

Article

Trainability of Physical Function and Threshold Age for Decline in Frail Older Women: A 6-Year Community-Based Multicomponent Exercise Program

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Abstract

Japan is a super-aged society where community group multicomponent exercise is widely implemented, yet the age at which a fixed, low-frequency exercise dose no longer offsets functional decline is unclear. We examined 6-year trainability and explored “zero-change” ages in frail older women. Twenty community-dwelling frail women (80–86 years) participated in a once-weekly 90 min multicomponent exercise program for 6 years. Nine physical tests were assessed at baseline (Pre), 6 months, and annually. Overall time effects were tested using repeated-measures ANOVA and generalized estimating equations, with planned paired *t*-tests versus Pre. Age-specific annual percent changes (%/year) from Pre to each follow-up were annualized, grouped by age at follow-up (81–91 years), and tested against 0%/year. Separately, regression analyses related age to annual percent change across seven consecutive intervals to estimate “zero-change age” (predicted change = 0%). Time effects were significant for all nine measures (all $p \leq 0.032$). Chair stand, 10 m fast/zigzag walk, supine-to-stand, maximal 5-step length, and 10-times knee lift generally improved in the early follow-up, whereas handgrip strength and sit-and-reach declined over time. In 6/9 tests, annual percent change diminished with advancing age; estimated zero-change ages ranged from ≈ 82 years (maximal 5-step length) to ≈ 88 years (chair stand and one-leg stance). Attendance remained high ($\approx 90\%$). In this single-arm community program, several mobility-related functions improved or were maintained in frail women in their early 80s, whereas reduced trainability beyond the mid-80s may limit further protection. Threshold ages are exploratory statistical estimates; controlled trials are warranted.

Keywords: frail older women; multicomponent exercise; physical function; trainability; threshold age



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1. Introduction

Japan is a super-aged society, with adults aged ≥ 65 years accounting for almost 30% of the population and this proportion expected to continue rising [1]. Extending healthy life expectancy and preventing certification for long-term care are major policy priorities, and systematic management of physical function and frailty has become essential [1,2].

Frailty, characterized by reduced physiological reserve and increased vulnerability, is strongly associated with disability, falls, and mortality [2]. Habitual physical activity and physical fitness are closely linked to the onset and progression of frailty, and numerous

studies have shown that appropriate exercise can attenuate or even reverse it [3,4]. In particular, multicomponent programs that combine resistance, balance, and aerobic training have demonstrated broad benefits for physical function, fall risk, and independence in community-dwelling older adults [5,6].

In Japan, group-based multicomponent exercise classes delivered at community centers are widely implemented as part of long-term care prevention services. Once-weekly participation has been reported to help maintain or improve lower-limb strength and balance and to delay the progression of frailty [7,8]. However, most interventions have been short to medium term (approximately 3–12 months), and longitudinal follow-up beyond 1–2 years remains limited [5]. Very few studies have followed participants for more than 5 years, and evidence on long-term trainability in programs targeting frail older adults or those in their 80s and beyond (the “older-old”) is particularly scarce [5]. In addition, real-world municipal programs are often delivered at low frequency (e.g., once weekly) because of practical constraints, and evidence on whether such doses can meaningfully offset functional decline in the oldest old remains limited.

Although age-related declines in physical function are considered unavoidable, it remains unclear up to what age a given exercise dose can still produce meaningful improvements or maintenance and beyond what age functional decline predominates despite continued training. Most previous studies have compared different age strata at baseline or reported average changes during the intervention period; only a few have analyzed long-term annualized rates of change or age-specific patterns of improvement and decline. To our knowledge, no study has simultaneously examined longitudinal trajectories of physical function and age-specific trainability over as long as 6 years among frail older women participating in the same community-based multicomponent program.

Therefore, the present study targeted community-dwelling frail older women who participated for 6 years in a once-weekly, 90 min community-based multicomponent exercise program. We analyzed longitudinal changes in nine physical function measures and calculated annualized rates of change (%/year) for each interval from baseline to 72 months. We then examined age-specific profiles and regression relationships between age and rate of change to: (1) clarify 6-year trajectories of physical function trainability; (2) identify the age range in which improvements or maintenance can be expected with a constant exercise load; and (3) explore threshold ages at which significant decline becomes difficult to avoid. These findings are expected to inform the design of age-appropriate exercise strategies and long-term care prevention programs for frail older adults in Japan’s super-aged society.

2. Methods

2.1. Participants

This longitudinal observational study included older women who attended a municipal long-term care prevention service (“exercise classes to improve physical function”) in Wakayama City. Eligibility for the municipal program required community-dwelling status and the ability to participate safely in group exercise and assessments. For the present analysis, we included women aged ≥ 80 years who (1) were not certified as requiring support or long-term care under the public long-term care insurance system, (2) were classified as frail using the 25-item Basic (Kihon) Checklist (KCL; total score ≥ 8) [9,10], and (3) completed all eight assessments at baseline (Pre) and at 6, 12, 24, 36, 48, 60, and 72 months. The KCL comprises 25 yes/no items covering multiple domains (e.g., instrumental activities of daily living, physical function, nutrition, oral function, socialization, cognition, and mood). Frailty status for this analysis was determined at baseline using the total score criterion (≥ 8) and was not used as a repeated eligibility criterion during follow-up. We performed a

complete-case analysis restricted to participants with data at all time points; no imputation for missing values was conducted.

After receiving a detailed explanation of the study purpose and procedures, all participants provided written informed consent and took part in the once-weekly exercise program for 6 years. Because this study was embedded in a real-world municipal service, a non-exercising control group was not available.

In total, 20 women aged 80–86 years who met the above criteria and completed all follow-up assessments were included in the analyses. At baseline, mean age was 81.9 ± 1.8 years, mean height was 148.3 ± 6.7 cm, and mean body weight was 49.0 ± 6.7 kg.

Participant flow: At baseline, 28 women aged ≥ 80 years consented to participate in the municipal program and completed baseline assessment; 8 were excluded for not meeting the present study criteria. The analytic sample comprised 20 women with complete data at all eight time points (0 dropouts; no missed follow-up assessments).

2.2. Exercise Program

The multicomponent exercise program followed the protocol of the “Wakayama Senior Exercise” for high-risk older adults. Sessions were conducted once weekly in groups, lasted 90 min, and consisted of approximately 10 min of warm-up, 10 min of stretching, 20 min of resistance training (5–7 exercises), 10–20 min of step exercise, 20 min of recreational activities, and 10 min of cool-down. Each class was supervised by trained care or exercise instructors, and safety was prioritized.

Resistance training used body weight and focused on the lower limbs and trunk, with seven basic movements (thigh lift, leg lift, squat, standing knee lift, leg curl, side leg raise, heel raise). Each movement was performed for 10 repetitions with a 4 s concentric and 4 s eccentric phase to music at 60 beats/min, targeting approximately 40–50% of maximal strength (≈ 1.5 –3 METs) and a perceived exertion of 11–13 on the Borg 6–20 scale.

Step exercise was implemented to improve lower-limb strength and endurance. According to individual fitness levels, step height was set at 10–20 cm, and participants performed step-up/step-down movements to music at 40 beats/min (≈ 10 cycles/min) for 10–20 min, targeting about 40–50% of maximal oxygen uptake ($\text{VO}_{2\text{max}}$; ≈ 3 METs) and a Borg rating of 11–13.

Recreational activities consisted of low-intensity group games lasting about 20 min. To monitor exercise intensity and ensure safety, blood pressure, heart rate, and subjective symptoms were checked as needed, and walkers or similar supports were placed near participants during step exercise and standing resistance training to help prevent falls. Exercise loads were adjusted as needed for safety and feasibility (e.g., step height within the 10–20 cm range and individual movement modifications), but the overall frequency and structure of the program remained broadly constant over the 6-year period and formal progressive overload was not implemented. Exercise-related adverse events were monitored during sessions; no serious adverse events were noted during routine monitoring, although minor events were not systematically recorded.

2.3. Physical Function Tests

Physical function was assessed using nine tests: 30 s chair stand test (CS-30), handgrip strength, sit-and-reach, 10 m fast walk, 10 m zigzag walk, one-leg stance with eyes open, supine-to-stand test, maximal 5-step length test, and 10-times knee lift test. CS-30 was performed according to Nakatani et al. [11], and handgrip strength and sit-and-reach were measured in line with the Japanese “New Physical Fitness Test” manual [12].

For the 10 m fast walk, participants walked a straight 10 m course on a flat surface as quickly and safely as possible, and the time required was recorded. For the 10 m zigzag

walk, cones were placed alternately 50 cm to the left and right of a central line at 2 m intervals, and participants walked 10 m as quickly as possible while passing outside each cone; the time required was recorded.

In the one-leg stance test, participants stood on their preferred leg with eyes open, and the continuous holding time was measured. In the supine-to-stand test, the time from a verbal cue in the supine position on a mat to achieving upright stance was measured. In the maximal 5-step length test, participants took five maximal strides, and the total distance was recorded. In the 10-times knee lift test, participants alternately lifted the knees to hip height 10 times, and the time required was recorded.

CS-30 was performed once, whereas the other tests were performed twice and the better value was used for analysis. Handgrip and sit-and-reach were measured using digital devices (Grip-D, T.K.K. 5401; sit-and-reach tester, T.K.K. 5412; Takei Scientific Instruments Co., Ltd., Niigata, Japan).

2.4. Statistical Analysis

Continuous variables were expressed as mean $\pm$ standard deviation (SD) for age, height, body weight, and nine physical function measures. Analyses were performed using Python 3.11 with the pandas, SciPy, and statsmodels libraries. All tests were two-sided with $p < 0.05$ considered statistically significant. To evaluate overall change across the eight repeated measurements, we performed repeated-measures ANOVA with time point (Pre, Post6, Post12, Post24, Post36, Post48, Post60, Post72) as the within-subject factor. For planned comparisons versus baseline, we additionally conducted paired t -tests (Pre vs. each follow-up). For multiple comparisons, the false discovery rate (FDR) was controlled using the Benjamini–Hochberg procedure, and FDR-adjusted q values are reported for selected analyses; figures and most results text present unadjusted p values. In Figure 1, error bars represent SD, whereas in Figure 2, annual percent change values are presented as means $\pm$ standard error (SE) (error bars), as indicated in the figure legends. Because numerous outcomes and repeated time point contrasts were analyzed, we interpreted p values conservatively and emphasized consistency across methods (repeated-measures ANOVA and GEE) and effect sizes. Longitudinal mixed-effects models may provide an alternative robust framework, particularly in the presence of missing data; however, our primary aim was descriptive characterization of long-term trajectories in this complete-case cohort.

For each Pre-to-follow-up contrast, mean and percent change, 95% confidence intervals, and effect sizes (Cohen's d_z) were calculated. For the proportion of participants achieving one-leg stance for ≥ 10 s, 2×2 contingency tables (Pre vs. each follow-up) were analyzed using McNemar's test; asymptotic and mid- p values were obtained, and FDR-adjusted p values were computed across the seven comparisons. As sensitivity analyses accounting for within-participant correlation, we also fitted generalized estimating equation (GEE) models with time point as a categorical predictor and participant ID as the clustering variable.

To examine age-specific trainability (Figure 2), annual percent change (%/year) for each physical function measure was calculated from baseline (Pre) to each follow-up time point and annualized by the elapsed time since Pre. The age at each follow-up assessment was grouped into 1-year bins (81–91 years), and for each age bin, we calculated the mean, SD, and standard error of annual percent change and performed exploratory one-sample t -tests against 0%/year. For time-based outcomes (10 m fast/zigzag walk, supine-to-stand, and 10-times knee lift), signs were inverted so that positive values indicate improvement (shorter completion time). Separately, for regression analyses, annual percent change was also calculated for seven consecutive intervals (Pre $\rightarrow$ Post6 through Post60 $\rightarrow$ Post72) and related to age using linear regression (for those interval-based analyses, negative

values indicate improvement for time-based outcomes). The annual percent change metric facilitates comparison across measures with different units and intervals; however, it may amplify variability for time-based outcomes and when baseline values are small. Therefore, these analyses are considered exploratory and should be interpreted cautiously.

For age-related changes from baseline, Pearson correlation coefficients (r) and p values were calculated between baseline age and change from baseline (Post6–Post72 pooled; $n = 140$) and corresponding percent change (%) in each measure. These correlations are descriptive and do not account for within-participant clustering.

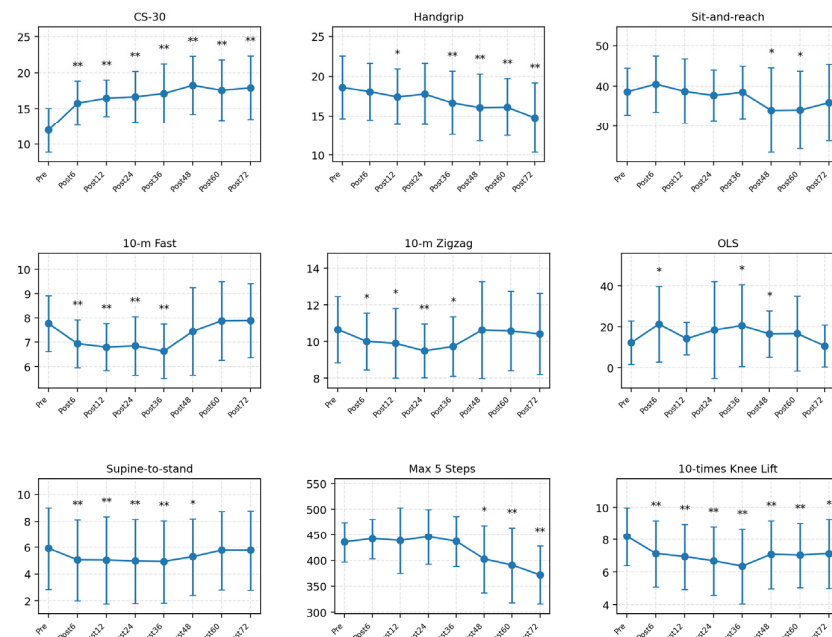


Figure 1. Mean $\pm$ SD values at Pre and each follow-up (Post6–Post72) in nine physical function tests ($n = 20$). Asterisks indicate significant differences from Pre (* $p \leq 0.05$, ** $p \leq 0.01$). Error bars represent SD.

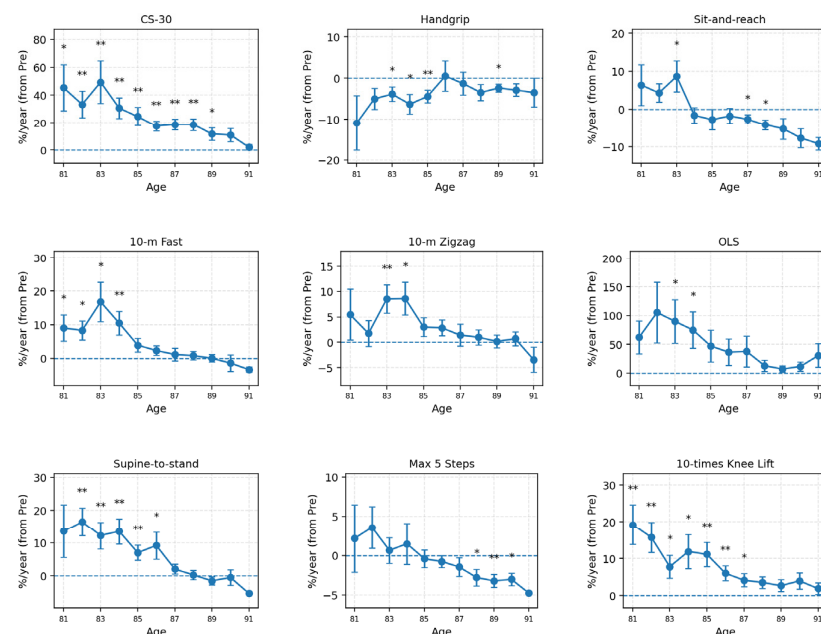


Figure 2. Age-specific annual percent changes (%/year) from Pre to each follow-up time point, summarized in 1-year age bands. Values are means $\pm$ SE. Asterisks indicate significant differences from 0%/year (* $p \leq 0.05$, ** $p \leq 0.01$). For time-based tests (10 m fast/zigzag walk, supine-to-stand, and 10-times knee lift), signs are inverted so that improvement is positive. Error bars represent SE.

3. Results

Attendance rate over time was examined using one-way repeated-measures ANOVA with period (seven levels: Post6–Post72) as the factor. The main effect of period was not significant ($F(6, 114) = 1.21, p = 0.308$), indicating no significant change in attendance over 6 years (Post6: $89.1 \pm 3.3\%$, Post12: $90.4 \pm 3.4\%$, Post24: $91.1 \pm 3.6\%$, Post36: $91.5 \pm 3.8\%$, Post48: $91.6 \pm 4.0\%$, Post60: $89.5 \pm 2.8\%$, Post72: $89.8 \pm 2.8\%$). These consistently high values (≈ 89 – 92%) indicate excellent adherence to the once-weekly program throughout the 6-year period.

Repeated-measures ANOVA showed a significant main effect of time for all nine measures (all $p \leq 0.032$; Table 1; Figure 1). GEE sensitivity analyses showed a similar pattern of time effects.

Table 1. Repeated-measures ANOVA main effect of time for nine physical function measures.

Outcome	RM ANOVA Time Effect	<i>p</i> Value	Partial η^2
CS-30 (30 s chair stand)	$F(7, 133) = 10.10$	4.27×10^{-10}	0.347
Handgrip strength	$F(7, 133) = 8.94$	5.32×10^{-9}	0.320
Sit-and-reach	$F(7, 133) = 4.33$	2.40×10^{-4}	0.186
10 m fast walk	$F(7, 133) = 7.65$	9.46×10^{-8}	0.287
10 m zigzag walk	$F(7, 133) = 2.83$	0.0087	0.130
One-leg stance	$F(7, 133) = 2.28$	0.032	0.107
Supine-to-stand	$F(7, 133) = 4.23$	3.06×10^{-4}	0.182
Max 5-step length	$F(7, 133) = 14.29$	9.37×10^{-14}	0.429
10-times knee lift	$F(7, 133) = 6.61$	1.03×10^{-6}	0.258

Note: Degrees of freedom were $df_1 = 7$ and $df_2 = 133$ for all outcomes. partial $\eta^2 = (F \times df_1) / (F \times df_1 + df_2)$.

The CS-30, reflecting lower-limb muscular endurance, showed significant increases throughout follow-up ($p \leq 0.001$), with a $>50\%$ increase at 36 months. In contrast, handgrip strength, representing upper-limb strength, showed small declines at 6–24 months and significant decreases of approximately 10–21% at 36–72 months ($p \leq 0.01$). For flexibility (sit-and-reach), a transient increase was observed at 6 months, but values then remained around baseline, with declines of $\approx 11\%$ at 48 and 60 months ($p = 0.043$ and 0.028 ; $q = 0.151$ after FDR adjustment). Maximal 5-step length was largely maintained up to 36 months but declined by 7–10% at 48 and 60 months ($p \leq 0.030$), indicating progressive reduction in step length. The 10-times knee lift test showed 13–23% reductions in time (faster performance) at all time points ($p \leq 0.032$).

Supine-to-stand time, an index of transfer ability, was shortened by 10–18% at 6–48 months ($p \leq 0.011$), indicating improved or maintained rising-from-floor ability for much of the 6-year period; however, significant differences were not sustained at 60 and 72 months. For one-leg stance time with eyes open, a 150% increase was observed at 6 months ($p = 0.025$), and an $\approx 105\%$ increase at 36 months remained significant ($p = 0.029$). Values remained higher than baseline at 48 months ($p = 0.037$), but differences were not significant at 60 and 72 months ($p \geq 0.307$).

3.1. Age-Specific Annual Percent Changes (Figure 2)

Age-specific annual percent changes (%/year) were summarized in 1-year age bands across all follow-up assessments from Pre to Post72 and are shown in Figure 2. For many tests, participants in their early 80s showed significant improvements or maintenance, whereas with advancing age, annual percent change approached 0% and for some measures shifted toward decline.

For time-based tests, annual percent change in 10 m fast walk was significantly positive at ages 81–84 ($+8$ – 17% /year, $p < 0.05$), and 10 m zigzag walk showed significant

improvements of around +9%/year at ages 83–84 ($p < 0.05$). CS-30 showed significant annual increases of +12–49%/year from 81 to 89 years, and the 10-times knee lift test showed significant improvements of +4–19%/year at ages 81–87 ($p < 0.05$). Supine-to-stand time improved by approximately +7–17%/year at ages 82–86, and one-leg stance time increased by approximately +75–90%/year at ages 83–84 (all $p < 0.05$), indicating preserved trainability to the exercise program up to at least the early 80s.

Furthermore, a deterioration of −5.3%/year (time prolongation) in supine-to-stand was observed at age 91 ($n = 2$, $p = 0.040$), suggesting that decline in rising-from-floor ability may be difficult to avoid in the oldest age group; however, estimates for the oldest age bins should be interpreted cautiously because sample sizes were small.

Overall, these findings indicate that while improvements or maintenance in time-based tests, lower-limb endurance, and dynamic balance can be expected across a wide age range up to the early 80s, there appear to be “threshold ages” beyond the mid-80s at which significant declines emerge in functions such as handgrip strength, flexibility, step length, and transfer ability.

3.2. Regression Analysis of Age and Annual Percent Change (Table 2)

Linear regression analyses examined relationships between age and annual percent change for 140 intervals from Pre → Post6 to Post60 → Post72 (Table 2). Significant associations between age and annual percent change were observed for CS-30, 10 m fast walk, one-leg stance time, supine-to-stand time, maximal 5-step length, and 10-times knee lift time ($R^2 = 0.031$ – 0.061 , $p_{\text{slope}} \leq 0.038$). The estimated ages at which the regression line crossed 0% (zero-change age) were 82.4 years for maximal 5-step length, 85.7 years for 10-times knee lift time, 84.5 years for 10 m fast walk, 84.3 years for supine-to-stand time, 88.4 years for CS-30, and 88.1 years for one-leg stance time. Overall, annual percent change approached 0% with advancing age, and for several measures tended to reverse direction beyond these ages, indicating reduced trainability (for time-based outcomes, negative values indicate improvement). For handgrip strength, sit-and-reach, and 10 m zigzag walk, the regression slopes were not significant, and no clear linear relationship with age was seen.

Table 2. Association between age and annual percent change in physical performance: linear regression using all consecutive measurement intervals (for time-based outcomes, negative annual percent change indicates improvement [shorter completion time].) [†] Zero-change age was calculated only when the slope was statistically significant ($p < 0.05$); otherwise reported as NA.

Outcome	<i>n</i> (Intervals)	Slope (%/Year per 1-Year Age)	Intercept (%/Year)	R^2	p (Slope)	Zero-Change Age (Years) [†]
CS-30	140	−3.40	300.5	0.048	0.009	88.4
Handgrip strength	140	−0.23	16.4	0.001	0.712	NA
Sit-and-reach	140	0.45	−36.4	0.001	0.650	NA
10 m fast walk	140	1.79	−151.3	0.061	0.003	84.5
10 m zigzag walk	140	0.95	−80.1	0.02	0.092	NA
One-leg stance	140	−15.44	1359.7	0.032	0.034	88.1
Supine-to-stand	140	2.72	−229.7	0.058	0.004	84.3
Max 5-step length	140	−0.93	76.5	0.031	0.038	82.4
10-times knee lift	140	1.93	−165.6	0.045	0.012	85.7

3.3. Associations Between Baseline Age and Changes from Baseline (Table 3)

Table 3 presents correlations between (1) age at measurement and physical function pooled across all repeated observations ($n = 160$) and (2) baseline age and change from baseline pooled across all follow-up assessments (Post6–Post72; $n = 140$).

Table 3. Correlations between age and physical performance (pooled age–performance correlations across all repeated observations, $n = 160$; baseline age vs. change from baseline pooled across follow-up assessments Post6–Post72, $n = 140$).

Outcome	Pooled Age—Performance			Baseline Age vs. Change from Baseline			Baseline Age vs. % Change from Baseline		
	<i>n</i>	<i>r</i>	<i>p</i>	<i>n</i>	<i>r</i>	<i>p</i>	<i>n</i>	<i>r</i>	<i>p</i>
CS-30	160	0.288	<0.001	140	0.131	0.122	140	0.120	0.160
Handgrip strength	160	−0.254	0.001	140	−0.044	0.609	140	−0.028	0.744
Sit-and-reach	160	−0.411	<0.001	140	−0.496	<0.001	140	−0.504	<0.001
10 m fast walk	160	0.391	<0.001	140	0.041	0.631	140	0.077	0.367
10 m zigzag walk	160	0.374	<0.001	140	0.00	0.969	140	0.059	0.487
One-leg stance	160	−0.171	0.031	140	−0.094	0.269	140	−0.041	0.630
Supine-to-stand	160	0.212	0.007	140	0.146	0.084	140	0.273	0.001
Max 5-step length	160	−0.485	<0.001	140	−0.177	0.036	140	−0.214	0.011
10-times knee lift	160	0.042	0.597	140	−0.146	0.086	140	−0.050	0.560

3.4. Correlations Among Baseline Physical Function Measures (Table 4)

Pearson correlation coefficients among the nine baseline measures are shown in Table 4. One-leg stance time showed no significant correlations with the other measures (all $p > 0.28$). Among mobility-related tests, 10 m fast walk time correlated strongly with 10 m zigzag walk time ($r = 0.896$, $p < 0.001$). Both walking times correlated inversely with maximal 5-step length (fast walk: $r = -0.524$, $p = 0.018$; zigzag walk: $r = -0.581$, $p = 0.007$), suggesting that shorter step length is associated with slower walking. Supine-to-stand time was positively correlated with 10-times knee lift time ($r = 0.646$, $p = 0.002$), indicating that slower transfer performance is associated with slower repetitive knee lifts. Other pairwise correlations were generally small and should be interpreted cautiously given the limited sample size ($n = 20$).

Table 4. Correlation matrix among nine physical performance measures at baseline (upper triangle: p values; lower triangle: Pearson r).

	CS-30	Handgrip Strength	Sit-and-Reach	10 m Fast Walk	10 m Zigzag Walk	One-Leg Stance	Supine-to-Stand	Max 5-Step Length	10-Times Knee Lift
CS-30	—	0.011	0.661	0.45	0.774	0.875	0.76	0.674	0.311
Handgrip strength	−0.554	—	0.606	0.21	0.161	0.504	0.211	0.137	0.712
Sit-and-reach	0.104	0.123	—	0.404	0.128	0.708	0.065	0.561	0.041
10 m fast walk	−0.179	−0.293	−0.197	—	<0.001	0.371	0.285	0.018	0.777
10 m zigzag walk	−0.068	−0.326	−0.352	0.896	—	0.359	0.047	0.007	0.293
One-leg stance	0.038	0.159	0.089	−0.212	−0.217	—	0.284	0.318	0.537
Supine-to-stand	0.073	−0.293	−0.42	0.251	0.449	−0.252	—	0.337	0.002
Max 5-step length	−0.100	0.344	0.138	−0.524	−0.581	0.236	−0.226	—	0.554
10-times knee lift	−0.239	0.088	−0.461	0.068	0.247	0.147	0.646	0.141	—

3.5. Time Course of One-Leg Stance Achievement Rate (Table 5)

Table 5 shows the time course of the proportion of participants who achieved ≥ 10 s in the one-leg stance test with eyes open. The achievement rate increased from 45% at baseline to 80% at 6 months and remained at 70–75% between 12 and 48 months, before decreasing to 55–50% at 60 and 72 months. McNemar's test suggested improvements relative to baseline at 6 months ($p = 0.046$; $q = 0.075$) and 48 months ($p = 0.041$; $q = 0.075$); however, these comparisons did not remain significant after FDR adjustment. Overall, postural control appeared to be maintained through the medium term, but over 6 years, some participants became unable to meet the 10 s criterion.

Table 5. Achievement rates and McNemar tests ≥ 10 s one-leg stance, eyes open (s).

(A) Achievement rate at each time point								
Time	<i>n</i>	Achievers	Proportion_ %					
Pre	20	9	45					
Post6	20	16	80					
Post12	20	15	75					
Post24	20	14	70					
Post36	20	14	70					
Post48	20	15	75					
Post60	20	11	55					
Post72	20	10	50					
(B) Within-group improvement (McNemar: <i>p</i> and <i>q</i>)								
Comparison	<i>n</i> _pairs	a: 0 → 0	b: 0 → 1	c: 1 → 0	d: 1 → 1	<i>p</i> _(McNemar)	<i>p</i> (mid- <i>p</i>)	<i>q</i> (BH-FDR)
Pre vs. Post6	20	3	8	1	8	0.046	0.021	0.075
Pre vs. Post12	20	4	7	1	8	0.077	0.039	0.091
Pre vs. Post24	20	5	6	1	8	0.131	0.070	0.098
Pre vs. Post36	20	5	6	1	8	0.131	0.070	0.098
Pre vs. Post48	20	5	6	0	9	0.041	0.016	0.075
Pre vs. Post60	20	6	5	3	6	0.724	0.508	0.592
Pre vs. Post72	20	6	5	4	5	1.000	0.754	0.754

a: 0 → 0 (Pre <10 s → follow-up <10 s), below the threshold at both Pre and follow-up (no change). b: 0 → 1 (Pre <10 s → follow-up ≥ 10 s), changed from below to above the threshold (improvement). c: 1 → 0 (Pre ≥ 10 s → follow-up <10 s), changed from above to below the threshold (decline). d: 1 → 1 (Pre ≥ 10 s → follow-up ≥ 10 s), above the threshold at both Pre and follow-up (no change).

4. Discussion

This longitudinal study examined 6-year changes in physical function among community-dwelling frail older women participating in a once-weekly, 90 min community-based multicomponent exercise program. We found that walking ability, lower-limb muscular endurance, and static balance improved in the short term and were largely maintained, whereas handgrip strength, flexibility, step length, and supine-to-stand ability showed progressive age-related decline, with changes becoming particularly unfavorable beyond the mid-80s. At baseline, walking time, rising time, step length, and repetitive lower-limb movement time formed a common “mobility/walking” cluster, whereas CS-30, flexibility, and static balance represented relatively independent dimensions, highlighting both the benefits and limits of such programs as long-term care prevention services in a super-aged society.

Limitations should be considered. This study was a single-arm observational analysis embedded in a municipal long-term care prevention service; therefore, causal inference is limited and secular trends or concurrent lifestyle changes cannot be fully ruled out. The sample size was small ($n = 20$) and included only women who completed all 6 years, which may overestimate adherence and trainability (survivor/selection bias). In addition, age trainability analyses used multiple consecutive intervals per participant; however, the main findings were supported by clustered repeated-measures analyses (GEE). Accordingly, the present results should be interpreted as preliminary and hypothesis-generating rather than definitive evidence of efficacy. In addition to the absence of a control group, alternative explanations such as regression to the mean and repeated testing effects cannot be excluded [13]. Because the analytic sample was restricted to women who completed all assessments over 6 years, survivorship/attrition bias may have led to overestimation of adherence and trainability; participants who discontinued or missed assessments may have experienced greater functional decline. Moreover, because multiple outcomes and repeated contrasts were examined, some risk of type I error may remain despite FDR control; thus, the overall pattern of findings should be emphasized over any single comparison. Similarly,

“threshold/zero-change ages” derived from regression should be viewed as exploratory statistical estimates rather than physiological cut-offs, particularly given the low R^2 values.

Firstly, it is noteworthy that, despite once-weekly multicomponent exercise continuing for 6 years, most functions showed no abrupt decline and CS-30 and several walking-related indices remained improved relative to baseline. The participants were frail older women at high risk of future long-term care certification. Given that age-related declines in muscle strength and walking ability are typically observed in community-dwelling older adults, these findings suggest that even this low frequency attenuated functional decline. In contrast to the two- to three-times-weekly multicomponent programs typically recommended in intervention studies, which meta-analyses in frail older adults have shown to improve strength, walking speed, and balance over approximately 12 weeks [14,15], municipal long-term care prevention services are often limited to once-weekly sessions because of constraints in transportation, staffing, and budget. The present results therefore have practical significance in indicating that, even under such field-level conditions, a certain long-term protective effect can be expected. However, this interpretation should be viewed cautiously in the absence of a control group and in light of potential selection and repeated testing effects.

However, not all functions improved or were maintained to the same extent. Indices of lower-limb muscular endurance and repetitive movement, such as CS-30 and the 10-times knee lift test, improved relatively quickly and remained at a high level in the medium term. In contrast, sit-and-reach flexibility and maximal 5-step length tended to show larger unfavorable 6-year changes among women with higher baseline age, suggesting that age-related declines in joint range of motion and postural control could not be fully compensated by once-weekly exercise alone. Handgrip strength, widely used as an index of overall muscle mass and sarcopenia [16,17], also declined over the long term, likely reflecting the lower-limb-oriented nature of the program and the limited high-intensity resistance training for the upper limbs. To better maintain flexibility and handgrip strength, future programs may need to incorporate stretching and upper-limb resistance exercises more intentionally and systematically.

The observed associations between baseline age and 6-year and annual percent changes suggest the existence of threshold ages at which scope for improvement decreases and decline predominates. Significant correlations with age were observed for maximal 5-step length, flexibility, and supine-to-stand time, and annual percent change tended to shift from around 0% to negative values from the early to mid-80s. These findings are consistent with the proposed redefinition of older adults by the Japan Gerontological Society and the Japan Geriatrics Society, which suggests that functional decline becomes more apparent from around age 75 years [1,18]. Given that step length and flexibility are closely related to fall and disability risk [19], our results support the importance of initiating interventions to maintain these functions before age 80, when individuals are still relatively younger within old age. In this sense, the present study provides concrete benchmarks for the question of up to what age the same exercise stimulus can realistically be expected to improve or maintain function. Notably, the coefficients of determination (R^2) were small, indicating that baseline age explains only a modest proportion of variability in annual percent change; thus, other individual factors (e.g., habitual activity outside the program, nutrition, comorbidities/medication, and biological/genetic susceptibility) likely contribute to heterogeneity in trainability.

At the same time, our findings do not imply that exercise becomes meaningless once individuals exceed a threshold age. For CS-30, one-leg stance, and the 10-times knee lift test, improvements or maintenance were observed even in older age groups. The proportion of participants achieving ≥ 10 s in one-leg stance with eyes open increased from

approximately half at baseline to nearly 80% at 6 months, remained high for several years, and, although it declined at 6 years, still exceeded baseline. Achieving ≥ 10 s may have clinical significance for fall and fracture risk; Chang et al. reported that inability to maintain single-leg stance for ≥ 10 s was associated with fall experience and that this test is a useful screening index for fall risk [20], and Larsson et al. showed that women with a one-leg stance time < 10 s had a significantly higher risk of fractures than those with ≥ 10 s [21,22]. Thus, improvements in the proportion achieving ≥ 10 s in this study may represent not only better test performance but also potential reductions in fall and fracture risk. These findings suggest that even frail adults over 80 years can, at least for a certain period, achieve improvements or maintenance in balance and lower-limb muscular endurance through continued multicomponent exercise of appropriate frequency and volume, extending previous reports that long-term community exercise classes delay transition to frailty and attenuate decline in walking function [7,8] to an older and frailer population.

Exploring relationships among physical function indices at baseline may help characterize mobility profiles and inform streamlined assessment batteries in community programs. In this cohort, a strong association was observed between 10 m fast and zigzag walk times, and both walking times were inversely related to maximal 5-step length, suggesting that step length is closely linked to walking performance (Table 4). In addition, supine-to-stand time correlated with 10-times knee lift time, indicating shared demands related to lower-limb movement speed and transfers. Given the small sample size, these baseline correlations should be interpreted as exploratory.

From a practical standpoint, the present findings provide guidance for planning exercise interventions within community-based integrated care systems. For frail older adults, it may be effective to begin interventions as early as possible, ideally before the early 80s; to prioritize assessment and support of mobility functions directly related to daily life, such as walking speed, step length, and transfer ability; and to address functions that become more difficult to improve with advancing age, such as flexibility and upper-limb strength, with more intensive approaches from the early phases of the program. Another notable strength of the present program was the sustained high attendance rate of approximately 90% over 6 years. This suggests that once-weekly group-based multicomponent exercise is feasible and acceptable even for frail older women in community-based long-term care prevention services. Although the program in this study was based on once-weekly group sessions, meta-analyses indicate that exercise frequency influences effect sizes for walking function [14,19]. Future work should therefore consider hybrid models that combine once-weekly classes with simple home-based exercises and increased daily physical activity (e.g., stair climbing, brisk walking during errands).

The strength of this study lies in its comprehensive examination of long-term changes in physical function, age dependence of trainability, and structural relationships among physical function indices over 6 years under real-world conditions of a municipal long-term care prevention program for frail older women. Building on the concepts of threshold age and mobility clusters, future intervention research that combines different exercise frequencies and intensities with nutritional support and promotion of social participation may help optimize long-term care prevention programs in super-aged societies.

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Institutional Review Board Statement: This study was conducted in accordance with the regulations of the Research Ethics Committee of Wakayama University and was approved by the committee (approval no. H26-02-1; approved on 7 January 2015). The study adhered to the principles of the Declaration of Helsinki. Participants received detailed explanations of the study purpose, procedures, and methods; the expected benefits and possible risks; the voluntary nature of participation; and their right to withdraw at any time without disadvantage. Written informed consent was obtained from all participants. Collected personal data were anonymized and managed securely using identification codes. The intervention consisted solely of non-invasive exercise programs, which were delivered with careful attention to safety by trained instructors, who continuously monitored for the occurrence of adverse events. The authors declare that they have no conflicts of interest related to this study.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data underlying this study contain potentially identifiable personal information and are therefore not publicly available owing to ethical and legal restrictions. De-identified data and analysis code may be made available from the corresponding author upon reasonable request and with approval from the Wakayama University Ethics Committee.

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