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The Effect of COP Progression Velocity Among Gait Phases on Walking Velocity in Elderly with and Without Cognitive Decline

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Abstract

This study examined the relationship between gait speed and center of pressure (COP) progression velocity during different gait phases in elderly individuals with and without cognitive impairment. Sixty elderly participants (≥65 years) were enrolled in this cross-sectional study. They were divided into two groups: 30 without cognitive decline (EWOCD) and 30 with cognitive decline (EWCD). Gait metrics, including speed, cadence, and COP progression velocity, were measured using the F-Scan system during steady-state walking. The stance phase was segmented into four sub-phases: loading response, mid-stance, terminal stance, and pre-swing. Relationships between gait speed and COP progression velocity were assessed using Pearson's correlation and multiple regression analyses. The EWCD group exhibited significantly slower gait speeds, reduced cadence, and lower COP progression velocities compared to the EWOCD group ($p < 0.05$). In the EWOCD group, mid-stance COP progression velocity was the most significant predictor of gait speed ($F = 6.367$, $p < 0.05$, $R^2 = 0.185$). Conversely, in the EWCD group, COP progression velocities during the loading response, mid-stance, and pre-swing phases significantly predicted gait speed ($F = 7.669$, $p < 0.05$, $R^2 = 0.551$). Mid-stance COP progression velocity had the greatest influence on gait speed in the EWCD group. Mid-stance COP progression velocity is a key determinant of walking speed in elderly individuals, particularly those with cognitive decline. Enhancing mid-stance stability may improve mobility in this population.

Keywords: *Gait Speed, Center of Pressure, Cognitive Decline, Elderly, Gait Phases.*

Introduction

Cognitive decline is a prevalent condition among older adults, characterized by a gradual deterioration in cognitive abilities as individuals age [1]. In elderly with cognitive decline, impairments in executive function and attention negatively impact postural stability and gait, thereby increasing the risk of falls [2]. These issues are primarily attributed to a decline of frontal lobe function [3-5]. In addition to cognitive status, age, lower limb functionality, and Center of Pressure (COP) progression velocity also influence gait speed [6-9].

Prior research has demonstrated that among elderly individuals without cognitive impairment, COP progression velocity during specific phases of the gait cycle plays a crucial role in determining gait speed. For example, Fuchioka et al. identified mid-stance COP progression velocity as the most influential factor affecting gait speed [9]. Their findings emphasized that the mid-stance phase is critical for maintaining gait speed, suggesting that preserving lower limb mobility during single-leg stance is essential for preventing reductions in walking speed.

In populations with osteoarthritis—a condition commonly observed in aging individuals—spending an increased proportion of the gait cycle in the mid-stance phase has been associated with changes in COP location and tibiofemoral angle [10]. Since crossing obstacles requires sufficient time to stabilize COP movement, the time required to step over an obstacle is longest during the mid-stance phase [11]. Therefore, ensuring stable COP movement during mid-stance is crucial for maintaining balance and appropriate gait speed in the elderly.

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For elderly individuals with cognitive decline, reduced attention and impaired balance control further diminish their ability to stabilize COP movement, leading to slower gait speeds [3, 6-8]. However, studies analyzing COP progression velocity concerning stable gait maintenance in this population remain limited. Therefore, this study seeks to investigate the relationship between COP progression velocity and gait speed in elderly individuals with and without cognitive impairment. Additionally, it aims to identify which phase of the gait cycle is most affected by cognitive decline.

Materials and Methods

Participants

This cross-sectional study was conducted from October 1, 2018, to December 31, 2019, at two Senior Welfare Centers in Seongnam City and one Dementia Relief Center in Guri City, South Korea. A total of 60 elderly individuals aged 65 years or older were enrolled through convenience sampling. Participants were divided into two groups: 30 elderly individuals without cognitive decline (EWOCD) and 30 with cognitive decline (EWCD). The demographic and clinical characteristics of the participants are presented in (Table 1).

Inclusion Criteria

1. No communication difficulties.
2. Ability to walk independently for more than 10 meters without an assistive device.
3. Cognitive ability sufficient to understand verbal instructions provided by the tester.
4. For the EWCD group: a diagnosis of mild cognitive impairment confirmed by a physician.

Exclusion Criteria

1. Visual or auditory impairments that could interfere with the experiment.
2. Musculoskeletal or cardiorespiratory diseases significantly affecting walking ability.

This study was approved by the Institutional Review Board (IRB) of Eulji University (Approval Numbers: EU18-72[2018], EU19-19[2019]). Written informed consent was obtained from all participants before data collection, in accordance with the Declaration of Helsinki.

Table 1. General Characteristics of Participants(N=60)

	EWOCD (n=30)	EWCD (n=30)	P
Sex (Women, n [%])	24/30 (52.2%)	22/30 (47.8%)	0.542
Age (years)	76.20±4.99	77.40±6.20	0.412
Height (cm)	154.64±7.52	153.98±8.63	0.753
Weight (kg)	65.40±12.93	67.41±10.09	0.795
Body mass index (kg/m ^{2})	23.25±2.16	23.59±2.74	0.591
MMSE-K (score)	26.23±2.27	20.27±3.55	0.000*

Procedure and Data Processing

Participants were instructed to walk along a straight, level, six-meter path while wearing F-Scan insoles (Tekscan Inc., USA). Each participant completed three walking trials, and the average values of the recorded gait parameters were used for subsequent analysis. Gait variables such as gait velocity, gait cycle, cadence, and COP progression velocity were measured using the F-Scan system. To ensure steady-state walking data, the first and last steps of each trial were excluded from analysis. (12) The COP coordinates during the stance phase were extracted using F-Scan software (version 7.50) and converted into ASCII format for further processing. (13) The stance phase was categorized into four sub-phases based on the Rancho Los Amigos classification (14) (Figure 1): Loading response, Mid-stance, Terminal stance, Pre-swing.

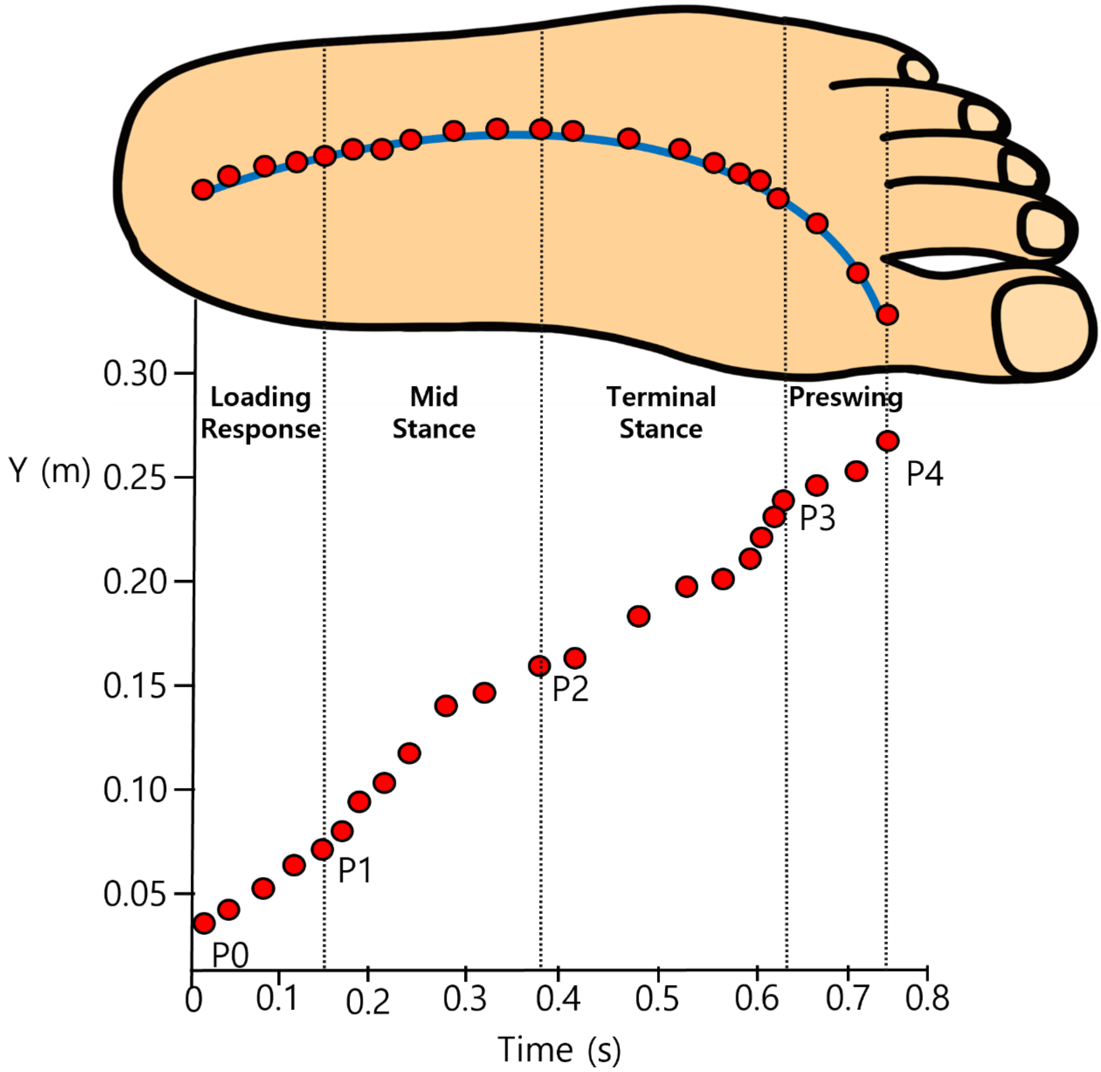

Figure 1. COP displacement pattern during different phases of the stance phase, categorized into four sub-phases based on the Rancho Los Amigos classification: Loading response, Mid-stance, Terminal stance, Pre-swing. P0 signifies the initial point of the gait cycle, whereas P1 through P4 represent the terminal points of each stance phase. The average velocity between the starting and ending points of each stance phase was calculated to determine COP progression velocity.

Statistical Analysis

The Shapiro-Wilk test was used to confirm the normal distribution of all variables. Independent t-tests and Chi-square tests were performed to compare general characteristics and gait parameters between groups. Multiple regression analysis was conducted using a stepwise method to identify variables influencing gait speed. The independent variables included COP progression velocity for each stance phase (loading response, mid-stance, terminal stance, and pre-swing), while gait speed served as the dependent variable, with age adjusted as a covariate. Statistical analyses were conducted using SPSS version 21 (IBM Corporation, Chicago, IL, USA), with the significance level set at $\alpha=0.05$.

Results

Significant differences were identified between the EWOCD and EWCD groups in COP progression velocity and gait speed during the mid-stance phase ($p < 0.05$). The EWCD group demonstrated slower walking speeds, reduced cadence, and lower COP progression velocity across the stance phase compared to the EWOCD group (Table 2).

Table 2. Comparison of Gait Variables Between Groups

Factors		EWOCD (n=30)	EWCD (n=30)	P
Gait speed (m/s)		0.76±.0.13	0.61±0.17	0.000 *
Cadence (step/minute)		97.95±19.22	92.56±18.52	0.274
The COP progression velocity in stance phase	Loading response (m/s)	0.22±0.09	0.18±0.08	0.058
	Mid stance (m/s)	0.30±0.09	0.22±0.11	0.003 *
	Terminal stance (m/s)	0.35±0.12	0.34±0.21	0.900
	Pre-swing (m/s)	0.23±0.11	0.21±0.02	0.267

EWOCD = Elderly without cognitive decline; EWCD = Elderly with cognitive decline; Values = Mean ± standard deviation; *p<0.05

Multiple Regression Analysis

EWOCD Group

In the EWOCD group, multiple regression analysis revealed that mid-stance COP progression velocity was the most significant predictor of gait speed, even after adjusting for age ($F = 6.367$, $p < 0.05$, $R^2 = 0.185$). Detailed regression coefficients are provided in Table 3.

Table 3. Multiple Regression Analysis in the EWOCD Group

Predictable Variables	B	S.E.	β	t	P	VIF
Mid stance COP progression velocity	0.587	0.232	0.430	2.523	0.018 *	1.000

NOTE. B = Unstandardized Regression Coefficient; β = standardized regression coefficient; SE = standard error; VIF = Variance Inflation Factor; *p<0.05

EWCD Group

For the EWCD group, multiple regression analysis showed that COP progression velocities during the loading response, mid-stance, and pre-swing phases were all significant predictors of gait speed ($F = 7.669$, $p < 0.05$, $R^2 = 0.551$). Among these variables, mid-stance COP progression velocity had the strongest influence on gait speed (Table 4).

Table 4. Multiple Regression Analysis in the EWCD Group

Predictable Variables	B	S.E.	β	t	P	VIF
Loading response COP progression velocity	0.739	0.337	0.330	2.196	0.038 *	1.259
Mid stance COP progression velocity	0.735	0.236	0.481	3.122	0.004 *	1.322
Pre-swing COP progression velocity	-2.192	0.867	-0.369	-2.527	0.018 *	1.186

NOTE. B = Unstandardized Regression Coefficient; β = standardized regression coefficient; SE = standard error; VIF = Variance Inflation Factor; *p<0.05

Discussion

This study explored the impact of COP progression velocity during the stance phase on gait speed in elderly individuals with and without cognitive decline. The results indicated that mid-stance COP progression velocity was the most critical factor influencing gait speed in both groups. However, participants with cognitive decline (EWCD) exhibited significantly slower COP progression velocities compared to those without cognitive decline (EWOCD).

Walking requires coordinated forward movement and stability. These depend on effective COP transfer during the stance phase [15]. Analyzing COP progression velocity provides insights into the relationship between body stability and gait speed. Consistent with previous studies, such as Fuchioka et al., this study confirmed that mid-stance COP progression velocity plays a critical role in maintaining gait speed [9]. The mid-stance phase is particularly crucial because it involves single-leg support. During this phase, the body's center of mass transitions over the supporting foot.

Age-related declines in walking ability among elderly individuals are often characterized by shorter stride lengths, increased double-support time, and reduced single-leg stance duration [16,17]. These changes likely reflect compensatory mechanisms to maintain stability at the expense of forward propulsion. Reduced dorsiflexion at initial contact and diminished push-off during the pre-swing phase further contribute to slower gait speeds, as these factors limit effective force production by distal muscles, particularly the plantar flexors [18-20]. Since plantar flexor activity is essential for forward propulsion during mid-stance [21], its decline may explain the reduced COP progression velocity observed in this study.

The EWCD group exhibited significantly slower gait speeds and reduced mid-stance COP progression velocities compared to the EWOCD group. These differences may be attributed to muscle weakness and deficits in spatial memory commonly associated with cognitive decline. The mid-stance phase requires coordinated movements involving ankle dorsiflexion, knee extension, and hip extension. These movement facilitate heel lift and forward propulsion [21–23]. if these movements are impaired, mid-stance duration may be prolonged, leading to a reduction in COP progression velocity.

Cognitive impairment further exacerbates these issues. It limits attention and balance control, both of which are critical for stabilizing COP movement.

Previous studies have highlighted a positive relationship between hip abductor strength and cognitive function. Hip abductors play a vital role during mid-stance by stabilizing the pelvis during mid-stance [24–26]. Weakness in these muscles can cause pelvic tilting and compensatory trunk movements. As a result, walking efficiency is reduced, leading to slower gait speed.

Additionally, during mid-stance, the ankle rocker mechanism helps maintain balance by allowing the center of mass to move forward within the base of support [27]. Weakness of the gluteus medius can lead to compensatory trunk flexion to prevent contralateral pelvic drop, increasing the height of the center of mass and reducing forward movement efficiency. Since COP progression velocity governs the forward displacement of the center of mass [28], its reduction may explain slower gait speeds observed in elderly individuals with cognitive decline.

Spatial memory impairment may also contribute to slower gait speeds in elderly individuals with cognitive decline. Cognitive decline is associated with hippocampal atrophy and memory deficits [29,30], both of which impact gait [31-34]. Research has shown that attention and memory are significant predictors of gait speed [35].

Spatial memory, which is processed within the hippocampus. It is essential for anticipating spatial positioning, which is a critical component of walking [36,37]. If spatial memory is impaired, individuals may struggle to anticipate and regulate movement patterns. This can contribute to slower gait speeds [38].

The findings underscore the importance of targeted interventions aimed at improving mid-stance stability to enhance walking ability among elderly individuals, particularly those with cognitive decline. Rehabilitation programs focusing on strengthening plantar flexors and hip abductors may improve COP progression velocity and gait speed. Additionally, cognitive training interventions targeting spatial memory and executive function may further enhance walking performance in this population.

This study has several limitations. First, the relatively small sample size limits the generalizability of the findings to a broader elderly population. As a result, the conclusions drawn from this study may not fully represent the characteristics of a larger elderly population.

Second, the analysis of gait parameters was limited to center of pressure (COP) progression velocity, without incorporating other biomechanical factors such as joint moments or muscle activation patterns. Including these additional parameters could provide a more comprehensive understanding of gait mechanics in elderly individuals. Third, muscle strength was not assessed using electromyography, nor were kinematic analyses conducted through video recording. These additional assessments could have offered deeper insights into the neuromuscular aspects of gait control. Finally, brain imaging was not performed to evaluate the function of the frontal lobe or hippocampus. Given the known associations between cognitive function and gait performance, neuroimaging data could have further clarified the relationship between cognitive decline and gait characteristics in the elderly.

Future studies should address these limitations by incorporating larger sample sizes, electromyography to assess muscle activation patterns, kinematic analysis for detailed movement evaluation, and neuroimaging to explore brain structures involved in gait control. Additionally, longitudinal studies are needed to investigate causal relationships between cognitive decline and changes in gait parameters over time.

Conclusion

This study examined the relationship between COP (Center of Pressure) progression velocity and gait speed in elderly individuals with and without cognitive decline. The findings confirmed that mid-stance COP progression velocity significantly impacts gait speed in both groups. Notably, elderly with cognitive impairment exhibited lower COP progression velocity during the mid-stance phase, indicating reduced stability in this critical phase, which likely contributes to their slower walking speeds.

These results highlight the need for therapeutic interventions aimed at improving mid-stance stability to enhance walking ability in elderly individuals, particularly those with cognitive decline.

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