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The Correlation between Dynamic Balance Measures and Stance Sub-phase COP Displacement Time in Older Adults during Obstacle Crossing

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Abstract. [Purpose] This study examined the relationship between the center of pressure (COP) displacement time during the stance subphases and dynamic balance ability when elderly cross obstacles 0, 10, and 40 cm in height. [Subjects] Fifteen older adults were enrolled in this study (≥65 years of age). [Methods] An F-Scan System was used to measure the COP displacement time when subjects crossed obstacles 0, 10, and 40 cm in height, and the Dynamic Gait Index, Berg Balance Scale, and Four Square Step Test were used to measure dynamic balance ability. [Results] The Dynamic Gait Index, Berg Balance Scale, and Four Square Step Test were correlated with each other. Dynamic balance tests were correlated with the COP displacement time during the stance phase. At obstacle heights of 10 and 40 cm during loading response and at all heights during pre-swing, there were correlations with dynamic balance ability. However, dynamic balance ability did not affect the COP displacement time during mid-stance and terminal stance. [Conclusion] People with a lower dynamic balance ability show a larger COP displacement time during loading response and pre-swing. Therefore, dynamic balance ability can be predicted by measuring the COP displacement time.

Key words: Dynamic balance, Obstacle crossing, Center of pressure

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INTRODUCTION

Falling due to aging problems has become a social problem as well as an individual, physical, psychological, and economic problem due to a steady increase in the proportion of the elderly. In particular, obstacle crossing is the most common cause of falls in older adults[1, 2)]. Thus, it is meaningful to analyze the biomechanical characteristics of obstacle crossing in terms of preventing falls[3–6)]. Among them, the center of pressure (COP) during the stance phase in the normal gait moves along the path and creates a characteristic pattern. Thus, the displacement path of the COP during walking may be an important criterion for judging a normal gait[7)].

Obstacle crossing strategies are needed for the gait, and the ability to respond to unexpected situations is required for obstacle crossing. If patients with gait disabilities or if elderly people face obstacles, they clearly shown an abnormal gait pattern and are at increased risk of falls[3)]. During walking, elderly individuals improve stability by increasing the time in double limb support. However, when they cross obstacles, the time in single limb support is increased, and as a result, it increases the risk of falls[8–10)]. In addition, the higher the height of obstacles, the longer the time in single limb support, which increases the risk of falling. To prevent this, the elderly use compensatory strategies, such as slower gait speed, narrower step length, and slower cadence[10, 11)].

In order to accurately understand these compensatory strategies for the prevention of falls in the elderly, a clear distinction of the gait cycle is necessary[12–15)]. Also, the characteristics of the displacement of the COP during the gait cycle are being used as a tool for evaluation and treatment of balance disorders. Therefore, analyzing the time required to move the COP during the subphases in the gait cycle has become a parameter that can be used to determine the dynamic balance ability in the elderly[16–24)].

However, there are no studies demonstrating the relationship between dynamic balance and displacement time of the COP. Hence, our study was designed to analyze the correlations between dynamic balance and COP displacement time in the stance phase when crossing obstacles. For this, we measured the COP displacement time using a foot pressure measurement system when crossing obstacles 0, 10, and 40 cm in height and determined whether the dynamic balance ability affects COP displacement time through the measurement of dynamic balance.

SUBJECTS AND METHODS

Fifteen older adults (3 male, 12 female) were enrolled in this study (all ≥65 years of age). The mean age, mean height, mean weight, and mean foot size of the subjects

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Table 1. The correlation between the DGI, BBS, and FSST

	DGI	BBS	FSST
Value (M±SD)	20.40±3.16	51.60±3.76	21.18±7.64
DGI	1	0.92*	−0.91*
BBS		1	−0.99*

*p<0.01
DGI: Dynamic Gait Index, BBS: Berg Balance Scale, FSST: Four Square Step Test

were 72.8±5.2 years, 160.3±5.2 cm, 59.3±5.7 kg, and 249.0±12.1 mm, respectively. Subjects had no problems in their cognitive abilities: their K-MMSE (Mini-Mental State Examination − Korea) scores were over 24 points, they had no neurological history, and their Berg Balance Scores were over 41 points, which correlate to a lower risk of falls[10]. Subjects voluntarily agreed to participate in the experiment after listening to the purpose and methods of the study.

The 0, 10, and 40 cm obstacles were circular wooden bars (2 m in length and 2.5 cm in diameter). The obstacle heights were chosen based on previous research[11]. Each obstacle was installed so that the bar would fall in the direction of the gait to prevent falling if the subject tripped over the bar.

An F-Scan System was used to measure the COP displacement time when crossing an obstacle. The participants wore a converted device on their ankles and waist. Then, they put on shoes that had pressure probes (in the insole) tailored to their foot length. The subjects walked or stepped over an obstacle at their own pace[25]. When crossing an obstacle, they were limited to crossing over with the left foot. We measured the displacement time of the right foot by measuring the step time.

The DGI (Dynamic Gait Index)[26], BBS (Berg Balance Scale)[10], and FSST (Four Square Step Test)[27] were used to measure dynamic balance ability. They have been widely used to measure dynamic balance ability. Subjects had sufficient breaks to avoid fatigue caused by the experiments.

An F-Scan System (F-Scan version 3.623, Tekscan, South Boston, MA, USA), foot pressure measurement system, was used to measure the COP displacement time when crossing an obstacle. The reliability of the F-Scan System was demonstrated in previous studies[28–30]. Three hundred frames were collected 22 times a second for 10 seconds at 0.01 seconds per frame. So one can easily obtain the number of frames and times, including those during the stance phase.

The gait cycle is defined by the distribution of plantar foot pressure. Loading response is defined as the period from the initial contact to toe off in the contralateral foot. Mid-stance is defined as the period until the body weight moves onto the forefoot after loading response. Terminal stance is defined as the period until the contralateral foot makes initial contact after mid-stance. Finally, pre-swing is defined as the period until the toe clears after the terminal stance[31]. The time of each subphase was calculated.

Spearman analysis was used to characterize the relationship between dynamic balance ability and COP displacement time during obstacle crossing. Simple linear regression tests were used for causal relationships. The independent variable was the dynamic balance ability, and the dependent variable was the COP displacement time during the stance phase. Statistical analyses were performed using SPSS ver. 12.0, and p-values less than 0.05 were used to identify significant differences.

Table 2. The correlation coefficient between COP displacement time and dynamic balance ability during the stance phase.

	Dynamic balance	0 cm	10 cm	40 cm
Stance phase	DGI	−0.54*	−0.64*	−0.79**
	BBS	−0.59*	−0.72**	−0.73**
	FSST	0.59*	0.73**	0.76**
Loading response	DGI	−0.27	−0.96**	−0.98**
	BBS	−0.31	−0.93**	−0.85**
	FSST	0.32	0.91**	0.85**
Mid-stance	DGI	0.05	0.00	−0.22
	BBS	−0.05	−0.16	−0.23
	FSST	0.02	0.19	0.27
Terminal stance	DGI	−0.71**	−0.16	0.15
	BBS	−0.59*	−0.01	0.14
	FSST	0.61*	0.02	−0.16
Pre-swing	DGI	−0.52*	−0.56*	−0.86**
	BBS	−0.61*	−0.73**	−0.77**
	FSST	0.62*	0.73**	0.80**

*p<0.05, **p<0.01
DGI: Dynamic Gait Index, BBS: Berg Balance Scale, FSST: Four Square Step Test

RESULTS

The DGI, BBS, and FSST, which measured the dynamic balance in this study, were strongly correlated with each other (Table 1).

The COP displacement times during the stance phase when crossing obstacles 0, 10, and 40 cm in height were 1.30±0.38, 1.54±0.55, and 2.13±0.64 seconds, respectively. The means of the three scales–the DGI, BBS, FSST–measured to investigate dynamic balance ability were 20.40±3.16, 51.60±3.76, and 21.18±7.64, respectively. Dynamic balance ability was correlated with the COP displacement time during the stance phase when crossing all the obstacles in older adults. The COP displacement time was negatively correlated with DGI and BBS, and positively correlated with FSST.

The COP displacement time during mid-stance when crossing all obstacles was not correlated with the dynamic balance ability.

The COP displacement time during terminal stance when crossing the obstacle 0 cm in height was negatively correlated with the DGI and BBS and positively correlated with the FSST. The COP displacement time when crossing the obstacles 10 cm and 40 cm in height was not correlated with dynamic balance ability.

The COP displacement time during pre-swing when

Table 3. The estimated regression formula from each height

	Height	DGI		BBS		FSST	
		Regression formula	R^2	Regression formula	R^2	Regression formula	R^2
Stance phase	0 cm	−0.07 × DGI + 2.69	0.31	−0.07 × BBS + 4.64	0.41	0.03 × FSST + 0.62	0.42
	10 cm	−0.12 × DGI + 3.89	0.43	−0.10 × BBS + 6.66	0.46	0.05 × FSST + 0.54	0.43
	40 cm	−0.16 × DGI + 5.44	0.65	−0.14 × BBS + 9.28	0.67	0.07 × FSST + 0.72	0.64
Loading response	10 cm	−0.07 × DGI + 1.64	0.43	−0.05 × BBS + 3.05	0.60	0.02 × FSST − 0.21	0.53
	40 cm	−0.08 × DGI + 2.09	0.64	−0.07 × BBS + 3.76	0.79	0.03 × FSST − 0.23	0.60
Pre-swing	0 cm	−0.03 × DGI + 0.83	0.45	−0.02 × BBS + 1.51	0.52	0.01 × FSST + 0.05	0.51
	10 cm	−0.04 × DGI + 1.01	0.37	−0.03 × BBS + 1.97	0.436	0.02 × FSST − 0.06	0.42
	40 cm	−0.08 × DGI + 1.98	0.86	−0.06 × BBS + 3.56	0.78	0.03 × FSST − 0.19	0.76

DGI: Dynamic Gait Index, BBS: Berg Balance Scale, FSST: Four Square Step Test

crossing all obstacles was negatively correlated with the DGI and BBS and positively correlated with the FSST (Table 2 and 3).

DISCUSSION

Obstacle crossing is the most common cause of falls in elderly people[32], and a decline in dynamic balance ability due to aging leads to poor walking ability[33]. Thus, elderly people use a variety of compensation strategies when crossing obstacles. In order to accurately understand these compensatory strategies for the prevention of falls in the elderly, a clear distinction of the gait cycle is necessary[12–15]. Also, the characteristics of the displacement of the COP during the gait cycle are being used as a tool for evaluation and treatment of balance disorders. Also, analysis of the time required to move the COP during the subphases in the gait cycle has become a parameter that can be used to determine dynamic balance ability in the elderly. Therefore, this study analyzed the changes in the center of pressure (COP) displacement time as one of the compensation strategies that can result in loss of dynamic balance when elderly individuals cross obstacles.

The DGI, BBS, and FSST were used to measure dynamic balance ability. The mean values for each scale were 20.40±3.16, 51.60±3.76, and 21.18±7.64, respectively, and were strongly correlated with one another. This was consistent with the results of previous research: the FSST was strongly correlated with the DGI[34], and the correlation between the DGI and BBS, as well as the correlation between elderly Parkinson's patients and patients who had suffered a stroke, has been demonstrated[35, 36].

There were relationships between dynamic balance ability and COP displacement time at all heights of obstacles during the stance phase. This implies the better the dynamic balance ability, the shorter the COP displacement time is during the stance phase.

The COP displacement time during loading response was strongly correlated with dynamic balance ability when crossing obstacles 10 cm and 40 cm in height. This means that the better dynamic balance ability, the shorter the COP displacement time is for these obstacles during loading response.

The COP displacement time during mid-stance when crossing all the obstacles was not correlated with dynamic balance ability. This means that the displacement time cannot predict dynamic balance ability, whereas the higher the height of obstacles, the larger the increase in displacement time during mid-stance.

The COP displacement time during terminal stance also did not affect dynamic balance ability. Wang and Watanabe[15] found that there were no changes in the COP velocity according to the height of obstacles during terminal stance; this is because the subjects were young adults and were asked to walk at a comfortable pace. They also found that people who had damaged postural stability could be placed in dangerous situations due to factors related to postural control. In this study, however, there was no relationship with dynamic balance ability during terminal stance when elderly individuals crossed obstacles. Hence, we could obtain results showing that the changes in displacement time during terminal stance were not the result of changes in dynamic balance ability. Berg et al.[10] found that when elderly people face obstacles, their single limb support will increase. This means that they spend a long time in potentially unstable postures. However, Rosengren et al.[11] found that the higher the height of obstacles, the slower the walking speed is. Neumann[12] found that the slower the walking speed, the bigger the rate of double limb support while walking; this is a common characteristic in the elderly in order to prevent falls by improving stability. In addition, Rosengren et al.[11] found that the time during single limb support was not correlated with the BBS in the measure of balance. These were consistent with the findings of our study.

The COP displacement during pre-swing was correlated with dynamic balance ability at all heights of obstacles. Specifically, this showed that the better the dynamic balance ability, the shorter the COP displacement time. This means that measuring the COP displacement time during pre-swing can predict dynamic balance ability. Loading response and pre-swing occur during double limb support, and the elderly retained stability by increasing the rate of these two subphases; thus the elderly people seem to be using them as one of the compensation strategies for their poor dynamic balance ability.

During mid-stance, terminal stance, and pre-swing, differences in displacement time according to the height of the obstacles existed. However, only the loading response and pre-swing subphases were correlated with dynamic balance ability. More specifically, differences were present in the COP displacement time during each sub-phase according to the height of the obstacles; however, these differences were not engendered by the dynamic balance ability.

Park and Park[37] measured the COP displacement time in older adults during the stance subphases while crossing obstacles 0, 10, and 40 cm in height. In that study, they found significant differences in displacement time according to the height of the obstacles during mid-stance, terminal stance, and pre-swing. Thus, they proposed that the elderly used different strategies during each stance subphase for maintaining balance according to the height of the obstacles. In the results of this study, only the loading response and pre-swing subphases were correlated with dynamic balance ability. In other words, the COP displacement time during each sub-phase was different depending on the height of the obstacles; however, these differences were not caused by dynamic balance ability. Subjects with poor dynamic balance ability spent more time in loading response and pre-swing while crossing obstacles. It appeared that elderly people retained more time in double limb support and were thereby able to prevent falls due to the increase in the stability of the gait. Specifically, in those with poor dynamic balance ability, the time that their feet touch the ground in loading response and pre-swing increases while crossing obstacles. Therefore, we believed that the COP displacement time during each phase can be used as a parameter that measures dynamic balance ability.

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