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Effects of age and gender on spatiotemporal and kinematic gait parameters in older adults

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Purpose: Gait changes are more prominently observed in older adults than in young adults, especially in kinematics of lower extremities and trunk. These changes can result in incidental falls during gait, possibly leading to inability to perform activities of daily living independently. This study aimed to investigate the effect of gender and age on gait changes, such as spatiotemporal parameters and peak joint angles in lower extremities and trunk during gait. *Methods*: A total of 387 participants (223 women) were included. The Microsoft Kinect V2 sensor was used to obtain the coordinate data of lower extremities and trunk during gait. The coordinate data obtained were processed using the software. Walking speed, stride length, stride time and cadence were calculated as spatiotemporal variables of walking. Forward trunk tilt angle (FTT), hip flexion and extension, and knee flexion and extension were measured as peak angles during one-gait cycle. Participants were categorized into five groups according to age by five years. Multivariate analysis of variance was performed to compare the spatiotemporal and kinematical data among groups. *Results*: Significant differences among age groups were noted in terms of the walking speed and stride length. Significant differences were also observed in the FTT and hip extension angle. *Conclusions*: Increased gait changes, increased peak FTT and decreased peak hip extension angle were observed with an increase of age. These altered symptoms may contribute to the screening of older adults at risk of declined physical function at an early stage.

Key words: *aging, gait, lower extremity, older adult, trunk*

1. Introduction

Physical function decreases with age. As the main physical function changes among healthy, older community-dwelling older adults, walking speed, timed up and go test time, stability, and knee extensor and flexor reductions were explained by advancing age [1], [4]. Furthermore, adults aged ≥75 years have more age-related physical function loss [7]. The National Health Interview Survey ascertained that 22.9% of older adults aged 60–69 years and 42.9% aged ≥80 years reported to have physical function limitations (e.g., walk a quarter of a mile, walk up 10 steps without resting) in 2001–2007 [14]. Gait is negatively affected by impaired balance, reduced stability and lower extremity strength weakness [6]. This altered gait is associated with functional decline, less independence, impaired quality of life and falls [6], [9].

Spatiotemporal gait changes with age generally occur in older adults, compared to young adults, including

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reduced walking speed, cadence and step length [19], [24]. A study comparing only older adults, mixed men and women, also reported shorter stride length, shorter step length, and slower walking speed, altered with advancing age [23]. These changes during gait can result in incident falling, leading to inability to perform activities of daily living (ADL) independently [6], [16], [20]. Furthermore, a previous cross-sectional study showed that gait parameters, such as step lengths and stride lengths, were equivalent among older adults in the 70–74 and 75–79 age groups but decreased significantly past the age of 80 years [13]. Thus, spatiotemporal gait changes with age in older adults with regard to the effect of gender have been studied to some extent.

The kinematic changes in gait in older adults have also been examined in several studies. With regard to peak joint angles during gait, reduced hip extension, knee flexion, and ankle dorsiflexion were observed [2], [13]. Furthermore, the trunk angle relative to pelvis during gait differed between young and older adults [21]. As for gender, a study investigating gender-specific differences in gait patterns revealed that women's gait is characterized by greater ankle range of motion (ROM) than men, whereas men tend to have greater hip ROM than women [18]. A cross-sectional study on 191 healthy adults aged 20–75 years reported that a significant age–gender interaction was observed in the lower-extremity joint kinematic variables during gait [17]. However, to the best of our knowledge, the changes of gait kinematics in lower extremities and trunk with age in older adults, considering the effects of gender, are still unclear. Given that oldest adults are more likely to have a walking disability, an underlying cause of dependence on ADL [14], [6], assessing alterations with age in spatiotemporal parameters and peak joint angles during gait would help in the screening of those at risk of declined physical function at an early stage.

Therefore, this study aimed to investigate gait changes with age, including spatiotemporal parameters and peak joint angles in lower extremities and trunk during gait, considering the effects of gender. We hypothesized that oldest adults would reveal altered gait characteristics that differed according to age.

2. Materials and methods

2.1. Participants

This was a cross-sectional observational study on older adults aged ≥65 years, living in a community. We recruited participants in community centers and gymnasiums in Hiroshima City, Higashi-Hiroshima City, Kure City and Yamaguchi City, Japan, from August 2019 to March 2020. Inclusion criteria were having 65 years and more, and the ability to walk without walking aids. Exclusion criteria were having neurological disorders such as stroke and a clearly asymmetrical walking posture. Before the study enrollment, participants were informed about the study purpose and signed a consent form. This study was conducted according to the Declaration of Helsinki and with the approval of the institutional review board of the author's affiliated institution (No. 30–70).

2.2. Measurement system

The Microsoft Kinect V2 sensor (Microsoft Corporation, Washington, USA) was used as a marker-less motion capture system. Data obtained from measurements were processed using Mobile Motion Visualizer AKIRA (MMV AKIRA, System Friend Inc., Hiroshima, Japan). Data reliability and validity obtained using this device and software were confirmed [25], [26].

2.3. Procedure

The participant stood at a distance of at least 7 m from the Kinect sensor and was instructed to walk at his or her usual walking speed. After the measurer signals to start walking, the participant walked on a horizontal floor toward the Kinect sensor, which was fixed at a height of 70–80 cm from the front of the floor. Furthermore, to prevent collisions with the Kinect sensor and a reduced walking speed near the Kinect sensor, participants were instructed to maintain their walking speed when approaching the Kinect sensor and avoid the Kinect sensor.

2.4. Measurement items

Using the coordinate data of skeletal extraction points recorded by MMV AKIRA, walking speed, stride length, stride time, and cadence were measured as spatiotemporal variables of walking. Forward trunk tilt angle (FTT), hip flexion and extension, and knee flexion and extension were the angles to be measured. The angle projected on the sagittal plane was analyzed. For spatiotemporal variables and each angle, left and right averages were used in the analysis.

2.5. Data processing

A third-order Butterworth low-pass filter with a cut-off frequency of 7.5 Hz was used to remove noise from the coordinate data of skeletal extraction points recorded by MMV AKIRA. From the coordinate data after noise removal, the difference between *Z*-coordinates (the anterior–posterior direction) of SpineBase and AnkleRight or AnkleLeft was calculated, and the point of the largest difference was defined as the timing of heel–ground contact [28], and one-gait cycle was extracted for each of the left and right sides.

Using the extracted one-gait cycle data, spatiotemporal variables were calculated first: walking speed, stride length, stride time and cadence. Walking speed was obtained from SpineBase coordinate data, and stride length, stride time, and cadence were obtained from AnkleRight and AnkleLeft coordinate data. If more than one-gait cycle could be extracted, we extracted one-gait cycle that included a point at a distance of 3–4 m from the sensor, which is considered as the most sensitive point of the Kinect sensor.

Next, the extracted one-gait cycle data was time normalized. FTT, hip flexion and extension, and knee flexion and extension angles were calculated from the normalized coordinate data of one-gait cycle. The FTT angle was defined as the angle between the line connecting the SpineBase and SpineShoulder and the vertical line to the floor. The hip flexion and extension angle was defined as the angle between the line connecting HipRight/HipLeft and KneeRight/KneeLeft and the vertical line to the floor. The flexion and extension angle of the knee joint was defined as the angle between the line connecting the HipRight/HipLeft and KneeRight/KneeLeft and the line connecting the KneeRight/KneeLeft and AnkleRight/AnkleLeft. Spatiotemporal variables and joint angles were calculated using MATLAB R2020a, a numerical software package from MathWorks.

Data judged to not accurately capture the participants' body due to clothing or other factors; data that significantly deviated from the distribution and data for which one-gait cycle for both feet could not be measured were excluded. Outliers were then removed using the Smirnov–Grubbs test using the statistical software EZR [15].

2.6. Statistical analysis

Multivariate analysis of variance (MANOVA) was used to analyze the association between the age and sex of each subject and the gait parameters for each model. The subjects were divided into five groups according to their sex and age starting from 65 years old: 65–69 years old, 70–74 years old, 75–79 years old, 80–84 years old, and 85 years old and above. MANOVA was conducted with age group and sex as independent variables and gait parameters as dependent variables. Post-hoc Bonferroni corrections for multiple comparisons were performed for significant MANOVAs. SPSS 22.0 software (IBM, Tokyo, Japan) was used for statistical analysis.

3. Results

A total of 387 participants, 164 men and 223 women, were included in this study. Individual characteristics of study participants are shown in Table 1.

Table1. Individual characteristics of participants

	Men	Women
Number of people	164	223
Age [years]	75.8 ± 6.3	74.4 ± 5.6
Height [cm]	158.7 ± 9.4	152.8 ± 5.7
Weight [kg]	57.1 ± 10.1	51.8 ± 7.4

Mean ± SD.

The values of gait parameters for spatiotemporal parameters, with the sex main effects not being significant ($F_{4,374} = 0.983$, $p = 0.417$, $\eta^2 = 0.010$), age group main effects being significant ($F_{16,1143} = 4.303$, $p < 0.001$, $\eta^2 = 0.044$), and the gender × age group interaction not being significant ($F_{16,1143} = 0.704$, $p = 0.792$, $\eta^2 = 0.007$) are shown in Table 2. On further analysis, age group effects were found to be present in the walking speed ($F_{4,377} = 14.165$, $p < 0.001$, $\eta^2 = 0.131$) and stride length ($F_{4,377} = 16.487$, $p < 0.001$, $\eta^2 = 0.149$).

The values of gait parameters for kinematics parameters are shown in Table 3. Both the sex ($F_{5,373} = 4.145$, $p = 0.001$, $\eta^2 = 0.053$) and age group main effects ($F_{20,1238.051} = 2.308$, $p = 0.001$, $\eta^2 = 0.030$) were significant, although the gender × age group interaction was not significant ($F_{20,1238.051} = 0.762$, $p = 0.761$, $\eta^2 = 0.010$). In further analysis, age group effects were found to be present in the FTT ($F_{4,377} = 3.534$, $p = 0.008$, $\eta^2 = 0.036$) and hip extension ($F_{4,377} = 2.830$, $p = 0.025$, $\eta^2 = 0.029$).

Table 2. Spatiotemporal variables by age group during walking

Age group [years] / Parameter	Men					Women						
	(a) 65–69 *n* = 22	(b) 70–74 *n* = 59	(c) 75–79 *n* = 41	(d) 80–84 *n* = 25	(e) 85 ≤ *n* = 17	(a) 65–69 *n* = 44	(b) 70–74 *n* = 75	(c) 75–79 *n* = 67	(d) 80–84 *n* = 26	(e) 85≤ *n* = 11	*P*-value	*Post hoc* test
Walk speed [m/sec]	1.25 ± 0.16	1.28 ± 0.20	1.25 ± 0.20	1.11 ± 0.20	1.05 ± 0.21	1.30 ± 0.19	1.26 ± 0.18	1.18 ± 0.18	1.13 ± 0.22	1.01 ± 0.19	<0.001	a, b, c > d, e
Stride length [m]	1.29 ± 0.15	1.30 ± 0.17	1.28 ± 0.17	1.15 ± 0.17	1.08 ± 0.17	1.30 ± 0.15	1.26 ± 0.14	1.19 ± 0.12	1.16 ± 0.19	1.05 ± 0.10	<0.001	a, b, c > d, e
Stride time [s]	1.02 ± 0.07	1.00 ± 0.07	1.00 ± 0.07	1.02 ± 0.07	1.01 ± 0.11	0.99 ± 0.07	0.98 ± 0.08	0.99 ± 0.08	1.01 ± 0.07	1.02 ± 0.07	N. S	
Cadence [steps/min]	118.7 ± 8.13	121.0 ± 8.88	121.1 ± 9.60	118.7 ± 8.97	119.8 ± 12.50	121.7 ± 9.02	123.0 ± 9.84	121.8 ± 9.43	119.1 ± 7.91	119.1 ± 9.65	N. S	

Mean ± SD.

Table 3. Kinematics variables by age group during walking

Age group [years] / Parameter	Men					Women						
	(a) 65–69 *n* = 22	(b) 70–74 *n* = 59	(c) 75–79 *n* = 41	(d) 80–84 *n* = 25	(e) 85 ≤ *n* = 17	(a) 65–69 *n* = 44	(b) 70–74 *n* = 75	(c) 75–79 *n* = 67	(d) 80–84 *n* = 26	(e) 85 ≤ *n* = 11	*P*-value	*Post hoc* test
FTT [°]	3.67 ± 2.03	4.67 ± 2.20	4.24 ± 2.26	5.12 ± 2.31	5.87 ± 2.24	4.07 ± 2.52	4.19 ± 2.46	4.39 ± 2.75	4.95 ± 2.95	5.67 ± 2.34	0.008	a < e
Hip flexion [°]	26.72 ± 5.26	28.60 ± 4.84	29.19 ± 4.59	29.03 ± 3.86	29.07 ± 5.61	30.01 ± 3.92	31.36 ± 3.45	30.41 ± 3.65	30.25 ± 5.69	30.66 ± 6.51	N. S	
Hip extension [°]	20.79 ± 4.07	20.85 ± 4.07	21.11 ± 3.98	19.25 ± 4.11	19.06 ± 5.90	21.56 ± 3.77	21.73 ± 4.27	20.47 ± 3.88	19.97 ± 4.63	19.02 ± 2.72	0.025	
Knee flexion [°]	43.80 ± 4.07	44.77 ± 5.01	42.91 ± 3.92	43.66 ± 4.91	43.06 ± 6.65	46.17 ± 3.67	46.71 ± 4.20	45.91 ± 4.57	45.63 ± 4.04	44.38 ± 6.42	N. S	
Knee extension [°]	0.68 ± 1.52	0.84 ± 1.37	1.08 ± 1.54	0.96 ± 1.34	1.29 ± 1.78	1.08 ± 1.37	1.43 ± 2.23	1.10 ± 1.55	1.62 ± 2.26	1.25 ± 1.76	N. S	

FTT – Forward trunk tilt angle, Mean ± SD.

4. Discussion

Our study investigated age-related changes of spatiotemporal gait parameters and peak joint angles about hip, knee, and trunk during gait in a large sample of community-dwelling older adults, considering the effects of gender. This study showed that spatiotemporal gait parameters, such as decreased walking speed and shortened stride length, changed with age. Further, peak joint angles revealed increased FTT and decreased hip extension changed by age.

Moe-Nilssen and Helbostad [22] indicated that spatiotemporal gait parameters for older adults are affected by their gender, age, and body height. Hollman et al. [13] showed significant gender differences in walking speed and stride length. Previous studies showed that walking speed and stride length decreased significantly by age, advancing among older adults, which is consistent with our study results [23], [13]. In this study, gender differences in spatiotemporal gait parameters were not observed because there was only a slight difference (5.9 cm) in body height between sexes. This finding was contradictory to that of a previous study that reported gender differences in spatiotemporal gait parameters, with a body height difference of 13.1 cm between older men and women [5].

A cross-sectional study showed that 10 older adults (aged 75–86 years) walked with about 30% smaller hip extension range than 10 young adults (aged 20–31 years) [2]. Another study reported that 12 older adults with an average age of 68.8 years had reduced knee flexion and ankle plantarflexion during gait compared with 12 young adults with an average age of 28.1 years [3]. Furthermore, the trunk angle relative to pelvis during gait was different in 44 older adults aged over 50 years in comparison with 49 young adults aged 20–49 years [21]. In contrast with previous studies, our study is the first that analyzed spatiotemporal and kinematic variables in lower extremities and trunk during gait in a large sample of older adults exhibiting different gait characteristics and examined the effect of gender and age on gait parameters. Our study also demonstrated a novel finding in gait kinematic parameters, i.e., increased FTT with advancing age among older adults. This novel gait characteristic in our study has potentially important implications for older adults. Therefore, detecting signs of gait changes in older adults can be useful for the screening of those at risk of declined physical function at an early stage.

A study on healthy adults aged between 19 and 67 years assessed the trunk motor control using force-controlled perturbations directly applied to the trunk [11]. They reported that trunk admittance (inverse of lumped intrinsic and reflexive impedance) decreased with age and indicated that lower admittance could be strongly associated with difficulty to perform an extensive and faster change in trunk posture to regain balance after a perturbation. They also reported that trunk admittance did not differ between sexes [11]. FTT is caused by diminished trunk muscle strength facilitating altered body biomechanics, which unwittingly leads individuals into trying to balance different postures, such as shorter stride length [10], which maintain the gait cycle [6]. FTT moves the center of gravity, possibly negatively influencing the gait pattern, increasing the risk for falls and disability, and reducing the quality of life [8]. Furthermore, this study found remarkably increased FTT in oldest adults ≥85 years as compared with older adults aged 65–69 years, indicating that it could diminish trunk muscle strength, thereby impairing the trunk motor control.

Our study found that the peak hip extension angle during gait, which is affected by age, tends to reduce with an increase in age. Peak hip extension associated with anterior pelvic tilt during gait, accompanied by hip flexor activity [27], contributes to stride length and walking speed. Moreover, peak hip extension was lower in older adults with a history of recurrent falls than those without a history of fall [16]. Therefore, our study indicated that the peak hip extension angle reduced with age during gait, which consequently reduced gait ability, thereby increasing the risk of falling.

Our study had several limitations. The first study limitation is the sample bias of community-dwelling older adults. Participants attended through information available at community centers and gymnasiums, indicating that they are active and interested in walking and health. It may imply that less-active older adults who tend to stay at home were not included in this study. Further studies are needed to recruit less-active older adults to identify gait changes. The second study limitation is the lack of information about upper limbs and ankle joints. In this study, we did not deal with upper limbs and ankle joints because data reliability and validity were not confirmed in previous studies [25], [26]. If variables about upper limbs and ankle joints are additionally dealt with in further studies, information regarding gait changes by age may likely be obtained using these variables. The third study limitation is that information about factors, such as lower extremity muscle strength, trunk strength, neutral activation, among others, which are possibly related to gait change, was not obtained. Thus, we cannot explain gait changes by age that are directly related to these factors. The fourth study limitation is the distance from the Kinect sensor to the participants' bodies. In our study, the gait cycle data closest to the Kinect sensor were used to calculate spatiotemporal parameters and peak joint angles in the lower extremities and trunk [12]. We excluded other data from our analysis owing to the distance between the point of data collection and the sensor. If gait analysis is continuously performed, a means of maintaining adequate distance between the participant and the sensor would be developed.

5. Conclusions

This study demonstrated a decrease in walking speed and a shortening of stride length with age in a sample of older adults. Noticeable changes with age increased the peak FTT angle and decreased peak hip extension angle during gait.

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Disclosure statement

The authors have no conflicts of interest to declare.

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