Variations in gait features in elderly adults during walking considering their balance

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Abstract The aim of this study was to evaluate the influence of balance on the spatiotemporal features, lower-limb kinematics, and center of mass (COM) of the non-faller elderly during walking. In this study, 20 healthy elderly women (age, 76.2 ± 5.6 years; height, 150.1 ± 3.2 cm; weight, 55.8 ± 9.0 kg) were enrolled. Based on the Berg balance scale (BBS), the elderly were classified into two groups: poor balance (PB; BBS scores <46 ; $n = 10$; 43.8 ± 1.8) and good balance (GB; BBS scores ≥ 46 ; $n = 10$; 50.4 ± 2.5). The two groups had no differences in terms of the spatiotemporal features and range of motion (ROM) of the vertical COM (all $p > 0.05$). The ROM of the mediolateral COM was greater in PB than in GB. Hip transversal movements in the two groups were different. The impairment of the lateral balance function might contribute to an increase in the incidence of fall events in the elderly with poor balance.

Keywords Berg balance scale · Non-faller elderly · Center of mass · Spatiotemporal features · Joint motion

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1 Introduction

Falls in the elderly cause injuries, leading to an increase in morbidity. Therefore, it is important to prevent falls in the elderly, and to achieve this, the early identification of fall risk individuals and strategies to prevent falls are required [1]. Falls in the elderly often occur during walking. One of the risk factors associated with falling in the elderly is the impairment of balance. For the early identification of fall risk and the prevention of falls, the gait features of the elderly considering their balance have been investigated. However, in most of these investigations, a faller elderly is classified as an elderly with poor balance, whereas a non-faller elderly is classified as an elderly with good balance [2–4]. The faller elderly have a higher fear of falling. Fear of falling can affect the gait features of the elderly [5]. Therefore, the gait differences observed in previous studies might be due to the interaction between the fear of falling and balance.

Furthermore, many previous studies have evaluated only spatiotemporal parameters [2, 3]. However, walking, which is a sophisticated task that facilitates mobility, is executed by the movement and coordination of the lower limbs; the movement and coordination are produced by neuromuscular control associated with several sensory inputs. Therefore, it is important to evaluate lower limb movement as well as spatiotemporal parameters. By comparing fallers and non-fallers, Chiu and Chou showed the variability in joint coordination during walking of the elderly considering their balance [4]. Although the Berg balance scale (BBS) score for the non-faller group (55.5 ± 0.7) was higher than that for the faller group (53.4 ± 1.2), the differences in balance between the two groups from the clinical aspect were minor [6, 7].

Therefore, this study aims to overcome these issues by evaluating the influence of balance on the spatiotemporal features, lower-limb kinematics, and center of mass (COM) of the non-faller elderly during walking.

2 Methods

2.1 Participants

Twenty elderly women (age, 76.2 ± 5.6 years; height, 150.1 ± 3.2 cm; weight, 55.8 ± 9.0) were enrolled. They had no fall, cognitive impairment, history of serious surgery and not serious pain. They could walk independently without any gait-assistive tools/devices. Based on BBS evaluation, the participants were classified into two groups: poor balance (PB; BBS scores <46 ; $n = 10$; 43.4 ± 2.1) and good balance (GB; scores ≥ 46 ; $n = 10$; 50.6 ± 2.4).

We notified the participants regarding the purpose and procedures of this study. All procedures were performed according to a protocol approved by the Institutional Review Board of the Korea Orthopedics & Rehabilitation Engineering Center (KOREC-IRB-130702-1).

2.2 Three-dimensional biomechanical parameters

In this study, a three-dimensional (3D) motion analysis system with eight infrared cameras (Eagle 4, Motion Analysis, USA) and a Helen Hayes full body marker set were used. Kinematic data from all the markers were acquired by using Cortex (Motion Analysis Corp., USA) and calculated by using OrthoTrak 6.5 (Motion Analysis Corp., USA). Then COM was evaluated by using the

segmental analysis [8]. The gait cycle, which included the stance and swing phases, was normalized from 0 to 100%.

The subjects were asked to walk barefoot at a self-selected walking speed along a 10-m walkway. Then, the following spatiotemporal kinematic parameters were calculated: cadence (steps/min), speed (cm/s), stride length (cm), step length (cm), step time (s), step width (cm), single support (% of gait cycle), double support (% of gait cycle), total support (% of gait cycle), stand phase (% of gait cycle), and swing phase (% of gait cycle). The gait cycle was determined by visual inspection. Additionally, the trajectory of the COM and 3D kinematics in the hip, knee, and ankle were calculated. During a gait, the variation in the joint angle at each gait cycle was calculated as reference at 0% gait cycle (i.e., angle at each gait cycle—angle at 0% gait cycle). Additionally, the vertical and mediolateral COM values were calculated.

2.3 Statistical analysis

Shapiro–Wilk normality test was performed to test normality for all data. A two-way analysis of variance (ANOVA) for parametric data or Kruskal–Wallis test for nonparametric data was performed to compare spatial and temporal gait parameters and lower extremity angles at 10% of the interval gait cycle. One-way *t* tests for parametric data or Mann–Whitney test for nonparametric data were performed to compare the range of motion (ROM) in the COM and BBS between groups. Pearson's correlation analysis for parametric data or spearman correlation analysis for nonparametric data was performed to evaluate correlation between BBS and COM spatial and temporal gait parameters and lower extremity angles. These analyses were performed for each group using SPSS 20.0 (SPSS

Table 1 Results of spatiotemporal parameters (mean $\pm$ standard deviation)

	Poor balance		Good balance	
	Left	Right	Left	Right
Cadence (steps/min)	101.9 ± 7.8	101.5 ± 6.8	106.5 ± 19.2	106.1 ± 18.6
Speed (cm/s)	73.8 ± 11.3	73.7 ± 11.6	84.1 ± 26.3	84.3 ± 25.9
Stride length (cm)	87.3 ± 11.4	87.6 ± 11.9	93.3 ± 12.9	93.6 ± 12.6
Step length (cm)	43.3 ± 6.1	44.1 ± 5.5	46.5 ± 6.3	46.9 ± 6.5
Step time (s)	0.6 ± 0.0	0.6 ± 0.0	0.6 ± 0.1	0.6 ± 0.1
Step width (cm)	11.3 ± 2.1		12.3 ± 3.7	
Single support (% gait cycle)	39.6 ± 1.2	38.5 ± 1.9	39.7 ± 2.6	39.4 ± 1.7
Double support (% gait cycle)	21.9 ± 2.7	21.9 ± 2.7	20.9 ± 3.6	20.9 ± 3.6
Total support (% gait cycle)	61.5 ± 1.6	60.4 ± 1.2	60.6 ± 1.7	60.3 ± 2.6
Stance (% gait cycle)	61.5 ± 1.9	60.4 ± 1.2	60.6 ± 1.7	60.3 ± 2.6
Swing (% gait cycle)	38.5 ± 1.9	39.6 ± 1.2	39.4 ± 1.7	39.7 ± 2.6

Fig. 1 Displacement of COM: **a** vertical COM displacements and **b** mediolateral COM displacements with feet location

Inc., Chicago, IL, USA). The significance level was set at 0.05.

3 Results

Significant differences in the BBS scores were observed between the two groups (7.2, $p < 0.05$), indicating differences in the clinical balance between the groups [6]. No differences were observed in any of the spatiotemporal parameters between the groups (Table 1, all $p > 0.05$).

Figure 1 shows the COM fluctuation. No differences were observed ($p = 0.36$) in the ROM of the vertical COM

between PB (29.5 ± 4.7) and GB (28.6 ± 5.5). The ROM of the mediolateral COM was greater in PB than in GB (Fig. 1b, 62.4 ± 11.3 mm vs. 48.8 ± 19.5 mm, $p = 0.045$). The width between feet in GB tended to be wider than that in PB (Table 1; Fig. 1).

Table 2 and suppl. Figs. 1–3 show the results of angles. For the ankle, the toe-out angle was greater in PB than in GB at 10 and 20% gait cycles ($p < 0.05$). However, there were no differences in the other angles for the ankle ($p > 0.05$). Most of ROM was no differences between groups and between sites (all $p > 0.05$). Only transverse ROM was different between sites ($p < 0.05$). For the knee, the knee flexion at 10, 20, and 80% gait cycles and the

Table 2 Statistical analysis results of joint angle alteration (between groups, between sites, group $\times$ site)

	Hip			Knee			Ankle		
	Sagittal	Transversal	Coronal	Sagittal	Transversal	Coronal	Sagittal	Transversal	Coronal
10%	<0.01,	<0.01,	0.01,	<0.01,	0.76,	0.64,	0.48,	0.02,	0.80,
	0.99,	0.86,	0.52	0.93,	0.60,	0.52,	0.93,	0.65,	0.52,
	0.26	0.71	0.76	0.24	0.16	0.17	0.48	0.35	0.50
20%	0.07–,	<0.01,	>0.05,	<0.01,	0.16,	0.49,	0.48,	0.02,	0.75,
	0.86,	0.66,	0.71,	0.81	0.25,	0.54,	0.64,	0.93,	0.66,
	0.25	0.53	0.35	0.16	0.15	0.28	0.63	0.38	0.40
30%	0.76,	<0.01,	0.27,	0.14,	0.24,	0.92,	0.92,	0.09,	0.75,
	0.71,	0.42,	0.72,	0.72	0.57,	0.73,	0.43,	0.72,	0.85,
	0.35	0.45	0.33	0.21	0.26	0.76	0.57	0.66	0.62
40%	0.57,	<0.01,	0.69,	0.67	0.39,	0.39,	0.54,	0.45,	0.64,
	0.88,	0.24,	0.42,	0.67	0.81,	0.92,	0.18,	0.63,	0.71,
	0.43	0.29	0.39	0.45	0.29	0.92	0.39	0.99	0.23
50%	0.45,	<0.01,	0.73,	0.89,	0.84,	0.69,	0.40	0.80,	0.18,
	0.70,	0.15,	0.16,	0.31,	0.91,	0.51,	0.33	0.57,	0.71,
	0.55	0.43	0.33	0.74	0.26	0.70	0.79	0.86	0.17
60%	0.37,	0.01,	0.45,	0.90,	0.64,	0.18,	0.48,	0.76,	0.25,
	0.29,	0.28,	0.13,	0.15,	0.52,	0.27,	0.93,	0.61,	0.71,
	>0.99	0.47	0.31	0.81	0.43	0.88	0.61	0.48	0.17
70%	0.76,	0.13,	0.40,	0.06,	>0.99,	0.07,	0.28,	0.84,	0.75,
	0.26,	0.43,	0.71,	0.39,	0.52,	0.58,	0.37,	0.58,	0.64,
	0.53	0.30	0.40	0.32	0.43	0.42	0.97	0.75	0.71
80%	0.88,	<0.05,	0.50,	0.04,	0.97,	0.02,	0.54,	0.28,	0.33,
	0.71,	0.81,	0.37,	0.75,	0.56,	0.71,	0.95,	0.97,	0.64,
	0.21	0.73	0.21	0.77	0.97	0.21	0.58	0.87	0.99
90%	0.19,	<0.01,	0.25,	0.94,	0.50,	0.09,	0.09,	0.87,	0.46,
	0.68,	0.09,	0.34,	0.87,	0.13,	0.59,	0.48,	0.92,	0.55,
	0.21	0.94	0.10	0.73	0.31	0.15	0.87	0.98	0.58
100%	0.13,	0.15,	0.01,	>0.99,	0.22,	0.47,	0.39,	0.47,	0.22,
	0.82,	>0.99,	0.83	0.41,	0.83,	0.49,	0.86,	0.28,	0.22,
	0.30	0.35	0.06	0.68	0.25	0.29	0.25	0.71	0.55
Range of motion	0.58,	0.54,	0.57,	0.04,	0.54,	0.57,	0.63,	0.67,	0.45,
	<0.01,	<0.01,	0.81,	<0.01,	<0.01,	<0.01,	0.63,	<0.01,	0.95,
	0.77	0.67	0.07	0.02	0.24	0.31	0.63	0.06	0.54

Table 3 Correlation coefficient between BBS and COM, spatiotemporal parameters, and ROM of joints

Parameters		Correlation coefficient	Parameters		Correlation coefficient
Vertical COM ROM		−0.27	Step width		0.255
Mediolateral COM ROM		−0.37	Ankle	Sagittal Right	0.01
Cadence	Right	−0.03		Left	−0.18
	Left	−0.03	Transverse	Right	0.35
Speed	Right	0.03		Left	−0.45*
	Left	0.06	Coronal	Right	0.17
Stride length	Right	0.06		Left	0.17
	Left	0.07	Knee	Sagittal Right	0.32
Step time	Right	−0.09		Left	−0.15
	Left	−0.09	Transverse	Right	−0.06
Single support	Right	−0.24		Left	0.10
	Left	0.08	Coronal	Right	−0.09
Double support	Right	0.09		Left	0.30
	Left	0.09	Hip	Sagittal Right	−0.08
Total support	Right	−0.08		Left	0.06
	Left	0.24	Transverse	Right	−0.40*
Stance	Right	−0.08		Left	−0.22
	Left	0.24	Coronal	Right	0.45*
Swing	Right	0.08		Left	−0.22
	Left	−0.24			

* $p < 0.05$

valgus at 80% gait cycle were smaller in PB than in GB ($p < 0.05$). However, there were no differences in the other angles for the knee ($p > 0.05$). Sagittal ROM was different between groups, between sites and between groups and sites (all $p < 0.05$). Transverse and coronal ROMs were different between sites (all $p < 0.05$). For the hip, most angles in the transversal plane were different ($p < 0.05$), except for 70 and 100% gait cycles ($p > 0.05$). Only the angles in the sagittal plane at 10% gait cycle and those in the coronal plane at 10 and 100% gait cycles were different ($p < 0.05$). Most of ROM was no differences between groups and between sites (all $p > 0.05$). Sagittal and transversal ROM were different between sites ($p < 0.05$).

Table 3 shows the correlation coefficient between BBS, and COM, spatiotemporal parameters, and ROM of each joint. There were no significant correlations (all $p < 0.05$). Transverse ROM in the left ankle and the right hip and coronal ROM in the right hip were correlated with BBS (all $p < 0.05$).

4 Discussion

In this study, no differences were observed in the spatiotemporal parameters between GB and PB. This indicated that the balance in the elderly might be less affected by spatiotemporal gait features, consistent with the result of

Hahn and Chou [9]. However, most other studies found differences in the spatiotemporal parameters in the elderly with poor balance. The inconsistent results might be because in the previous studies, the elderly with poor balance had experienced falls whereas this was not the case in the present study. Therefore, in the previous studies, the elderly had a greater fear of falling, which affected their gait [5].

The mediolateral COM displacement in PB was greater than that in GB, whereas no differences were observed in the vertical COM displacement. These results indicated that the decline in senile balance might increase the mediolateral fluctuation of the body during a gait [9]. These increased mediolateral COM motions may necessitate additional balance to be provided to the elderly during walking [10]. Additionally, the COM tended to be closer to a supporting limb in PB than in GB. This feature might be due to the lack of gait confidence in cases with single limb support or in cases where balance needs to be maintained or enhanced, which might result in an increase in gait safety. In addition, the width between the left and right feet tended to be narrower in PB than in GB, leading to a decrease in the base of support (BOS). These results implied that the fall risk could increase in PB.

There were no differences in the knee flexion during the mid-stance and the ankle dorsiflexion during the terminal stance. Additionally, hip and knee flexion during the early

stance was greater in PB than in GB, whereas hip adduction was smaller in PB. Furthermore, there were no differences of most of ROMs in any planes in each joint between groups. These joint angles might produce no differences in the vertical COM displacement between the two groups [11]. Additionally, less adduction of the hip and valgus positions of the knee was observed. This phenomenon induced an increase in the ROM of the mediolateral COM in PB [10, 12]. The hip transversal angle were different. Although the toe-out angles for the ankle increased in the early stance phase, the differences tended to be smaller in terms of the toe-out angle than the hip transversal angle. These phenomena might contribute to the feet being closer in PB than in GB, leading to a decrease in the BOS. These lower-extremity kinematics might be associated with COM movement [10–12].

BBS was correlated with transverse ROM in the ankle and the hip and coronal ROM in the hip. However, there were no correlations between BBS and COM motion, spatiotemporal parameters and ROM of other joints. These results might imply that balance alteration might affect the transversal motion of the lower-extremity motions, or vice versa [4]. Although the differences of mediolateral COM motion between groups, no correlation between BBS and COM was found. This result might be explained by the fact that several gait determinants control COM motions [11].

In conclusion, we verified that the alteration in the mediolateral COM motion associated with lower-extremity motions, especially the transversal motion of the hip, caused by the gait of the elderly would be greater in the non-faller elderly with poor balance than in the elderly with good balance. The impairment of the lateral balance function might contribute to an increase in the incidence of fall events in the elderly with poor balance, which is similar to the situation for a faller elderly [13]. Additionally, the results could help us understand the differences in the use of gait-assistive devices or tools between the elderly with good balance and those with poor balance [14].

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Conflict of interest There are no conflict of interest.

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