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Identification of healthy elderly's gait characteristics by analyzing gait parameters

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***Abstract*— For the elderly, the deterioration in the quality of life owing to the decline in walking function causes various problems like tripping and falling. Thus, it is important to improve the walking function by gait characteristics. In this study, Some gait parameters based on gait data were introduced, and gait characteristics of the elderly were analyzed by comparing with those of the young. The gait data published by the National Institute of Advanced Industrial Science and Technology were used. Data from 103 young (27 $\pm$ 6 years) and 107 elderly (69 $\pm$ 3 years) subjects were used. The following points characterize gait of the elderly in comparison with the gait of young adults. (1) The elderly's center of mass is located in a forward position in the area of the base of the support when walking. (2) A longer step length is correlated to the steeper inclination of lower limb axis on heel contact timing. (3) On the toe-off timing, steeper foot angle is less accompanied by the flexion of knee, unlike in young adults. (4) The increase in minimum foot clearance is accompanied by knee flexion at heel contact and backward swing of the lower leg at the toe-off timing. These findings are useful to develop walking assist suits that improve walking function in the elderly.**

I. INTRODUCTION

Nowadays, the population is aging rapidly in advanced countries. The gait ability of the elderly decreases owing to aging effects such as the deterioration of muscle strength and balance ability. The limitation of gait ability may decrease the quality of life by limiting daily living activities. Therefore, maintaining walking function is important for improving the quality of life.

Thus, it is important to understand the characteristics of the gait of the elderly in order to maintain walking function. Furthermore, the elderly's gait analysis is considered to be extremely useful for determining the elderly's falling mechanism and the developing walking assist suits based on the gait characteristics.

Thus, in this study, the gait motion of the elderly and young adults recorded in a database were analyzed. Parameters representing gait motion were calculated and compared. Furthermore, characteristics of elderly's gait useful for the development of walking assist suits, were revealed.

II. METHODS

In this study, parameters representing gait characteristics were calculated. To compare and evaluate the gait motion of the elderly, data from sufficient number of samples were collected from people with various attributes. Therefore, the AIST gait database published by the National Institute of Advanced Industrial Science and Technology (AIST) was used [1].

The AIST gait database contains the gait data of 300 healthy adults. For one subject, 10 gait cycles, which are determined as the interval between heel contact (HC) and successive HC, starting from both legs, were recorded [1]. A motion capture system was used to measure gait data, and the sampling frequency was 200 Hz. The joint angle and center of mass were obtained from the motion capture data using Visual 3D (C-motion, Inc., MD). The ground reaction force was measured by force plates at the sampling frequency of 1 kHz.

A. Gait Parameter

The data of eight out of 111 subjects aged 20-40 years and four out of 111 subjects aged 65 and above years did not fit the model. In the two excluded cases, subjects didn't put their feet correctly on the force plate. In nine excluded cases, the data at HC was not obtained. In one excluded case, the data of the left toe marker was not obtained. Thus, the data of 103 subjects aged 20-40 years and 107 subjects aged 65 and above years were used, except for abnormal results.

A gait event was detected from the force plates, and a single stride was extracted from each trial. Sixteen parameters were introduced for characterization of the gait. These parameters were calculated from the joint angles, marker positions, and center of gravity (COG) positions using the following method. The *t*-test was used to compare the parameters between the elderly and young adults..

The correlation value was calculated to compare the trend of the distribution of each parameter. It was calculated for the young and elderly respectively. The parameters whoes correlation value clearly differed between the young and elderly were further analyzed. In addition, the variables that show a correlation value exceeding 0.2 or below -0.2 were chosen.

1) Step length: Step length is defined as the distance in the forward direction between the position of the heel marker at the HC of the leading leg and the position of the heel marker at the HC of the opposite leg.

2) Step width: Step width is defined as the lateral distance between the right heel marker at the right HC and the left heel marker at the left HC.

3) Pelvis angle: Pelvis angle is defined as the inclination of the plane around the lateral axis created by the markers of the left and right anterior superior iliac spines and the markers of the sacral point.

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4) Minimum foot clearance: Minimum foot clearance (MFC) is defined as the distance from the floor to the sole when the foot is horizontal to the ground during the swing phase. The heel marker and toe marker are used to estimate the MFC. Fig. 1 shows a geometric model for calculating the MFC.

As shown in Fig 1(a), the timing when the entire sole contacts the ground is estimated. The vector α is defined as the vector from the heel to toe marker. The entire sole is considered to contact with the ground when the rate of change in the slope of this vector α is close to 0. The angle between the vector α and the ground at this time is $\theta_{horizon}$, and the height from the ground to the heel marker is h_{heel}. After toe-off (TO), as shown in Fig 1(c), the angle between the vector α and the ground again becomes $\theta_{horizon}$. When θ equals to $\theta_{horizon}$, the foot is assumed to be horizontal and h is defined as the height from the ground to the heel marker. MFC is calculated by the difference between h and h_{heel}.

5) Thigh tilt: Thigh tilt is defined as the angle between the thigh and horizontal axis in the sagittal plane. Thigh is defined as the vector from the hip joint point to the midpoint between the lateral epicondyle and the medial epicondyle of the femur. Thigh tilt was calculated at HC and TO. Fig. 2 shows the thigh tilt.

6) Knee angle: Knee angle is defined as the angle between the thigh and the lower thigh. The thigh is defined above. the distal end of the shank is defined as the midpoint between the lateral malleolus and medial malleolus. The proximal end is defined as the midpoint between the lateral epicondyle and the medial epicondyle of the femur. The lower thigh is defined as the vector from the proximal end to the distal end. The knee angle was calculated at HC and TO. Fig. 2 shows the knee angle.

7) Lower thigh tilt: Lower thigh tilt is defined as the angle between the lower and the horizontal direction. The definition of the lower thigh is as described above. The lower thigh tilt was calculated at HC and TO. Fig. 2 shows the lower thigh tilt.

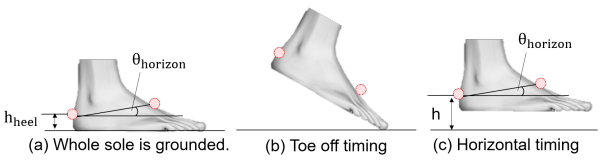

Fig. 1. Geometric model for calculation of minimum foot clearance

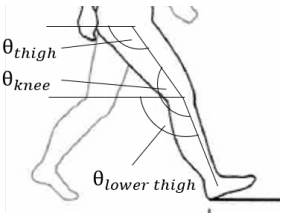

Fig. 2. The definition of lower leg angle

8) Foot angle: Foot angle was introduced as a representative parameter of the strength of kicking at TO. The distal end is defined as the midpoint between the first and fifth metatarsal heads. The proximal end is defined as the midpoint between the lateral and medial malleolus. Foot angle is defined as the angle which the vector from the distal end to proximal end, makes with the horizontal direction. The foot angle is offset to 0 when the entire sole contacts the ground. The foot angle was calculated at TO. Fig. 3 shows the foot angle.

9) Upper body tilt: Upper body tilt is defined as the inclination of the line connecting the midpoint between C7 and the upper margin of the sternum with the midpoint between the xiphold process and the point directly behind it. The backward tilt direction is defined as the positive direction.

10) Ratio of center of gravity position: Ratio of center of gravity (COG) position is defined as the ratio of COG positions on the area of the base of support (BOS), which is a rectangle consisting of the heel positions of both the feet at the time of HC. The ratio of the COG position in the lateral direction ($COG_{r\_lateral}$) against forward direction and the ratio of COG position in the forward direction ($COG_{r\_forward}$) were calculated following formulas, using distance between left heel and COG position in lateral direction ($COG_{p\_lateral}$), distance between right heel and COG position in the forward direction ($COG_{p\_forward}$), right step length (RS), and step width (SW). Ratio of COG position was calculated at the right HC. Fig. 4 shows the ratio of COG position.

$$COG_{r\_lateral} = \frac{COG_{p\_lateral}}{SW}$$
$$COG_{r\_forward} = \frac{COG_{p\_forward}}{RS}$$

III. RESULTS

The values of gait parameters between the young and the elderly that showed a p-value are given in Table I. The values of step length, knee angle at HC, lower thigh tilt at HC, and foot angle were significantly smaller in

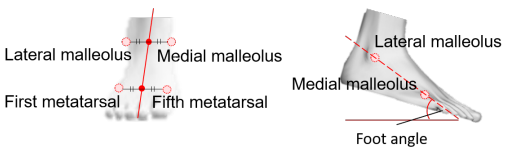

Fig. 3. The definition of foot angle

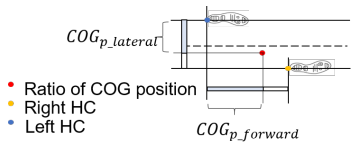

Fig. 4. Ratio of center of gravity position

elderly subjects than in young subjects. Regarding step length normalized with height, p-value is less than 0.01, and the value is significantly smaller in elderly subjects than in young subjects. In addition, the ratio of the COG position in the forward direction was significantly higher in elderly subjects than in young subjects. The correlation coefficient of thigh tilt at TO, knee angle at TO, lower thigh tilt at HC and TO, and foot angle with respect to right step length are given in Table II. Knee angle at TO, lower thigh tilt at HC, and foot angle showed a positive correlation with right step length in both young and elderly subjects. Thigh tilt and lower thigh tilt at TO showed a negative correlation with right step length in both young and elderly subjects.

The correlation values of thigh tilt and lower thigh tilt at HC with respect to the ratio of COG position in the forward direction are given in Table III. Thigh tilt and lower thigh tilt at HC showed a negative correlation with the ratio of COG position in the forward direction.

The correlation values of thigh tilt and knee angle at TO with respect to foot angle are given in Table IV. There was a slight correlation between foot angle and thigh tilt at TO in young subjects. In contrast, foot angle showed a negative correlation with thigh tilt at TO in elderly subjects. In addition, foot angle showed a negative correlation with knee angle at TO in young subjects. On the contrary, there was no correlation between foot angle and knee angle at TO in elderly subjects.

The correlation values of right step length, knee angle at HC, foot angle, and lower thigh tilt at TO with respect to MFC are given in Table V. MFC showed a positive correlation with step length in elderly subjects. MFC showed a negative correlation with knee angle at HC and lower thigh tilt at TO in both elderly and young subjects. There was no correlation between MFC and foot angle in elderly subjects. In contrast, MFC showed a positive correlation with foot angle in young subjects.

IV. DISCUSSION

In this study, gait parameters were calculated based on AIST gait data to elucidate the characteristics of the elderly's gait to develop the countermeasures such as a gait assist device for the elderly against fall. We compared the distribution of gait parameters between the young and elderly.

A. Characteristics of gait regarding to step length

From the results in Table I, step length of the elderly was approximately 4 cm smaller than that of the young. The walking speed of the young and elderly was 1.36 $\pm$ 0.03 m/s and 1.31 $\pm$ 0.15 m/s, respectively, expressed by average and standard deviation. The p-value was 0.03, and the walking speed was significantly higher in young subjects. The correlation coefficient between the walking speed and step length was 0.77 in young subjects and 0.74 in elderly subjects. The decrease in walking speed is considered to be one of the causes of the elderly's decrease in step length. This is consistent with the report [2][3] that the higher the walking speed, the larger the step length.

From the results in Table II, the step length showed a positive correlation with knee angle TO, the lower thigh tilt at HC, and foot angle in both young and elderly subjects. In addition, step length showed a negative correlation with the thigh tilt at TO and the lower thigh tilt at TO in both young and elderly subjects. The hip extension, the knee extension at TO, forward swing of the lower leg at HC, backward swing of the lower leg at TO, and the foot angle accompanied the increase in step length and walking speed. It is considered that the smaller lower thigh tilt at HC and foot angle of the elderly corresponds to a smaller step length.

B. Characteristics of gait regarding to ratio of COG position

From the results in Table I, the ratio of COG position in the forward direction is located forward in the elderly than in the young. There is a possibility that the tilt of upper body affects COG. However, there was no significant difference in the tilt of the upper body between the young and the elderly. In addition, the correlation value was very small in both of them, which showed no correlation. Thus, it is considered that the ratio of COG position in the forward direction is affected by the posture and motion of the lower limbs.

According to Table III, the ratio of COG position in the forward direction showed a negative correlation with thigh tilt at HC and lower thigh tilt at HC. This indicates that

TABLE I

THE COMPARISON OF PARAMETER VALUE BETWEEN YOUNG SUBJECTS AND ELDERLY SUBJECTS

	young (n = 103)		elderly (n = 107)		
	mean	SD	mean	SD	p value
Right step length (m)	0.684	0.049	0.645	0.059	<.01
Left step length (m)	0.683	0.054	0.649	0.058	<.01
Step width (m)	0.065	0.024	0.069	0.028	>.10
Pelvis angle (IC)	12.0	6.3	11.5	6.2	>.10
Pelvis angle (TO)	11.4	6.3	11.5	6.2	>.10
MFC	0.023	0.004	0.023	0.005	>.10
Thigh tilt (HC) (deg)	117.8	3.5	117.7	3.3	>.10
Thigh tilt (TO) (deg)	79.6	3.5	80.2	4.7	>.10
Knee angle (HC) (deg)	172.7	3.9	171.1	4.2	<.01
Knee angle (TO) (deg)	139.8	4.6	138.7	5.7	>.10
Lower thigh tilt (HC) (deg)	110.8	2.1	109.3	2.8	<.01
Lower thigh tilt (TO) (deg)	38.6	3.0	38.1	2.7	>.10
Foot angle (deg)	70.4	8.2	67.1	8.7	<.01
Tilt of upper body (deg)	17.2	7.6	16.1	8.1	>.10
Ratio of COG position (lateral)	0.445	0.194	0.528	0.470	>.10
Ratio of COG position (forward)	0.644	0.023	0.658	0.025	<.01

TABLE II

THE CORRELATION COEFFICIENT VALUE ABOUT STEP LENGTH

	Right step length	
	young (n = 103)	elderly (n = 107)
Thigh tilt (TO)	-0.47	-0.57
Knee angle (TO)	0.20	0.32
Lower thigh tilt (HC)	0.32	0.45
Lower thigh tilt (TO)	-0.27	-0.29
Foot angle	0.41	0.48

TABLE III

THE CORRELATION COEFFICIENT VALUE ABOUT RATIO OF COG POSITION IN FORWARD DIRECTION

	Ratio of COG position (forward)	
	young (n = 103)	elderly (n = 107)
Thigh tilt (HC)	-0.21	-0.34
Lower thigh tilt (HC)	-0.54	-0.53

the ratio of COG position is located forward in the BOS if the foot is not placed well in the forward position at HC. According to Table I, lower thigh tilt at HC is smaller in the elderly than in the young, so the step length is small, and BOS did not expand. As a result, ratio of COG position is located relatively forward in the elderly.

The correlation value between the ratio of COG in the forward direction and thigh tilt at HC was smaller in the elderly than in the young. This is because the elderly's ratio of COG position in the forward direction was originally forward than in that of the young.

C. Characteristics of gait regarding to foot angle

From the results in Table IV, foot angle showed a negative correlation with knee angle at TO in the young. In contrast, in the elderly, foot angle showed a negative correlation with thigh tilt at TO. The difference in the correlation between young and elderly individuals suggests a difference in the motion mechanism, which determines their foot angle.

D. Characteristics of gait regarding to MFC

From the results in Table I, there was no significant difference in MFC between the young and the elderly. Rezaul [4] reported that there was no significant difference in MFC. However, it seems important to analyze MFC because many studies [5][6][7][8] reported that trip and fall occur owing to the decrease of MFC in the elderly.

According to Table V, MFC showed a positive correlation with right step length in the elderly. Thus, it is considered that the increase in MFC is accompanied by an increase in step length in elderly subjects. In addition, MFC showed a negative correlation with knee angle at HC and the lower thigh tilt at TO in both young and elderly subjects. Thus, it is considered that the increase in MFC is accompanied by knee flexion at HC and backward swing of the lower leg at TO. Additionally, MFC showed a positive correlation with foot angle in young subjects. In contrast, there was no correlation between MFC and foot angle in elderly subjects. The difference in the correlation between young and elderly individuals suggests a difference in the motion mechanism, which determines their MFC.

TABLE IV

THE CORRELATION COEFFICIENT VALUE ABOUT FOOT ANGLE

	Foot angle	
	young (n = 103)	elderly (n = 107)
Thigh tilt (TO)	-0.17	-0.30
Knee angle (TO)	-0.48	0.04

TABLE V

THE CORRELATION COEFFICIENT VALUE ABOUT MFC

	MFC	
	young (n = 103)	elderly (n = 107)
Right step length	0.19	0.28
Knee angle (HC)	-0.20	-0.26
Foot angle	0.23	0.004
Lower thigh tilt (TO)	-0.20	-0.26

V. CONCLUSIONS

In this study, we calculated some gait parameters that characterize gait from the AIST Gait Database. In addition, we investigated the gait characteristics of the elderly by comparing these parameters between the young and the elderly.

From the analysis results, it was found that the elderly have a smaller step length because the lower leg swing at HC and foot angle, which affects the increase in step length, are small. Furthermore, the ratio of COG position was relatively forward in BOS. In terms of foot angle, the increase in foot angle is accompanied by knee flexion in the young and with hip extension in the elderly. With respect to MFC, there was no significant difference between the young and the elderly. However, as a result of comparing correlation, the increase in MFC is accompanied by an increase in step length in the elderly. The increase in MFC is accompanied by knee flexion at TO and the motion of increasing the tilt angle of the lower thigh at TO in both the young and the elderly.

The results of this study are considered to be useful for deciding effective walking strategies to improve gait in the elderly, and to develop walking assist suits. However, the number of parameters that lead to findings was small. Therefore, it is necessary to select and introduce appropriate parameters such as the parameters at MFC timing to explain gait characteristics.

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