area, n (%)			<0.001
NANGAI	434(20.0)	592(23.5)	
ITABASHI02	448(20.7)	385(15.3)	
YOITA	250(11.5)	352(14.0)	
KUSATSU	255(11.8)	339(13.5)	
HATOYAMA	425(19.6)	309(12.3)	
ITABASHI11	356(16.4)	538(21.4)	
Height, cm	160.7±6.3	147.6±6.2	<0.001
Weight, kg	59.9±9.4	50.5±8.4	<0.001
Body mass index, kg/m^2	23.2±3.0	23.2±3.5	0.917
Chronic disease, n (%)			
Hypertension	981(45.3)	1216(48.4)	0.033
Stroke	179(8.3)	104(4.1)	<0.001
Heart disease	459(21.3)	420(16.8)	<0.001
Diabetes mellitus	300(13.9)	232(9.2)	<0.001
Self-rated health, n (%)			<0.001
Excellent to good	1777(82.0)	1997(79.4)	
Fair to poor	389(18.0)	518(20.6)	
Alcohol drinking status, n (%)			<0.001
Current	1426(65.9)	581(23.1)	
Past	245(11.3)	137(5.4)	
Never	494(22.8)	1796(71.4)	
Smoking status, n (%)			<0.001
Current	526(24.3)	107(4.3)	
Past	1048(48.4)	130(5.2)	
Never	590(27.3)	2276(90.6)	
TMIG-IC, score (0–13)	12.0±1.6	12.0±1.7	0.527
Instrumental self-maintenance (0–5)	4.8±0.6	4.9±0.6	0.002
Intellectual activity (0–4)	3.7±0.7	3.5±0.9	<0.001
Social role (0–4)	3.5±0.8	3.7±0.7	<0.001
Physical performance measures			
Hand-grip strength, kg	31.7±6.7	20.4±5.0	<0.001
One-legged stance with eyes open, s	39.3±23.0	36.8±23.4	0.003
Usual gait speed, m/s	1.29±0.25	1.25±0.27	<0.001
Usual gait step length, cm	67.7±10.0	60.8±10.0	<0.001
Maximum gait speed, m/s	1.94±0.38	1.73±0.36	<0.001
Maximum gait step length, cm	82.3±11.6	69.7±10.8	<0.001

NANGAI = Nangai Cohort Study; ITABASHI02 = Itabashi Cohort Study 2002; YOITA = Yoita Longitudinal Study; KUSATSU = Kusatsu Longitudinal Study; HATOYAMA = Hatoyama Cohort Study; ITABASHI11 = Itabashi Cohort Study 2011; TMIG-IC = Tokyo Metropolitan Institute of Gerontology Index of Competence.
doi:10.1371/journal.pone.0099487.t002

Table 3. Descriptive statistics for physical performance measures according to age group (men).

Variables	Mean ± standard deviation						P for trend
	Overall	Age group: 65–69	70–74	75–79	80–84	85 or over	
Hand-grip strength, kg	31.7 ± 6.7	35.4 ± 5.8	32.7 ± 6.6	30.2 ± 6.1	27.7 ± 5.9	23.2 ± 5.3	<0.001
Weight-adjusted hand-grip strength, [strength (kg)/weight (kg)]	0.54 ± 0.11	0.58 ± 0.11	0.54 ± 0.11	0.52 ± 0.11	0.49 ± 0.11	0.45 ± 0.10	<0.001
(n)	(2097)	(473)	(699)	(597)	(281)	(47)	
One-legged stance with eyes open, s	39.3 ± 23.0	46.9 ± 20.6	41.7 ± 21.9	33.2 ± 22.9	26.0 ± 22.5	21.9 ± 23.5	<0.001
(n)	(1463)	(480)	(452)	(338)	(166)	(27)	
Usual gait speed, m/s	1.29 ± 0.25	1.39 ± 0.22	1.33 ± 0.23	1.26 ± 0.24	1.16 ± 0.25	1.11 ± 0.28	<0.001
Height-adjusted usual gait speed, [speed (m/s)/height (m)]	0.81 ± 0.16	0.86 ± 0.14	0.83 ± 0.14	0.79 ± 0.16	0.73 ± 0.16	0.72 ± 0.18	<0.001
(n)	(2154)	(479)	(722)	(612)	(293)	(48)	
Usual gait step length, cm	67.7 ± 10.0	71.4 ± 8.1	69.6 ± 9.2	65.4 ± 9.8	60.7 ± 9.9	57.3 ± 11.3	<0.001
Height-adjusted usual gait step length, [length (cm)/height (m)]	42.3 ± 5.9	44.1 ± 5.0	43.3 ± 5.4	41.3 ± 6.2	38.6 ± 6.1	37.2 ± 6.8	<0.001
(n)	(1352)	(389)	(444)	(322)	(149)	(48)	
Maximum gait speed, m/s	1.94 ± 0.38	2.09 ± 0.36	2.00 ± 0.36	1.87 ± 0.36	1.73 ± 0.37	1.65 ± 0.41	<0.001
Height-adjusted maximum gait speed, [speed (m/s)/height (m)]	1.21 ± 0.23	1.29 ± 0.22	1.24 ± 0.22	1.17 ± 0.22	1.09 ± 0.23	1.07 ± 0.26	<0.001
(n)	(2075)	(468)	(697)	(588)	(275)	(47)	
Maximum gait step length, cm	82.3 ± 11.6	86.8 ± 9.2	84.6 ± 10.6	79.2 ± 11.1	73.9 ± 12.0	70.7 ± 13.2	<0.001
Height-adjusted maximum gait step length, [length (cm)/height (m)]	51.4 ± 6.8	53.6 ± 5.5	52.7 ± 6.2	49.9 ± 6.8	46.9 ± 7.4	45.8 ± 8.0	<0.001
(n)	(1326)	(382)	(438)	(317)	(142)	(47)	

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Table 4. Descriptive statistics for physical performance measures according to age group (women).

Variables	Mean ± standard deviation						*P* for trend
		Age group					
	Overall	65–69	70–74	75–79	80–84	85 or over	
Hand-grip strength, kg	20.4 ± 5.0	22.8 ± 4.4	21.2 ± 4.5	19.1 ± 4.8	17.4 ± 4.3	15.2 ± 4.8	<0.001
Weight-adjusted hand-grip strength, [strength (kg)/weight (kg)]	0.41 ± 0.10	0.44 ± 0.10	0.42 ± 0.10	0.39 ± 0.10	0.37 ± 0.10	0.35 ± 0.12	<0.001
(n)	(2454)	(581)	(822)	(645)	(345)	(61)	
One-legged stance with eyes open, s	36.8 ± 23.4	48.5 ± 18.7	38.9 ± 22.7	28.4 ± 22.4	20.0 ± 19.9	10.6 ± 15.2	<0.001
(n)	(1766)	(587)	(543)	(375)	(213)	(48)	
Usual gait speed, m/s	1.25 ± 0.27	1.39 ± 0.22	1.31 ± 0.23	1.18 ± 0.25	1.05 ± 0.28	0.92 ± 0.25	<0.001
Height-adjusted usual gait speed, [speed (m/s)/height (m)]	0.84 ± 0.18	0.93 ± 0.14	0.88 ± 0.15	0.80 ± 0.17	0.72 ± 0.19	0.65 ± 0.17	<0.001
(n)	(2506)	(588)	(845)	(653)	(352)	(68)	
Usual gait step length, cm	60.8 ± 10.0	65.4 ± 7.4	63.3 ± 8.4	58.1 ± 9.9	54.1 ± 10.1	48.1 ± 9.9	<0.001
Height-adjusted usual gait step length, [length (cm)/height (m)]	41.5 ± 6.2	43.9 ± 4.7	42.9 ± 5.2	40.1 ± 6.5	37.7 ± 6.7	34.2 ± 6.4	<0.001
(n)	(1582)	(448)	(490)	(374)	(202)	(68)	
Maximum gait speed, m/s	1.73 ± 0.36	1.92 ± 0.30	1.79 ± 0.31	1.64 ± 0.33	1.48 ± 0.35	1.33 ± 0.37	<0.001
Height-adjusted maximum gait speed, [speed (m/s)/height (m)]	1.17 ± 0.23	1.28 ± 0.19	1.20 ± 0.20	1.12 ± 0.22	1.02 ± 0.23	0.94 ± 0.25	<0.001
(n)	(2414)	(577)	(817)	(629)	(332)	(59)	
Maximum gait step length, cm	69.7 ± 10.8	74.8 ± 8.1	71.5 ± 9.1	67.3 ± 10.5	62.0 ± 11.3	56.3 ± 11.6	<0.001
Height-adjusted maximum gait step length, [length (cm)/height (m)]	47.5 ± 6.8	50.1 ± 5.1	48.5 ± 5.7	46.3 ± 7.0	43.1 ± 7.5	39.9 ± 7.6	<0.001
(n)	(1519)	(440)	(475)	(355)	(190)	(59)	

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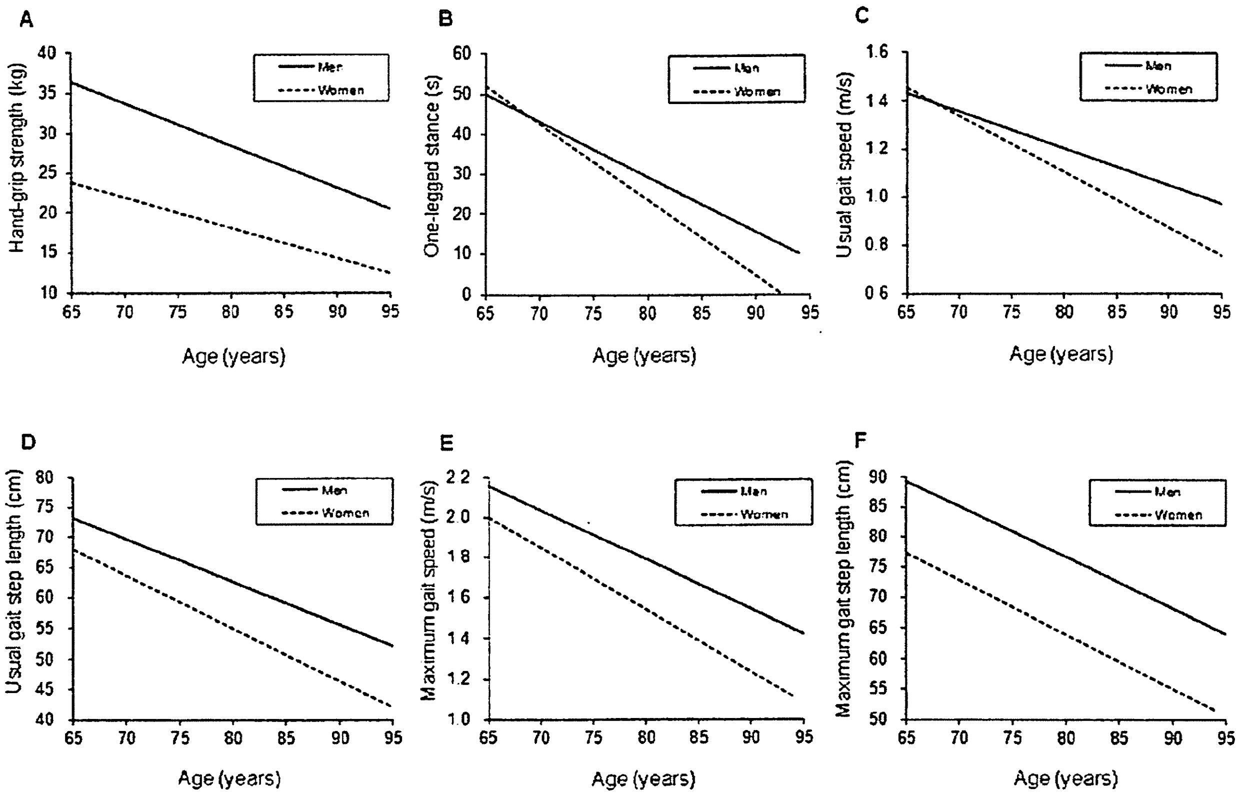

Figure 2. Univariate linear regression lines between age and physical performance (A–F) in men and women. Univariate linear regression analysis showed significant associations between age and all physical performance measures in both sexes (all $P<0.001$). **A** = hand-grip strength, **B** = one-legged balance with eyes open, **C** = usual gait speed, **D** = usual gait step length, **E** = maximum gait speed, and **F** = maximum gait step length.
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effect on the ability to sit, squat, and rise from floor level to a standing position [20]. However, a more important factor in the discrepancy in gait performance may be the difference in measuring protocols used in the Western and Japanese studies. In Western studies, a "static-start" protocol, whereby the individual stands at the starting line, and timing begins with a verbal "go" command, is more common [23]. However, in Japan, gait speed is measured over a 5 m, with acceleration and deceleration phases of 3 m each [7], i.e. a "dynamic-start" protocol [23]. The gait speed at usual and maximum paces measured by dynamic-start protocols was significantly faster than that measured by static-start protocols [35]. These differences should be considered when values for PPMs are compared between Western and Japanese adults.

Age and sex differences. Interestingly, although the absolute levels of PPMs in the present study were somewhat different from those in Western populations, the identified age and sex differences were consistent with those in previous studies [25,48]. A decrease in the sex difference in hand-grip strength with increasing age is fairly common [25,48,49]. Moreover, most studies reported higher gait performance in men than in women [12,15–19], comparable to our results. When usual gait speed and step length were normalized to height, the sex difference in usual gait speed was inverted (normalized usual gait speed in women exceeded that in men), whereas usual gait step length was still longer in men. This suggests that men tend to walk with longer strides but lower cadences and women tend to walk with higher cadences, especially in younger age groups. These results have interesting implications and are consistent with the findings of a previous study [50]. Thus, populations may be similar in how physical performance changes with aging in men and women. Such sex differences in physical performance levels are likely partially due to differences in body size and/or body composition [51]; thus, future research in this area is needed.

The Asian Working Group on Sarcopenia [11] developed a case-finding algorithm for sarcopenia that recommends measuring muscle mass in older adults with slow gait speeds ($<=0.8$ m/s) and/or with low hand-grip strength (<26 kg in men, <18 kg in women). Both measures were also included as surrogate markers of a frailty phenotype [52]. These operational definitions are used as across-the-board criteria regardless of age. However, age-related decline in PPMs is inevitable, even in a nondisabled older population, as shown in the present study. In addition, it was obvious that there were age and sex differences in physical performance and that absolute levels of PPMs vary between countries. Therefore, age- and sex-based PPM criteria specific to sarcopenia or frailty in Japanese should be defined in the future. For example, Verghese et al. [53] defined motoric cognitive risk syndrome as a value 1 SD below age- and sex-specific mean usual gait speeds.

Table 5. Quintiles of physical performance measures according to age group (men).

Physical performance measures	Quintile levels		Age					
			Overall	65–69	70–74	75–79	80–84	85 or over
Hand-grip strength, kg	5	(Highest)	38.0<=	40.0<=	39.0<=	35.0<=	32.0<=	27.0<=
	4		34.0–37.9	37.0–39.9	35.0–38.9	32.0–34.9	29.0–31.9	25.0–26.9
	3		30.0–33.9	34.0–36.9	31.0–34.9	29.0–31.9	26.0–28.9	22.0–24.9
	2		26.0–29.9	31.0–33.9	27.0–30.9	25.0–28.9	23.0–25.9	19.0–21.9
	1	(Lowest)	<26.0	<31.0	<27.0	<25.0	<23.0	<19.0
One-legged stance with eyes open, s	5	(Highest)	60.0<=	60.0<=	60.0<=	60.0<=	60.0<=	56.0<=
	4		60.0<=	60.0<=	60.0<=	42.0–59.9	28.0–59.9	15.0–55.9
	3		33.0–59.9	60.0<=	40.0–59.9	22.0–41.9	12.0–27.9	5.0–14.9
	2		10.0–32.9	25.0–59.9	15.0–39.9	7.0–21.9	4.0–11.9	3.0–4.9
	1	(Lowest)	<10.0	<25.0	<15.0	<7.0	<4.0	<3.0
Usual gait speed, m/s	5	(Highest)	1.49<=	1.56<=	1.52<=	1.47<=	1.36<=	1.31<=
	4		1.35–1.48	1.43–1.55	1.39–1.51	1.32–1.46	1.25–1.35	1.15–1.30
	3		1.25–1.34	1.35–1.42	1.28–1.38	1.20–1.31	1.11–1.24	1.08–1.14
	2		1.11–1.24	1.22–1.34	1.16–1.27	1.10–1.19	0.96–1.10	0.90–1.07
	1	(Lowest)	<1.11	<1.22	<1.16	<1.10	<0.96	<0.90
Usual gait step length, cm	5	(Highest)	76.0<=	78.0<=	76.0<=	73.0<=	68.0<=	66.0<=
	4		71.0–75.9	73.0–77.9	71.0–75.9	69.0–72.9	64.0–67.9	61.0–65.9
	3		66.0–70.9	70.0–72.9	68.0–70.9	64.0–68.9	59.0–63.9	54.0–60.9
	2		60.0–65.9	65.0–69.9	63.0–67.9	58.0–63.9	52.0–58.9	48.0–53.9
	1	(Lowest)	<60.0	<65.0	<63.0	<58.0	<52.0	<48.0
Maximum gait speed, m/s	5	(Highest)	2.27<=	2.38<=	2.27<=	2.17<=	2.00<=	1.91<=
	4		2.00–2.26	2.17–2.37	2.08–2.26	1.92–2.16	1.85–1.99	1.80–1.90
	3		1.85–1.99	2.00–2.16	1.92–2.07	1.80–1.91	1.67–1.84	1.61–1.79
	2		1.68–1.84	1.86–1.99	1.72–1.91	1.61–1.79	1.45–1.66	1.32–1.60
	1	(Lowest)	<1.68	<1.86	<1.72	<1.61	<1.45	<1.32
Maximum gait step length, cm	5	(Highest)	91.0<=	93.0<=	93.0<=	88.0<=	83.0<=	81.0<=
	4		85.0–90.9	88.0–92.9	87.0–92.9	83.0–87.9	78.0–82.9	73.0–80.9
	3		81.0–84.9	85.0–87.9	82.0–86.9	78.0–82.9	72.0–77.9	68.0–72.9
	2		75.0–80.9	80.0–84.9	78.0–81.9	71.0–77.9	63.0–71.9	62.0–67.9
	1	(Lowest)	<75.0	<80.0	<78.0	<71.0	<63.0	<62.0

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Table 6. Quintiles of physical performance measures according to age group (women).

Physical performance measures	Quintile levels		Age					
			Overall	65–69	70–74	75–79	80–84	85 or over
Hand-grip strength, kg	5	(Highest)	24.0<=	26.0<=	25.0<=	23.0<=	21.0<=	20.0<=
	4		22.0–23.9	24.0–25.9	23.0–24.9	20.0–22.9	19.0–20.9	16.0–19.9
	3		19.0–21.9	22.0–23.9	20.0–22.9	18.0–19.9	17.0–18.9	14.0–15.9
	2		16.0–18.9	19.1–21.9	18.0–19.9	15.0–17.9	14.0–16.9	11.0–13.9
	1	(Lowest)	<16.0	<19.0	<18.0	<15.0	<14.0	<11.0
One-legged stance with eyes open, s	5	(Highest)	60.0<=	60.0<=	60.0<=	60.0<=	39.0<=	17.0<=
	4		60.0<=	60.0<=	60.0<=	30.0–59.9	17.0–38.9	5.0–16.9
	3		26.0–59.9	60.0<=	31.0–59.9	14.0–29.9	8.0–16.9	3.0–4.9
	2		9.0–25.9	29.0–59.9	12.0–30.9	6.0–13.9	3.0–7.9	2.0–2.9
	1	(Lowest)	<9.0	<29.0	<12.0	<6.0	<3.0	<2.0
Usual gait speed, m/s	5	(Highest)	1.47<=	1.55<=	1.52<=	1.39<=	1.28<=	1.15<=
	4		1.32–1.46	1.43–1.54	1.39–1.51	1.25–1.38	1.14–1.27	0.94–1.14
	3		1.20–1.31	1.34–1.42	1.27–1.38	1.14–1.24	1.00–1.13	0.83–0.93
	2		1.05–1.19	1.22–1.33	1.14–1.26	0.98–1.13	0.80–0.99	0.70–0.82
	1	(Lowest)	<1.05	<1.22	<1.14	<0.98	<0.80	<0.70
Usual gait step length, cm	5	(Highest)	69.0<=	71.0<=	70.0<=	66.0<=	63.0<=	56.0<=
	4		64.0–68.9	67.0–70.9	66.0–69.9	61.0–65.9	57.0–62.9	50.0–55.9
	3		60.0–63.9	64.0–66.9	62.0–65.9	57.0–60.9	51.0–56.9	45.0–49.9
	2		53.0–59.9	60.0–63.9	57.0–61.9	51.0–56.9	46.0–50.9	40.0–44.9
	1	(Lowest)	<53.0	<60.0	<57.0	<51.0	<46.0	<40.0
Maximum gait speed, m/s	5	(Highest)	2.00<=	2.13<=	2.04<=	1.89<=	1.79<=	1.66<=
	4		1.85–1.99	2.00–2.12	1.85–2.03	1.72–1.88	1.61–1.78	1.40–1.65
	3		1.67–1.84	1.85–1.99	1.72–1.84	1.59–1.71	1.39–1.60	1.20–1.39
	2		1.47–1.66	1.72–1.84	1.56–1.71	1.39–1.58	1.21–1.38	0.96–1.19
	1	(Lowest)	<1.47	<1.72	<1.56	<1.39	<1.21	<0.96
Maximum gait step length, cm	5	(Highest)	78.0<=	81.0<=	79.0<=	75.0<=	72.0<=	67.0<=
	4		73.0–77.9	76.0–80.9	74.0–78.9	70.0–74.9	65.0–71.9	59.0–66.9
	3		69.0–72.9	73.0–75.9	70.0–73.9	65.0–69.9	59.0–64.9	54.0–58.9
	2		62.0–68.9	70.0–72.9	65.0–69.9	60.0–64.9	53.0–58.9	47.0–53.9
	1	(Lowest)	<62.0	<70.0	<65.0	<60.0	<53.0	<47.0

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Uniformity of measuring protocols

The uniformity of measuring protocols within our pooled analysis may be better than in previous meta-analyses because there were few differences in measuring techniques across the studies. Such differences can limit comparability. Although the number of assessments of hand-grip strength differed according to cohort (one or two trials) in the present study, a previous study reported similar test-retest reliability after only one trial, the mean of two or three trials, and a maximum of three trials [54]. Coldham et al. [55] also found that one trial was as reliable and less tiring than three trials.

We analyzed gait speed by combining 5-m and 10-m gait speed measurements because different distances are comparable if acceleration and deceleration phases are used [35]. The means (±SD) of usual (1.29±0.25 m/s in men, 1.25±0.27 m/s in women) and maximum (1.94±0.38 m/s in men, 1.73±0.36 m/s in women) 5- and 10-m gait speeds combined were not substantially different from those of usual (1.29±0.25 m/s in men, 1.22±0.28 m/s in women) and maximum (1.94±0.38 m/s in men, 1.71±0.37 m/s in women) 5-m gait speeds (data not shown). However, we recommend a distance of 5 m with acceleration and deceleration phases of 3 m (>=2.5 m [36]) each to assess steady-state gait speed, since more space is needed for a measuring distance of 10 m.

Strengths and limitations

A strength of this study is the large sample size achieved by combining data from six cohorts. Generally, there tends to be fewer male participants than female participants in population-based studies; however, our rates of participation of the target population was similar between men (28.8%) and women (28.7%). Moreover, having a large number of randomly recruited male participants, such as in the ITABASHI02 and HATOYAMA studies, strengthens our analyses for age- and sex-specific reference values. At the present stage, there is no better representative data that is applicable for older Japanese adults. Our results can be used as the best guess in terms of reference values.

In contrast, the main limitation in this study was selection bias. The total participation rate in health checkups in our study was approximately 30% of the target population. Significant factors associated with non-participation in these community-based health checkups in older Japanese adults were low mental and physical functions such as cognitive dysfunction, low self-rated health and instrumental ADL, and mobility limitation [56 58]. Thus, relatively healthier people tend to participate. More specifically, the age group 85 years or older encompassed a relatively small sample size in both sexes. There may be a healthy volunteer effect in the strata. Practically speaking, since older people who are similar to our study population are the ones who participate in community-based health checkups and interventions, our reference values will be applicable to them. However, our findings might not be generalizable to older adults who are more frail. Finally, causality cannot be inferred regarding age and sex differences in PPMs due to the cross-sectional design of the study.

Conclusions

This pooled analysis yielded age- and sex-specific reference values and appraisal standards for six PPMs in nondisabled, community-dwelling, older Japanese adults. Although absolute physical performance levels vary among populations, the characteristics of age and sex differences in PPMs may be broadly shared.

Supporting Information

File S1 Contains Table S1, Numbers of participants with complete data, by variable and cohort. NANGAI = Nangai Cohort Study; ITABASHI02 = Itabashi Cohort Study 2002; YOITA = Yoita Longitudinal Study; KUSATSU = Kusatsu Longitudinal Study; HATOYAMA = Hatoyama Cohort Study; ITABASHI11 = Itabashi Cohort Study 2011; TMIG-IC = Tokyo Metropolitan Institute of Gerontology Index of Competence. Table S2, Characteristics of male participants according to cohort. [a] gait speed measured over 5 m, [b] gait speed measured over 10 m, *one-way analysis of variance or χ^2 test. NANGAI = Nangai Cohort Study; ITABASHI02 = Itabashi Cohort Study 2002; YOITA = Yoita Longitudinal Study; KUSATSU = Kusatsu Longitudinal Study; HATOYAMA = Hatoyama Cohort Study; ITABASHI11 = Itabashi Cohort Study 2011; TMIG-IC = Tokyo Metropolitan Institute of Gerontology Index of Competence. Table S3, Characteristics of female participants according to cohort. [a] gait speed measured over 5 m, [b] gait speed measured over 10 m, *one-way analysis of variance or χ^2 test. NANGAI = Nangai Cohort Study; ITABASHI02 = Itabashi Cohort Study 2002; YOITA = Yoita Longitudinal Study; KUSATSU = Kusatsu Longitudinal Study; HATOYAMA = Hatoyama Cohort Study; ITABASHI11 = Itabashi Cohort Study 2011; TMIG-IC = Tokyo Metropolitan Institute of Gerontology Index of Competence. Table S4, Characteristics of male participants according to age group. *weighted one-way analysis of variance or χ^2 test. NANGAI = Nangai Cohort Study; ITABASHI02 = Itabashi Cohort Study 2002; YOITA = Yoita Longitudinal Study; KUSATSU = Kusatsu Longitudinal Study; HATOYAMA = Hatoyama Cohort Study; ITABASHI11 = Itabashi Cohort Study 2011; TMIG-IC = Tokyo Metropolitan Institute of Gerontology Index of Competence. Table S5, Characteristics of female participants according to age group. *weighted one-way analysis of variance or χ^2 test. NANGAI = Nangai Cohort Study; ITABASHI02 = Itabashi Cohort Study 2002; YOITA = Yoita Longitudinal Study; KUSATSU = Kusatsu Longitudinal Study; HATOYAMA = Hatoyama Cohort Study; ITABASHI11 = Itabashi Cohort Study 2011; TMIG-IC = Tokyo Metropolitan Institute of Gerontology Index of Competence. Table S6, Weighted means of physical performance measures obtained from a random effects meta-analysis model according to sex and age group across all studies. CI = confidence interval. All *P* values for Cochran's *Q* statistic exceed 0.05. Table S7. Quintiles of weight-adjusted hand-grip strength and height-adjusted gait speed and step length according to age group (men). Table S8, Quintiles of weight-adjusted hand-grip strength and height-adjusted gait speed and step length according to age group (women).
(XLSX)

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Author Contributions

Conceived and designed the experiments: S. Shinkai. Analyzed the data: S. Seino. Wrote the paper: S. Seino. Data acquisition: S. Shinkai YF SO HY. Comments and approval of final version: S. Shinkai YF SO HY HH HKK TI RT.

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ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Association of knee-extension strength with instrumental activities of daily living in community-dwelling older adults

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Aim: The purpose of the present study was to investigate the relationship between knee-extension (KE) strength and instrumental activities of daily living (IADL), and to examine the risk of IADL disability in relation to KE strength in community-dwelling older adults.

Methods: The participants were 1235 community-dwelling older adults (261 men and 974 women) in Tokyo who underwent a comprehensive health survey in 2009. The health survey included measurement of KE strength and a questionnaire on the Tokyo Metropolitan Institute of Gerontology (TMIG)-IADL. Pearson product-moment correlation coefficients and partial correlation coefficients were calculated separately for each sex for four parameters representing quadriceps muscle strength and TMIG-IADL. Pearson's χ^2-test of independence and the Cochran–Armitage test of trend were also carried out to determine the relationship between KE strength and IADL disability.

Results: In women, all correlations between the quadriceps muscle strength parameters and the TMIG-IADL score were statistically significant ($P < 0.0005$). The significance persisted remained even after factors regarding cognition or depression were taken into consideration. Furthermore, the percentage of female participants with IADL disability was dependent on KE strength; there was an inverse trend between KE strength and the percentage of people with IADL disability. In men, no significant relationship was found between KE strength and IADL.

Conclusions: KE strength and IADL correlated positively, and the percentage of people with IADL disability decreased with increasing KE strength in women. **Geriatr Gerontol Int 2014; 14: 674–680.**

Keywords: activities of daily living, aged, knee, muscle strength, quadriceps muscle.

Introduction

The instrumental activities of daily living (IADL) are the activities often carried out by a person who is living independently in a community setting during the course of a normal day, such as managing money, shopping, telephone use, travel in the community, housekeeping, preparing meals and taking medications correctly.[1] Declines in the ability to carry out these activities might result in the need for long-term care. Therefore, the unprecedented rate of aging seen in Japan today necessitates the identification of measures to prevent the decline of IADL in the elderly.

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Several studies have reported that hand muscle strength is related to IADL. For example, a meta-analysis of community-dwelling older participants by Judge *et al.* showed that handgrip strength was negatively related to the total number of IADL requiring assistance from others.[2] Sallinen *et al.* reported that handgrip strength below 37 kg for men and 21 kg for women increased the likelihood of mobility limitations, which are directly related to IADL disability.[3] A 3-year follow-up study by Ishizaki *et al.* also pointed out that weak handgrip strength was a significant predictor of functional decline in IADL performance.[4]

As most IADL involve walking, leg muscle strength might also greatly affect the performance of IADL. However, an association between lower-limb muscle strength and IADL cannot be assumed, as one could, for example, substitute a wheelchair for walking, to carry out each activity included in the IADL.

A multivariate analysis carried out by Uchida *et al.* showed that poor performance on the knee-raising test correlated strongly with decreased IADL performance.[5] A study by Azegami *et al.* involving 47 elderly people investigated the effect of lower-extremity muscle strength on IADL status in two ways: knee-extension (KE) in a single-joint task and total leg extension (TLE) in a multijoint task.[6] The authors found that there was a significant difference in TLE strength between participants with total and only partial IADL independence, whereas no such difference was found for KE strength in a single joint.

In many studies, the strength of lower-limb muscles has often been represented by KE strength,[7–9] as this measurement of the isometric strength of the quadriceps muscles in the sitting position is well established. The purpose of the present study was to examine the relationship between KE strength and IADL performance in a local elderly population.

Methods

Participants

The data were taken from a health survey carried out by Tokyo Metropolitan Institute of Gerontology (TMIG) for community-dwelling older adults in the Itabashi ward of Tokyo in 2009. The participants in the 2009 survey consisted of 1235 people (261 men and 974 women). This group of participants included two cohorts (2002 and 2006 cohorts). All the men ($n = 261$) and 405 of the women participated in a health survey carried out in 2002 (2002 cohort). Follow-up surveys were carried out for this cohort four times, including the survey in 2009. The remaining 569 women first participated in the health survey carried out in 2006 (2006 cohort). Follow-up surveys for this cohort were carried out once in 2007 and once in 2009.

A total of 15 men and 47 women whose IADL or KE data were not available were excluded from the study; the present study analyzed data from 246 men (age range, 77–91 years) and 927 women (age range, 72–91 years) (Table 1). The TMIG ethics committee approved this study. All participants gave their written consent.

Measurement of KE strength

KE strength was measured isometrically using a handheld dynamometer (μTas F-1; ANIMA, Tokyo, Japan). The participants were seated on a custom-made chair with their feet hanging. Participants practiced isometric knee extension by pushing against the tester's hand. The dynamometer was then placed 5 cm above the top of the lateral malleolus, and the chair was adjusted to ensure that the participant's knees were flexed at 90°. Voluntary maximal isometric knee extension effort was exerted twice on the dominant leg. Participants received consistent verbal encouragement as reinforcement. The greater value of two trials was used for analysis. The distance from the lateral knee joint space to the lateral point of the height of the dynamometer pad (F-L distance in Table 1) was measured to convert KE strength into KE torque. Those who were diagnosed with a serious medical problem (e.g. systolic blood pressure over 180 mmHg, diastolic blood pressure over 110 mmHg, or heart attack or cerebral stroke in the past 6 months) were excluded from the test for safety reasons.

Evaluation of IADL performance

IADL performance was assessed using a five-item list from the TMIG Index of Competence for instrumental self-maintenance,[10] which was developed for elderly Japanese participants and has been widely used in Japanese communities. The list assessed the following five activities: (i) using public transportation; (ii) shopping for daily necessities; (iii) preparing meals; (iv) paying bills; and (v) handling a bank account (Table 2). The response to each item was either "yes" (able to accomplish, 1 point) or "no" (unable to accomplish, 0 points). The IADL score (TMIG-IADL hereafter) was calculated as the total number of points.

Evaluation of other parameters potentially related to KE strength and IADL performance

To identify parameters that were related to both KE strength and IADL, which might result in a spurious correlation between the two, data on several other parameters were collected. Bodyweight was measured as a part of the body fat measurement. Cognitive function was evaluated using the Mini-Mental State Examination (MMSE), for which a higher score indicates better cognitive function.[11] Depression was assessed using the Mini-International Neuropsychiatric Interview (MINI);[12] those who gave a negative response to both of the first two questions were categorized as normal, and those who gave a positive response to either of these questions were categorized as depressed. A history of disease (hypertension, stroke, heart disease, diabetes mellitus, hyperlipidemia, osteoporosis, anemia, chronic kidney deficiency, asthma, chronic occlusive pulmonary disease [COPD], pneumonia, osteoarthritis of the hip, gonarthritis, or fracture occurring above the age of 60 years) and the use of drugs was assessed using yes/no questions. Family status was examined using one multiple-choice question, and the participants were categorized as "living alone" or "living with someone".

Data analysis

For quantitative variables, means and standard deviations were calculated. For qualitative variables assessed

Table 1 Basic participant characteristics

			Male (n = 246) Mean ± SD	Female (n = 927) Mean ± SD	Difference between sexes
Mean ± SD		Age (years)	82.2 ± 3.5	79.5 ± 4.2	‡
		Height (cm)	160.8 ± 5.8	147.8 ± 5.6	‡
		Weight (kg)	58.4 ± 8.6	48.8 ± 7.6	‡
		F-L Distance (cm)	27.1 ± 2.3	25.0 ± 2.0	‡
		KES (N)	292.4 ± 82.8	209.1 ± 58.5	‡
		TMIG-IADL	4.9 ± 0.4	4.9 ± 0.5	N.S.
		MMSE	27.7 ± 2.3	27.6 ± 2.3	N.S.
Percent Positive	History	Depression	4.9%	3.9%	N.S.
		Hypertension	58.1%	55.8%	N.S.
		Stroke	10.2%	6.6%	N.S.
		Heart disease	23.6%	22.0%	N.S.
		Diabetes mellitus	11.8%	8.5%	N.S.
		Hyperlipidemia	18.7%	36.1%	‡
		Osteoporosis	6.1%	34.1%	‡
		Anemia	2.8%	3.8%	N.S.
		CKD	2.0%	1.1%	N.S.
		Asthma	4.1%	3.2%	N.S.
		COPD	4.5%	1.5%	‡
		Pneumonia	11.0%	6.9%	†
		Osteoarthritis of hip	2.4%	4.0%	N.S.
		Gonarthritis	15.4%	28.0%	‡
		Fracture after 60 years	13.0%	23.5%	‡
	Drug use	Anti-inflammatory	6.5%	9.5%	N.S.
		Oral steroid	1.2%	1.3%	N.S.
		Anti-osteoporosis	4.9%	30.3%	‡
		Living alone	8.1%	37.2%	‡

†$P < 0.05$, ‡$P < 0.01$. CDK, chronic kidney deficiency; COPD, chronic occlusive pulmonary disease; F-L Distance, distance from fulcrum to the point of load in knee extension task; KES, knee extension strength; SD, standard deviation.

Table 2 English translation of the questions constituting the Tokyo Metropolitan Institute of Gerontology instrumental activities of daily living

Question	Answer
1. Can you use public transportation (bus or train) by yourself?	Yes/No
2. Are you able to shop for daily necessities?	Yes/No
3. Are you able to prepare meals by yourself?	Yes/No
4. Are you able to pay bills?	Yes/No
5. Can you handle your own banking?	Yes/No

by yes/no questions, the percentage of positive responses was calculated. Differences between sexes were analyzed using the t-test or the χ^2-test.

We carried out a preliminary analysis to determine potentially confounding factors for the relationship between KE strength and IADL; correlations between parameters, such as body weight, MMSE, MINI, medical conditions and diseases, medication use, family status, and KE strength or TMIG-IADL, were examined individually. The statistical significance of Pearson's or Spearman's correlation coefficients was tested.

Pearson's correlation coefficients between four parameters representing quadriceps muscle strength (KE strength, KE torque, bodyweight-adjusted KE strength and bodyweight-adjusted KE torque) and TMIG-IADL scores were examined. Partial correlation coefficients using MMSE and MINI as the controlling variables were also calculated. The statistical significance of the correlations was tested.

The participants were classified according to quintiles of KE strength into five categories, and were also classified into two categories according to the presence of IADL disability; participants with a TMIG-IADL score of 1–4 were defined as having IADL disability.[13,14] The χ^2-test was carried out to determine the relationship between the percentage of participants with IADL disability and KE strength. Cochran–Armitage tests of trend were carried out to determine whether there were any trends in the prevalence of IADL disability according to the KE strength.

As the distribution of TMIG-IADL was very skewed (just 2% of men and 3% of women scored ≤3 points), the analyses were also applied to a subgroup of participants whose TMIG-IADL score was between 4 and 5. All of these analyses were carried out using PASW Statistics 18 (IBM Japan, Tokyo, Japan), except for Cochran–Armitage tests, which were carried out using an Excel program (Microsoft, Redmond, WA, USA). The level of significance was set at $P < 0.05$.

Results

Participant characteristics

The age, height, weight, F-L distance and KE strength were greater in men than in women. Hyperlipidemia, osteoporosis, gonarthritis, fracture after 60 years-of-age, use of anti-osteoporosis drugs and living alone were higher in women than in men. COPD and pneumonia were higher in men than in women. (Table 1).

Preliminary analysis of individual correlations

In men, statistically significant correlations with KE strength were observed for bodyweight ($r = 0.346$; $P < 0.0005$) and the MMSE score ($r = 0.230$; $P < 0.0005$). Statistically significant correlations with the TMIG-IADL score were observed for the MINI ($\rho = -0.134$; $P = 0.035$), stroke ($\rho = -0.145$; $P = 0.023$), heart disease ($\rho = -0.138$; $P = 0.030$) and asthma ($\rho = -0.159$; $P = 0.012$). No parameters correlated with both KE strength and the TMIG-IADL score.

In women, statistically significant correlations with KE strength were observed for bodyweight ($r = 0.343$; $P < 0.0005$), MMSE ($r = 0.160$; $P < 0.0005$), MINI ($r = -0.089$; $P = 0.007$), heart disease ($r = -0.105$; $P = 0.001$), osteoporosis ($r = -0.111$; $P = 0.001$), anemia ($r = -0.087$; $P = 0.008$) and the use of anti-osteoporosis drugs ($r = -0.084$; $P = 0.010$). Statistically significant correlations with the TMIG-IADL score were observed for the MMSE ($r = 0.302$; $P < 0.0005$), MINI ($\rho = -0.208$; $P < 0.0005$) and stroke ($\rho = -0.097$; $P = 0.003$). Thus, the MMSE and MINI correlated with both KE strength and the TMIG-IADL score. We therefore took these two parameters into consideration when we carried out the partial correlation analysis.

Correlation analysis

In men, all correlations between quadriceps muscle strength parameters and the TMIG-IADL score were statistically non-significant (Table 3). In women, all the correlations were weak (R 0.157–0.173), but statistically significant ($P < 0.0005$) (Table 3). These correlations remained significant for women even when the analysis

Table 3 Correlation coefficients between parameters related to quadriceps muscle strength and Tokyo Metropolitan Institute of Gerontology instrumental activities of daily living score

	Sex	Parameter	Correlation coefficient	Statistical significance
All participants	Male ($n = 246$)	KES	0.022	N.S.
		KET	0.030	N.S.
		WA-KES	0.066	N.S.
		WA-KET	0.072	N.S.
	Female ($n = 927$)	KES	0.173	‡
		KET	0.173	‡
		WA-KES	0.157	‡
		WA-KET	0.166	‡
Subgroup of TMIG-IADL ≥ 4	Male ($n = 241$)	KES	−0.005	N.S.
		KET	−0.001	N.S.
		WA-KES	0.010	N.S.
		WA-KET	0.012	N.S.
	Female ($n = 899$)	KES	0.109	‡
		KET	0.100	‡
		WA-KES	0.133	‡
		WA-KET	0.128	‡

†$P < 0.05$, ‡$P < 0.01$. KES, knee extension strength; KET, knee extension torque; TMIG-IADL, Tokyo Metropolitan Institute of Gerontology instrumental activities of daily living; WA-KES, weight-adjusted knee extension strength; WA-KET, weight-adjusted knee extension torque.

Table 4 Partial correlation coefficients, with Mini-Mental State examination and depression as the control variable, between parameters related to quadriceps muscle strength and Tokyo Metropolitan Institute of Gerontology instrumental activities of daily living score

	Sex	Parameter	Partial correlation coefficient	Statistical significance
All participants	Male (n = 234)	KES	0.009	NS
		KET	0.018	NS
		WA-KES	0.066	NS
		WA-KET	0.071	NS
	Female (n = 913)	KES	0.091	‡
		KET	0.091	‡
		WA-KES	0.085	†
		WA-KET	0.090	‡
Subgroup of TMIG-IADL ≥ 4	Male (n = 229)	KES	−0.017	NS
		KET	−0.011	NS
		WA-KES	0.014	NS
		WA-KET	0.017	NS
	Female (n = 879)	KES	0.088	‡
		KET	0.078	†
		WA-KES	0.115	‡
		WA-KET	0.108	‡

†$P < 0.05$, ‡$P < 0.01$. KES, knee extension strength; KET, knee extension torque; WA-KES, weight-adjusted knee extension strength; WA-KET, weight-adjusted knee extension torque.

included only those with TMIG-IADL scores of 4–5 (R 0.100–0.133; $P < 0.005$) (Table 3).

Using the MMSE and MINI as the controlling variables, all the partial correlations between the quadriceps muscle strength parameters and the TMIG-IADL score in men were statistically non-significant (Table 4). In women, all the partial correlations were weak (R 0.085–0.091), but statistically significant ($P < 0.05$; Table 4). These partial correlations for women remained significant even when analysis included only those with TMIG-IADL scores of 4–5 (R 0.078–0.115; $P < 0.05$) (Table 4).

Analysis of the ratio of IADL disability to KE strength

Male participants were classified by KE strength quintiles into the following five categories: very low, KE strength <229 N; low, KE strength 229–267 N; normal, 267–311 N; high, 311–355 N; and very high, KE strength >355N. The χ^2-test showed that IADL disability was independent of KE strength (Pearson's χ^2, 5.199; df, 4; $P = 0.267$) in men. The occurrence of IADL disability showed no trend related to KE strength (Cochran–Armitage test, $P = 0.828$) (Fig. 1). These results were also true for the subgroup of men whose TMIG-IADL scores were between 4 and 5.

Female participants were classified by KE strength quintiles into the following five categories: very low, KE strength <159 N; low, KE strength 159–192 N; normal, KE strength 192–221 N; high, KE strength 221–254 N; and very high, KE strength >254 N. IADL disability was dependent of KE strength (Pearson's χ^2, 23.685; df, 4; $P < 0.0005$). The occurrence of IADL disability decreased as KE strength increased; the percentage of participants with IADL disability was 12.9%, 6.5%, 6.3%, 4.3% and 1.1% for the grades very low, low, normal, high, and very high, respectively (Fig. 1), and this inverse trend was statistically significant (Cochran–Armitage test, $P < 0.0005$). These results were also true for the subgroup with TMIG-IADL scores between 4 and 5 (Pearson's χ^2, 11.811; df, 4; $P = 0.019$; Cochran–Armitage test, $P = 0.019$).

Discussion

The present study examined the relationship between KE strength and IADL in older adults living in a local area of Tokyo. In contrast to the study by Azegami *et al.*, the present results suggest that single-joint-task KE strength is significantly related to IADL in women.[6] In women, every KE strength parameter correlated with IADL. As partial correlations adjusted by cognitive function and depressive scale were also present, it is suggested that KE strength affects IADL independently. In women, KE strength was related to the prevalence of IADL disability. In men, no correlation between KE strength and IADL was observed. These results were the

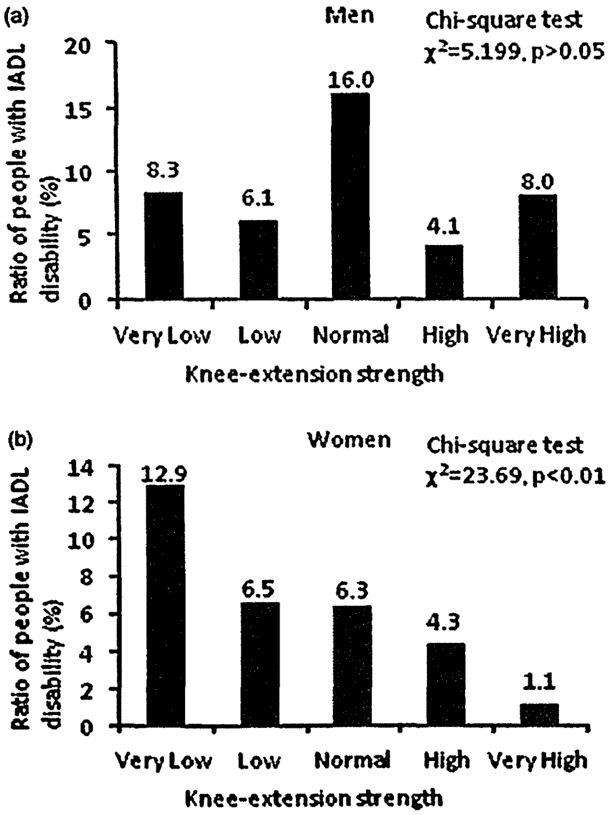

Figure 1 Prevalence of in instrumental activities of daily living (IADL) disability in relation to knee-extension strength (KES) in (a) men and (b) women. KES, men: very low, <229 N; low, 229–267 N; normal, 267–311 N; high, 311–355 N; very high, >355 N. KES, women: very low, <159 N; low, 159–192 N; normal, 192–221 N; high, 221–254 N; very high, >254 N. IADL, instrumental activities of daily living; KES, knee-extension strength.

same even when the subject population was limited to those who had relatively high TMIG-IADL scores (≥4).

Basic ADL has been reported to be affected by the knee extension strength; participants whose strength test scores were in the lowest tertile had two- to three-fold the risk of ADL dependence than those in the highest tertile.[15] Therefore, the present result for men, suggesting no relationship between KE strength and the degree of IADL disability, seems counterintuitive.

To determine whether any one question specifically affected the sex-based differences, we carried out Pearson's χ^2-tests to assess the relationship between KE strength and the answer to each specific question (Q1–Q5). This result showed that, in women, the KE strength and answers to specific questions were related for all items except Q3, with a same trend as total IADL. In men, KE strength and the responses to every specific question were independent. This result suggests that the sex-based difference was not due to any particular item.

One possible explanation for the lack of such a relationship in men is that men had a generally higher KE strength than women. The muscular strength threshold required to carry out IADL independently is 2.8 N/kg (force divided by bodyweight) in the Japanese elderly population.[16] A total of 95% of our male and 92% of female participants had a KE strength above this threshold. This suggests that based on KE strength, more men were able to carry out IADL independently than women. This factor could partly explain the lack of correlation in men.

Another possible explanation for the lack of a correlation between KE strength and IADL performance in men is that cognitive function might have contributed more to IADL performance in men than in women. IADL were reported to be associated with memory and executive functioning in patients with mild Alzheimer's disease.[17] The absence of a relationship between KE strength and IADL performance in men could be partly explained if one argued that cognitive function played a greater role in men, especially because the men were older than the women. As aforementioned, however, the MMSE was related to IADL in women only. The average MMSE score was not different between men and women. Thus, it seems unlikely that cognitive function played a greater role in men than in women in determining IADL performance.

Another possible explanation is that effects of diseases were overshadowing the effect of KE strength. IADL was associated with a history of stroke, heart disease and asthma in men, but only with stroke in women. It is conceivable that IADL in men was more affected by medical conditions than women. Conceptual tradition in Japan regarding family roles might result in the maintenance of IADL irrespective of diseases. According to an international social survey, 77.7% of Japanese married people stated that grocery shopping was usually done by the woman within a couple, compared with 34–57% in six other developed countries.[18] The same trend follows for doing laundry and preparing meals.[18] Our data also show that 37.2% of the women were living alone compared with 8.1% of the men. High dependency on the woman for household jobs and the high percentage of women living alone suggest that women were carrying out many daily physical activities, which might have prevented the deterioration of IADL in response to disease.

Relative dominance by women of household jobs could also suggest a limitation of using TMIG-IADL to evaluate the IADL, especially in Japanese men. At least two questions in TMIG-IADL (Table 2) are closely related to jobs mainly carried out by women in Japan. We might need an improved index of IADL that is more sensitive in healthier men.

The present study showed that in women, KE strength correlated positively with IADL score, and the degree of IADL disability decreased with increasing KE strength. This correlation was not observed in men. We might need to study a frail population to identify a correlation in men. We conclude that elderly women need to take measures to prevent lower-limb muscles from declining to maintain IADL.

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Disclosure statement

No potential conflicts of interest were disclosed.

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Association between Self-Reported Urinary Incontinence and Musculoskeletal Conditions in Community-Dwelling Elderly Women: A Cross-Sectional Study

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Aims: Urinary incontinence (UI) and musculoskeletal conditions, particularly low back pain (LBP), and osteoarthritis (OA), are common problems that have been associated with mobility limitations and future dependence in activities of daily living in the elderly. The purpose of this study was to explore the relationship between UI, UI types, and musculoskeletal conditions in elderly community-dwelling women. **Methods:** A cross-sectional study was performed on 1,399 community-dwelling Japanese women aged 75–84 years. Face-to-face interviews, body composition, and physical function, including grip strength, and usual walking speed, were conducted. UI was defined as experience of urine leakage episodes more than once per week. Self-reported presence and degree of pain, LBP, and OA were assessed. Student's *t*-tests and chi-square tests were used to analyze continuous and categorical variables. Associations between selected variables, UI, and UI types were assessed using stepwise multiple logistic regression models. **Results:** A total of 260 participants had UI (18.6%) and 399 had LBP (28.5%). Participants with UI were more likely to experience pain (76.0%) and LBP (36.2%) than those without UI ($P<0.001$ and $P=0.002$, respectively). Age, body mass index, falls, walking speed, grip strength, LBP, and pain coupled with OA were significantly associated with UI. There were significant associations between urge UI and mild (odds ratio (OR) = 1.653, 95% confidence interval (CI) = 1.031–2.650) and severe LBP (OR = 2.617, 95% CI = 1.193–5.739). **Conclusions:** This study showed that UI was significantly associated with musculoskeletal conditions, including LBP, and the combination of pain and OA. The risk of urge UI was greater with increasing severity of LBP. *Neurourol. Urodynam.* © 2014 Wiley Periodicals, Inc.

Key words: elderly women; musculoskeletal conditions; low back pain; urinary incontinence

INTRODUCTION

In Japan, many elderly people between the ages of 65 and 74 years are often independent, healthy, with jobs, and are not considered burdens for society. However, elderly people over 75 years are increasingly affected by multimorbidity and geriatric syndromes. Evaluation of this particular age category is of great importance. Urinary incontinence (UI) is a common condition among elderly women, with an estimated prevalence rate ranging from 14% to 61% in elderly women between 60 and 79 years of age, and 25–63% in elderly women over 80 years or age.[1] Factors such as age, childbirth, lower urinary tract infections, obesity, and physical activity are considered to be risk factors in the development of UI, alone or in combination.[2] Different UI types have varying risk factors and mechanisms. Stress UI occurs with exertion, sneezing or coughing, urgency UI is accompanied by or immediately preceded by urgency, and mixed UI is leakage associated with both urgency and exertion.[3] Urgency to urinate can result from an imbalance of facilitatory and excitatory control systems, causing detrusor overactivity or overactive bladder.[4,5]

One study reported that UI was associated with medical conditions such as strokes, arthritis, back problems, and respiratory conditions.[6] Among them, osteoarthritis (OA) and lower back pain (LBP) are common musculoskeletal conditions, which lead to mobility limitation in elderly women. Evidence from epidemiological studies suggests an association between UI and LBP.[2,7–10] Some previous studies have discussed that pelvic floor muscle dysfunction contributes to urinary disorders or lumbopelvic pain. Moreover, researchers have also indicated neurological associations between LBP and urgency symptoms of the overactive bladder core symptom complex.

However, there are very few studies available that investigate the relationship between musculoskeletal conditions and UI despite the major problems that both conditions have on the disability of elderly women. Moreover, the association between LBP and UI type has not yet been reported.

The primary objective of this study was to explore the association between LBP and UI, and the secondary objective was to estimate the association between UI and other musculoskeletal conditions, such as pain, multi-site pain, and OA. We hypothesize that musculoskeletal conditions, specifically LBP will be associated with UI in elderly Japanese women.

Conflict of interest: none.
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