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Effects of Obstacle Crossing on Dynamic Postural Control of Parkinson's Disease Patients

Hyeong-Dong Kim, PhD, PT[1)], Hyun Dong Je, PhD[2)], Ji Hoon Jeong, PhD[3)], Kwang-Ho Cho, PhD RT[4)], Sang-Yeol Ma, PhD, PT[5)]

1)Department of Physical Therapy, College of Health Science, Korea University: 1 Jeongneung 3-dong, Sungbuk-gu, Seoul, 136-703, Republic of Korea. TEL: +82 2-940-2835, FAX: +82 2-940-2830, E-mail: hdkimx0286@yahoo.com
2)Department of Pharmacology, College of Pharmacy, Catholic University of Daegu
3)Department of Pharmacology, College of Medicine, Chung-Ang University
4)Department of Radiological Science, Baekseok Culture University
5) Department of Physical Therapy, Masan University

Abstract. [Purpose] This study examined whether people with Parkinson's disease (PD) have postural instability while negotiating obstacles starting from a position of a quiet stance compared to healthy older adults. [Subjects] Ten participants (3 males, 7 females; mean age, 67.8 ± 6.16 years) diagnosed with idiopathic PD (Hoehn & Yahr disability scores ranging from 1 to 3) and ten healthy older adults (4 males, 6 females; mean age, 72.2 ± 4.83 years) were enrolled in this study. [Methods] For each trial, the participants stood quietly in a self-selected foot position with each foot on a force platform. The participants were then instructed to begin stepping over a 10 cm high obstacle or initiate gait at their self-selected pace with the right limb in response to the verbal cue "GO", and continued to walk. The subjects' performance was measured by calculating the changes in the center of pressure (COP) displacements in the anteroposterior (A-P) and mediolateral (M-L) directions using two force platforms. [Results] Using the data of both gait initiation (GI) and obstacle crossing tasks combined for both feet, the A-P and M-L displacements of the COP of the older adults were significantly higher than those of people with PD. On the other hand, the mean COP displacement in the A-P and M-L directions between GI and obstacle crossing were similar. [Conclusion] A decrease in the magnitude of the COP excursion in GI and obstacle avoidance reduced the ability of people with PD to generate forward momentum and maintain lateral stability and motion, factors which are highly related to lateral falling.
Key words: Ageing, Obstacle negotiation, Parkinson's disease

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INTRODUCTION

People with Parkinson's disease (PD) in the late and most advanced stage typically show difficulties with postural control and locomotion. Falls and fall-related injuries have also been reported, even in the relatively early course of PD[1–5)]. The risk of falling for people with PD is twice that of the general healthy population and approximately 64% of people with PD are at risk of falling[6–8)]. These falls result in serious injuries and hospitalization: where 27% of people with PD 10 years after being diagnosed with PD had new hip fractures[9)], and 3% of hospitalized people with PD became wheelchair dependent[10)].

Tripping during obstacle negotiation is one of the most commonly reported causes of falls among older people[11, 12)], and falls during obstacle negotiation is the leading cause of death among the elderly in the United States[13)]. Therefore, it is possible that people with PD who have deficits in postural control and gait are also at a high risk of tripping over obstacle negotiation and falls. Obstacle negotiation requires precise and consistent regulation of foot contact. This involves continuous processing of visual information in advance of the obstacle(s), and adjusting the gait patterns accordingly. Four studies have examined the obstacle crossing behavior of people with PD; two studies[14, 15)] investigated obstacle crossing on a treadmill and the others[13, 16)] introduced different heights of obstacles while subjects walked along a walkway. The two previous treadmill studies compared the obstacle crossing behavior of people mildly affected with PD with age matched healthy people[14, 15)]. In both studies, the subjects were instructed to walk on a treadmill while approaching an obstacle with instructions to step as close as possible to the top of the obstacle, without touching it. The results showed that people with PD demonstrated a slightly higher lead foot clearance. In general, the performance of an obstacle negotiation task by people with PD was worse than that of the age-matched healthy subjects. The increased foot clearance of people with PD might indicate a strategy of securely overcoming the obstacle. However, with task repetition, people with PD could achieve an obstacle crossing performance similar to the age-matched healthy subjects by increasing the duration of the swing phase to clear the obstacle, and by learning the obstacle crossing task well[15].

The two other studies introduced two different heights (an ankle height obstacle and a half knee height obstacle) of obstacles or obstacle heights of 10% of the leg length while people with PD and age-matched healthy subjects walked along a walkway[13, 16]. When the lead foot was placed closer to the obstacle, more frequent stepping on the obstacle with the lead foot, slower approaching speed to the obstacle, shorter step and stride lengths, wider step width, greater stance duration, and greater stride duration were observed in the people with PD compared to the age-matched control group. In addition, the performance of the obstacle crossing task was more disturbed in people with PD as the height of the obstacle increased[16]; however, the foot clearance was not shown to be different between people with PD and controls[16]. Therefore, PD populations demonstrate deficits in postural stability and have a high risk of falling and fall-related injuries during obstacle negotiation.

A difficulty in initiating gait is the one of the most commonly reported movement disorders in PD and is considered an important sign of akinesia. Moreover, many falls in the elderly often occur during postural transitions from the states of static to dynamic postural control, such as the initiation and termination of gait and turning. Therefore, initiating gait can be used as a functionally appropriate investigative tool to provide insight into dynamic postural control and measure the changes in the pathological gait patterns or age-related changes of gait. On the other hand, studies utilizing the gait initiation (GI) of people with PD, to examine static and dynamic postural control and the changes resulting from an advancing age and pathological conditions, have been limited to walking on an even surface. The fact that the effects of obstacle crossing on GI of people with PD have received little attention is somewhat surprising, given that many older adults fall while stepping over obstacles[11, 12], and people with PD have difficulty in performing simultaneous motor or cognitive tasks, crossing obstacles, or attempting to walk in complex environmental settings[17–19].

The center of pressure (COP) is defined as the point where the vertical ground reaction forces (GRFs) are applied to the force platform, and quantification of the movement of the COP during the quiet stance or locomotion can provide useful insights into the postural control instability of people with pathological gait patterns, such as those with PD. For example, people with PD have a reduced ability to generate a COP shift during GI compared to the ability to generate a COP shift in older adults transitioning to frailty[20]. Therefore, examining the COP trajectory variables when people with PD perform obstacle crossing tasks might provide useful information for understanding the mechanisms of balance impairment related to PD, because the COP reflects the response of the central nervous system to movement of the whole body center of mass (COM)[21]. Furthermore, obstacle negotiation is a common skilled motor task commonly used in daily life, and attention is seldom fully focused on obstacles because most obstacles appear suddenly in the field of view.

On the other hand, no study has compared stepping over an obstacle from the position of a quiet stance by adult subjects with different levels of functional ability, such as healthy older adults and people with PD, whose postural control and gait has deteriorated. Therefore, the purpose of the current study was to examine whether people with PD have postural instability while negotiating obstacles from the position of the quiet stance compared to healthy older adults. The COP measures reflect the muscle responses during the maintenance of dynamic stability while negotiating obstacles. A reduced displacement of the COP in either direction can indicate instability[21] or the possible use of an alternative postural control strategy, which is possibly less efficient at developing the momentum needed to initiate gait[22]. In the present study, the postural instability was quantified by measuring the COP variables, such as the COP displacement. It was hypothesized that people with PD would exhibit decreased COP movements suggesting greater instability than healthy older adults. We also hypothesized that people with PD would have more difficulty with an increased postural challenge associated with the transition from GI to stepping over obstacles.

SUBJECTS AND METHODS

Ten participants (3 males, 7 females; mean age, 67.8 ± 6.16 years) diagnosed with idiopathic PD and ten healthy older adults (4 males, 6 females; mean age, 72.2 ± 4.83 years) were enrolled in this study. All participants with PD had Hoehn & Yahr (H&Y) disability[23] scores ranging from 1.5 to 3 and could walk independently at least 5 m without ambulatory aids. They were being treated with anti-Parkinson's medication, fully responding to their PD medications, and were tested in the "on medication" state, which is approximately 1–1.5 hours after taking their anti-Parkinson's medications. No freezing gait was observed in the participants with PD during the study. The exclusion criteria were 1) severe dementia (a Mini Mental Status Examination (MMSE)[24] score < 20); 2) a previous history or evidence of neurological impairment, other than PD, which could interfere in locomotion; and 3) inability to walk independently.

The inclusion criteria for healthy elderly participants was a Berg Balance Scale (BBS)[25, 26] score > 50, a Frenchay Activities Index (FAI)[27] score > 50, and a Physical Function (PF)[28] score > 20. All elderly participants scored a minimum of 25 on the MMSE[24]. Previous studies[29–31] reported that these tests are reliable and valid. The elderly participants had no history of neurological or orthopedic or cardiac problems that prevented their participation. No elderly participant reported falls in the previous 12 months. All participants provided their written informed consent and this study was approved by the University Institutional Review Board. Table 1 summarizes the subjects' characteristics.

The participants with PD were first evaluated using the Unified Parkinson's Disease Rating Scale Motor Subscale[32], and then evaluated using the MMSE. Older adults were also evaluated using BBS, MMSE, FAI, and PF. Two force platforms (AMTI, Newton, MA, USA), which

Table 1. Characteristics of the patients with PD and healthy older adults

Participant details	Patients with PD	Healthy older adults
Age (years)	67.8 (6.16)	72.2 (4.83)
Male/female	3/7	4/6
Height (cm)	160.1 (5.15)	159.4 (4.2)
Weight (kg)	55.3 (7.65)	58.5 (6.55)
MMSE/30	26.1 (0.74)	28.5 (1.27)
Time with PD (years)	6.7 (3.14)	N/A
Hoehn and Yahr scale/range	1.9 (0.39)/1-3	N/A
UPDRS motor subscale score/56	18 (2.45)	N/A
BBS/56	N/A	53.1 (1.66)
FAI/60	N/A	52.7 (3.5)
PF/30	N/A	28 (1.5)

Note. The values represent the mean ± standard deviation (SD). Abbreviations: PD, Parkinson's disease; MMSE, Mini Mental Status Examination; UPDRS, Unified Parkinson's Disease Rating Scale; BBS, Berg Balance Scale; FAI, Frenchal Activities Index; PF, Physical Functioning of the SF-36 Health Surveys.

were mounted level to a walkway surface (5 m in length and 1.5 m in width), were used to measure the ground reaction forces (GRFs) when the participants stepped over obstacles or initiated gait. The amplified force platform signals were sampled on-line at a rate of 1000 Hz for 10 seconds (AMTI). The GRFs collected from the force platforms were processed and the COP data were analyzed using BioAnalysis v2.0 software (AMTI, Watertown, MA, USA). The test conditions also included the use of obstacles (10 cm in height, 10 cm in depth and 140 cm in width) made of wood for obstacle clearance.

The experimental set-up is shown in Figure 1. For each trial, the participants stood quietly in a self-selected foot position with each foot on a force platform in a relaxed posture. Each participant's foot on the force plate was traced and the tracings were used before starting a new trial of GI or obstacle crossing to reposition the foot on the force plate to increase the between-trial consistency. The participants were then instructed to begin stepping over a 10 cm high obstacle or initiate gait at their self-selected pace with the right limb in response to the verbal cue "GO", and continued to walk with the left limb. For both GI and the obstacle crossing conditions, the two force platforms were placed adjacent to each other with narrow edges to measure the GRFs. For all conditions, each participant was instructed to complete two practice trials to familiarize themselves with the experimental procedure and performed approximately five successful experimental trials. The participants completed the experimental trials under the following conditions: (1) GI, (2) stepping over a 10 cm high obstacle. The order of each condition was selected randomly for each participant. All participants were required to wear flat-soled shoes normally used for everyday walking or sports activities.

Two-way repeated analysis of variance (ANOVA) was used to determine the main and interaction effects. The single degree of freedom mean contrasts were used to determine the source of significant effects. Statistical significance was accepted at $p<0.05$. The independent variables were groups (people with PD, older adults) and stepping condition (GI, stepping over an obstacle). The dependent variables selected for analysis included the anteroposterior (A-P) and mediolateral (M-L) displacement of the COP. The A-P (or M-L) displacement of the COP was defined as the total distance (or difference) between the minimum and maximum A-P (or M-L) COP location for the length of time either the right or left foot was in contact with the force platform. Statistical software SPSS 14.0 KO (SPSS, Chicago, IL, USA) was used for all statistical analyses.

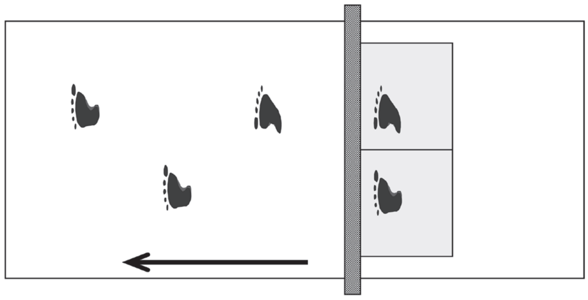

Fig. 1. Experimental set-up. The arrow indicates the direction of movement.

RESULTS

This study examined whether there is differential modulation of COP variables, such as COP displacement in the A-P and M-L directions in response to GI and crossing an obstacle and whether there are group-related differences. The COP displacement in the A-P and M-L directions was greater for older adults than for people with PD for both the right and left feet. With the data for both GI and obstacle crossing tasks combined for both the right and left feet, the A-P and M-L displacements of the COP of people with PD

Table 2. Mean values (± SD) of the COP variables (cm) of both feet

Dependent variables	GI	10 cm obstacle
Right foot		
A-P displacement*		
PD group	11.56 (2.26)	10.94 (1.90)
Elderly group	26.26 (7.16)	23.09 (7.67)
M-L displacement*		
PD group	7.99 (2.35)	6.99 (1.70)
Elderly group	15.40 (6.36)	12.04 (4.60)
Left foot		
A-P displacement*		
PD group	13.45 (1.72)	13.91 (1.01)
Elderly group	21.62 (4.47)	20.13 (5.94)
M-L displacement*		
PD group	9.80 (2.10)	9.69 (1.99)
Elderly group	16.76 (6.25)	13.46 (5.41)

*significant difference among all groups ($p<0.05$). SD: Standard deviation; PD: Parkinson's disease; A-P: anteroposterior; M-L: mediolateral; COP: center of pressure.

were significantly lower than those of the elderly subjects ($p<0.01$) (Table 2). The COP displacement in the A-P and M-L directions of the elderly subjects was 183% and 167% higher than those of people with PD, respectively. On the other hand, there were no significant differences in GI and obstacle crossing for the COP displacement in the A-P and M-L directions when combining the data for both groups for both the right and left feet ($p>0.05$). The mean COP displacement in the A-P and M-L directions between the GI and obstacle crossing were similar. Table 2 lists the mean COP variables for both groups.

DISCUSSION

This study examined how people with PD and older adults modulated the A-P and M-L displacements of the COP while stepping over an obstacle or initiating gait. As expected, the A-P and M-L displacements of the COP while stepping over an obstacle and initiating gait were significantly lower for people with PD than the older adults. When the data for both tasks were combined, the mean COP displacements in the A-P and M-L directions in people with PD were 55% and 60%, respectively, of the mean COP displacement values of older adults. Reduced COP displacement in the A-P and M-L directions in PD patients may be related to impaired balance, akinesia, hypokinesia or tremor/movement discontinuities associated with PD[20]. These findings are in agreement with previous studies[21, 22, 33–36], which have reported that the magnitude of backward COP displacement decreases with advancing age and disability, such as PD, thereby reducing the amount of forward momentum needed to move the body forward.

Backward displacement of the COP is needed to generate forward momentum to initiate gait[37]. A decrease in the magnitude of the forward momentum while initiating gait results in a decreased forward COM in people with PD. A dysfunction in centrally mediated anticipatory postural adjustments is believed to be responsible for a decrease in the backward displacement of the COP[37]. When initiating gait, there is an inhibition of tonic soleus (SOL), which is active during the quiet stance, followed by the onset of tibialis anterior (TA) in both the swing and stance limbs. This combination is responsible for the backward movement of the COP[38–40]. Previous studies[37, 41] have reported that with advancing age, the initial activation of the ankle plantar flexors, such as the SOL and the gastrocnemius (GA), remains active, even after the onset of the TA during the initial phase of GI. This results in a reduced backward displacement of the COP. PD patients were also observed to generate insufficient dorsiflexion torque due to the inappropriate and/or inefficient TA activation during the initiation of gait, which limited backward displacement of the COP[34, 35]. These findings of decreased A-P displacement of the COP in PD patients indicate that PD subjects are unable to turn off previously activated muscles, such as the SOL and GA, due to an inability to gate or scale the postural and voluntary components of the motor task, leading to less forceful postural control and less stabilization[42].

When initiating gait, the M-L displacement of the COP created by the swing limb hip abductors moves laterally toward the swing limb and propels the body toward the stance limb[29]. Therefore, stance limb loading and swing limb unloading are achieved simultaneously before the stepping motion. The displacement of the COP towards the swing limb of individuals with PD during GI is significantly smaller than that of healthy age-matched older adults[21, 34, 36]. In the present study, the mean M-L displacement of the COP of the subjects with PD was 8.62 cm (ranging 6.99–9.80 cm), which was 5.8 cm less than the displacement of the elderly subjects (14.42 cm, ranging 12.04–16.76 cm). These values are similar to those reported in previous studies (people with PD: 10.5 cm, older adults: 18 cm)[20, 43]. The M-L displacement of the COP while initiating gait is controlled by the coordinated action of the hip abductor and adductor muscles[44]. Moreover, muscle action at the ankle and hip moves the COM forward and toward the intended stance limb. A previous study[45] reported that the swing limb unloading during a self-initiated sideways weight shift followed by a forward stepping is accompanied by large increases in the activities of the stance limb gluteus medius and swing limb adductors. The reduced ability to modulate COP excursion in the M-L direction in GI by people with PD might be due to the alterations in the proximal musculature strength[46], and particularly the muscles of the hip[47].

In contrast to the original hypothesis, no differences were detected in both COP variables between the GI and obstacle crossing for both groups. When both PD patients and elderly subjects initiated gait or stepped over an obstacle, their A-P and M-L displacements of the COP tended to remain similar in both tasks. The finding that the A-P and M-L displacements of COP in subjects with PD and elderly subjects during GI were similar to those observed during obstacle crossing suggests that the 10 cm high obstacle used in this study was not a threat to the losing balance of those with unimpaired balance, such as healthy older adults or individuals with postural instability related to central nervous system disease (e.g. PD). This is consistent with the findings of a previous obstacle crossing study using an obstacle, 10 cm in height[43], which showed no differences in the COP variables, such as COP displacement in the A-P and M-L directions, between GI and obstacle crossing of older and young adults. Future research using a higher obstacle or dynamic obstacle crossing, which requires greater balance demand than unobstructed walking in more advanced stage of PD patients, will be needed to determine if changes in the COP variables can occur under more complex and demanding conditions.

This study had several limitations. There was a relatively small sample size. In addition, the COP measures not the movements themselves, but the secondary consequences of swaying movements, such as movements of COM. Therefore, it is essential to measure the spatial and temporal events of the gait parameters to provide useful insight into the deterioration of postural-control in people with PD. The collective analysis of the kinematic and kinetic data in conjunction with electromyographic recordings may help explain the differences between the population of the interest in the performance of functional tasks, such as sit to stance, GI, obstacle crossing, and stair negotiation. Finally, the relationship between the COP and COM has attracted considerable interest as an indicator of balance. The magnitude of the separation between the COP and COM, which is referred to as the COP-COM moment arm, is considered a sensitive and valid tool for examining the changes or problems in postural stability[20]. Further studies will be needed to assess the dynamic stability of people with PD during a range of activities, such as rising from a chair, stair climbing, and stepping over obstacles using this technique.

In conclusion, these findings suggest that people with PD produce significantly less movement of the COP in the A-P and M-L directions during obstacle crossing and GI than older adults. A decrease in the magnitude of a COP excursion in GI and obstacle avoidance reduces the ability of people with PD to generate forward momentum and maintain lateral stability and motion, factors which are strongly related to lateral falling. These results provide preliminary data on postural deficiencies during obstacle avoidance and GI as well as a scientific basis for the development of gait rehabilitation strategies in these populations, specifically aimed at improving the COP displacement in both the posterior and lateral directions.

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