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Relationship Between Frontal-Plane Gait Parameters and Balance Tests in Older Adults

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Abstract

The gait parameters of the older adults are closely related to balance function. However, there have been no studies in which the relationship between gait parameters and frequently used balance tests, such as CoP excursion and Mini-Balance Evaluation Systems Test, were investigated with a focus on the frontal plane. Therefore, the purpose of this study is to elucidate the relationship between frontal-plane gait parameters and balance tests in older adults. Eighteen older adults who attended health classes participated in the study. Step length, step width, and foot angle were measured at a normal walking speed and maximum walking speed, using a sheet-like force plate. To assess postural balance, we measured center of pressure excursion and administered a Mini-Balance Evaluation Systems Test. As a result, no correlation between step width/foot angle and age or postural balance was observed. Moreover, step width and foot angle did not change at different walking speeds. In conclusion, step width and foot angle are not affected by postural balance in healthy older adults. Rather, step width and foot angle may be determined by gait efficiency and structural factors.

Key words: *balance test, frontal-plane, gait parameter, older adults*.

Introduction

Gait is a major form of movement for humans. Parameters, such as walking speed, step length, and walking rate, are used as quantitative measures of gait. It is well known that gait parameters such as walking speed and step length decrease with age [1-4]. It has been reported that, in addition to the difficulty of generating propulsive force due to an age-related decline in hip range of motion and ankle plantar-flexion strength [5], the fear of falling also contributes to changes in gait parameters in older adults [6]. Therefore, changes in gait parameters may represent adaptations to alterations in sensory or motor systems to produce a safer and more stable gait pattern [4].

Control of center of pressure (CoP) is necessary for gait stability. Furthermore, step width and foot angle are among the gait parameters (see Figure 1) that are involved in maintaining CoP in the frontal plane. Step width is the lateral distance between both heels, and it is known to increase in response to lateral instability [7,8]. Foot angle is the angle formed between the long axis of the foot and the direction of body progression [9]. It is also referred to as the foot progression angle and foot offset angle. Extensive research has established that CoP shifts laterally during the single-leg stance phase of gait due to an increase in foot angle (toe-out position), decreasing the external knee adduction moment in people with osteoarthritis of the knee [10,11]. In addition to the base of support widening in the frontal plane, as the foot angle increases, ankle plantar flexors with a strong torque are likely to be involved in the lateral control of CoP. Therefore, increasing foot angle may increase stability in the frontal plane. Conversely, it has been reported that individuals with a higher risk of falling exhibited smaller foot angles [12]. Therefore, step width and foot angle during gait are likely to increase as older adults' postural balance declines due to age-related changes, such as a decline in muscle strength, range of motion, sensory system function, and reaction speed [13]. However, there have been no studies in which the relationship between gait parameters and frequently used balance tests, such as CoP excursion and Mini-Balance Evaluation Systems Test (Mini-BESTest), were investigated with a focus on the frontal plane.

Therefore, the purpose of this study is to elucidate the relationship between frontal-plane gait parameters and balance tests in older adults.

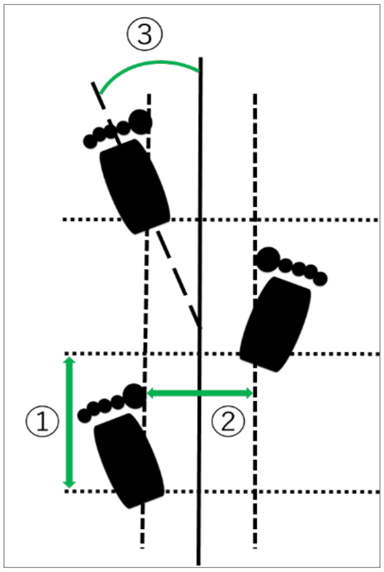

Figure 1. *Gait parameters (①, Step length; ②, Step width; ③, Foot angle.*

Materials and Methods

Participants

The participants in this study consisted of 18 older adults (4 men (age: 79.5 ± 6.1 years, height: 157.9 ± 6.2 cm, weight: 57.5 ± 8.1 kg) and 14 women (age: 77.8 + 6.6 years, height: 151.9 + 8.2 cm, weight: 51.1 ± 10.0 kg)) who attended local health classes. The participants were provided oral and written explanations about the purpose and methods of this study. Subsequently, their informed consent to voluntarily participate in the study was obtained in writing. We selected older adults who had sufficient autonomy to independently participate in this study. Those who were suspected to have dementia, could not appropriately understand the purpose and methods of this study, complained of severe pain that interfered with their daily lives, or had typical physical health conditions, such as cerebrovascular disorders and rheumatoid arthritis, were excluded. This study was approved by the Research Ethics Committee of Kyoto Tachibana University (approval number: 18 – 36).

Measurement of Gait Parameters

A sheet-like force plate (WalkWay MW-1000, Anima Inc., Japan) was used to measure gait parameters in accordance with the method outlined by Murata et al. [14]. The parameters that were measured were walking speed, step length, step width, and foot angle. The measurements were obtained at a comfortable walking speed (CWS) and maximum walking speed (MWS). Measurements were taken during one gait cycle at each walking speed. The WalkWay apparatus can register data pertaining to spatial parameters (e.g., stride length, step length) and temporal parameters (e.g., walking speed, standing time), while a person walks on it. The force plate was 2400 mm long and 800 mm wide. It had four 5-mm-thick sensor sheets (600 mm × 600 mm). The spatial resolution of the sensors was 10 mm × 10 mm, and the number of measurement points was 14,000. During the experiments, the subjects walked barefoot. For CWS, the participants were instructed to walk as they normally would. For MWS, the participants were instructed to walk as fast as possible, but without running. To account for acceleration at the start of walking and deceleration at the end of walking, two-meter walking distances were included before and after the 2.4-meter measured section, which amounted to 6.4 meters of total walking distance (see Figure 2a).

Evaluation of Balance Tests

The static balance test was performed using CoP excursion in the open-eyed standing position, and the Mini-BES Test was used as a comprehensive dynamic balance test. A stabilometer (Gravicoder GP-7, Anima Inc., Japan) was used to measure CoP excursion (see Figure 2b). During the measurement of CoP sway, participants were instructed to maintain a standing position for 30 seconds with their eyes open. The sampling frequency was 20 Hz. During the measurement, the participants stood barefoot with the inner edges of their soles 1 cm apart, toes facing forward, knees extended, and both upper limbs next to the sides of their bodies. The participants' line of sight was directed at a mark 2 meters ahead, adjusted according to each participant's height. Data extraction items were anterior-posterior (AP) path length, mediolateral (ML) path length, maximum AP amplitude, and maximum ML amplitude. Maximum amplitude refers to the maximum excursion that CoP reaches away from its mean. Mini-BESTest consists of

14 items addressing 4 sections (anticipatory postural adjustment, reactive postural control, sensory orientation, gait stability). Each item is scored on a 3-level ordinal scale (severe: 0, moderate: 1, normal: 2). The maximum score is 28 points [15,16]. With regard to scoring the Mini-BESTest, the investigators practiced scoring in advance and unified the evaluation criteria so that the evaluation results would be consistent.

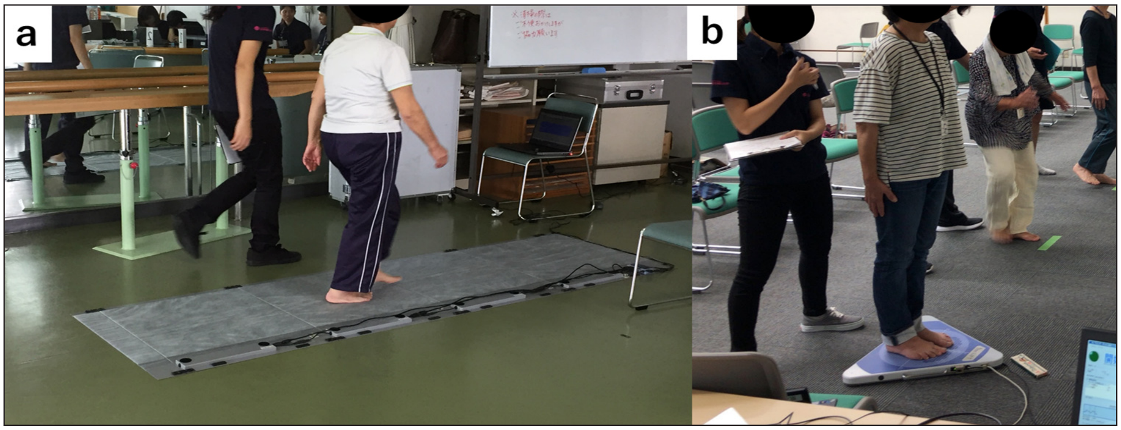

Figure 2. a). *Measurement of gait parameters using walk way, b). Measurement of CoP excursion using stabilometer*

Statistical Analysis

Statistical analyses were performed using SPSS Ver. 24 (IBM SPSS Statistics, IBM Japan, Tokyo, Japan). A paired t-test was applied for the comparison of gait parameters under the two walking speeds. Pearson's correlation coefficient was applied to evaluate the relationships between age, gait parameters, and postural balance. The significance level was set at 0.05. All values are shown as mean ± standard deviation.

Results

Gait parameters at CWS and MWS are presented in Table 1. Walking speed and step length were significantly greater at MWS in comparison with those at CWS. No significant difference in step width or foot angle was observed at CWS and MWS. The data pertaining to postural balance are presented in Table 2. Coefficients of correlation between age, gait parameters, and postural balance are provided in Table 3. We established that age had a significant negative correlation with Mini-BESTest score ($p=0.01$, $r=-0.62$) and step length at MWS ($p \leq 0.01$, $r=-0.64$). Furthermore, a significant positive correlation was established between age and maximum mediolateral amplitude ($p=0.01$, $r=0.49$). However, no correlation was established between the other gait parameters and postural balance.

Table 1. *Differences in gait parameters, depending on walking speed.*

Walking Speed Parameters	Comfortable walking speed	Maximum walking speed
Walking speed (cm/sec)	114.8 ± 29.7	161.6 ± 36.8*
Step length (cm)	53.4 ± 13.2	61.1 ± 12.8*
Step width (cm)	7.6 ± 3.2	8.1 ± 4.1
Foot angle (°)	0.9 ± 3.3	1.1 ± 2.2

Data are presented as the mean ± standard deviation.

*Statistically significant differences between Comfortable walking speed and Maximum walking speed ($p < 0.05$).

Table 2. *Values pertaining to CoP excursion and Mini-BES Test*

CoP excursion	ML path length (cm)	39.2 ± 13.7
	AP path length (cm)	35.3 ± 13.9
	Maximum ML amplitude (cm)	2.9 ± 0.8
	Maximum AP amplitude (cm)	2.7 ± 0.7
Mini-BESTest		22.8 ± 3.5

Data are presented as the mean ± standard deviation.

AP, anterior-posterior; CoP, center of pressure; ML, mediolateral.

Table 3. *Coefficients of correlation between gait parameters and postural balance*

		Age (years old)	Comfortable walking speed			Maximum walking speed		
			Step length (cm)	Step width (cm)	Foot angle (°)	Step length (cm)	Step width (cm)	Foot angle (°)
Age (years old)		-	-0.38*	0.34	-0.05	-0.64*	0.12	0.06
CoP excursion	ML path length (cm)	0.26	0.01	-0.20	-0.39	0.13	0.21	-0.46
	AP path length (cm)	0.45	-0.27	-0.09	-0.37	-0.36	0.08	-0.40
	Maximum ML amplitude (cm)	0.49*	0.03	0.05	-0.34	0.02	-0.07	-0.13
	Maximum AP amplitude (cm)	0.37	-0.20	0.00	0.08	-0.11	0.28	-0.01
Mini-BESTest score		-0.62*	0.52*	0.02	-0.20	0.47	0.08	0.18

* Statistically significant correlation ($p<0.05$).

AP, anterior-posterior; CoP, center of pressure; ML, mediolateral.

Discussion

This study examined the relationship between gait parameters and postural balance in older adults. The findings of this study are expected to be valuable when considering treatment pertaining to gait problem on frontal-plane in older adults.

During the course of this study, it was established that age had a significant negative correlation with Mini-BESTest score and step length at MWS. These findings are consistent with those of previous studies that reported an age-related decline in postural balance [13] and step length [1-4]. Regarding CoP excursion, only maximum mediolateral amplitude had a significant positive correlation with age, suggesting that an age-related decline in static balance is more pronounced in the mediolateral rather than anterior-posterior direction. In contrast, step width and foot angle were not correlated with age. This may be because, unlike step length, step width and foot angle do not require a large hip extension angle and plantar flexor activity to obtain propulsive force. These parameters require only small adjustments, unless balance is greatly disturbed laterally. Blazek et al., who measured step width and foot angle in healthy adults aged 20 to 59 years, reported that step width and foot angle were not associated with age [17]. It is possible that age-related changes that impair gait stability observed in the participants of the study were minor because their age group ranged from young adults to middle-aged people. As the participants of this study consisted of healthy and active older adults, similar to the study conducted by Blazek et al. [17], no notable imbalance was observed in the frontal plane, suggesting that step width and foot angle were not affected by age. The fact that Mini-BESTest score and CoP excursion were not correlated with step width and foot angle supports this hypothesis. Since Panjavi et al. [18] posited that the normal foot angle ranged from -3° to 20°, it can be assumed that the participants of this study did not exhibit excessive foot angles. Furthermore, Bajelan et al. reported that walking with wide steps may reduce energy efficiency [19]. Therefore, it can be supposed that, because of a minor decline in postural balance, the participants of this study, who consisted of active older adults, prioritized efficiency to increase propulsive force over frontal-plane gait stability. As step width is known to increase in response to postural instability in the frontal plane [7,8], it is quite possible that changes in step width and foot angle are related to postural balance in participants with a certain degree of postural balance decline.

Differences in step length were observed at CWS and MWS. As walking speed is determined by step length and cadence (number of steps per minute), it can be supposed that step length is increased to increase walking speed. However, no difference in step width and foot angle were observed at CWS and MWS. As mentioned previously, since healthy older adults do not need to focus on gait stability, they may prioritize efficiency to obtain propulsive force. Therefore, it can be supposed that by reducing step width and foot angle, not only at MWS but also at CWS, and by obtaining propulsive force, lower limbs were efficiently coordinated. However, it has been reported that external tibial torsion affects foot angle more than femoral torsion [20]. Furthermore, the effect of gastrocnemius muscle flexibility on foot angle has also been reported. In particular, low gastrocnemius muscle flexibility was found to result in greater foot angle [21]. Therefore, it is necessary to take into account that structural factors, such as bone shape and muscle flexibility, influence foot angle as well as the strategy towards achieving gait stability.

Regarding the limitations of this study, it should be noted that we did not examine each joint angle and bone torsion during gait. Moreover, we did not examine factors, such as muscular strength and reaction speed, which help maintain balance in the frontal plane. The effect of aging on these factors was not investigated either. Therefore, as it was not clarified which factors affected step width and foot angle, it will be necessary to specifically examine the factors that affect these gait parameters. Furthermore, in addition to small sample size, as the participants were healthy older adults who could walk independently, different findings may be obtained from participants with inferior postural balance. Furthermore, differences in gender characteristics have not been examined due to the small number of participants. Therefore, in further research, it will be necessary to increase sample size and divide participants into groups according to their physical characteristics. Moreover, it is possible that CoP excursion, which was used as a measure of postural balance in this study, was not adequately reflected in postural balance during gait. In addition, the direction of postural imbalance cannot be evaluated using the Mini-BESTest. Therefore, it is also necessary to conduct a study that takes the direction of postural imbalance into account, with the addition of a measure of postural balance that is strongly associated with gait.

Conclusions

In conclusions of this study, no association was established between age, balance tests, and frontal-plane gait parameters, namely step width and foot angle. Step width and foot angle are not affected by balance tests in healthy older adults; rather, these gait parameters may be determined by gait efficiency and structural factors.

Acknowledgments

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