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Original article

Temporal trends in 6-minute walking distance for older Japanese adults between 1998 and 2017

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Abstract

Background: The 6-minute walking distance (6MWD) is an excellent measure of both functional endurance and health. The primary aim of this study was to estimate temporal trends in 6MWD for older Japanese adults between 1998 and 2017; the secondary aim was to estimate concurrent trends in body size (i.e., height and mass) and self-reported participation in exercise/sport.

Methods: Adults aged 65–79 years were included. Annual nationally representative 6MWD data ($n = 103,505$) for the entire period were obtained from the Japanese Ministry of Education, Culture, Sports, Science and Technology. Temporal trends in means (and relative frequencies) were estimated at the gender–age level by best-fitting sample-weighted linear/polynomial regression models, with national trends estimated by a post-stratified population-weighting procedure. Temporal trends in distributional variability were estimated as the ratio of coefficients of variation.

Results: Between 1998 and 2017 there was a steady, moderate improvement in mean 6MWD (absolute = 45 m (95% confidence interval (CI): 43–47); percent = 8.0% (95%CI: 7.6–8.4); effect size = 0.51 (95%CI: 0.48–0.54)). Gender- and age-related temporal differences in means were negligible. Variability in 6MWD declined substantially (ratio of coefficients of variation = 0.89, 95%CI: 0.87–0.92), with declines larger for women compared to men, and for 75–79-year-olds compared to 65–74-year-olds. Correspondingly, there were moderate and negligible increases in mean height and mass, respectively, and negligible increases in the percentage who participated in exercise/sport at least 3 days per week and at least 30 min per session.

Conclusions: There has been a steady, moderate improvement in mean 6MWD for older Japanese adults since 1998, which is suggestive of corresponding improvements in both functional endurance and health. The substantial decline in variability indicates that the temporal improvement in mean 6MWD was not uniform across the distribution. Trends in 6MWD are probably influenced by corresponding trends in body size and/or participation in exercise/sport.

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Keywords: Aerobic exercise; Aged; Fitness testing; Physical fitness; Secular change

1. Introduction

Cardiorespiratory endurance reflects the overall capacity of the cardiovascular, respiratory, metabolic, and neuromuscular systems to perform large-muscle, dynamic, moderate- to vigorous-intensity exercise for long periods.¹ The 6-minute walk test

(6MWT)—a self-paced, submaximal field test—is an acceptable, feasible, ecologically valid, widely used, and scalable measure of functional endurance (i.e., the ability to perform aerobic exercise in conventional physical activity conditions) for clinical screening and population surveillance.^{2–4} The 6MWT is recommended by both the American Thoracic Society and the European Respiratory Society³ and is included in the senior fitness test⁵ to assess functional endurance in older adults. The 6MWT has moderate to very high criterion validity for

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estimating both gas-analyzed maximum oxygen uptake (VO_{2max} in mL/kg/min) and functional capacity for adults,^{3,6,7} and it can be used as a marker for one and/or the other. The 6MWT is safe, well-tolerated, and has very high to nearly perfect test–retest reliability.^{3,6,8}

Among older adults, slow walking speed (also often referred to as “gait speed”) is significantly associated with all-cause mortality,^{9,10} cardiovascular disease,⁹ and a range of adverse health outcomes.¹⁰ A recent systematic review and meta-analysis of 44 prospective cohort studies, which collectively followed up 101,945 participants (mean age: 72 years; 55% women) for a median of 5.4 years, indicated that every 0.1 m/s reduction in walking speed was associated with a 12% increased risk of earlier mortality and an 8% increased risk of cardiovascular disease.⁹ Specifically, reduced 6MWT performance (i.e., 6-minute walking distance (6MWD)) is significantly associated with all-cause mortality (independent of body size, physical activity levels, and other covariates)¹¹ and cardiovascular mortality in both apparently healthy¹¹ and disease-limited³ older adults. It is also associated with increased cardiovascular disease risk,¹² poorer resting cardiovascular function,¹² hospitalization,³ dyspnea,³ poorer quality of life,¹³ and functional limitations.¹⁴ In fact, 6MWD is as strong a predictor of all-cause and cardiovascular mortality as gas-analyzed VO_{2max} .¹¹ This health-related evidence supports the promotion of aerobic exercise in national¹⁵ and global¹⁶ physical activity guidelines for older adults. Because endurance is a powerful marker of adult health, examination of temporal trends in 6MWD for older adults may provide important insights into corresponding trends in functional capability and population health.

We recently published a large systematic analysis of temporal trends in functional endurance for adults, which showed a moderate international decline of 1.6%, or an effect size (ES) of 0.13, per decade across 2,525,827 adults (aged 18–59 years) representing 8 high- and upper-middle-income countries between 1967 and 2016.¹⁷ Although much less is known about temporal trends in functional endurance for older adults (aged ≥ 65 years), several studies, which have relied on different exercise modalities and effort criteria including maximal treadmill exercise,¹⁸ submaximal cycle ergometry,¹⁹ and submaximal bench stepping,²⁰ show mixed trends in recent decades. Willis et al.¹⁸ found that mean treadmill exercise predicted VO_{2max} in American men aged 65–74 years improved by ~ 3.5 mL/kg/min, or $\sim 10\%$ – 12% , from the 1970s to the 1980s, with little change through to the end of the 2000s. In contrast, Ekblom-Bak et al.¹⁹ found that a decline in mean cycle ergometry predicted VO_{2max} of 0.6 mL/kg/min, or 2.8%, per decade between 1995 and 2017 in 48,284 Swedish adults aged 50–74 years. Moreover, Craig et al.²⁰ found that a decline in mean bench stepping predicted VO_{2max} of 0.3–0.6 mL/kg/min, or 1.0%–2.6%, per decade from 1981 to 2007–2009 in a nationally representative sample of 677 Canadian adults aged 60–69 years. While these studies reported trends in mean functional endurance for older adults, it is not known whether there have been temporal trends in distributional characteristics (i.e., trends in distributional variability and/or asymmetry).

Examination of temporal trends in functional endurance for older adults from a variety of countries will improve insights into trends in population health for such countries, facilitate cross-country comparisons, provide insight for interventions, help evaluate the impact of healthy public policy, and potentially predict future trends.^{21,22} For example, because functional endurance is sensitive to changes in physical activity levels,²³ trends in 6MWD could help evaluate the effectiveness and progress of the ActiveGuide (Japan’s official physical activity guidelines for health promotion),¹⁵ which recommends that older adults increase their physical activity levels by adding 10 min of moderate to vigorous physical activity every day and build up to a minimum of 40 min of aerobic exercise at any intensity every day.^{15,24} The Japanese Ministry of Education, Culture, Sports, Science and Technology has conducted annual national fitness surveillance of 65–79-year-olds since 1998, and published descriptive data in its annual “Report Book on the Survey of Physical Fitness and Athletic Ability”.⁴ Using these nationally representative fitness data, the primary aim of this study was to estimate temporal trends (in means and variability) in 6MWD for older Japanese adults (aged 65–79 years) between 1998 and 2017. The secondary aim was to estimate corresponding trends in potential mechanistic factors (body size (height and mass) and self-reported participation in exercise/sport).

2. Methods

2.1. Participants and sampling procedures

While annual national fitness surveillance of Japanese children and adults (aged 6–59 years) has been performed by the Ministry of Education, Culture, Sports, Science and Technology since 1964,²⁵ the national surveillance system was revised in 1998 to include new fitness constructs, test measures, and a wider age demographic (aged 6–79 years). The national fitness surveillance system, which involves annual cross-sectional sampling of the Japanese population, is described in detail elsewhere.²⁵ Briefly, nationally representative samples of older adults had their physical fitness tested yearly between May and October, with fitness test results statistically processed and reported descriptively (e.g., sample sizes, means, and standard deviations) each year from 1998 onward.⁴ Older adults were recruited from all parts of Japan (i.e., all 47 prefectures), with descriptive fitness data available for 6 gender–age groups (men and women aged 65–69 years, 70–74 years, and 75–79 years). Local education boards tried to recruit representative samples by recruiting residents from geographically diverse areas (both urban and rural areas) within each prefecture, with target sample sizes of $n = 20$ per gender–age prefecture group.

Prior to participating in exercise, participants underwent a health exam administered by a doctor or a nurse and completed an activities of daily living questionnaire.²⁶ Participants were excluded from the 6MWT for safety reasons if they (a) were receiving medical treatment; (b) had a cold, fever, or hangover; (c) had high blood pressure (i.e., systolic blood pressure

≥160 mm Hg and/or diastolic blood pressure ≥95 mm Hg); or (d) were physically limited (i.e., they self-reported as being unable to walk continuously for at least 20 min, or stand up from a seated (“seiza”) position, or stand unsupported on 1 leg).²⁶ Unfortunately, no data on medical exclusions were available. In total, 6MWT data were available for 103,505 older adults (men, 50.4% or $n = 52,130$; women 49.6% or $n = 51,375$) aged 65–79 years over the period 1998–2017, with an average sample size of 17,251 (range: 16,060–17,814) per gender–age group. Means ± standard deviations for the period 1998–2017 were: men—height = 163 ± 6 cm, mass = 61 ± 8 kg, 6MWD = 587 ± 94 m; women—height = 151 ± 5 cm, mass = 51 ± 7 kg, 6MWD = 543 ± 59 m. Collectively, 94% of the sample self-reported as apparently healthy, 76% as having average physical fitness, 40% as belonging to a sporting club, 30% as regularly participating in exercise/sport at least three days per week, and 70% as regularly participating in exercise/sport for at least 30 min per session.

2.2. Testing procedures

Functional endurance was measured to the nearest 5 m by trained technicians using a standardized 6MWT protocol.²⁶ After warming up, participants continuously walked laps around either a flat 30 m circular course or up and back along a flat 50 m straight course, with the aim of walking as far as possible in 6 min. Participants were asked to maintain their usual walking pace, but not to run or compete with their peers. Those who were measured for functional endurance also completed a questionnaire regarding their participation in exercise/sport.²⁶ The questionnaire comprised 2 items, one on exercise/sport frequency and the other on exercise/sport duration, with both items having four response choices. Participants were asked to select 1 response per item that best described their current levels. Body mass was measured to the nearest 0.1 kg using a digital weighing scale, and standing height was measured to the nearest 0.1 cm using a stadiometer.

2.3. Statistical analyses

Temporal trends in means were analyzed in separate gender–age groups using best-fitting (and most parsimonious) sample-weighted linear or polynomial (quadratic or cubic) regression models relating the year of testing to mean 6MWD, height, and mass.¹⁷ The square root of sample size was chosen as the sample-weighting method because our confidence in the estimation of each group mean (i.e., the standard error) is proportional to the square root of the sample size. Trends in means were expressed as absolute changes, percent changes (i.e., change in means expressed as a percentage of the overall mean), and as standardized ES (i.e., change in means divided by the pooled standard deviation). To interpret the magnitude of changes in means, ES of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with ES <0.2 considered to be negligible.²⁷ Positive changes indicated temporal improvements in means, and negative changes indicated temporal declines in means. Using linear or polynomial (quadratic or cubic) regression, trends in exercise/sport

frequency were estimated as trends in the percentage who participated in exercise/sport at least 3 days per week, with trends in exercise/sport duration estimated as trends in the percentage who participated at least 30 min per session. ES (changes in relative frequencies) of 10%, 30%, and 50% were used as thresholds for small, moderate, and large, respectively, with ES <10% considered to be negligible.²⁷

National trends (for men, women, 65–69-year-olds, 70–74-year-olds, 75–79-year-olds, and all older adults (65–79-year-olds)) were calculated using a post-stratified population-weighting procedure that has been described in detail elsewhere.¹⁷ Population estimates were standardized to the year 2000—a common testing year to all gender–age groups—using United Nations data.²⁸

Distributional variability was quantified as the coefficient of variation (CV) (i.e., the ratio of the standard deviation to the mean). Trends in CVs were analyzed from descriptive data by (a) calculating the CVs for all gender–age–year groups; (b) fitting sample-weighted linear regression models relating the year of testing to the CVs; (c) predicting the CVs corresponding to the first (i.e., 1998) and last (i.e., 2017) testing years (this eliminated any distortion that may have arisen from atypical CVs in those years); and (d) calculating the ratio of CVs between 2017 and 1998 by dividing the 2017 CVs by the 1998 CVs.²⁹ Ratios >1.1 indicated substantial increases in distributional variability (i.e., the magnitude of variability in relation to the mean increased over time), ratios <0.9 indicated substantial declines in variability (i.e., the magnitude of variability in relation to the mean decreased over time), and ratios between 0.9 and 1.1 inclusive indicated negligible trends in variability (i.e., the magnitude of variability in relation to the mean did not change meaningfully over time).³⁰

3. Results

3.1. Trends in 6MWD

Collectively, there was a steady, moderate improvement in mean 6MWD (absolute = 45 m (95% confidence interval (CI): 43–47); percent = 8.0% (95%CI: 7.6–8.4); ES = 0.51 (95%CI: 0.48–0.54) between 1998 and 2017 (Table 1 and Fig. 1). There were negligible gender- and age-related temporal differences, with moderate improvements for women (ES = 0.57, 95%CI: 0.55–0.59), 70–74-year-olds (ES = 0.55, 95%CI: 0.54–0.56), and 75–79-year-olds (ES = 0.60, 95%CI: 0.58–0.62), and small improvements for men (ES = 0.44, 95%CI: 0.40–0.48) and 65–69-year-olds (ES = 0.42, 95%CI: 0.36–0.48). The rate of improvement was steady for women, 70–74-year-olds, and 75–79-year-olds; yet it slowed for men and 65–69-year-olds, with recent values (post-2008) 1.4–1.5-fold smaller than earlier values.

Distributional variability in 6MWD declined substantially between 1998 and 2017 (ratio of CVs = 0.89, 95%CI: 0.87–0.92) (Table 1). Variability declined substantially for women but not men, with the decline 1.8-fold larger for women. The magnitude of decline in variability increased with age, ranging from a negligible decline for 65–69-year-olds (ratio of CVs = 0.95, 95%CI: 0.91–1.00) to a 3.0-fold larger

Table 1
Temporal trends in mean and CV 6MWD performance for 65- to 79-year-old Japanese adults between 1998 and 2017.

Group	n	Change in means (95%CI)			Ratio of CVs (95%CI)
		Absolute	Percent	Standardized ES	
All					
65- to 79-year-olds	103,505	45 (43–47)	8.0% (7.6–8.4)	0.51 (0.48–0.54)	0.89 (0.87–0.92)
Gender					
Men	52,130	40 (36–44)	6.8% (6.1–7.5)	0.44 (0.40–0.48)	0.92 (0.89–0.96)
Women	51,375	48 (46–50)	8.9% (8.5–9.3)	0.57 (0.55–0.59)	0.86 (0.83–0.89)
Age, years					
65–69	35,602	37 (31–43)	6.2% (5.3–7.1)	0.42 (0.36–0.48)	0.95 (0.91–1.00)
70–74	35,214	48 (47–49)	8.5% (8.3–8.7)	0.55 (0.54–0.56)	0.88 (0.84–0.92)
75–79	32,689	53 (51–55)	10.1% (9.7–10.5)	0.60 (0.58–0.62)	0.85 (0.81–0.89)

Notes: All absolute changes in mean 6MWD are in meters. Positive changes in means indicated temporal improvements in means and negative changes indicated temporal declines in means; standardized changes (ES) in means of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with ES <0.2 considered to be negligible; ratio of CVs >1.1 indicated substantial temporal increases in variability, and ratios <0.9 indicated substantial temporal declines. Abbreviations: 6MWD = 6-minute walking distance; 95%CI = 95% confidence interval; CV = coefficient of variation; ES = effect size.

substantial decline for 75–79-year-olds (ratio of CVs = 0.85, 95%CI: 0.81–0.89).

3.2. Trends in height, mass, and self-reported participation in exercise/sport

Overall, there was moderate increase in mean height (change in means = 2.8 cm (95%CI: 2.6–3.0); percent = 1.8% (95%CI: 1.7–1.9); ES = 0.51 (95%CI: 0.47–0.55)) and a negligible increase in mean mass (change in means = 0.9 kg (95%CI: 0.5–1.3); percent = 1.5% (95%CI: 0.8–2.2); ES = 0.12 (95%CI: 0.06–0.18)) over the entire period (Table 2). Gender- and age-related temporal differences for height and mass were negligible to small. Rates of increase for height were generally steady, whereas rates of increase for mass slowed and stabilized (men, 65–69-year-olds, and 75–79-year-olds) or shifted to declines (women and 70–74-year-olds) from 2012 to 2013 onwards. Trends in distributional variability for height and mass were negligible.

There were also negligible increases in the percentage of older adults who participated in exercise/sport at least 3 days per week (change = 7.7%, 95%CI: 7.3–8.1) and at least 30 min per session (change = 5.0%, 95%CI: 4.3–5.7) over the 19-year period. Gender- and age-related temporal differences were negligible, with rates of improvement reasonably steady.

4. Discussion

This study estimated temporal trends in 6MWD for 103,505 older Japanese adults aged 65–79 years between 1998 and 2017. The principal findings were that (a) there was a moderate population-level improvement in 6MWD, which was equivalent to 75–79-year-olds' mean 6MWD improving to better than that seen for 70–74-year-olds in 1998 (i.e., when 5 years younger); (b) 6MWD improved in all gender and age groups, with negligible gender- and age-related temporal differences; (c) variability in 6MWD declined substantially over time, with declines larger for women compared to men, and for 75–79-year-olds compared to 65–74-year-olds; and (d) there were

moderate and negligible increases in mean height and mass, respectively, and negligible increases in the percentage who participated in exercise/sport at least 3 days per week and at least 30 min per session. Our findings of improved 6MWD suggests that the functional endurance of today's older Japanese adults is better than that of their peers from two decades past. This may be meaningful to public health given the significant associations between 6MWD and health-related outcomes,^{3,11–14} and evidence of corresponding improvements in healthy life expectancy among older Japanese adults (e.g., declines in disability and mortality rates, and treatment rates of chronic medical conditions).³¹ This is especially important given that Japan is an aging society and has the highest proportion of older adults in the world.³²

4.1. Explanation of main findings

We have previously argued that a network of physiological, physical, behavioral, social, and/or environmental factors probably influences temporal trends in functional endurance.^{17,33} Because 6MWD has moderate to very-high criterion validity for estimating gas-analyzed $\text{VO}_{2\text{max}}$ (in mL/kg/min) and functional capacity,^{3,6,7} improved 6MWD is suggestive of a corresponding improvement in underlying $\text{VO}_{2\text{max}}$ (and/or relative oxygen transport capability) and other aerobic factors (i.e., mechanical efficiency and fractional utilization of oxygen) leading to enhanced functional endurance performance. Trends in psychosocial (e.g., improved motivation, ability to tolerate discomfort, pacing) factors are also probably involved.¹⁷ Specifically, improved 6MWD reflects an improved ability to perform submaximal ambulatory aerobic exercise, and therefore an improved functional capability for daily physical activities.

Trends in 6MWD are also likely influenced by concurrent trends in physical characteristics, such as trends in body size and composition.^{34,35} Trends in functional endurance and body size are, in turn, likely influenced by improved standards of living (e.g., improved health, education, and income), healthier lifestyles (e.g., improved nutrition and physical

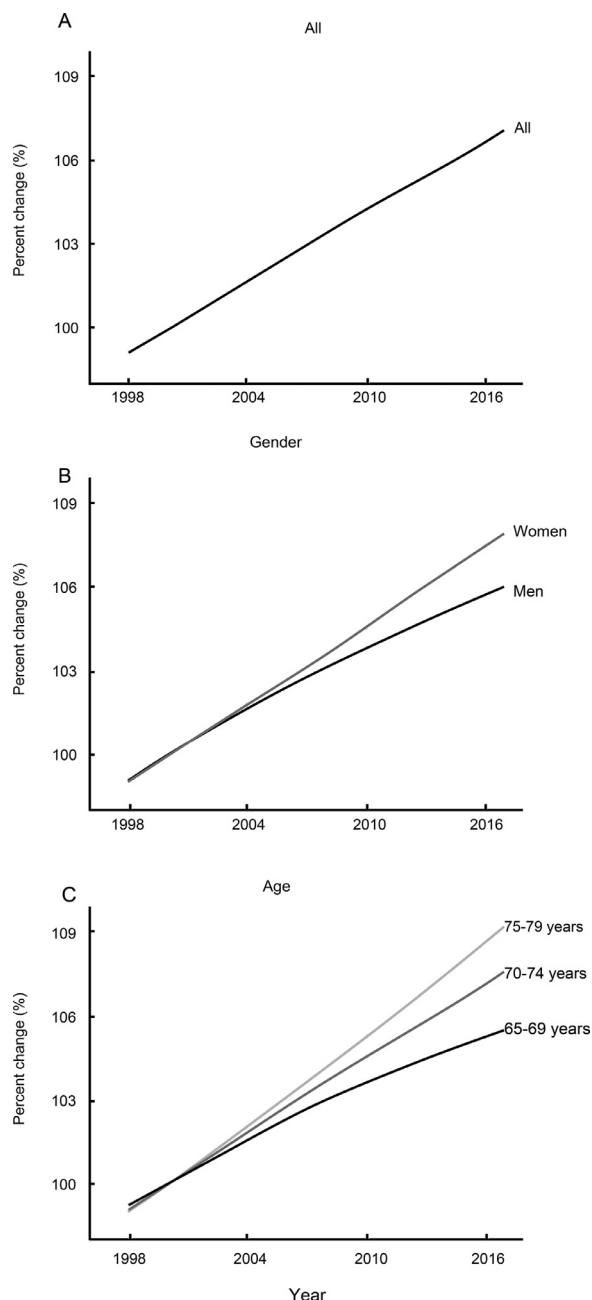


Fig. 1. Temporal trends in mean 6MWD for 65- to 79-year-old Japanese adults between 1998 and 2017. Temporal trends are shown for all (A) Japanese adults aged 65–79 years as well as different gender (B) and age (C) groups; data are standardized to the year 2000 (considered as 100%), with values of >100% indicating better 6MWD and values <100% indicating poorer 6MWD; the solid lines are the LOcally WEighted Scatter-plot Smoother (LOWESS) curves (tension = 66), which are used to represent the trends in mean 6MWD, with upward sloping lines indicating temporal improvements and downward sloping lines indicating temporal declines. 6MWD = 6-minute walking distance; CV = coefficient of variation.

activity levels), and more effective disease prevention and treatment,³⁶ although it is difficult to estimate the effect of such trends. Our analysis indicated concurrent increases in height (ES: moderate) and mass (ES: negligible) for older Japanese adults.⁴ Because height is a strong positive correlate of 6MWD^{34,35} and a very strong positive correlate of both leg

length and stride length,³⁴ increased height probably reflects increased leg and stride lengths and improved 6MWD. On the other hand, because body mass is a weak to moderate negative correlate of 6MWD,^{34,35} a decline in 6MWD would be expected given the recent increase in body mass. However, the increase in body mass probably reflected an increase in both fat mass and fat-free muscle mass,³⁷ which in turn affect energy supply and energy demand. It is possible that 6MWD improved because the increase in fat-free muscle mass, which improves the metabolic potential of the exercising muscles (e.g., increased glycogen storage capacity, increased number of mitochondria, *etc.*) and increases energy supply, was larger than the increase in fat mass resulting in increased energy demand. In addition, increased fat-free muscle mass may have enhanced mechanical efficiency during walking (e.g., reduced antagonist co-activation needed for stability), reducing the energy cost for any given work rate.³⁸

Given that objectively measured physical activity is a moderate to very strong correlate of 6MWD,³ behavioral changes such as increased physical activity levels probably also help explain the improvement in 6MWD. Our analysis indicated significant increases of 7.7% and 5.0% in the percentage of older Japanese adults who participated in exercise/sport at least 3 days per week and at least 30 min per session, respectively. Such increases could have been influenced by Japan's physical activity guidelines (released in 2013), which recommend that older adults accumulate at least 40 min of aerobic exercise at any intensity every day¹⁵ and far exceed global recommendations of at least 150 min of aerobic exercise at any intensity per week.¹⁶ Assuming this temporal connection is causal, then the national promotion of physical activity (e.g., Japan's physical activity guidelines)¹⁵ might be a suitable population approach to improving functional endurance in older adults.

The distribution of 6MWD values in older Japanese adults changed substantially since 1998, although the distribution of height and mass values did not. Our finding of a substantial decline in variability indicates that the improvement in mean 6MWD was not uniform across the population, either because one or both tails of the distribution have moved towards the middle over time. Unfortunately, without evidence of corresponding trends in measures of distributional asymmetry (e.g., skewness), we were unable to determine whether the left tail (i.e., those with low functional endurance), right tail (i.e., those with high functional endurance), or both tails of the distribution changed over time. Future studies should include measures of distributional asymmetry when evaluating trends in functional endurance, especially as health-related criterion-referenced cut-points emerge.³⁹

4.2. Comparisons with other studies

While few studies have reported temporal trends in functional endurance for older adults, recent results have been mixed, indicating declines in older Canadian²⁰ and Swedish¹⁹ adults, and an improvement followed by a more recent stabilization in older American men.¹⁸ These between-country

Table 2
Temporal trends in mean and CV height and mass for 65- to 79-year-old Japanese adults between 1998 and 2017.

Group	n	Change in means (95%CI)			Ratio of CVs (95%CI)
		Absolute	Percent	Standardized ES	
Height					
All					
65–79-year-olds	105,067	2.8 (2.6–3.0)	1.8% (1.7–1.9)	0.51 (0.47–0.55)	0.95 (0.92–0.97)
Gender					
Men	52,995	3.1 (2.7–3.5)	1.9% (1.7–2.1)	0.55 (0.48–0.62)	0.94 (0.91–0.98)
Women	52,072	2.4 (2.1–2.7)	1.6% (1.4–1.8)	0.48 (0.43–0.53)	0.95 (0.92–0.99)
Age, years					
65–69	36,082	3.4 (2.9–3.9)	2.1% (1.8–2.4)	0.63 (0.54–0.72)	0.95 (0.91–1.00)
70–74	34,121	2.5 (2.1–2.9)	1.6% (1.3–1.9)	0.46 (0.39–0.53)	0.94 (0.89–0.98)
75–79	34,864	2.1 (2.0–2.2)	1.4% (1.3–1.5)	0.38 (0.36–0.40)	0.95 (0.91–1.00)
Mass					
All					
65–79-year-olds	104,940	0.9 (0.5–1.3)	1.5% (0.8–2.2)	0.12 (0.06–0.18)	0.96 (0.94–0.99)
Gender					
Men	52,922	2.5 (2.0–3.0)	4.1% (3.3–4.9)	0.33 (0.26–0.40)	0.96 (0.93–1.00)
Women	52,018	–0.3 (–0.7 to 0.1)	–0.6% (–1.5 to 0.3)	–0.05 (–0.12 to 0.02)	0.96 (0.92–1.00)
Age, years					
65–69	35,971	0.5 (–0.1 to 1.1)	0.7% (–0.3 to 1.7)	0.06 (–0.02 to 0.14)	0.99 (0.94–1.03)
70–74	35,597	0.8 (–0.1 to 1.7)	1.2% (–0.3 to 2.7)	0.10 (–0.02 to 0.22)	0.94 (0.89–0.98)
75–79	33,372	1.7 (1.0–2.4)	3.0% (1.8–4.2)	0.23 (0.14–0.32)	0.96 (0.92–1.01)

Notes: Absolute changes in mean height are in centimeters and absolute changes in mass are in kilograms. Positive changes in means indicated temporal improvements in means and negative changes indicated temporal declines in means; standardized changes (ES) in means of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with an ES of <0.2 considered to be negligible; ratio of CVs of >1.1 indicated substantial temporal increases in variability and ratios of <0.9 indicated substantial temporal declines.

Abbreviations: 95%CI = 95% confidence interval; CV = coefficient of variation; ES = effect size.

temporal differences among older adults are possibly due to differences in populations, sampling, exercise modalities, effort criteria, and span of testing years, as well as temporal differences in physical, behavioral, sociodemographic, and/or environmental factors.¹⁷ Moreover, the temporal trend in functional endurance for older American men has coincided with temporal increases in both self-reported physical activity levels and body mass, as well as a general improvement in health as evidenced by improved total and high-density lipoprotein cholesterol levels and reduced cigarette smoking rates.¹⁸ Similarly, our finding of a moderate improvement in 6MWD for older Japanese adults has coincided with increases in height, mass, and exercise/sport participation,⁴ which in combination with evidence of reduced resting blood pressure levels⁴⁰ and improved healthy life expectancy,³¹ suggest improved population health. In a study specific to Japan, Lamoureux et al.¹⁷ found a decline in mean functional endurance (operationalized as 1000 m (women) and 1500 m (men) walk test performance) of 1.1%, or ES = 0.11, per decade from 1998 to 2016 in a nationally representative sample of 913,398 Japanese adults aged 20–59 years. Age-related temporal differences in functional endurance between young and middle-aged Japanese adults (20–59 years) and older adults (65–79 years) may reflect temporal differences in exercise modalities, effort criteria, body size, and/or exercise/sport participation.^{4,17,41} Furthermore, we recently reported a corresponding improvement in mean handgrip strength (and decline in distributional variability) for older Japanese adults since 1998, which is suggestive of improved strength capacity.⁴²

4.3. Strengths and limitations

This was the first study to examine temporal trends in the functional endurance of older Japanese adults. Using national fitness surveillance data comprising repeated cross-sectional sampling and collected using a consistent sampling strategy, we estimated trends in means using weighted regression and a post-stratification population weighting procedure, which helped adjust the trends for sampling bias by incorporating the underlying population demographics. We also estimated concurrent trends in physical and behavioral factors likely to have influenced the trends in 6MWD. All trend data were collected by the Japanese Ministry of Education, Culture, Sports, Science and Technology using trained measurement teams, which conducted all testing at the same time of year using the same standardized testing protocols. Unique to the older adult literature, we also estimated trends in distributional variability.

Unfortunately, because we could only estimate temporal trends using descriptive 6MWT data, we could not (a) statistically account for the effects of underlying mechanistic factors (e.g., body size, physical activity levels) and other confounders (e.g., income, education), (b) assess trends in distributional asymmetry, or (c) assess the potential influence of trends in 6MWD on health outcomes. Future research should determine the population health and/or clinical significance of improved functional endurance for older Japanese adults. Although affective (e.g., motivation, pacing) and testing/environmental factors (e.g., weather, temperature, clothing, walking surface, track length, practice, group vs. individual testing) can affect

675 6MWT performance,^{3,7} it is unlikely that such factors system-
 676 atically biased our trends because 6MWT was measured at the
 677 same time of year by trained technicians using a standardized
 678 protocol. Because descriptive data were reported in 5-year age
 679 bands, we could not rule out the possibility that our trends
 680 were affected by aggregation bias related to differences in age
 681 distributions within age bands. In addition, the access to only
 682 descriptive data, coupled with the fact that the national fitness
 683 surveillance system relied on repeated cross-sectional sam-
 684 pling rather than mixed longitudinal sampling, meant we were
 685 unable to examine period and cohort effects. The use of pre-
 686 exercise screening criteria to ensure participant safety could
 687 have biased the 6MWD estimates, because only apparently
 688 healthy, able-bodied, ambulatory older adults who passed the
 689 health exam were included, with less fit/less healthy and physi-
 690 cally impaired older adults more likely to have been excluded.
 691 In addition, 6MWD estimates could have further been biased
 692 if less fit individuals chose to opt out of the fitness testing.
 693 However, while such factors may limit the generalizability of
 694 our findings to all older Japanese adults, without any temporal
 695 data on pre-exercise exclusions or overall non-response rates,
 696 it is difficult to determine whether our trends in 6MWD were
 697 biased. It is unlikely that our trends are biased because analysis
 698 of two proxy measures indicates (a) no significant temporal
 699 differences in samples sizes for standing height and 6MWT,
 700 and (b) no significant temporal trends in the proportion of
 701 participants who self-reported as apparently healthy or
 702 physically fit.

705 5. Conclusion

706 Using annual national fitness surveillance data, we found
 707 a steady, moderate improvement in 6MWD for older Japa-
 708 nese adults since 1998, indicating a general improvement
 709 in functional endurance. We found negligible gender- and
 710 age-related temporal differences in mean values, and sub-
 711 stantial declines in variability, which indicated that tempo-
 712 ral trends were not uniform across the distribution. These
 713 trends in 6MWD are probably influenced by corresponding
 714 increases in body size and/or participation in exercise/sport.
 715 The continued national surveillance of functional endurance
 716 in older Japanese adults improves insights into trends in
 717 population health and fitness, as well as the effectiveness
 718 and progress of broad public policy and interventions
 719 aimed at improving population health and fitness. Given
 720 that routine assessment of physical fitness is rare, Japan's
 721 continued annual surveillance of national fitness levels in
 722 older adults not only highlights the importance of func-
 723 tional endurance as a marker of functional capability and
 724 population health, but also provides other countries with a
 725 lesson learnt in population health and fitness surveillance.

728 Data availability statement

729 The datasets analyzed in this review are available from the
 730 corresponding author on reasonable request.

732 Authors' contributions

733 GRT developed the research question, designed the study,
 734 had full access to the data, takes responsibility for the integrity
 735 of the data, led the statistical analysis, and drafted the manu-
 736 script; TK developed the research question, designed the study,
 737 had full access to the data, takes responsibility for the integrity
 738 of the data, and helped to draft the manuscript; TD had full
 739 access to the data, assisted with the statistical analysis, and
 740 takes responsibility for the integrity of the data; SN had full
 741 access to the data, contributed to the interpretation of results,
 742 and critically reviewed the manuscript for important intellec-
 743 tual content; JSF contributed to the interpretation of results
 744 and critically reviewed the manuscript for important intellec-
 745 tual content; and HBB contributed to the interpretation of
 746 results and critically reviewed the manuscript for important
 747 intellectual content. All authors have read and approved the
 748 final version of the manuscript, and agree with the order of pre-
 749 sentation of the authors.

752 Competing interests

753 All authors declare that they have no competing interests.

755 Supplementary materials

756 Supplementary material associated with this article can be
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