TITLE PAGE

Title:

Age-related changes in gait speeds and asymmetry during circular gait and straight-line gait in older individuals aged 60 to 79 years

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7. See Appendix

Appendix

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Running Title:

Circular gait in older adults

Abstract

Aim: The present study aimed to investigate the age-related changes in gait speeds and asymmetry during circular and straight-line gaits among older adults aged 60 to 79 years.

Methods: The study included 391 community-dwelling older adults aged over 60 years, who participated in the Nagahama cohort study. They were assigned to four age groups: 60 to 64 years (early 60s), 65 to 69 years (late 60s), 70 to 74 years (early 70s), and 75 to 79 years (late 70s). For the circular gait test, the time required to walk twice around a 1-m diameter circle for right and left rotations were measured. The average time of the two trials was measured as the circular gait time, and the side-to-side difference in the circular gait times was calculated as an asymmetry index. Walking speed, asymmetry of step length, and asymmetry of stance duration time during straight-line gait at comfortable and maximal walking pace were also measured.

Results: Circular gait time in older women in the late 70s group was significantly slower than that in other age groups; however, no age-related change was observed in older men. Maximal gait speeds in the early and late 70s groups were significantly slower than those in the early 60s group.

Conclusions: Age-related decline in circular gait speed was observed in older women aged ≥75 years, but not in older men. Maximal straight-line gait speed decreased significantly in both genders after the age of 70 years.

Keywords

age-related change; asymmetry; circular walking; gait assessment; older adults; walking speed

Introduction

Maintaining or improving the ability to perform activities of daily living is a critically important issue for older individuals. Among the functional restrictions on daily living activities, decline in mobility is one of the major issues in older adults.[1, 2] In particular, a decline in walking ability can lead to a worsening in quality of life in older adults. Although straight-line gait speed is often used to assess walking ability, a mobility assessment including the ability to turn is also important when considering the activities of daily living.[3]

Some previous studies[4-9] have used gait assessment during walking around a circle (the circular gait), as the tool to evaluate mobility including the turning ability. During the circular gait, the outer limb trajectory is longer than the inner limb trajectory.[6] Based on this observation, the circular gait is used as one of the training methods for patients of stroke and Parkinson's disease, by coordinating both legs to improve their gait asymmetry and larger swing in the outer leg.[7, 8] Furthermore, the mobilities of patients with cerebellar ataxia,[6] stroke,[7] and Parkinson's disease[4, 8, 9] have been evaluated using circular gait because the circular gait requires asymmetrical stepping and high postural control. In even healthy older individuals, circular gait speed may decline or asymmetry during circular gait may increase with aging due to asymmetry during quiet standing posture[10] and disorder of postural balance.[11]

Our previous study revealed that circular gait speed in older adults was significantly slower than that in young adults, and the side-to-side difference in the circular gait times between right and left rotations in older adults was greater than that in young adults.[5] However, the sample size in the previous study was small, and the characteristics of gender or age group was not clear. The aging process of motor function among older adults has a difference in motor abilities between individuals in 60s and 70s,[12, 13] and gait speed declines from 60s to 70s.[2] Therefore, it is interesting to investigate age-related changes in circular gait ability among older individuals.

On comparing gender differences in old adults, women have a higher risk of falls[14, 15] and a poor ability to turn suddenly while walking, than men.[16] Additionally, the factors that contributed to walking abilities were different between older men and women.[17] Considering these findings, gait characteristics during circular gait may also differ between older men and women. However, to the best of our knowledge, no study has investigated age-related changes and gender-based differences in circular gait abilities in older individuals. The purpose of the present study was to investigate whether gait speeds and asymmetry during circular gait and straight-line gait change with age from 60 to 79 years in each gender. The hypotheses of the study were as follows: gait speed would decrease and asymmetry would increase with age in straight-line gait as well as in circular gait, and the age-related changes in gait characteristics are greater, especially in older women.

Methods

Participants

We analyzed a part of the second visit dataset of the Nagahama Prospective Cohort for Comprehensive Human Bioscience conducted between 2012 and 2016. The participant recruitment details are listed elsewhere.[18] The residents of Nagahama City, Shiga Prefecture, aged 30–74 years without serious health problems were recruited between 2008 and 2010 with the help of mass media, like the public relations magazines and newspapers of the city. Among 9,850 participants in the second-visit dataset between 2012 and 2016, a total of 2,121 participants voluntarily participated in the physical performance tests, which was an optional examination for community-dwelling older adults aged ≥ 60 years (n = 5,018). Circular gait and straight-line gait measurements were conducted from October 2015 to February 2016 (n = 402). Six participants with missing data and five participants older than 80 years were also excluded because the 80s group had a small sample size. Finally, complete data were available for 391 older adults in this analysis. The participants were classified into four age groups: 60 – 64 years (early 60s), 65 – 69 years (late 60s), 70 – 74 years (early 70s), and 75 – 79 years (late 70s). The flow chart of this study is shown in Figure 1.

The study was approved by the ethical committee of Kyoto University Graduate School and the Faculty of Medicine (G278) and the Nagahama Municipal Review Board, and the study conformed to the principles of the Declaration of Helsinki. Before participating in the study, the participants received a detailed explanation of the protocol and gave written informed consent.

Circular gait assessment

The circular gait test was evaluated as the time taken to walk twice around a 1-m diameter circle line at a comfortable pace using photoelectric tubes (Test Center Timing System, Brower Timing Systems Co., Ltd., UT, USA). The photoelectric tubes were placed at the starting line and were set approximately 40 cm from the floor. The walking time was measured automatically when the participants passed through the photoelectric tubes. Without an auxiliary distance for acceleration, participants were instructed to walk around the circle for two and a half rounds from the starting point. When they passed the second round, the time was recorded.[5] Measurements were conducted twice in each right and left rotation in random order, and the average times of the two trials were calculated for each direction. The average time of the right and left rotations was used as the circular gait time. As for the circular gait asymmetry, the absolute value of the side-to-side difference in gait times was calculated and then divided by the average time of circular gait. [5] The percentage of the value was defined as the circular gait asymmetry.

Straight-line gait assessments

Straight-line gait assessments were performed on a 12 m straight-line walkway at usual and maximal speeds. [17, 19] Participants were instructed to walk along a 12 m walkway, including initial 4 m acceleration and terminal 2 m deceleration paths at a usual speed or with maximal effort. The passing time at 4 m and 10 m from the starting point of the walkway was recorded using photoelectric tubes (Test Center Timing System, Brower Timing Systems Co., Ltd., UT, USA). Both usual and maximal gait speeds were calculated from the time required to walk 6 m. In addition, step lengths and stance durations of the left and right lower limbs during the straight-line gait were calculated using a wireless sensor consisting of a triaxial accelerometer, magnetic sensor, and triaxial gyroscope (G-walk, BTS Bioengineering SpA., Italy). The sensor was placed around the fifth lumbar vertebra with a semi-elastic belt. [20, 21] The sampled data were transmitted by Bluetooth to a special software program (BTS G-Studio, BTS Bioengineering SpA., Italy), which calculated gait cycle characteristics, such as step lengths and stance durations, using the software's algorithm.[5] The stance duration was calculated by detecting the contact and lift-off of each lower limb from the anterior–posterior acceleration signal.

The step length was predicted from the cadence and time of the gait cycle. The average step length and stance duration of the left and right lower limbs was calculated from all steps and stances. The G-walk system is comparable to the GaitRITE system regarding the ability to evaluate gait characteristics.[21] The GaitRITE system has been considered the gold standard in the assessment of gait parameters, such as step length or stance duration, using the examination mat.[22, 23] The absolute values of side-to-side difference in step lengths and stance durations were divided by the average of left and right step lengths and stance durations, respectively, and then the percentage values were used as the asymmetry of straight-line gait. [5] The usual gait was evaluated as the average of two trials, and the maximal gait was evaluated as a single trial.

Statistical analyses

All data are presented as mean ± standard deviation. Two-way analysis of variance (ANOVA; age group × gender) was used to compare the differences in gait speed and asymmetry during the circular gait and straight-line gait at usual and maximal speeds. When a significant interaction was found, one-way ANOVA, followed by Tukey's corrected post-hoc multiple comparisons, was used to compare the differences in the variables among the age groups in each gender, and independent t-tests were used to compare the variables between the genders. When there was a main effect of age groups, but no significant interaction, post-hoc multiple comparisons with Tukey's correction were used to determine where differences existed between the age groups. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS version 22.0; IBM Japan, Inc., Tokyo, Japan). Differences were considered statistically significant at p value < 0.05.

Results

Table 1 shows the height, body weight, and body mass index of participants in each age group.

Table 2 and Figure 2 show the circular gait time and asymmetry, straight-line gait speed, and asymmetry of step length and stance duration. Two-way ANOVA revealed a significant interaction only in the circular gait time. It also showed the main effects of age groups and gender on the circular gait time, usual straight-line gait asymmetry of step length, and maximal straight-line gait speed. One-way ANOVA for the circular gait time revealed a main effect of age groups in older women, but not in older men. Post-hoc tests for age groups in older women showed that circular gait time in the late 70s group was significantly slower than that in other age groups. Post-hoc independent t-tests to compare the difference between genders showed significant differences in the early 60s and late 60s groups. In addition, there were differences in the maximal straight-line gait speed between the early 60s and early 70s groups, the early 60s and late 70s groups, and the late 60s and early 70s groups. Additionally, there was a trend for slower maximal gait speed in the late 70s group compared to the late 60s group (p = 0.056). Post-hoc tests to confirm the differences among age groups in usual straight-line gait asymmetry of step length showed significant differences between the early 60s and early 70s groups.

Discussion

The present study investigated age-related changes in circular and straight-line gait speed and gait asymmetry in community-dwelling older adults between 60 and 79 years of age. A decline in the circular gait speed was observed in older women aged ≥75 years. However, age-related changes in gait asymmetry during the circular gait were not observed. This is the first study to reveal age-related changes in circular gait characteristics in older individuals aged 60 to 79 years in each gender.

An age-related decline in the circular gait speed was observed only in older women, but not in older men. Maximal straight-line gait speed declined after the age of 70 in both genders. Age-related changes were not observed in the usual straight-line gait speed in both genders. These findings suggest that the circular gait speed might be a more sensitive marker of decreased gait ability among older adults than the usual straight-line gait speed, but not when compared to the maximal straight-line gait speed. When performing a circular gait test at maximal speed, there is a risk of falling. Since previous studies have assessed the circular gait at a comfortable speed, [5, 7] the circular gait test in this study was performed at a comfortable speed for safety. The results of the present study indicated that circular gait time at a comfortable speed in the late 70s was significantly slower than that in the other age groups in older women. However, there was no significant difference in comfortable gait speed during straight-line gait between age groups. When walking in a circular path, the trajectory of the inner limb differs from that of the outer limb, and the direction of the trunk is required to be constantly controlled with turning; therefore, circular gait requires coordinated movements of both legs and greater postural control. [6] Interestingly, in the circular gait time, no change was observed from 60s to early 70s, but a marked decrease was observed after the late 70s. Compared with straight-line gait speed at a comfortable speed, circular gait time at a comfortable speed may be a more sensitive tool to detect the decline of mobility in older adults. A previous study reported that older adults aged over 80 years had greater trunk and pelvis sway during walking on a foam surface compared with an old group aged up to 75 years,[24] suggesting that the disability of postural control during walking seems to progress even in old age. In the present study, it is considered that older individuals aged over 75 years could not control their posture and coordinate their legs smoothly,[25] resulting in a slower circular gait speed. Controlling the posture in the left-right direction is necessary, especially for circular gait.[6] Decreased ability to control posture in the left-right direction may affect the decline in circular gait speed in the late 70s individuals. Additionally, an age-related decrease in postural control is associated with a greater use of double-limb support during the gait cycle in straight-line walking.[26] Since the circular gait requires a greater portion of inner single-limb support to swing the outer limb greater, the difficulty of single-limb support might result in a slower circular gait speed. On the other hand, our results suggested that a decrease in maximal straight-line gait speed was observed after early 70s, which occurred at an earlier age than a decrease in circular gait speed. Straight-line gait speed at maximal effort is influenced by some factors such as age-related changes in muscle strength and sensorimotor functions.[27-30] Therefore, maximal gait speed may decrease at an earlier age than comfortable gait speed.

Our results found age-related declines in circular gait speed in older women, as mentioned above, while no changes were found in older men. A previous study reported that changes in gait speed, step length, and cadence were closely associated with the aging process, and these associations were most pronounced for older women,[31] which supports our results. In particular, the ability to turn suddenly during walking decreases in older women,[16] which may cause an age-related decrease in circular gait speed in older women. Because the present study did not include individuals aged less than 60 years and more than 80 years, some gait variables in older men would possibly change with age before 60 years or after 80 years. Future research needs to investigate age-related changes in circular gait in middle-aged individuals or after late older individuals.

A decline in circular gait speed was observed in older women, while age-related changes in gait asymmetries were not observed. Side-to-side asymmetry in muscle activity of the lower limbs[32] and limb load asymmetry during quiet stance[10] increase with changes in postural control functions due to aging.[11] Therefore, we hypothesized that circular gait asymmetry increased with age. However, the results of the present study countered our hypothesis. Indeed, asymmetry of step length during usual straight-line gait was significantly different between the early 60s and early 70s groups in this study. Since stance duration of the inner lower limb and swing duration of the outer lower limb increase when walking along a circular path, the circular gait requires the support of the inner leg and the greater swing range of the outer leg. In a previous study,[5] the asymmetry index for the circular gait time was 3.58% in young adults and 9.06% in older adults with a mean age of 84 years. The present study showed that the asymmetry was 7.45% to 8.50%. These findings suggest that asymmetry in the circular gait time changed with aging before 60 years of age or after 80 years of age. Therefore, asymmetry in the circular gait should be investigated among various age groups, including these age groups in the future. Moreover, since the function required in circular gait is different between inner and outer limbs, future research may be necessary to analyze circular gait asymmetry by distinguishing the characteristics of the subjects, such as those who have less supportability in the stance phase and those who have difficulty in a greater range of swing.

A limitation of this study is that gait characteristics were assessed in older adults aged 60 to 79 years. In the future, it will be necessary to analyze the circular gait speed and asymmetry, by including older individuals aged <60 years and >80 years. In addition, it is necessary to clarify the effectiveness of circular gait tests as a clinical assessment tool for detecting the risk of falls by examining the relationship with the history of falls. Furthermore, gait variability data were not included in the present study. Since gait variabilities are related to fall risks in older adults,[33] it is interesting that there is a relationship between fall risks and gait characteristics, including circular gait, and the variabilities of step length and stance duration during straight-line gait. Future studies should investigate the effects of these characteristics, including gait speed, asymmetry, and variabilities on fall risks.

In conclusion, the present study investigated age-related changes in circular and straight-line gait speed and asymmetry in community-dwelling older individuals aged between 60 and 79 years. The results showed that the circular gait speed declined the age of 75 years, especially in older women.

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Disclosure statement

None

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Figure Legends

Fig. 1

Flow chart of this study

Fig. 2

Gait speed and asymmetry during circular gait and straight-line gait in older men and women

The bars represent the mean, and the error bars represent the standard deviation. The black bar graphs show data from men, while white bar graphs show data from women. a: Significant difference compared with the early 60s group ($p < 0.05$), b: significant difference compared with the late 60s group ($p < 0.05$), c: significant difference compared with the early 70s group ($p < 0.05$), d: significant difference between genders ($p < 0.05$). There was a significant interaction between age group and gender in the circular gait time ($p < 0.05$). There were main effects for gender and age groups in maximal gait speed and asymmetry index in step length during the usual straight-line gait ($p < 0.05$).

Table 1

Participants' characteristics

		Early 60s (n = 109)	Late 60s (n = 130)	Early 70s (n = 83)	Late 70s (n = 69)
Number of participants	Men	29	44	33	36
	Women	80	86	50	33
Height (cm)	Men	168.2 ± 5.2	167.2 ± 5.4	164.5 ± 5.1	162.8 ± 4.8
	Women	155.6 ± 5.1	154.3 ± 5.0	151.8 ± 5.2	150.3 ± 4.6
Body mass (kg)	Men	67.5 ± 9.7	66.7 ± 8.8	63.7 ± 7.3	59.3 ± 7.6
	Women	54.6 ± 8.8	51.3 ± 6.8	52.5 ± 7.8	48.7 ± 8.1
Body mass index (kg/m^2)	Men	23.8 ± 3.1	23.8 ± 2.5	23.6 ± 2.7	22.4 ± 2.8
	Women	22.6 ± 3.6	21.6 ± 2.8	22.8 ± 3.3	21.6 ± 3.4

Data are presented as mean ± SD

Table 2

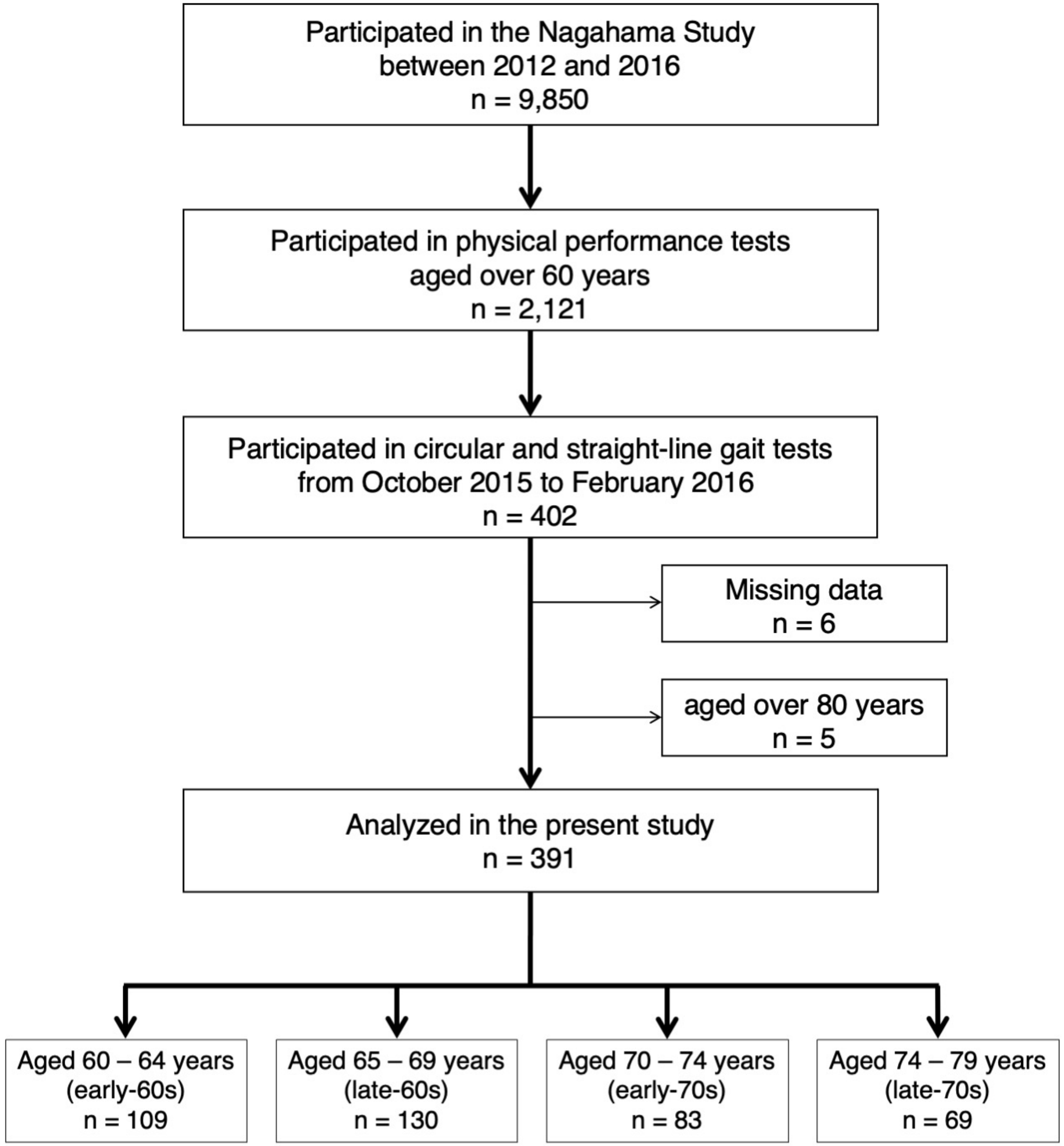
Gait speed and asymmetry during circular gait and straight-line gait in age groups

		Early 60s	Late 60s	Early 70s	Late 70s	All groups	Interaction gender × age group F-values	Interaction gender × age group p values	Main effect of age group F-values	Main effect of age group p values	Main effect of gender F-values	Main effect of gender p values
Circular gait time (s)	Men	8.66 ± 1.52 [d]	8.75 ± 1.53 [d]	9.02 ± 1.75	8.76 ± 1.07	8.80 ± 1.47			0.386	.763	5.899	.016
	Women	7.94 ± 1.05 [d]	8.17 ± 1.13 [d]	8.37 ± 1.35	9.29 ± 1.79 [a, b, c]	8.28 ± 1.32	3.600	.014	9.432	< .001		
	Both genders	8.13 ± 1.22	8.36 ± 1.30	8.63 ± 1.54	9.01 ± 1.47 [a, b, c]	8.47 ± 1.40			4.286	.005		
Asymmetry index in circular gait time (%)	Men	7.54 ± 5.56	8.96 ± 6.65	7.90 ± 6.09	7.04 ± 5.43	7.94 ± 5.99					0.007	.935
	Women	7.79 ± 5.46	8.26 ± 6.79	7.72 ± 5.44	7.89 ± 5.97	7.95 ± 5.98	0.263	.852				
	Both genders	7.72 ± 5.46	8.50 ± 6.72	7.79 ± 5.67	7.45 ± 5.67	7.95 ± 5.98			0.698	.554		

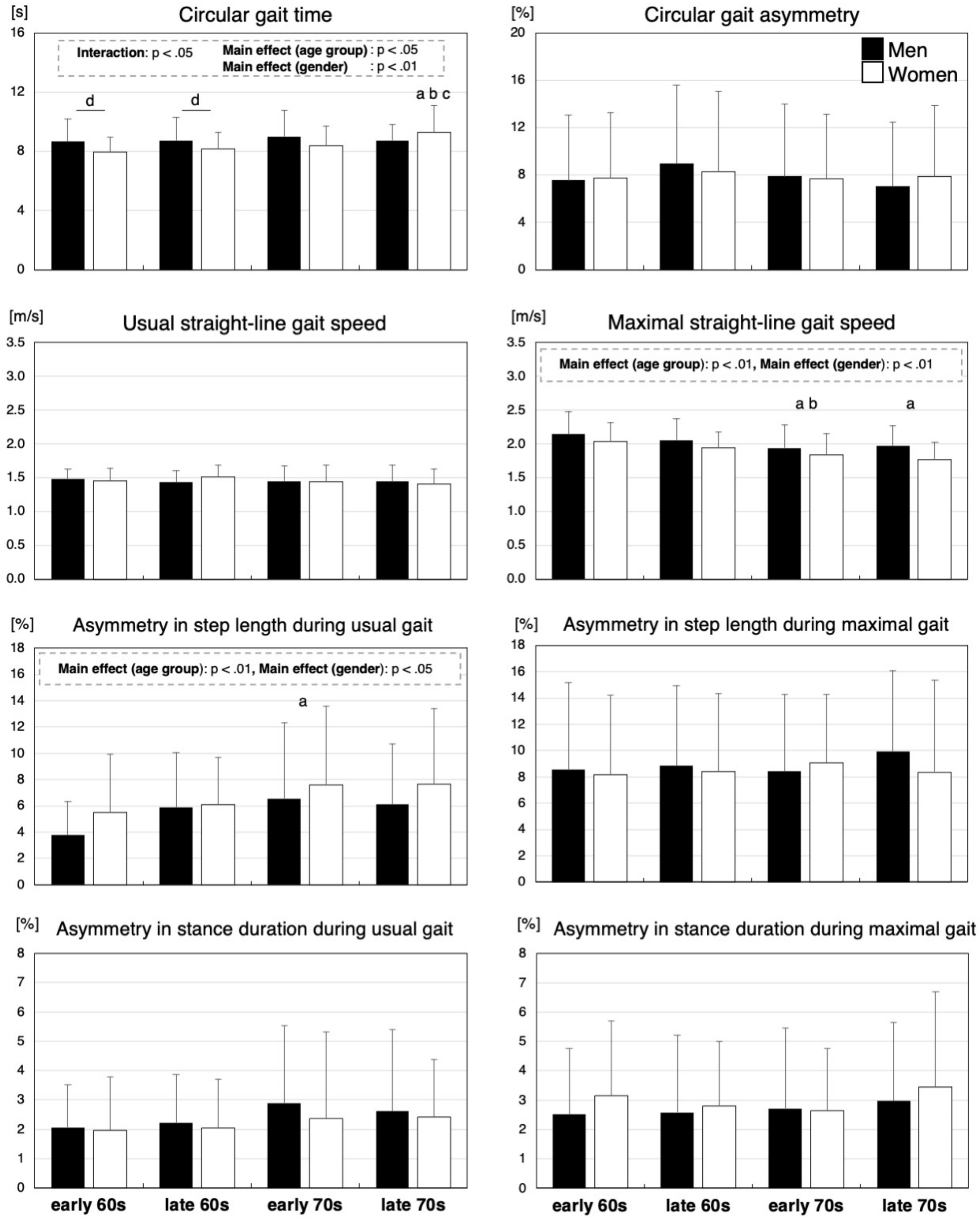
Usual straight-line gait speed (m/s)	Men	1.48 ± 0.15	1.43 ± 0.18	1.45 ± 0.23	1.44 ± 0.24	1.45 ± 0.20					0.005	.943
	Women	1.45 ± 0.19	1.51 ± 0.18	1.45 ± 0.24	1.41 ± 0.22	1.46 ± 0.20	1.773	.152				
	Both genders	1.46 ± 0.18	1.48 ± 0.18	1.45 ± 0.24	1.43 ± 0.23	1.46 ± 0.20			0.923	.430		
Asymmetry index in step length during usual straight-line gait (%)	Men	3.79 ± 2.54	5.86 ± 4.21	6.55 ± 5.79	6.16 ± 4.56	5.67 ± 4.52					4.813	.029
	Women	5.49 ± 4.43	6.08 ± 3.62	7.59 ± 6.00	7.64 ± 5.79	6.40 ± 4.79						
	Both genders	5.04 ± 4.08	6.00 ± 3.82	7.18 ± 5.90 [a]	6.87 ± 5.20	6.14 ± 4.70	0.502	.681	4.676	.003		
Asymmetry index in stance duration during usual straight-line gait (%)	Men	2.06 ± 1.45	2.22 ± 1.66	2.89 ± 2.64	2.61 ± 2.80	2.44 ± 2.21					1.235	.267
	Women	1.95 ± 1.85	2.03 ± 1.69	2.37 ± 2.95	2.41 ± 1.96	2.12 ± 2.08						
	Both genders	1.98 ± 1.75	2.09 ± 1.68	2.58 ± 2.82	2.51 ± 2.42	2.24 ± 2.13	0.150	.929	1.660	.175		
Maximal straight-line gait speed (m/s)	Men	2.15 ± 0.34	2.06 ± 0.32	1.94 ± 0.34	1.97 ± 0.30	2.03 ± 0.33					17.869	< .001
	Women	2.03 ± 0.28	1.95 ± 0.23	1.84 ± 0.31	1.77 ± 0.26	1.93 ± 0.28	0.530	.662				
	Both	2.06 ± 0.30	1.99 ± 0.27	1.88 ± 0.32	1.87 ± 0.30	1.96 ± 0.30			9.999	< .001		

	genders			[a, b]	[a]							
Asymmetry index in step length during maximal straight-line gait (%)	Men	8.59 ± 6.60	8.84 ± 6.07	8.43 ± 5.83	9.96 ± 6.13	8.98 ± 6.11	0.424	.736	0.222	.881	0.449	.503
	Women	8.19 ± 6.05	8.39 ± 5.96	9.09 ± 5.20	8.38 ± 6.98	8.47 ± 5.96						
	Both genders	8.30 ± 6.17	8.54 ± 5.98	8.83 ± 5.43	9.20 ± 6.55	8.65 ± 6.01						
Asymmetry index in stance duration during maximal straight-line gait (%)	Men	2.53 ± 2.23	2.58 ± 2.63	2.72 ± 2.74	2.98 ± 2.66	2.70 ± 2.57	0.293	.830	0.724	.538	1.285	.258
	Women	3.14 ± 2.57	2.81 ± 2.19	2.64 ± 2.12	3.44 ± 3.26	2.97 ± 2.47						
	Both genders	2.98 ± 2.49	2.74 ± 2.34	2.67 ± 2.37	3.20 ± 2.95	2.87 ± 2.50						

Data are presented as mean ± SD. a: Significant difference compared with early 60s ($p < 0.05$), b: significant difference compared with late 60s ($p < 0.05$), c; significant difference compared with early 70s ($p < 0.05$), d: significant difference between gender ($p < 0.05$)



Participated in the Nagahama Study
between 2012 and 2016
n = 9,850
Participated in physical performance tests
aged over 60 years
n = 2,121
Participated in circular and straight-line gait tests
from October 2015 to February 2016
n = 402
Missing data
n = 6
aged over 80 years
n = 5
Analyzed in the present study
n = 391
Aged 60 – 64 years
(early-60s)
n = 109
Aged 65 – 69 years
(late-60s)
n = 130
Aged 70 – 74 years
(early-70s)
n = 83
Aged 74 – 79 years
(late-70s)
n = 69


[s]
Circular gait time
Interaction: p < .05
Main effect (age group) : p < .05
Main effect (gender) : p < .01
d
d
a b c
[%]
Circular gait asymmetry
Men
Women
[m/s]
Usual straight-line gait speed
[m/s]
Maximal straight-line gait speed
Main effect (age group): p < .01, Main effect (gender): p < .01
a b
a
[%]
Asymmetry in step length during usual gait
Main effect (age group): p < .01, Main effect (gender): p < .05
a
[%]
Asymmetry in step length during maximal gait
[%]
Asymmetry in stance duration during usual gait
[%]
Asymmetry in stance duration during maximal gait
early 60s
late 60s
early 70s
late 70s
early 60s
late 60s
early 70s
late 70s