Table 1. Mean age, average daily dietary intake from 3-day diet records, body mass index, and blood pressure at first participation (first study wave) in the Japanese Longitudinal Study of Aging

	Men (n=544)			Women (n=512)		
Characteristic	**Mean±standard deviation**	**Min**	**Max**	**Mean±standard deviation**	**Min**	**Max**
Age (y)	56.5±9.3	40	79	55.8±9.4	40	78
Nutrition						
Salt (g/d)	12.8±3.3	5	28	10.6±2.5	3	23
Energy (kcal/d)	2,382.4±405.1	1,057	4,433	1,940±308.7	970	2,988
Protein (g/d)	89.5±16.4	39	148	75.2±14.4	40	136
Fat (g/d)	62.2±16.8	17	144	55.7±15.0	21	118
Carbohydrate (g/d)	330.6±67.6	155	608	277.3±48.9	146	483
Salt/energy (g/1,000 kcal)	5.4±1.2	2	10	5.5±1.2	2	10
Body mass index	23.0±2.7	15	33	22.6±2.9	15	38
Systolic blood pressure (mm Hg)	123.0±17.5	72	204	121.2±19.5	78	193
Diastolic blood pressure (mm Hg)	77.0±10.4	52	114	73.7±11.1	49	114

Table 2. Mean energy and salt intake according to age group[a] from the first to fifth study wave in the Japanese Longitudinal Study of Aging

		Study Wave						
Intake	**n**	**First**	**Second**	**Third**	**Fourth**	**Fifth**	**ANOVA[b] *P* value**	**Trend *P* value**
		← *mean±standard deviation* →						
Energy intake (kcal/d)								
Men (y)								
40-49	149	2,434±418	2,345±372	2,384±360	2,326±385	2,309±362	0.037	0.007
50-59	192	2,414±405	2,359±383	2,321±362	2,305±364	2,314±342	0.024	0.003
60-69	140	2,338±401	2,277±385	2,224±402	2,181±340	2,132±328	<0.001	<0.001
70-79	63	2,264±356	2,181±340	2,123±329	2,045±303	2,024±359	<0.001	<0.001
Women (y)								
40-49	156	1,957±292	1,891±332	1,930±300	1,876±273	1,867±291	0.039	0.010
50-59	174	1,976±314	1,895±303	1,889±283	1,845±308	1,852±288	<0.001	<0.001
60-69	126	1,919±317	1,853±308	1,848±294	1,786±285	1,757±275	<0.001	<0.001
70-79	56	1,828±294	1,781±300	1,754±285	1,723±264	1,680±257	0.007	0.003
Salt intake (g/d)								
Men (y)								
40-49	149	12.37±3.01	11.63±2.56	12.18±2.56	11.92±2.19	11.67±2.48	0.060	0.098
50-59	192	13.04±3.24	12.19±2.87	12.54±2.76	12.46±2.75	12.19±2.52	0.020	0.026
60-69	140	13.11±3.69	12.25±2.87	12.52±2.69	12.28±2.58	11.72±2.74	0.003	0.001
70-79	63	12.41±3.09	11.93±2.60	11.73±2.59	11.50±2.44	11.23±2.74	0.146	0.010
Women (y)								
40-49	156	10.28±2.46	9.81±1.95	10.17±2.00	10.39±1.74	9.95±2.02	0.086	0.899
50-59	174	10.83±2.44	10.22±2.02	10.80±2.16	10.48±1.92	10.86±2.58	0.028	0.560
60-69	126	10.76±2.43	10.36±2.29	10.85±2.31	10.60±1.80	10.32±2.25	0.237	0.311
70-79	56	10.81±2.97	10.14±2.49	10.48±2.38	10.19±2.28	10.04±2.17	0.469	0.157

[a]Age groups were categorized according to the age at first participation.
[b]ANOVA=one-way analysis of variance.

pressure of participants at first participation are shown in Table 1. Mean age of study participants was 56.5±9.3 years for men and 55.8±9.4 years for women. Average daily salt intake was 12.8±3.3 g/day in men and 10.6±2.5 g/day in women; energy intake was 2,382.4±405.1 kcal/day in men and 1,940.0±308.7 kcal/day in women.

Most dietary intakes were higher in men than in women, although intakes of several food items, including fruit, milk, and confectioneries, were higher in women (data not shown). Mean dietary intake was close to the data of the National Nutrition Survey (7), which indicated that the diet of this sample was comparable to that of average Japanese subjects.

Mean energy and salt intake according to age group from the first to fifth study waves are shown in Table 2. Mean energy intake was decreased in men and women in all age groups in the first to fifth study waves (analysis of variance $P<0.05$, trend $P<0.05$). Mean salt intake from

Table 3. Mixed-effects regression analyses of main effects of salt intake (g/day) for 8 years[a] in Japanese Longitudinal Study of Aging

Variable	Model 1[b] *F*	Model 1[b] *P* value	Model 2[c] *F*	Model 2[c] *P* value
Men (n=544)				
Study wave (5 categories)[d]	28.07	<0.001	5.21	0.023
Age group (4 categories)[e]	2.11	0.099	3.80	0.010
Interaction of study wave×age group	0.97	0.406	0.32	0.813
Energy intake (kcal/d)	—	—	631.20	<0.001
Women (n=512)				
Study wave (5 categories)[d]	3.46	0.063	1.69	0.194
Age group (4 categories)[e]	1.41	0.238	3.16	0.024
Interaction of study wave×age group	1.02	0.382	1.05	0.370
Energy intake (kcal/d)	—	—	617.17	<0.001

[a]Eight years was the entire follow-up period in individuals from first to fifth study waves.
[b]Model 1: Study-wave, age group, and interaction of study-wave×age group were entered into the mixed-model analyses.
[c]Model 2: Model 2 included energy intake into the covariates in model 1.
[d]Five categories: First to fifth study-waves.
[e]Four categories: 4 age groups (40-49, 50-59, 60-69, 70-79 years) were categorized according to age at first participation.

the first to fifth study waves decreased among 50- to 59-year-old and 60- to 69-year-old men (analysis of variance $P<0.05$, trend $P<0.05$). In men, salt intake at each study wave was higher among 50- to 59-year-olds and 60- to 69-year-olds than in 40- to 49-year-olds and 70- to 79-year-olds. There was no consistent change in salt intake in women across each age group or study wave.

The mixed-effects regression analyses of the main effects of salt intake for 8 years are shown in Table 3. The main effect of study wave was statistically significant, and after adjustment for energy intake, the main effects of study wave and age group in men and age group in women were significant.

Estimated linear changes in salt intake for 8 years by age group were estimated according to the slope of salt intake. Among men, the slope of salt intake (grams/day) per study wave declined by age group with values of 0.15 g among 40- to 49-year-olds ($P=0.057$), 0.19 g among 50- to 59-year-olds ($P=0.007$), 0.32 g among 60- to 69-year-olds ($P<0.0001$), and 0.29 g among 70- to 79-year-olds ($P=0.017$), respectively. Because each study wave was conducted for 2 years, mean salt intakes in men decreased 0.08 g/year among 40- to 49-year-olds, 0.09 g/year among 50- to 59-year-olds, 0.16 g/year among 60- to 69-year-olds, and 0.14 g/year among 70- to 79-year-olds. For women, the slope of salt intake (grams/day) per study wave among 70- to79-year-olds showed a decline toward a lower intake of 0.17 g or 0.08 g/year, although this value was marginally significant ($P=0.098$).

Estimated linear changes in salt intake by age group after adjusting for energy intake are shown in the Figure. In men, a 0.14-g per study wave decline was observed among 60- to 69-year-olds, which represented a decline of 0.07 g/year ($P=0.049$). In women, a 0.13-g per study wave increase was observed among 50- to 59-year-olds, which represented an increase of 0.06 g/year ($P=0.015$).

DISCUSSION

Eight-year longitudinal data showed that the trends in salt intake declined in men from age 40 to 79 years and in women from age 70 to 79 years among community-dwelling middle-aged and elderly Japanese subjects. After adjusting for energy intake, the trends in salt intake declined among 60- to 69-year-old men; on the other hand, among 50- to 59-year-old women, the trend in salt intake increased. This is the first longitudinal study to assess trends in salt intake stratified by age group categorized according to the age at first participation in the study among middle-aged and elderly Japanese people.

The slope of salt intake by age group declined from 0.08 g/year in 40- to 49-year-olds to 0.16 g/year in 60- 69-year-olds in men and 0.08 g/year in 70- to 79-year-olds in women. Moderate reductions in salt intake decrease systolic blood pressure (13). Intervention trials have shown that sodium reduction lowers blood pressure by 1.7 mm Hg/1 g/24 hour (2), and that increases in sodium intake by 11.7 g/day elevated 24-hour systolic blood pressure by 9 mm Hg among patients with hypertension (14). These studies support the effectiveness of salt restriction in the treatment of hypertension. The World Health Organization has estimated that reducing dietary sodium intake by 50 mmol (2.9 g salt) per day would lead to a 22% reduction in the number of deaths from stroke and a 16% reduction in deaths from coronary heart disease (15).

To estimate changes in blood pressure in this study, we performed subanalyses to examine linear changes in systolic blood pressure or diastolic blood pressure for 8 years by age group. In both men and women, the slope of systolic or diastolic blood pressure per study wave did not significantly decline in any age group (data not shown). In addition, the association between blood pressure and salt intake for 8 years, analyzed by the mixed effect model, was not statistically significant in any age group. Excessive salt intake is a known risk factor for hypertension, although several other risk factors, including age, body weight, and alcohol consumption, are also risk factors for hypertension (16). In this study, absolute salt intake declined in all age groups; however, the amount of salt reduction in this study might be too small to change blood

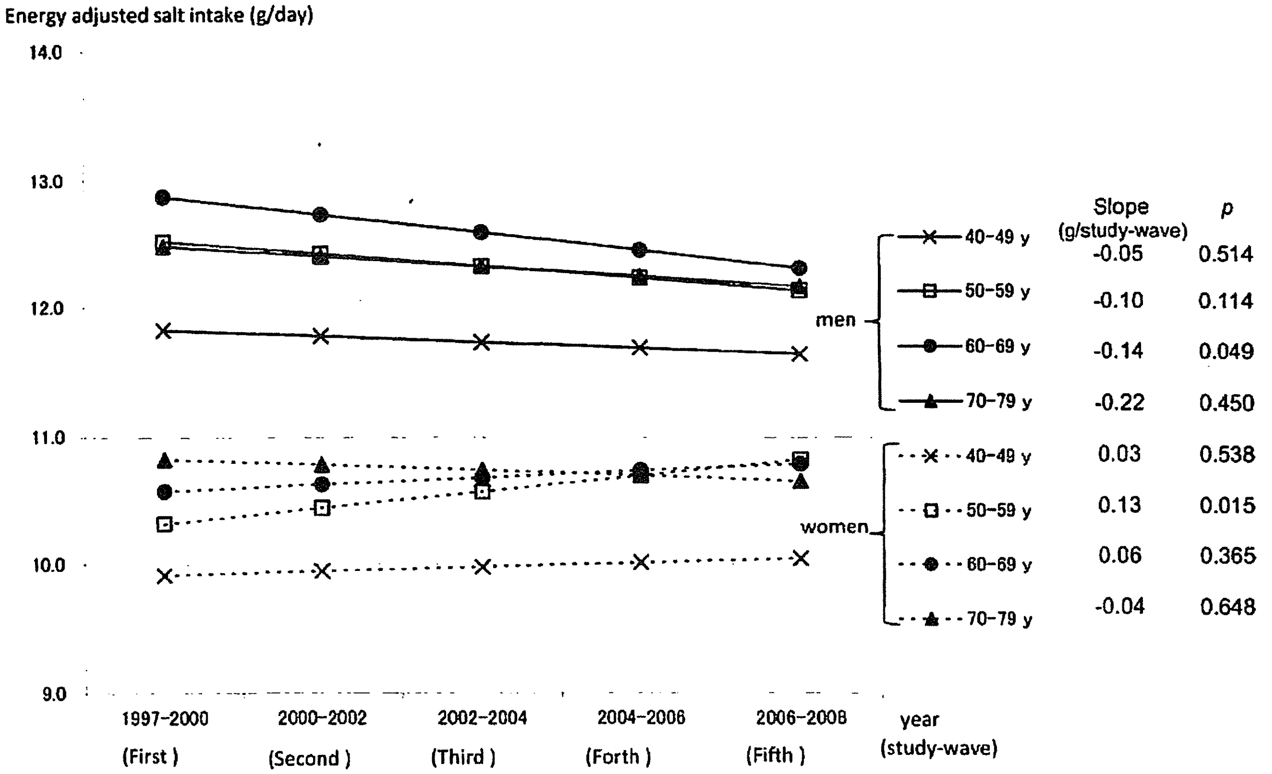

Figure. Estimated linear changes in energy adjusted for salt intake for 8 years[a] by age groups in the Japanese Longitudinal Study of Aging. [a]Eight years was the entire follow-up period in individuals from first to fifth study waves.

pressure. In addition, blood pressure may have been affected by the other above-mentioned risk factors.

Several factors are thought to contribute to the decline of salt intake seen in this study. First, obesity has gradually increased among Japanese men and middle-aged women; in parallel, metabolic syndrome, especially in men, has become a public health issue (17). The Japanese government developed a standard program to reduce visceral obesity that included weight control with restriction of total amounts of food intake (18). The decline of salt intake is mainly achieved by a decline in the quantity of food in the whole diet. Furthermore, Dietary Reference Intakes for Japanese and Healthy Japan 21 proposed by the Japan Ministry of Health, Labor, and Welfare recommend restricting dietary salt intake to <10 g/day for men and <8 g/day for women to achieve antihypertensive effects (19,20). Data on the importance of salt restriction are spread by public health practices and health education, and may have contributed to the decrease in salt intake over time seen in this study. In terms of salt consumption, "Food for special dietary uses" designated by the Japan Ministry of Health, Labor, and Welfare, is becoming more popular in Japan. New low-salt products such as low-salt soy sauce and low-salt *miso* have become available. These new products are essential, as soy sauce and *miso* are staple seasonings in Japanese cuisine. In the International Collaborative Study of Macronutrients, Micronutrients and Blood Pressure study (1), it was reported that sodium intake among Japanese mainly came from soy sauce, commercially processed fish/seafood, salted soups, and preserved vegetables (1). In addition, salt was usually added during home cooking and at the table. In our study, salt intake was assessed by a 3-day diet record. Trained registered dietitians estimated the weight of salt within the dish from diet records and photographs. All food sources, including commercial foods in the diet records, were coded. Thus, we could not examine changes in salt from food sources for methodologic reasons. In addition, Westernization of the Japanese diet during the past five decades might have led to reduced salt intake—the Japanese diet has dramatically changed from a traditional Japanese diet containing high-salt baked fish, *miso* soup, and Japanese pickles to a Westernized diet that contains less salt (21).

Mean energy intake from the first to fifth study waves was decreased in all age groups in both men and women, indicating that the total amount of food intake decreased with age. To eliminate the effects of total amount of food intake on salt intake, adjustment for energy intake was performed. Results showed that the trend of energy-adjusted salt intake declined only among male participants aged 60 to 69 years. This means that a tendency to decrease salt intake was strong in this generation. The reason for this finding may be that the prevalence of circulatory disease, as represented by hypertension, is high among Japanese men aged 60 to 69 years (22). Thus, these participants might make a conscious effort to restrict salt intake.

On the other hand, among women aged 50 to 59 years, the trend of energy-adjusted salt intake increased. This may imply that women aged 50 to 59 years prefer a saltier diet. Losses in both taste and smell occur during the normal aging process and with various diseases (23,24). In particular, the ability to recognize salty and bitter tastes is reported to decline with age, whereas the perception of sweet and sour tastes does not typically decline (25). Elderly male and female subjects have been shown to prefer higher concentrations of salt in cross-sectional studies (26-28). Higher salt intake among women aged 50 to 59 years might be caused by a decline in the perception of the taste of salt as well as an increased preference for salt (26,29-31). Considering that the mean age of menopause among Japanese women is 50.5 years (32), and the association between salty taste preferences and hypertension becomes stronger in women aged 50 years and older (33), it is possible that advising women older than age 50 years to reduce salt consumption might be an effective public health initiative.

Absolute salt intake was decreased among all age groups from the 40s to 70s in men and among 70- to 79-year-old women, but it did not reach the recommended dietary salt intake of <10 g/day for men and <8 g/day for women (19,20). The Dietary Reference Intakes for Japanese in 2010 (34) suggested greater restrictions in the upper recommended limit of salt intake—that is, 9 g/day for men and 7.5 g/day for women. Salt intake is still high in Japan, and promotion of salt restriction is important. Nutrition habits formed during childhood are difficult to change among elderly people, who prefer to stick to old customs (35). For example, strict restriction of salt intake from about 13 g/day (the mean salt intake in Japan) down to 6 g/day was thought to cause loss of appetite and decrease quality of life in elderly people (3). Therefore, it has been recommended that salt intake be initially restricted to below 10 g/day, and then slowly decreased thereafter (3). To prevent higher salt intake by elderly people, it may be useful to encourage a taste for less salt in childhood so that better dietary habits can be more easily carried over into adulthood.

Our study had several limitations. Eight years was too short a period to investigate trends in salt intake. However, because data from this study are drawn from NILS-LSA, a population-based prospective cohort study, future analyses will be able to examine ongoing trends in salt intake. In addition, adjustment for a wide range of potential confounding variables, including a history of hypertension, medications, or dietary interventions, was not performed. Because seniors are thought to have a higher incidence of these factors than younger participants, this lack of adjustment could have affected our results. In a subanalysis, we estimated linear changes in salt intake by age group after adjusting for a history of hypertension at first participation, and findings in this study did not change (data not shown). Drewnowski and colleagues (36) reported that factors other than salt preferences, including concerns about nutrition and health, might influence dietary salt consumption. Further analyses are needed to adjust for potential confounding variables that may affect salt intake.

One strength of our study was that it assessed trends of salt intake in the same population stratified by age groups. To the best of our knowledge, there are no longitudinal data that assess salt intake. Furthermore, our data have the advantage of investigating mean daily salt consumption using a 3-day diet record with photographs. The dietary study protocol has not changed from the baseline study, and most of the trained registered dietitians remained on board. The degree of agreement in dietary coding of salt intake between dietitians was high (data not shown), and the registered dietitians meet twice a month to adjust for differences of dietary coding based on a 3-day dietary record from the baseline survey. In addition, the average salt or dietary intake in the present study was similar to that given in Japanese participants aged 40 to 59 years in the International Collaborative Study of Macronutrients, Micronutrients and Blood Pressure (1) or the National Nutrition Survey in Japan (7). Therefore, our results may be more applicable in community-dwelling middle-aged and elderly subjects.

Another strength is that salt intake was analyzed by age group. Food consumption and nutrient intake among Japanese have changed during the past 5 decades. For example, Westernization of the Japanese diet has led to decreased consumption of carbohydrates and increased consumption of fat and meat (7,8). In addition, age differences in diet have been reported (9,10), with fat density (per 1,000 kcal energy intake) among older age groups showing a declining trend (10). In fact, food consumption was different among age cohorts in our subjects. Among both men and women, older age groups tended to eat more vegetables, fruits, dairy products, and fish, and less meats and fats compared with younger age groups (data not shown). Salt intake at each study wave was higher among those aged 50 to 59 years and 60 to 69 years than those aged 40 to 49 years and 70 to 79 years. Because dietary content differs between generations, it is essential to examine data separated by age groups to understand trends in salt intake among Japanese subjects.

CONCLUSIONS

Eight-year longitudinal data showed that the trend of absolute salt intake declined among all age groups from the 40s to 70s in men and among those aged 70 to 79 years in women. However, the increased focus on reducing energy intake has resulted in only a modest decrease in salt intake. Although we observed a decline, salt intake still exceeded recommended levels. Efforts that focus on salt reduction are needed to address this important public health problem.

STATEMENT OF POTENTIAL CONFLICT OF INTEREST: No potential conflict of interest was reported by the authors.

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ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Spatiotemporal components of the 3-D gait analysis of community-dwelling middle-aged and elderly Japanese: Age- and sex-related differences

Wataru Doyo,[1] Rumi Kozakai,[1] Heung-Youl Kim,[1] Fujiko Ando[1,2] and Hiroshi Shimokata[1]

[1]*Department of Epidemiology, National Institute for Longevity Sciences, National Center for Geriatrics and Gerontology, Obu, and* [2]*Department of Health Science, Faculty of Medical Welfare, Aichi Shukutoku University, Nagoya, Aichi, Japan*

Aim: To describe age- and sex-related differences in gait patterns of community-living men and women using 3-D gait analysis.

Methods: Subjects ($n = 2006$) aged 40–84 years participated in the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA). Spatiotemporal components, including velocity, step length, step frequency, and double support time during a gait cycle, were calculated from 3-D coordinates and vertical force data. Velocity, step length and step frequency were normalized by leg length and acceleration due to gravity, and double support time was normalized to gait cycle duration.

Results: Spatiotemporal walking variables of brisk velocity and step length were significantly greater in men than in women, while comfortable velocity and comfortable and brisk step frequencies and double support times were greater in women than in men. Age-related changes were marked at 70–84 years in most spatiotemporal variables in both sexes during comfortable walking. During brisk walking, age-related changes were observed from a younger age than during comfortable walking, and there were sex-related differences.

Conclusion: The age-related gait alteration was obvious among those aged 70 years and older, and it accelerated markedly in women's brisk walking intensity. **Geriatr Gerontol Int 2011; 11: 39–49.**

Keywords: aging, gait, sex, velocity, walking.

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Correspondence: Mr Wataru Doyo MA, Department of Epidemiology, National Institute for Longevity Sciences, National Center for Geriatrics and Gerontology, 36-3 Gengo, Morioka-machi, Obu, Aichi 474-8522, Japan. Email: doyo@toyota-ti.ac.jp

Author contributions: W. D. designed the study, obtained the funding, analyzed data and drafted the original article; R. K. interpreted data and advised on revising the article; K. H. Y. supervised data processing and prepared the article; and F. A. and H. S. originated the study, created the gait analysis program, supervised all aspects of its implementations, and contributed to obtaining the funding and revising the article. All authors conducted epidemiological studies on geriatric disease and human aging in Obu, Aichi, Japan, and read and approved the manuscript.

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Introduction

Age-related impairment of ambulatory ability is a critical component for inhibiting activities of daily living (ADL). For instance, decreased gait velocity observed in elderly is an indicator of common distinct diseases[1,2] and falls,[3–6] which lead to functional dependence[7–11] or death.[12] The prevalence and incidence of gait disorders increase with age in elderly persons.[13,14] The early presence of dynamic postural stability may provide more essential information for preserving adequate mobility, delaying the onset of functional decline and encouraging early appropriate lifestyle changes to promote active healthy aging.[6,8,10,11,15]

Previous studies examined age-related changes in spatiotemporal gait parameters including velocity, step length, step frequency (cadence) and selected stride time variables (single and double support time and swing time).[7,8,10,16–21] These performance-based gait variables were often measured by a 3-D gait system that computes the motions of the body center of mass (COM) and each segment, which can accurately evaluate the control of dynamic balance during walking.[22,23] The COM velocity on the 3-D gait system identified the effect of age on older gait in limited comparison between young and older groups.[24–26] It showed that the 3-D analyses conducted have not determined from which age group the accelerated decline of gait started. The collection of data using a large sample size with a broad age range could resolve the issue.

Age-related gait studies have recruited either men or women, or both sexes have been analyzed together: a few studies previously focused on sex-related changes on gait pattern with advancing age. Callisaya *et al.*[8] revealed the effects of sex and age on gait velocity in elderly men and women aged 60–86 years. The results of other studies of various age ranges and groups[17,19,27] to determine which sex shows an earlier age of accelerated gait velocity decrease have differed. The conflicts may partly depend on the sampling and subject characteristics.

Therefore, to understand the aging process in gait measures across the adult lifespan, a large sample size ranging from young or middle-aged to elderly men and women should be warranted. We decided to reinvestigate the previous findings. In the present study, the gait of elderly subjects was investigated based on comfortable and brisk spatiotemporal gait parameters with a 3-D gait analysis system; a large number of subjects were recruited. We found the age-related changes in gait by sex among middle-aged and elderly men and women in Japan. This may contribute to a beneficial effect on assessing gait in elderly people and making an adequate walking exercise program suitable for targeted age groups.

Methods

Study sampling

The present gait analysis is part of the third phase of the National Institute for Longevity Sciences Longitudinal Study of Aging (NILS-LSA); this study includes medical, physiological, nutritional and psychological examinations. The study began in November 1997 (the first phase), and the third phase lasted from May 2002 to May 2004. The subjects were age- and sex-stratified random samples of the population, aged 40–84 years, who lived in Obu-shi and Higashiura-cho, Aichi, Japan. These participants were chosen from the residents registered with local governments. All subjects lived or had lived at their home in the community and had Japanese nationality.[28] The NILS-LSA was approved by the Ethics Committee of the National Center for Geriatrics and Gerontology. Details of the NILS-LSA have been previously published.[28,29]

Of 2378 men and women aged 40–84 years in the third phase examination, 1017 men and 989 women (84.2% of all participants, Table 1) completed the walking tests and were included in the present analysis. The participants also completed a structured questionnaire dealing with their socioeconomic characteristics, cardiovascular risk factors and medical history.[28,29] Exclusion criteria included a current medical history of arthritis[6,8] and fractures (musculoskeletal disorders),[30] stroke[1] and Parkinson's disease (neurological disorders),[8,31] and ischemic heart disease and chronic bronchitis (Table 1).[32,33] These diseases were checked and excluded as the possible cause of gait disorders or spatiotemporal gait parameter changes by a physician before the walking tests. One participant who was diagnosed with dementia was excluded because she had a limited ability to comprehend or execute the test, which was judged by a physician. The existence of walking difficulty in activities of daily living (ADL)[11,15] was also excluded (Table 1). The participants who met the above-mentioned requirements and could walk 10 m independently without a walking aid were included in the current gait analysis and therefore 372 participants of the third phase examination were totally excluded.

Protocol

All participants wore short-sleeved T-shirts and shorts for testing. Shoes were made from the same material that had a vinylon/polyester and cotton blended upper part and a urethane foam outsole (Moonstar, Fukuoka, Japan), and were selected to exactly fit each participant's feet. Ten 2.5-cm diameter optical markers were placed on the participants' left and right sides on the fifth metatarsal heads, the lateral malleoli, the lateral epicondyles, and one-third of the way along the straight lines from the greater trochanters to the anterior

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Table 1 Inclusion/exclusion characteristics of 2378 participants in the third wave examination of the National Institute for Longevity Sciences-Longitudinal Study of Aging (NILS-LSA), 2002–2004

Characteristics	Men	Women
Inclusion (n = 2006)		
Total (n (%))	1017 (50.7)	989 (49.3)
Age group (n (%))†		
40s	250 (12.5)	279 (13.9)
50s	302 (15.1)	265 (13.2)
60s	250 (12.5)	242 (12.1)
≥70	215 (10.7)	203 (10.1)
Exclusion (n = 372)		
Total (n (%))	187 (50.3)	185 (49.7)
Prevalence of disease (n (%))		
Stroke	42 (22.5)	23 (12.4)
Ischemic heart disease	41 (21.9)	41 (22.2)
Chronic bronchitis	7 (3.7)	3 (1.6)
Arthritis	26 (13.9)	56 (30.3)
Fracture	5 (2.7)	6 (3.2)
Dementia	–	1 (0.5)
Parkinson's disease	3 (1.6)	–
Walking difficulties in ADL (n (%))	50 (26.7)	54 (29.2)
Not completed walking test (n (%))	55 (29.4)	53 (28.6)

†χ^2-Test test examines significance among each age group and sex. Values are numbers (% of total at each inclusion/exclusion category) of samples. ADL, activities of daily living.

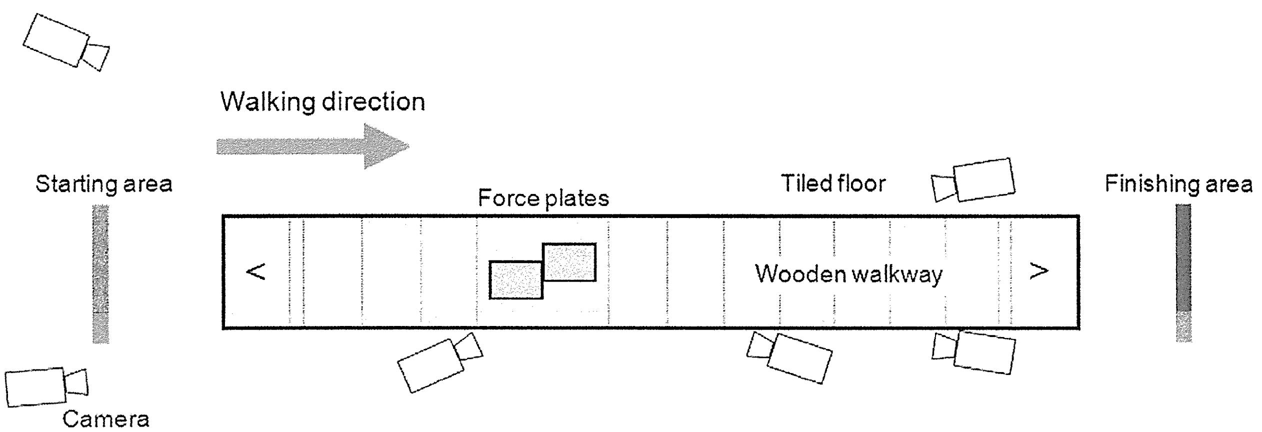

Figure 1 Setup of 3-D gait system: the 10-m walkway consisted of a wooden walkway. Six cameras were placed at various positions and two force platforms were embedded in the center of the walkway. Double support time in pre-swing phase of right foot was measured in this setting.

superior iliac spines and the acromions.[34] The subjects walked on a 10-m walkway at two speeds: (i) at a self-selected pace (comfortable walking); and (ii) as fast as possible without running (brisk walking). Each pace was repeated approximately twice on average. The walkway consisted of a tiled floor and a wooden walkway along the corridor (Fig. 1). The surface of the wooden walkway was covered with gray-colored, thin, stiff rubber, which measured 0.036 m in height from the tile floor surface of the corridor. Force platforms (0.6 m × 0.4 m) (9286; Kistler Instrumente AG, Winterthur, Switzerland), with surface colors similar to those of the walkways, were embedded in the center of the wooden walkway. The starting point for each trial was

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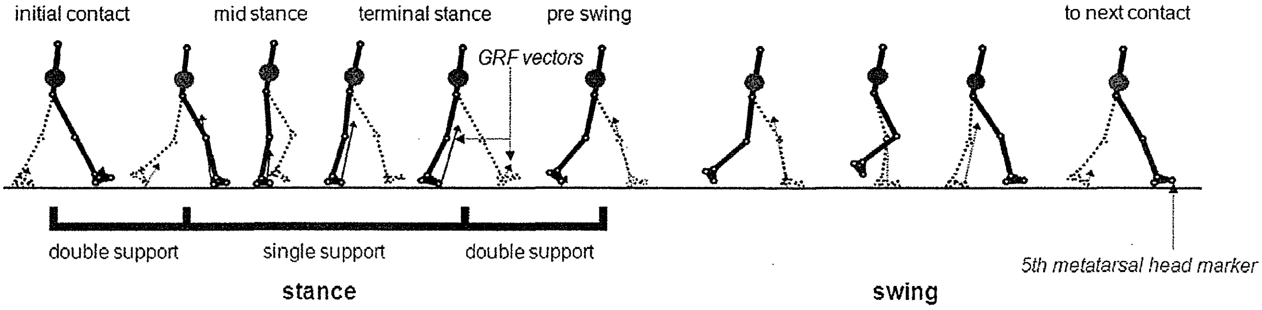

Figure 2 Definition of gait cycle using ground reaction force (GRF) and the fifth metatarsal head marker.

selected in relation to the foot contacts on the force platforms. The distance from each starting and departure point to the force platforms was approximately 3.5–4.5 m. One trial each of comfortable and brisk walking was used in the data analysis. The trials used were those that lacked the least data.

The Vicon 370 system (Oxford Metrics Ltd, Oxford, UK), which consisted of six cameras, was used to obtain the 3-D coordinates of the trunk, thighs, shins and feet. The calibration residual at each camera was set below 1.0 mm. The data were processed using a custom routine that was programmed by the Clinical Gait Analysis Forum of Japan.[34] The raw coordinate data at 60 Hz were digitally filtered with a fourth-order, zero-lag, Butterworth filter[22] with a cut-off at 5 Hz, and the raw ground reaction force data at 1200 Hz were digitally filtered with a cut-off at 10 Hz. The force data were interpolated to correspond with the coordinate data to synchronize the datasets. Smoothed coordinates of the lower extremities were used to construct a rigid link-segment model.[22] Segment masses and inertial properties were determined using previously reports[35] and the participants' mass and height, which were used for calculating COM.

Gait cycle and walking variable calculation

SAS ver. 9.1.3.[36] was used to automatically identify gait event times and each phase of the gait cycle based on kinematic and kinetic gait data. The divisions of the gait cycle are shown in Figure 2.[30] The gait event times for initial contacts and toe off were determined using vertical force data and the vertical motion of the optical marker on the fifth metatarsal head. The period from the first right initial contact to ipsilateral second initial contact was one gait cycle.[30]

Both the right and left leg motions were captured, and primarily the right stride was analyzed. Left leg motion was used for calculating the step length and double support times. The mean COM velocities, step lengths, step frequencies and double support times during a gait cycle were also automatically computed by SAS. The double support time was defined as the duration of time during which each foot was on the ground in the pre-swing phase. The mean COM velocity, step length, and step frequency were normalized as proposed by Hof[37] as follows:

Normalized COM velocity, $\hat{v} = \frac{v}{\sqrt{g l_0}}$,

Normalized step length, $\hat{l} = \frac{l}{l_0}$,

Normalized step frequency, $\hat{f} = \frac{f}{\sqrt{g/l_0}}$,

where v is actual mean COM velocity, l_0 is the leg length of each subject, l is the actual step length, f is the actual step frequency and g is the acceleration due to gravity (9.81 m/s^2). Leg length was measured from the ground to the greater trochanter during quiet standing. Patients with arthritis and fracture were excluded (Table 1), and no case of limited knee extension was observed in the present study. The double support time was also normalized by each subject's cycle duration, from right initial contact to next right initial contact (over one gait cycle).

For the calculation of walking variables, technical difficulties sometimes caused missing data due to the effect of occlusion while capturing motion. Thus, for example, the mean COM velocity over the gait cycle was calculated using data from 1716 men and women (85.5% of the total sample) during comfortable walking and using data from 1614 men and women during brisk walking (80.4%). To demonstrate the lack (or presence) of bias with respect to velocity data loss, the Student's t-test was used to compare the velocity between the group with all available data and that with data available only in the velocity category. The results showed that the velocities were not significantly different between the two groups, and this was confirmed for all walking variables.

Statistical analyses

All analyses were performed using SAS ver. 9.1.3. Sex differences were examined using the Student's t-test. For analysis of age differences, participants were divided

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into eight groups based on sex and age (40–49, 50–59, 60–69 and 70–84 years for each sex). Trends in differences across all age groups in the walking variables were tested using the General Linear Model (GLM), and differences by age group were tested using the Tukey–Kramer method for each sex. $P < 0.05$ was considered statistically significant.

Results

The proportion of the sample drawn from each age group and each sex group was the same (χ^2-test, $P > 0.05$). The mean ± standard deviation age was 58.1 ± 11.4 years in men and 58.7 ± 11.4 years in women, which was not significant ($P > 0.05$).

The results of the GLM and Tukey–Kramer tests revealed age-related changes in each age and sex group. Descriptive statistics for all values are shown in Tables 2 and 3 and Figure 3. Mean COM velocities during comfortable and brisk walking significantly decreased with age in both sexes ($P < 0.001$). Age-related changes in the comfortable COM velocity were marked in the 70–84-year group compared with other age groups. Similar changes were found in the brisk COM velocity. The step lengths and frequencies followed these COM velocity patterns in both sexes during both comfortable and brisk walking.

These age-related changes occurred earlier in the middle-aged group. Earlier patterns involving brisk gait parameters were more apparent in women: for example, the brisk COM velocity decreased at 60–69 years in men and at 50–59 years in women, then the decrease accelerated at 70–84 years (Tables 2,3, Fig. 3). The step length and frequency followed these COM velocity patterns. The double support time during pre-swing was significantly increased with age only at the women's comfortable walking pace; it was significantly longer in the 70–84-year group compared to other age groups (Table 3, Fig. 3). The men's double support times showed no significant age-related differences among age groups (P for trend >0.05, Fig. 3).

Descriptive statistics and the results of sex differences for gait parameters are depicted in Table 4. The results of mean COM velocity differed according to walking pace: the comfortable COM velocity was significantly faster in women than in men ($P < 0.001$), and the brisk COM velocity was significantly faster in men than in women. Step length pattern was similar to COM velocity pattern: the brisk step length was longer in men than in women ($P < 0.001$), but the comfortable step length was not significantly different. On the other hand, women had a higher step frequency during both walking paces ($P < 0.001$). The results of the pre-swing double support time were equal to the step frequency.

Discussion

Mobility is essential for independence in the elderly. A better understanding of age-related changes in gait provides useful information for appropriate intervention programs targeting specific age groups.[8] The present cross-sectional, descriptive study showed spatiotemporal components of gait over one gait cycle among community-living middle-aged and elderly Japanese subjects. The sample of 1017 men and 989 women was large enough to allow analysis by age group,[17] and, to the best of our knowledge, the sample size is the largest to be published in which gait characteristics have been analyzed using a 3-D gait system. There was no disproportionate lack of gait data caused by difficulties in capturing the 3-D coordinates.

Mean COM velocities decreased with age, which is in almost complete agreement with previous results, despite the use of different measurement equipment and instrumentation.[16–21,25,29] The age-related decreases in the normalized COM velocities accelerated at 70 years and over were noted at a relatively later age compared with the previous reports: they showed the accelerated decline occurred in 50–59- and 60–69-year age groups,[17] at 62 years,[19] between 60- and 70-year age groups,[20] and at 65 years and in the 67–73-year age group.[18] The differences in age of accelerated decline among the previous and the present findings were likely due to the differences in method and data characteristics.

The brisk COM velocity decreases advancing with age were earlier compared with the comfortable walking. Some previous studies showed the age-related decrease was independent of walking pace,[18–20] while another reported that the decrease depended on the pace.[7] In a report by Bohannon on the comfortable and maximum walking speeds of adults aged 20–79 years,[7] walking speed was found to be influenced by the interaction of pace and age. This result matched our present findings that the age-related decrease was clearer during brisk walking than during comfortable walking. Moreover, these earlier age-related declines in the brisk COM velocities were apparent in women. Some studies reported that the critical age for marked velocity decrease did not differ by sex,[16,19] while another found the critical age to be earlier in men.[17] However, Callisaya *et al.*[8] showed women's walking velocity to be an earlier age-related change compared to men's parameters during the preferred speed of walking among the subjects aged 60 years and older. These results are in agreement with our own, though our data was particularly strong in the brisk parameters across middle-aged and elderly persons. The brisk walking task required greater forward momentum and increased demands in muscle activity[24,38–40] and aerobic capacity[33,41] might alter the spatiotemporal gait parameters accompanying aging.

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Table 2 Men's normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking in each age group

Men: walking parameters	Mean COM velocity				Step length				Step frequency				Double support times (pre-swing)			
by age group	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI
Comfortable walking																
40s	211	0.524	0.053	0.517–0.531	240	0.892	0.065	0.884–0.900	207	0.587	0.043	0.582–0.593	208	14.8	1.5	14.6–15.0
50s	266	0.527	0.059	0.520–0.534	289	0.897	0.076	0.888–0.906	259	0.590	0.042	0.585–0.595	249	14.8	1.5	14.6–14.9
60s	218	0.523	0.067	0.514–0.532	240	0.901	0.089	0.890–0.913	215	0.583	0.046	0.577–0.589	205	14.5	1.6	14.3–14.7
70–	186	0.485	0.070	0.475–0.495	213	0.859	0.096	0.846–0.872	185	0.569	0.047	0.562–0.576	177	15.2	2.0	14.9–15.5
P for trend†	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s, 50s, 60s >70–				40s, 50s, 60s >70–				40s, 50s, 60s >70–				NA			
Brisk walking																
40s	190	0.705	0.078	0.694–0.716	229	0.998	0.074	0.989–1.008	180	0.707	0.070	0.696–0.717	173	13.3	6.0	12.4–14.2
50s	235	0.699	0.082	0.688–0.709	272	0.998	0.088	0.987–1.008	214	0.697	0.064	0.688–0.705	209	13.3	5.6	12.6–14.1
60s	191	0.678	0.079	0.667–0.690	237	1.000	0.094	0.988–1.012	185	0.685	0.066	0.676–0.695	180	13.4	5.0	12.6–14.1
70–	182	0.618	0.092	0.605–0.631	203	0.946	0.100	0.932–0.960	177	0.657	0.066	0.647–0.667	169	14.1	2.1	13.8–14.4
P for trend†	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s > 60s > 70–., 50s > 70–				40s, 50s, 60s >70–				40s > 60s > 70–., 50s > 70–				NA			

†Trend tests examine main effects of age in each gait parameter. ‡Tukey–Kramer tests examine the significant difference among each age group. '>' indicates the significant difference between the age groups, with *P*-value is less than 0.5. Values are numbers of samples (N), means (Mean), standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. Age group: 40s, 40–49 years age group; 50s, 50–59 years age group; 60s, 60–69 years age group; 70–, 70–84 years age group. COM, center of mass; NS, not significant; NA, not applicable.

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Table 3 Women's normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking in each age group

Women: walking parameters by age group	Mean COM velocity				Step length				Step frequency				Double support times (pre-swing)			
	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI	N	Mean	SD	95% CI
Comfortable walking																
40s	228	0.542	0.060	0.535–0.550	267	0.905	0.072	0.896–0.913	223	0.602	0.044	0.596–0.608	212	14.9	1.7	14.7–15.2
50s	224	0.547	0.066	0.538–0.556	252	0.902	0.082	0.891–0.912	219	0.607	0.051	0.600–0.614	214	14.9	1.7	14.7–15.1
60s	210	0.536	0.064	0.527–0.544	236	0.890	0.079	0.880–0.900	207	0.602	0.045	0.596–0.608	189	15.0	1.9	14.8–15.3
70–	173	0.472	0.071	0.461–0.483	189	0.833	0.093	0.820–0.847	169	0.570	0.051	0.562–0.578	148	15.8	1.9	15.5–16.1
P for trend†	<0.001				<0.001				<0.001				<0.001			
(Tukey–Kramer test)‡	40s, 50s, 60s >70–				40s, 50s, 60s >70–				40s, 50s, 60s >70–				70– > 60s, 50s, 40s			
Brisk walking																
40s	216	0.702	0.072	0.692–0.711	269	0.972	0.070	0.963–0.980	210	0.728	0.071	0.719–0.738	201	13.9	1.6	13.7–14.2
50s	215	0.675	0.080	0.665–0.686	252	0.960	0.087	0.950–0.971	212	0.706	0.073	0.696–0.715	209	14.2	1.7	13.9–14.4
60s	212	0.653	0.072	0.643–0.662	230	0.941	0.085	0.929–0.952	209	0.696	0.072	0.687–0.706	199	14.2	1.8	14.0–14.5
70–	173	0.577	0.084	0.565–0.590	187	0.890	0.109	0.875–0.906	163	0.651	0.064	0.562–0.578	157	14.3	8.8	12.9–15.7
P for trend†	<0.001				<0.001				<0.001				NS			
(Tukey–Kramer test)‡	40s > 50s > 60s > 70–				40s > 60s > 70–., 50s > 70–				40s > 50s, 60s > 70–				NA			

†Trend tests examine main effects of age in each gait parameter. ‡Tukey–Kramer tests examine the significant difference among each age group. '>' indicates the significant difference between the age groups, with $P < 0.05$. Values are numbers of samples (N), means, standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. Age group: 40s, 40–49 years age group; 50s, 50–59 years age group; 60s, 60–69 years age group; 70–, 70–84 years age group. COM, center of mass; NS, not significant; NA, not applicable.

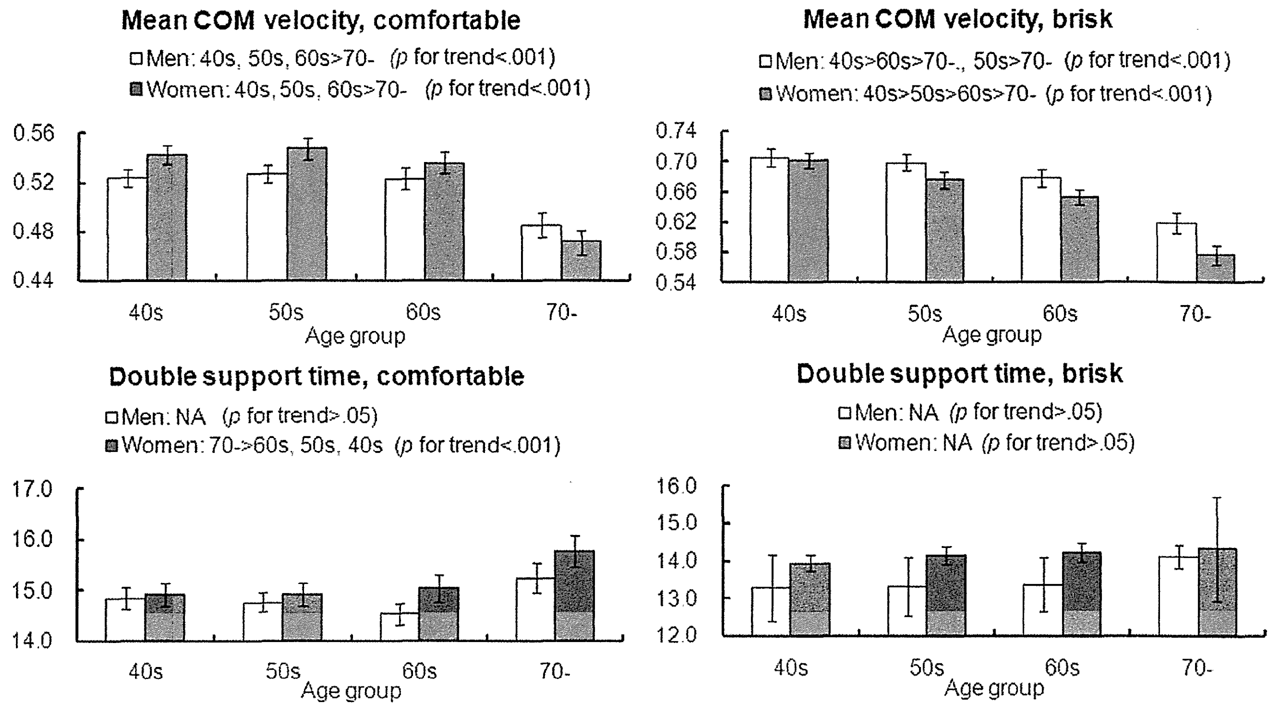

Figure 3 Age-related differences (trend tests and Tukey–Kramer tests); means and 95% confidence intervals of normalized mean center of mass (COM) velocities ($(\text{m/sec})/\sqrt{((\text{m/sec}^2)\times \text{m})}$) and double support times (s/s) during comfortable and brisk walking in men and women. Significant differences by age group in men and women are noted on the upper side of each figure. '>' indicates the significant difference between the age groups, with *P*-values of ≤0.05.

Table 4 Normalized mean COM velocities, step lengths and frequencies and double support times during comfortable and brisk walking among men and women

Walking parameters	Men N	Mean	SD	95% CI	Women N	Mean	SD	95% CI	*P*-value†
Comfortable walking									
Mean COM velocity	881	0.516	0.064	0.512–0.521	835	0.527	0.071	0.523–0.532	<0.001
Step length	982	0.889	0.083	0.883–0.894	944	0.886	0.085	0.881–0.891	NS
Step frequency	866	0.583	0.069	0.580–0.586	818	0.597	0.045	0.593–0.600	<0.001
Double support time (pre-swing)	839	14.8	1.7	14.7–14.9	763	15.1	1.8	15.0–15.2	<0.001
Brisk walking									
Mean COM velocity	798	0.677	0.089	0.671–0.683	816	0.656	0.089	0.650–0.662	<0.001
Step length	941	0.987	0.092	0.981–0.993	938	0.945	0.092	0.939–0.951	<0.001
Step frequency	756	0.687	0.075	0.682–0.692	794	0.698	0.049	0.693–0.703	<0.001
Double support time (pre-swing)	731	13.5	5.0	13.2–13.9	766	14.2	4.3	13.9–14.5	<0.01

†Student *t*-tests examine the sex differences. Values are numbers of samples (N), means, standard deviations (SD) and 95% confidence intervals (95% CI) at each variable. COM, center of mass; NS, not significant.

Further investigation should have discussed the difference between comfortable and brisk walking parameters.[38,42,43]

Age-related step length decreases during comfortable and brisk walking were almost concomitant with the COM velocity decreases, which was similar to the previous findings.[16,20] In brisk walking, however, age-related reduction in the step length seemed to be smaller than that in the step frequency compared with comfortable walking. For example, women's brisk step length decrease was 8.4% across middle-aged and elderly groups compared with their step frequency decrease of 10.7% (Table 3). This was observed also in men's. This may suggest that ambulatory ability observed in the COM velocity may be caused more by the step length during comfortable walking and the step frequency

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during brisk walking in the elderly. This was also apparent in middle-aged women. The interpretation was limited qualitatively and should be further explored.

Step frequencies also decreased with age and this decrease was found even in middle-aged women during brisk walking. Previous studies in step frequency reported no age-related changes,[16,17,21] age-related decrease[8,18–20,25] and age-related increase.[26] Moreover, the current age- and sex-related decrease depending on required walking pace was not previously reported.[16,17] One explanation of these conflicts was that degree of the age-related reduction in step frequency was relatively less than that in other gait parameters such as velocity or step length.[8,17,19,20] Therefore, sample size, subject characteristics and measuring instruments may affect the age-related decrease in the step frequency.[16,25] Double support times in the present study did not increase with age, with the exception of women's comfortable data. On the other hand, exploratory analyses of actual values of double support times showed age-related increases in both sexes during both walking paces (data not shown, P for trend <0.001, <0.022). This shows that the double support as a percentage of one gait cycle remained almost constant in middle-aged and elderly subjects. Ferrandez *et al.*[32] found that double support time increased as velocity decreased, and that prolonged double support time was affected more by walking velocity than age.

The present study found brisk COM velocity and step length to be greater in men than in women. By contrast, step frequencies and double support times were greater in women than in men. This is characteristic of sex differences and is supported by previous findings.[8,17,21] Although the comfortable COM velocity was faster in women than in men, this is believed to be a result of the difference in body size as the actual comfortable COM velocity was significantly faster in men than in women (men, 1.46 ± 0.18 m/s; women, 1.43 ± 0.20 m/s; $P < 0.001$). The comfortable step length did not differ significantly between either sex group, perhaps because of the slower men's COM velocity.

The present gait data may give some insight into gait assessment and preventive walking exercise programs for older persons as previously reported.[42,44,45] The values for the gait parameters during one gait cycle may be useful to clinicians judging the ambulatory ability of patients from a short indoor walk.[7,42] Patients whose gait parameters are lower than that of their appropriate age group are at increased risk of ADL difficulties.[8,11] Comfortable and brisk walking velocities are predictive of adverse outcomes such as loss of physical function, requirement of caregivers, hospitalization and increased mortality in elderly persons.[8,10–12] Decreased step length and prolonged double support time are correlated with fear of falling and/or future fall risk.[4,5,9] Also, the other gait parameters such as gait velocity,[9,11] stride-to-stride variability[4] and lateral sway[3,5,6,46] are associated with the falling events. We did not directly ascertain whether the participants had a history of falls and/or a fear of falling in our gait parameters. Further work should confirm which gait measure is the best independent predictor for future fall risk in a large sample.

A moderate workload prescription in walking exercise programs should be given by controlling both step length and step frequency during comfortable walking in the elderly. Brisk walking, which is recommended for moderately vigorous endurance training and has a high impact compared to comfortable pace walking, might be considered for middle-aged women and the elderly to improve physical functions such as muscle strength[7,40,43] and/or cardiovascular fitness.[33,41]

This study has some limitations. Some previous gait investigations used the results of several trials or mean values of gait, while we used gait data from one trial of each participant. This was done because of technical difficulties in the automatically computed 3-D gait parameters. Next, the conjunction of our excluding criteria with the potential diseases might overestimate gait disorders: the elderly subjects were more likely to be healthy and physically fit. Moreover, patients with dementia were considered to be less in the present sample. The general comparability of the present gait variables with previously reported data is limited because of the lack of data for young adults in their 20s and 30s. Furthermore, our cross-sectional analysis approach could not demonstrate a cause-and-effect relationship from aging. We are planning longitudinal studies to further determine the effects of aging on gait. The present study included regional limitations such as race, culture, lifestyle, genetics and socioeconomic status which also may be important. However, the findings did permit age- and sex-related differences in gait to be clarified in the elderly.

In conclusion, age- and sex-related gait alterations were apparent in one gait cycle of walking in a large sample of community-dwelling, middle-aged and elderly Japanese men and women, when analyzed by a 3-D gait system. There were marked age-related gait differences in subjects aged 70 years and over compared to subjects aged 40–69 years during comfortable walking, and subtle differences were also observed in subjects aged 40–69 years during brisk walking. The earlier age-related changes were clearer in women than in men. These results may guide the assessment of gait patterns attributed to usual aging and to develop moderate exercise programs for the elderly.

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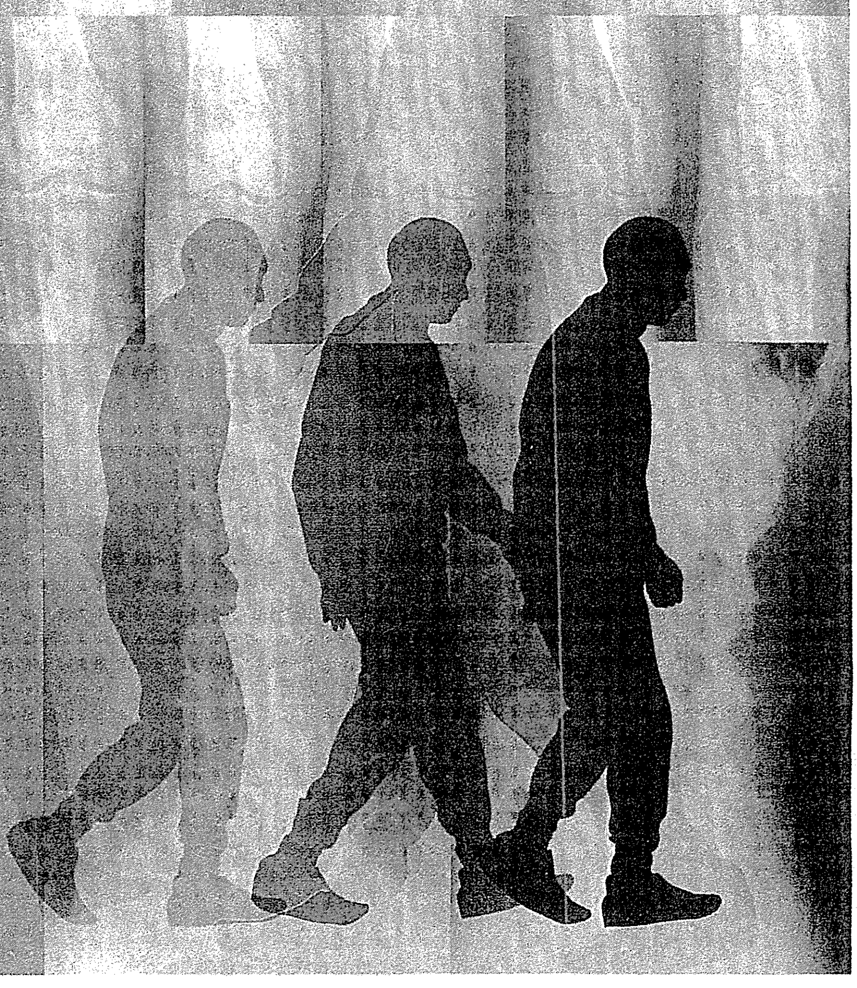

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企画　中村耕三（東京大学大学院医学系研究科感覚運動機能医学<整形外科学>）

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