Associations between physical function, falls, and the fear of falling among older adults participating in a community-based physical exercise program: A longitudinal multilevel modeling study

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Brief summary:
Falls were significantly associated with balance, age, previous fall history, fear of falling, and duration of participation in a community-based exercise program.

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Abstract

Objectives: Exercises that target muscle strength, balance, and gait prevent falls in older people. Moreover, exercise may reduce fear of falling by improving physical function. Many studies have examined the risk factors for falls and fear of falling separately. However, few studies have examined the associations between physical function, falls, and fear of falling simultaneously. This study aimed to identify the key physical functions influencing falls and fear of falling.

Design: Longitudinal observational study

Setting and Participants: This study included 2,397 older adults (women: 82.8%, mean age: 74.3±8.0 years) who participated in community-based physical exercise.

Methods: Physical functions such as muscle strength, balance, gait speed, and flexibility were measured regularly during the program. A questionnaire regarding falls and fear of falling was also administered simultaneously. Multilevel modelling was used to investigate the association between physical function and falls and fear of falling.

Results: The prevalence of falls and fear of falling at enrolment were 27.1% and 49.8%, respectively. Statistical analyses revealed that 1) falls were significantly associated with balance, age, fall history, fear of falling, and duration of participation; 2) fear of falling was significantly associated with muscle strength, balance, gait speed, age, and fall history. Long-term participation was significantly associated with an improvement in balance.

Conclusions and Implications: The risk factors for falls and fear of falling were different. Our research showed the importance of including balance training in all prevention programs.

Introduction

Falls and fear of falling are associated with serious physical and psychosocial consequences. The number of people living beyond 65 years of age is increasing rapidly, and fall-related injuries and hospitalizations are also increasing steadily [1,2]. Screening individuals and older people at risk of falls is critical to preventing falls. The risk of falls and fear of falling increase with age and age-related factors. Several risk factors for falls have been identified, including muscle strength [3], balance, gait [4–6], history of previous falls [2,7], and frailty [8,9]. These risk factors are also associated with fear of falling [10], which may lead to future falls [11].

There is a complex relationship between falls and fear of falling. While previous studies attempted to identify predictors of falls and fear of falling, few studies have simultaneously and longitudinally analyzed physical function, falls, and fear of falling. Because the data obtained from the same individual are not mutually independent, the mutual correlation of multiple data should be considered when analyzing longitudinal data with multilevel structures. Recently, research using multilevel regression models in repeated measures designs has been increasing, such as multiwave longitudinal and experience sampling studies of health behaviors [12]. A previous longitudinal observational study of older adults who participated in a community-based physical exercise program reported that long-term participation improved lower extremity muscle strength, delays age-related decline in walking speed and physical function, and delays the transition from robustness to frailty [13,14]. This study aimed to investigate the independent key components of physical functions related to falls and fear of falling in older people and to determine whether participating in community-based physical exercise reduces the prevalence of falls and fear of falling. Furthermore, we investigated the association between the key components of physical function and community-based physical exercise. These observations could be useful for detecting high-risk groups for falls, formulating efficient fall prevention programs, and developing exercise programs that improve participants' motivation.

Methods

Study design

We used data from a longitudinal observational study that included older adults who participated in independent community-based physical exercise groups in Japan starting in April 2010. This exercise program is called “lively 100-year-old physical exercise” and is conducted by the Care and Welfare Division in Sumoto City, Awaji Island, Hyogo Prefecture. There were no formal inclusion criteria for study participation other than a willingness to participate in the exercise program. In this program, physical functions

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such as muscle strength, balance, gait speed, and flexibility are measured every four months for the first year and once annually thereafter. A questionnaire regarding falls, fear of falling, and a wide range of health-related variables was also administered simultaneously. However, we did not perform physical tests for participants were who unable to walk even when assisted. In 2019, there were 85 small sub-groups and a total of 2,570 participants in the program. We analyzed physical test registry data pertaining to 2,397 participants (93.3%) who took at least one physical test (Figure 1). Finally, 5,127 physical test data from 1,637 participants and 7,154 physical tests from 2,290 participants were used for a generalized linear mixed model for falling and fear of falling, respectively. The average number of physical tests was 3.60 (standard deviation, SD: 2.53), and the duration of observation was 2.52 years (SD: 2.53 years). This study was approved by an appropriate Ethics Committee (No.2019F21).

The exercise program

The "Lively 100-year-old physical exercise" program is a community-based exercise program developed by a Japanese physiotherapist. It is an easy program that is widely deployed in many parts of Japan and is characterized by the participants taking the initiative themselves and there being no trainers with special qualifications in its operation. A regional participant leader takes the lead by using the program's digital versatile disc. The majority of the exercises are performed while sitting or in a chair and can be performed safely even by older people who require high level of care. This program includes stretching exercises and the following muscle-strengthening exercises [15]: 1) raising both arms; 2) raising both arms to the side; 3) rising from a chair; 4) knee extension exercises; 5) knee lift exercises; 6) lateral leg lifting exercises; and 7) standing hip extension exercises. Weights are attached to the limbs and can be increased up to 2.2 kg over 10 increments. The weight is increased at the participants' discretion. Exercises are conducted once a week for 40 minutes. The decision to participate is left to the individual.

All participants were grouped according to the duration of participation, as follows: short-term participation group: participation for ≤1 year (took the physical tests ≤3 times; N = 1,386); middle-term participation group: participation for two to four years (took the tests four to six times; N = 632); and long-term participation group: participation for ≥5 years (took the tests 7-13 times; N = 379).

Measurements

Falls and Fear of Falling

A yes/no question was used to determine the frequency of falls and fear of falling. Participants were asked if they had experienced falls in the past year (one or more falls).

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The definition for falls in the present study was unintentionally coming to the ground or some lower level. Slip, trip, stumble, and loss of balance were not considered falls. Falls resulting from outside events such as motor vehicle accidents or violence were also excluded. Fear of falling was investigated using the question "Are you afraid of falling?" The reliability and criterion validity of this question have been demonstrated in previous studies involving community-dwelling older adults [16].

Medical and Functional Assessments

Demographic characteristics included age, sex, weight, , and level of care needed. The knee extension strength test[17], one-leg standing time test[18], timed up and go (TUG)[19], and chair sit and reach test s[20], and single chair stand (with or without aid) were all functional assessments used. The methodological details are provided in the Supplementary Methods section.

Statistical analysis

We used a generalized linear mixed model for falling or fear of falling and a linear mixed model for balance (one-leg standing time); the effect of individual differences was incorporated into the models.

We investigated the associations between falls and fear of falling using the following: knee extension strength, one-leg standing time, single chair stand (with or without aid),

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TUG time, and sit and reach test. The following four models were used: Model 1 for falls and Model 3 for fear of falling were unadjusted models with a random slope model. Model 2 for falls was adjusted for age, sex, weight, level of care needed, fall history, and fear of falling with a random intercept and a random slope model. Model 4 for fear of falling was adjusted for age, sex, weight, level of care needed, and fall history with a random intercept and a random slope model. We computed the predicted values by conditional effects (these are conditioned on certain reference levels of factors) for binary outcomes such as falls and fear of falling. The reference levels were as follows: sex, female; weight, 52.0 kg; flexibility, 16.0 cm; lower extremity muscle strength, 62.0 kg/f; TUG, 6.0 sec; standing up from a chair without any aid; care needed, independent; and history of falls within one year, none.

We investigated the effect of program duration on one-leg standing time; Model 1 was an unadjusted model with a random intercept and a random slope model. Model 2 was adjusted for age, sex, weight, level of care needs, falls and fear of falling with a random intercept and a random slope model. For one-leg standing time, the marginal effect (the amount of change in the dependent variable per unit of the independent variable) was calculated.

The t-test and chi-square test were used to compare baseline data. Statistical significance was set at $p<0.05$. All statistical analyses were conducted using R version 4.1.0 (Vienna, Austria); the GLMM adaptive package [21] and lme4 package [22] were used to fit the mixed-effects models [23].

Results

Participant characteristics

The study included 2,397 participants (17.2% men) with a mean age of 74.3 years (SD 8.0). The prevalence of falls and fear of falling at enrolment were 27.1% and 49.8%, respectively. The demographic and baseline characteristics are presented in Table 1.

Participants who had experienced falls at enrolment had significantly shorter one-leg standing times (P = 0.003), experienced greater difficulty in the single chair stand (P = 0.013) and exhibited lower TUG times (P = 0.002). Participants who had fear of falling at enrolment were older (P<0.001), had significantly lower knee extension strength (P<0.001), shorter one-leg standing times (P<0.001), greater difficulty in the single chair stand (P<0.001), lower TUG time (P<0.001), and needed a higher level of care (P=0.016).

Factors associated with falls and fear of falling

The influence of independent risk factors on falls and fear of falling was examined

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using a multilevel logistic regression model (Table 2). In Model 2, the estimated probability of falls at 75 years old (approximate mean age) was 0.16 (95% confidence interval, (CI): 0.08-0.28). Thus, for an average participant (a participant with a random effect = 0), the probability of falling when the covariates were equal to zero or the mean value, was 0.16. The probability of falls increased significantly by 1.02 (95% CI: 0.91-1.15) for every additional 5-year increment in age ($p<0.001$). The following factors were significantly related to falls: one-leg standing time (odd ratios (OR) = 0.99, 95% CI: 0.990-0.998), long-term participant (OR = 0.79, 95% CI: 0.64-0.98), fall history (OR = 2.89, 95% CI: 2.40-3.47), and fear of falling (OR = 1.21, 95% CI: 1.03-1.41). In Model 4, the probability of fear of falling at 75 years old was 0.53 (95% CI: 0.31-0.74). The probability of fear of falling was 1.35 (95% CI: 1.18-1.54) for every additional 5-year increment in age ($p<0.001$). The following factors were significantly related to fear of falling: age (OR = 1.35, 95% CI: 1.18-1.54), one-leg standing time (OR = 0.99, 95% CI: 0.99-1.00), single chair stand (with aid) (OR = 2.79, 95% CI: 2.05-3.78), fall history (OR = 2.94, 95% CI: 2.47-3.50), sex (OR = 0.33, 95% CI: 2.47-3.50), knee extension strength (OR = 1.21, 95% CI: 1.03-1.41), and TUG time (OR = 1.09, 95% CI: 1.04-1.41). As these models control the cluster of each participant, the covariate effects have a within-cluster interpretation, which is in association with a characteristic (e.g., sex) and the outcome, after adjusting for the remaining characteristics within the same participant.

Factors associated with the one-leg standing time

Balance was a key component associated with both falls and fear of falling among the various physical functions in the present study; therefore, the influence of the one-leg standing time was examined using a linear mixed model (Table 3). In Model 2, one-leg standing time, estimated at an intercept centered at 75 years old, was 47.6 sec; this changed significantly at a rate of -8.43 sec for every additional 5 years of age ($p<0.001$). The following factors were significantly related to one-leg standing time: mid-term participant +2.93 sec (95% CI: 1.31-4.55), long-term participant +4.94 sec (95% CI: 3.05-6.84), level of care needed -2.17 sec (95% CI: -3.68--0.65), and weight -0.29 sec (95% CI: -0.360.21).

Figure 2 shows the effect of duration of participation, one-leg standing time, and age on predicted probabilities of falls. This translated into a fixed-effects interaction between one-leg standing time and groups. Estimated marginal means were obtained from linear regression models adjusted for frequency of participation, age, sex, weight (52.0 kg), sit and reach test (16.0 cm), knee extension strength (62.0 kg/f), TUG time (6.0 seconds), single chair stand (without any aid), level of care needed (independent), and history of falls (no). The predicted probabilities of falls decline with increasing one-leg standing time in each group. Figure 3 shows the effect of duration of participation, one-leg standing time, and age on the predicted probabilities of fear of falling. The predicted probabilities of fear of falling also declined with increasing one-leg standing time in each group. The predicted probabilities of fear of falling were largely influenced by age, and the effect of exercise was small in the younger sub-group of the older population (65 years old); however, it was decreased by long-term participation in the older sub-group of the older population (85 years old). While the predicted probabilities of falls were not influenced by age, they were decreased by mid or long-term participation in all age groups.

Discussion

In this study, we demonstrated that the physical function related to falls is balance, and the factors related to fear of falling are muscle strength, balance, and walking speed. Further, long-term participation in a community-based exercise intervention program helped prevent falls and was associated with improved balance. As fear of falling and past fall history also affect falls, we speculated that strategies for providing a better community-based physical exercise program should improve various physical functions to relieve fear of falling, increase motivation to exercise, and focus on improving

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balance to prevent falls.

It has been reported that approximately 30% of people aged ≥65 years living in a community and >50% of those living in residential care facilities/nursing homes fall every year, and about half of those who fall do so repeatedly [1]. A recent epidemiologic study on falls in Korea reported that 15.9-25.1% of community-dwelling Korean older people experienced falls yearly [24]. Fall history leads to fear of falling. However, fear of falling is common among those who have never fallen [25,26]. The prevalence of falls and fear of falling are influenced by age, physical function, and other risk factors. To guide the allocation of fall prevention interventions, fall risk assessment tools (FRATs) [27] and the Stopping Elderly Accidents, Deaths & Injuries (STEADI) tool developed by the Centers for Disease Control and Prevention[28] were used. Often, this involves scoring risk from 0 (no fall risk) to 10 (high fall risk), or as nil, mild, moderate, or severe. Similar to the World Health Organization Fracture Risk Assessment Tool (FRAX), [29,30] which calculates the 10-year probability of hip fracture and a major osteoporotic fracture from readily assessed clinical risk factors, the probability of falls and fear of falling can be predicted using the present longitudinal multilevel model based on various physical function tests. For example, a 75-year-old woman with a weight of 52.0 kg, flexibility of 16.0 cm, lower extremity muscle strength of 62.0 kg/f, TUG of

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6.0 sec, balance of 30 sec, short-term participation, and no clinical risk factors has an estimated 18.8% one-year probability of sustaining falls and 28.2% probability of sustaining fear of falling (see Appendix 2). The calculated probability for similar participants with a fall history was 54.3% for falls and 82.9% for fear of falling. Although the probability of falls is approximately 20% for all ages, improvements in muscle strength, balance, and gait speed could lead to a decrease in the probability of fear of falling. These calculations will help identify participants with increased fall risk and improve their motivation to participate in fall prevention programs.

Our data showed being female was one of the risk factors for fear of falling. Previous studies have showed similar results[25,31–34] . It was inferred that the muscle strength is generally lower in females than in males. Females were more likely to restrict their activity out of fear, may tend to over-estimate their risk of falling, and psychological anxiety tends to be more severe in them. In the present study, there was a significant difference in knee extension strength between females and males (52.3±18.7 Kgf versus 55.7±19.3 Kgf, P<0.001). However, there was no significant difference in one-leg standing time (30.9±23.5 vs 30.8±23.7 sec; P = 0.940) and TUG (7.4±2.8 vs 7.4±3.8 sec; P = 0.872) between males and females.

Our data showed that low muscle strength and a long TUG were factors for fear of falling. However, low muscle strength and a long TUG test was not predictive of falls. While muscle strength and functional abilities are important in preventing falls, balance is also an important risk factor for falls [4]. A study using video capture in long-term care facilities showed that the most common causes of falls were incorrect weight shifting and tripping, and the most common activities leading to falls were forward walking, standing quietly, and sitting down [5]. In addition to muscular strength, balance was also related to incorrect transfer or shift of body weight. Thus, muscular strength may not be a predictive factor for falls. Our data showed that an increase in muscle strength decreased fear of falling but did not lower fall prevalence.

In general, the exercise program included two types of exercises: balance-style exercises (standing on one leg, hopping, and agility) and resistance exercises (lifting weights)[35]. The meta-analysis confirmed that exercise (all types) reduces the number of falls over time by 23% [35]. While balance and coordination programs also led to significant reductions in falls, the efficacy of weight training was unclear. Our results add to previous research demonstrating the benefits of exercise; the long-term participation group was significantly better than the short-term and mid-term participation groups in terms of falls and fear of falling. A previous study reported that long-term participation in the “lively 100-yearsold physical exercise” program delays

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age-related decline in lower extremity muscle strength and walking speed and the transition from robustness to frailty among older people [13,14]; the duration of participation impacted age-related decline in physical function. In the present study, we found that mid-term and long-term participation could improve balance, which contributed to fall prevention. The muscle-strengthening exercises implemented in the present program (lateral leg lifting with weights attached to the limbs) might have contributed to improving one-leg standing time. Although there were no significant differences, we believe that the single chair stand (with or without aid) could help in risk assessment for falls. The chair stand test is used to evaluate lower body strength; however, it better represents muscle physical performance than muscle strength [36]. This test is associated with trunk stability [37], sensation, and balance [38]. The muscle-strengthening exercises in the present program included getting up from the chair using weights attached to the limbs.

The meta-analysis confirmed that exercise interventions reduce fear of falling to a small to moderate degree immediately post-intervention in community-dwelling older people; however, the quality of evidence was reportedly low [39]. Our results revealed that long-term participation in physical exercise did not reduce the prevalence of fear of falling. However, poor muscle strength, balance, and gait speed were strongly independently associated with fear of falling, while female sex, higher age, and fall history were not. There is a vicious cycle between previous falls and fear of falling, and previous falls make future falls more likely. Exercise may reduce fear of falling, though a concomitant improvement in physical function is required. Falls and fall fear were related; however, the key components of physical functions for each factor were different. The present study adds new insights by simultaneously examining the associations between physical function, falls, and fear of falling.

Our study had some limitations. First, it was confined to independent, community-based physical exercise groups in Japan. Moreover, all participants took part in an exercise program; thus, they did not represent the general population. The exercise included some assessment tools that could create a bias. Second, we could not assess other potentially related factors such as comorbid/prior diseases, secondary data were used. However, since various physical function tests were used for prediction, the effects of comorbidities may have relevance. Third, we could not assess the participants' final physical tests because the reasons for quitting the exercise group were unknown. As this retrospective cohort study used secondary data, we were unable to determine causal relationships. Fourth, the fall incidence was not recorded prospectively each day, but via a notification system with a minimum of monthly reporting[40]. Even if we excluded the events such as motor vehicle accidents, slip, and trip, the accuracy of the fall data may be inaccurate because the standard definition of fall was not used. Therefore, further details regarding the participants' falls and injuries are unknown. Finally, we did not use the Falls Efficacy Scale International (FES-I) [41] or the Short Falls Efficacy Scale International (Short FES-I) [42] to assess fear of falling. A priority for future research is to investigate the validity and reliability of our risk assessment tool.

Conclusion and Implication

We observed that the falls were significantly associated with balance, age, fall history, fear of falling, and duration of participation. Moreover, fear of falling was observed to be significantly associated with muscle strength, balance, gait speed, age, and fall history. The key components of physical functions influencing falls and fear of falling were different. Our research revealed that improving various physical functions reduced fear of falling and showed the importance of including balance training in all prevention programs.

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Figure legends

Figure 1. Cumulative number of participants and physical test registry data

Figure 2. The effect of duration of participation, one-leg standing time, and age on the predicted probabilities of falls

Figure 3. The effect of duration of participation, one-leg standing time, and age on the predicted probabilities of fear of falling

Physical function, falls, and fear of falling

Figure 1. Cumulative number of participants and physical test registry data

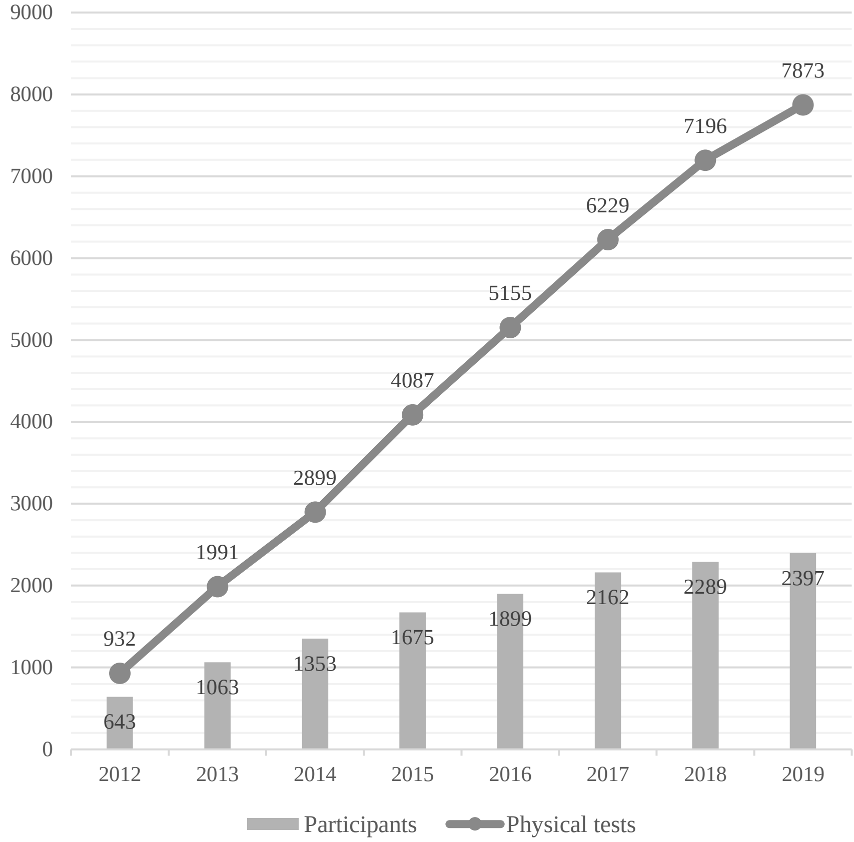


Figure 2.

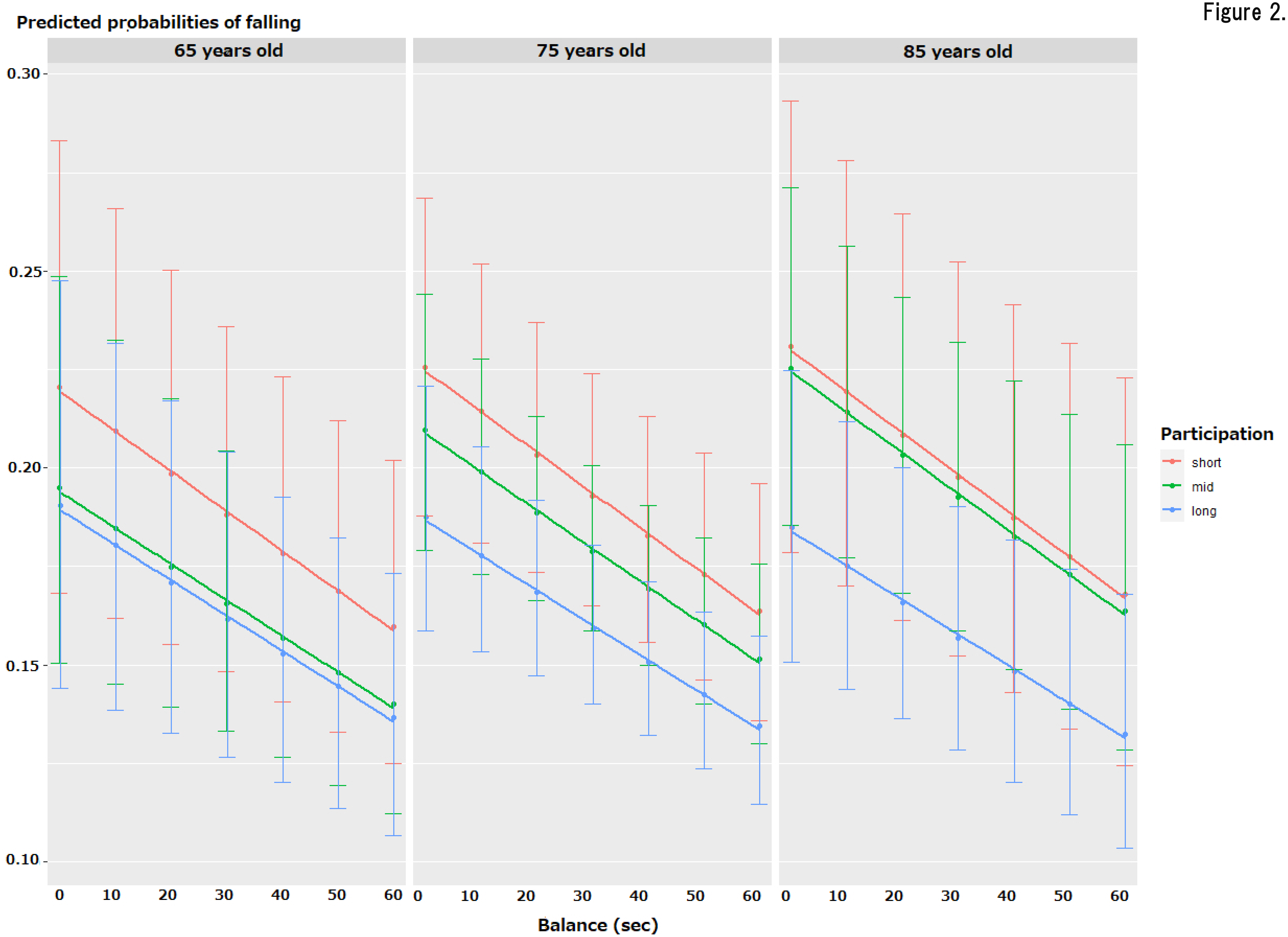
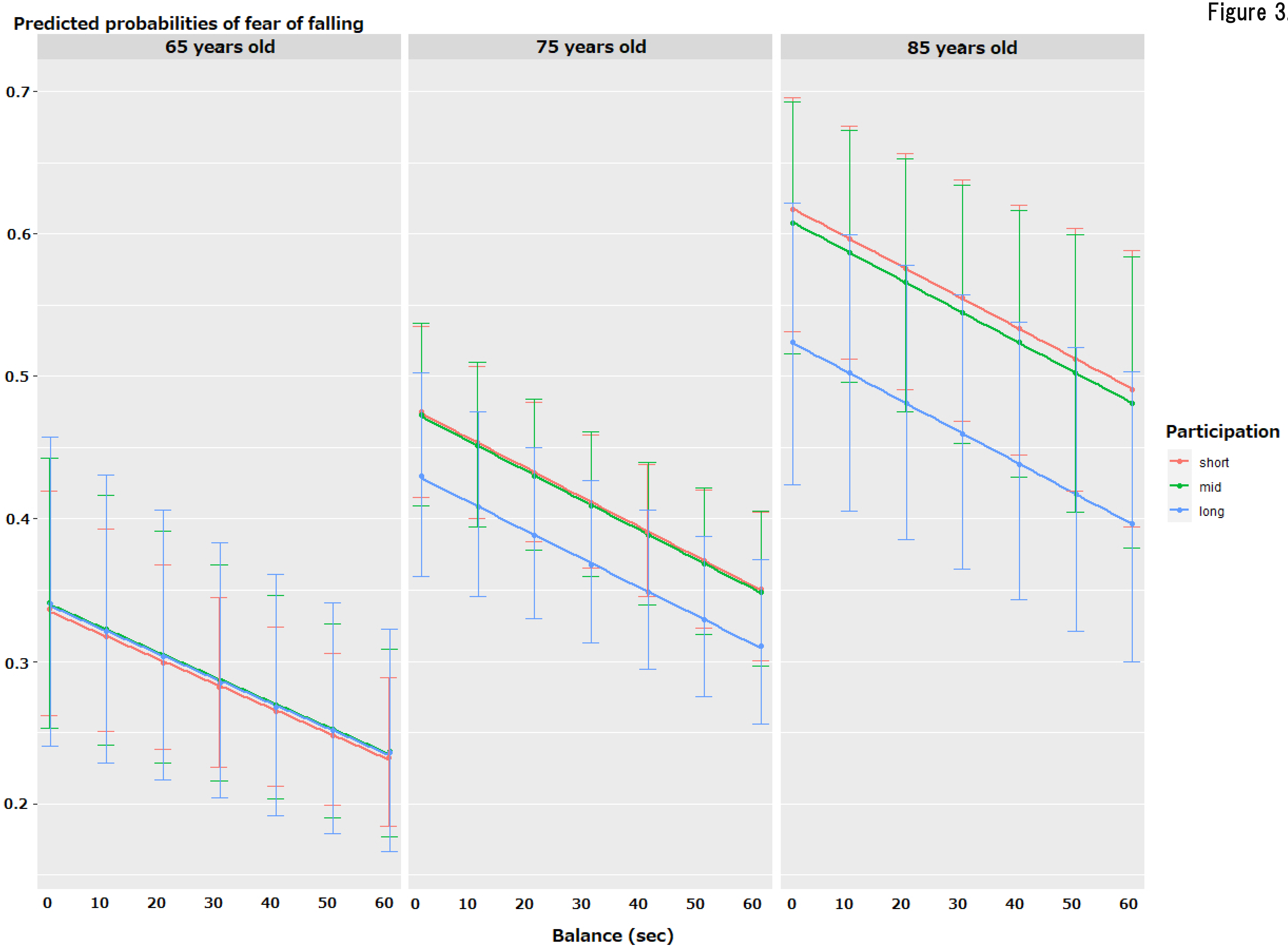

Predicted probabilities of falling
65 years old
75 years old
85 years old
0.30
0.25
0.20
0.15
0.10
0
10
20
30
40
50
60
Balance (sec)
Participation
short
mid
long

Figure 3.


Predicted probabilities of fear of falling
65 years old
75 years old
85 years old
0.7
0.6
0.5
0.4
0.3
0.2
0
10
20
30
40
50
60
Balance (sec)
Participation
short
mid
long

Physical function, falls, and fear of falling

Table 1. Baseline characteristics of all participants and each outcome

	All	Falls			Fear of falling		
		No	Yes	P-Value	No	Yes	P-Value
N	2,397	1,748 (72.9%)	649 (27.1%)		1,203 (50.2%)	1,194 (49.8%)	
Age				0.328			<.001
	74.3 (8.0)	74.2 (8.0)	74.6 (8.0)		72.5 (8.1)	76.1 (7.4)	
Sex				0.096			<.001
female	1,,984 (82.8%)	1,461 (83.6%)	523 (80.6%)		944 (78.5%)	1,040 (87.1%)	
male	413 (17.2%)	287 (16.4%)	126 (19.4%)		259 (21.5%)	154 (12.9%)	
Weight (Kg)				0.668			0.020
	53.2 (9.7)	53.2 (9.5)	53.4 (10.1)		53.7 (9.6)	52.8 (9.7)	
Level of care need							
independent	2,283 (95.2%)	1,672 (95.7%)	611 (94.1%)	0.202	1,175 (97.7%)	1,108 (92.8%)	<.001
needed support	78 (3.3%)	50 (2.9%)	28 (4.3%)		15 (1.2%)	63 (5.3%)	
nursing care	36 (1.5%)	26 (1.5%)	10 (1.5%)		13 (1.1%)	23 (1.9%)	
Knee extension strength (Kgf)				0.055			<.001
	52.8 (18.9)	53.3 (18.8)	51.6 (18.9)		56.0 (18.9)	49.7 (18.3)	
One-leg standing time (sec)				0.003			<.001
	30.9 (23.5)	31.8 (23.6)	28.5 (23.2)		35.4 (23.4)	26.1 (22.7)	
Single chair stand				0.013			<.001
without any aid	2,092 (87.3%)	1,544 (88.3%)	548 (84.4%)		1,,130 (93.9%)	962 (80.6%)	
with aid	305 (12.7%)	204 (11.7%)	101 (15.6%)		73 (6.1%)	232 (19.4%)	
TUG time (sec)				0.002			<.001
	7.4 (3.0)	7.3 (2.7)	7.8 (3.7)		6.8 (2.3)	8.1 (3.4)	
Sit and reach test (cm)				0.158			0.016
	12.7 (10.1)	12.8 (10.0)	12.2 (10.3)		13.2 (10.1)	12.2 (10.1)	

Physical function, falls, and fear of falling

Participate				0.227			0.298
short-term	1,386 (57.8%)	1,000 (57.2%)	386 (59.5%)		677 (56.3%)	709 (59.4%)	
mid-term	632 (26.4%)	458 (26.2%)	174 (26.8%)		327 (27.2%)	305 (25.5%)	
long-term	379 (15.8%)	290 (16.6%)	89 (13.7%)		199 (16.5%)	180 (15.1%)	

Legend: TUG, timed up and go (TUG)

Physical function, falls, and fear of falling

Table 2. Estimated odds ratios for multilevel logistic regression models

	Falls N=1,637 (total[1]=5,127)				Fear of falling N=2,290 (total[1]=7,154)			
	Model1[2] Odds ratio (95%CI)	p-value	**Model2** Odds ratio (95%CI)	p-value	**Model3**[2] Odds ratio (95%CI)	p-value	**Model4** Odds ratio (95%CI)	p-value
Slope changes of age (per 5-year increase)	1.157 (1.066, 1.255)	< 0.001	1.022 (0.909, 1.149)	0.714	1.635 (1.502, 1.780)	< 0.001	1.348 (1.183, 1.536)	< 0.001
One-leg standing time (sec)			0.994 (0.990, 0.998)	0.003			0.992 (0.987, 0.996)	< 0.001
Participation								
short-term			0 (Reference)				0 (Reference)	
mid-term			0.907 (0.737, 1.117)	0.360			0.991 (0.765, 1.284)	0.947
long-term			0.791 (0.637, 0.981)	0.033			0.833 (0.622, 1.116)	0.221
Single chair stand (with aid)			1.265 (0.986, 1.622)	0.064			2.786 (2.053, 3.780)	< 0.001
Previous falls history (yes)			2.889 (2.404, 3.472)	< 0.001			2.941 (2.470, 3.502)	< 0.001
Fear of falling (yes)			1.206 (1.035, 1.405)	0.017				
Interaction terms between age and participation								
age: short-term			0 (Reference)				0 (Reference)	
age: mid-term			1.025	0.722			0.986 (0.820,	0.884

			(0.895, 1.174)				1.186)	
age: long-term			0.961 (0.836, 1.105)	0.579			0.902 (0.738, 1.104)	0.317
Covariates								
sex (male)			0.850 (0.657, 1.098)	0.213			0.330 (0.235, 0.464)	< 0.001
weight (kg)			1.003 (0.994, 1.013)	0.497			1.001 (0.988, 1.014)	0.914
Sit and reach test (cm)			1.001 (0.992, 1.010)	0.843			0.996 (0.986, 1.006)	0.432
Knee extension strength[3] (%)			1.000 (0.996, 1.005)	0.852			0.989 (0.984, 0.993)	< 0.001
TUG time[4] (sec)			1.025 (0.985, 1.067)	0.227			1.091 (1.042, 1.143)	< 0.001
Level of care need (needed support=1, nursing care=2)			0.903 (0.684, 1.193)	0.472			1.178 (0.847, 1.639)	0.330
Intercept	0.239 (0.212, 0.269)	< 0.001	0.186 (0.088, 0.393)	< 0.001	0.931 (0.828, 1.047)	0.234	1.135 (0.453, 2.845)	0.787
Probability[5]	0.193 (0.189, 0.212)		0.157 (0.080, 0.282)		0.482 (0.453, 0.511)		0.532 (0.312, 0.562)	

[1] Records due to repeated physical test

[2] Model 1 and Model 3 was unadjusted

[3] Knee extension strength adjusted to body weight (%)

[4] TUG time obtained by timed up and go test

[5] Probability was obtained from the odds by using odds/1+odds

Table 3. Regression coefficients obtained from the multilevel linear regression models

	Balance Mean difference of one-leg standing time by 1-s increase of each explanatory variable N=2,314 (total[1]=7,262)			
	Model1[2]		**Model2**[3]	
	Regression coefficient (95%CI)	p-value	Regression coefficient (95%CI)	p-value
age[4] (years) (per 5-year increase)	-7.945 (-8.370, -7.530)	P<0.001	-8.427 (-9.081, -7.782)	P<0.001
Participation-short			0 (Reference)	
-mid			2.928 (1.304, 4.552)	P<0.001
-long			4.941 (3.045, 6.838)	P<0.001
Level of care needs (needed support=1, nursing care=2)			-2.165 (-3.681, -0.647)	P=0.005
Weight (kg)			-0.288 (-0.363, -0.213)	P<0.001
Sex (male)			0.890 (-0.978, 2.757)	P=0.349
			-2.254 (-3.093, -1.415)	P<0.001
			-0.431 (-1.295, 0.434)	P=0.329
Interaction terms between age and participation				
age: short			0 (Reference)	
age: mid			-0.473 (-1.460, 0.519)	P=0.344
age: long			0.637 (-0.399, 1.687)	P=0.222
Intercept	30.826 (30.103, 31.547)	P<0.001	47.559 (43.271, 51.852)	P<0.001

[1] Records due to repeated physical test. [2]Model 1 was unadjusted.

[3] Model 2 was adjusted for duration of participate, care needs, weight, sex, interaction terms, falls and fear of falling.

[4] Age was centered by 75 years old.

List of appendices

Appendix 1: Measurements *Medical and functional assessments*

Appendix 2: Estimated marginal means (95%, CI) of predicted probability of sustaining falls and fear of falling obtained by linear mixed models at each age

Appendix 1

Measurements

Medical and functional assessments

Isometric knee extension strength (Kgf) (an indicator of lower extremity muscle strength) was measured using a hand-held dynamometer (μTas F-1; Anima Co., Tokyo, Japan). The participants sat upright in a chair with their hips and knees flexed at approximately 90°. The higher of two consecutive measurements were recorded for further analysis. Knee extension strength was adjusted to body weight (%).

One-leg standing time was measured as an indicator of static balance. In the one-leg standing test, participants were asked to stand on their preferred leg with their eyes open and hands down alongside their trunk and to look straight ahead at a dot 1 m in front of them. The duration of standing time was measured for up to 60 s, and the higher of two consecutive measurements was used for further analysis.

The single chair stand was performed using a standard chair with a height of 40 cm without an armrest. The results were categorized as “with aid” and “without aid.”

Timed up and go (TUG) was measured for the test of usual walking speed. The time taken from standing up from the chair to walking and turning around a mark 3 m ahead, then back to being fully seated on the chair again was measured.

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The chair sit and reach test was used as an indicator of lower body flexibility. This test involved sitting on a chair while keeping one foot flat at 90° and extending the other leg. Legs were extended in front of the body, toes pointing up, and the soles of the feet pressed against the step's base. The following instructions were given: place one hand on top of the other, then reach slowly forward and push the ruler on the top of the step. At the point of your greatest reach, hold it for a couple of seconds, and measure how far you have reached. The sit and reach distance (score) were measured using a chair seat and reach anteflexion meter (T.K.K.5803, Takei Scientific Instrument Co., Niigata, Japan).

Appendix 2:

Estimated marginal means (95%, CI) of predicted probability of sustaining falls and fear of falling obtained by linear mixed models at each age

			Falls	Fear of falling
One-leg standing time (sec)	Age	Duration of participation	Estimate (95%CI)	Estimate (95%CI)
0	65	short	0.22 (0.17, 0.28)	0.34 (0.26, 0.42)
0	75	short	0.23 (0.19, 0.27)	0.47 (0.42, 0.53)
0	85	short	0.23 (0.18, 0.29)	0.62 (0.53, 0.7)
0	65	mid	0.19 (0.15, 0.25)	0.34 (0.25, 0.44)
0	75	mid	0.21 (0.18, 0.24)	0.47 (0.41, 0.54)
0	85	mid	0.23 (0.19, 0.27)	0.61 (0.52, 0.69)
0	65	long	0.19 (0.14, 0.25)	0.34 (0.24, 0.46)
0	75	long	0.19 (0.16, 0.22)	0.43 (0.36, 0.5)
0	85	long	0.19 (0.15, 0.22)	0.52 (0.42, 0.62)
10	65	short	0.21 (0.16, 0.27)	0.32 (0.25, 0.39)
10	75	short	0.21 (0.18, 0.25)	0.45 (0.4, 0.51)
10	85	short	0.22 (0.17, 0.28)	0.6 (0.51, 0.68)
10	65	mid	0.18 (0.15, 0.23)	0.32 (0.24, 0.42)
10	75	mid	0.2 (0.17, 0.23)	0.45 (0.39, 0.51)
10	85	mid	0.21 (0.18, 0.26)	0.59 (0.5, 0.67)
10	65	long	0.18 (0.14, 0.23)	0.32 (0.23, 0.43)
10	75	long	0.18 (0.15, 0.21)	0.41 (0.35, 0.48)
10	85	long	0.18 (0.14, 0.21)	0.5 (0.41, 0.6)
20	65	short	0.2 (0.16, 0.25)	0.3 (0.24, 0.37)
20	75	short	0.2 (0.17, 0.24)	0.43 (0.38, 0.48)
20	85	short	0.21 (0.16, 0.26)	0.58 (0.49, 0.66)
20	65	mid	0.17 (0.14, 0.22)	0.3 (0.23, 0.39)
20	75	mid	0.19 (0.17, 0.21)	0.43 (0.38, 0.48)
20	85	mid	0.2 (0.17, 0.24)	0.57 (0.48, 0.65)

20	65	long	0.17 (0.13, 0.22)	0.3 (0.22, 0.41)
20	75	long	0.17 (0.15, 0.19)	0.39 (0.33, 0.45)
20	85	long	0.17 (0.14, 0.2)	0.48 (0.39, 0.58)
30	65	short	0.19 (0.15, 0.24)	0.28 (0.23, 0.34)
30	75	short	0.19 (0.17, 0.22)	0.41 (0.37, 0.46)
30	85	short	0.2 (0.15, 0.25)	0.55 (0.47, 0.64)
30	65	mid	0.17 (0.13, 0.2)	0.29 (0.22, 0.37)
30	75	mid	0.18 (0.16, 0.2)	0.41 (0.36, 0.46)
30	85	mid	0.19 (0.16, 0.23)	0.54 (0.45, 0.63)
30	65	long	0.16 (0.13, 0.2)	0.29 (0.2, 0.38)
30	75	long	0.16 (0.14, 0.18)	0.37 (0.31, 0.43)
30	85	long	0.16 (0.13, 0.19)	0.46 (0.36, 0.56)
40	65	short	0.18 (0.14, 0.22)	0.26 (0.21, 0.32)
40	75	short	0.18 (0.16, 0.21)	0.39 (0.35, 0.44)
40	85	short	0.19 (0.14, 0.24)	0.53 (0.44, 0.62)
40	65	mid	0.16 (0.13, 0.19)	0.27 (0.2, 0.35)
40	75	mid	0.17 (0.15, 0.19)	0.39 (0.34, 0.44)
40	85	mid	0.18 (0.15, 0.22)	0.52 (0.43, 0.62)
40	65	long	0.15 (0.12, 0.19)	0.27 (0.19, 0.36)
40	75	long	0.15 (0.13, 0.17)	0.35 (0.29, 0.41)
40	85	long	0.15 (0.12, 0.18)	0.44 (0.34, 0.54)
50	65	short	0.17 (0.13, 0.21)	0.25 (0.2, 0.31)
50	75	short	0.17 (0.15, 0.2)	0.37 (0.32, 0.42)
50	85	short	0.18 (0.13, 0.23)	0.51 (0.42, 0.6)
50	65	mid	0.15 (0.12, 0.18)	0.25 (0.19, 0.33)
50	75	mid	0.16 (0.14, 0.18)	0.37 (0.32, 0.42)
50	85	mid	0.17 (0.14, 0.21)	0.5 (0.4, 0.6)
50	65	long	0.14 (0.11, 0.18)	0.25 (0.18, 0.34)
50	75	long	0.14 (0.12, 0.16)	0.33 (0.28, 0.39)
50	85	long	0.14 (0.11, 0.17)	0.42 (0.32, 0.52)
60	65	short	0.16 (0.12, 0.2)	0.23 (0.18, 0.29)
60	75	short	0.16 (0.14, 0.2)	0.35 (0.3, 0.4)
60	85	short	0.17 (0.12, 0.22)	0.49 (0.39, 0.59)
60	65	mid	0.14 (0.11, 0.17)	0.24 (0.18, 0.31)
60	75	mid	0.15 (0.13, 0.18)	0.35 (0.3, 0.41)
60	85	mid	0.16 (0.13, 0.21)	0.48 (0.38, 0.58)

60	65	long	0.14 (0.11, 0.17)	0.24 (0.17, 0.32)
60	75	long	0.13 (0.11, 0.16)	0.31 (0.26, 0.37)
60	85	long	0.13 (0.1, 0.17)	0.4 (0.3, 0.5)

[1] Estimated marginal means were obtained from linear regression models adjusted for frequency of participation, age, sex, weight (52.0 kg), sit and reach test (16.0 cm), knee extension strength (62.0 kg/f), TUG time (6.0 s), single chair stand (without any aid), level of care needed (independent), and history of falls (no).

CI, confidence interval