ORIGINAL ARTICLE

Gait Initiation and Dynamic Balance Control in Parkinson's Disease

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ABSTRACT. Hass CJ, Waddell DE, Fleming RP, Juncos JL, Gregor RJ. Gait initiation and dynamic balance control in Parkinson's disease. Arch Phys Med Rehabil 2005;86:2172-6.

Objective: To determine whether the magnitude of the separation between the center of pressure (COP) and the whole-body center of mass (COM) during gait initiation can differentiate patients with varying severity of Parkinson's disease (PD) disability.

Design: Cross-sectional, intact groups research design.

Setting: Biomechanics research laboratory.

Participants: Forty-three patients were stratified into 2 groups based on the Hoehn and Yahr (H&Y) disability score, which heavily favors balance in determining disability. The 2 groups were: H&Y score of 2.0 or less (n=23; age, 61±10y) or H&Y score of 2.5 or higher (n=20; age, 70±9y).

Interventions: Not applicable.

Main Outcome Measures: The peak COP-COM distance represents the maximum separation between the location of the whole-body COM and the ground reaction force's COP, and thus is an indicator of dynamic balance control. The peak COP-COM was evaluated during 3 phases of the COP trajectory during a gait initiation task.

Results: The peak magnitude of the COP-COM distance was significantly greater during the end of the single-support phase in the less disabled patients (H&Y score ≤2.0) than in more balance disabled patients (H&Y score ≥2.5) (P=.004).

Conclusions: The differences in COP-COM distances between these H&Y groups suggest that patients with PD who have impaired postural control produce shorter COM-COP distances than do persons without clinically detectable balance impairment. This method of evaluation could prove a useful quantitative index to examine the impact of interventions designed to improve ambulation and balance in PD.

Key Words: Balance; Gait; Parkinson disease; Rehabilitation.

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Supported by the National Institutes of Health (grant nos. 5 R01 AT000612, 5 P30 AT000609) and the Center for Human Movement Studies, Georgia Institute of Technology.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated.

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0003-9993/05/8611-9804$30.00/0

doi:10.1016/j.apmr.2005.05.013

POSTURAL INSTABILITY IS an important contributor to incapacitation in patients with Parkinson's disease (PD). Problems with posture and stability become increasingly severe as the disease progresses despite otherwise adequate pharmacologic therapies. Indeed, the problems with posture and balance observed in this population during balance testing are well documented.[1-4] Persons with PD exhibit a deficit in maintaining equilibrium not only during quiet stance but also during transitions between states of static and dynamic equilibrium, such as during gait initiation, termination, or turning.[5-9]

Quantification of the movement of the center of pressure (COP) during quiet stance has provided useful insight into postural-control deficiencies in balance-challenged people, such as those with PD.[10] However, 1 limitation of using the COP alone to evaluate postural stability is that it measures the secondary consequences of swaying movements, ie, movements of the center of mass (COM) and not the movements themselves.[11] It has been suggested that the combined analysis of the movements of the COP and COM during quiet stance and dynamic activity provides better insight into the assessment of balance than analyzing either variable alone.[11-15] Recently, the COP-COM distance has been proposed as a variable sensitive to changes or problems in postural stability. The COP-COM distance measured at a given time may enhance our interpretation of the COP and COM displacements and provide better insight into postural control. Static postural control[11,12] as well as dynamic stability during activities such as rising from a chair, stair climbing, stepping over obstacles, and gait initiation have been evaluated using this technique.[8,16-18]

Jian et al[19] suggest that gait initiation cannot begin unless the COM and COP separate. The ability to separate these 2 by manipulating the COP has major implications on momentum generation and balance control.[16] The greater the COP-COM distance, the greater the moment arm for the ground reaction forces to act for momentum generation. However, the greater the distance, the greater the need for active postural control to counteract the increased moment arm for the body-weight vector acting around centers of joint rotation. The ability of this measure to capture the interplay between momentum generation and dynamic stability arising from active postural control suggests that it may serve as an indicator of disability during gait initiation. Indeed, the peak magnitude of the COP-COM distance during this task has been used to discriminate between healthy adults and those with disability.[8,16] Chang and Krebs[16] reported that COP-COM was significantly greater in healthy elderly adults than in disabled elders and those with vestibular hypofunction. Further, they reported that the peak COP-COM distance is a sensitive screening tool able to discriminate between healthy and disabled elders. Recently, Martin et al[8] reported that persons with PD displayed smaller COP-COM magnitudes compared with healthy older adults throughout the gait initiation cycle and suggested that the COP-COM relation provided a means of identifying problems during gait initiation in patients during the early stages of PD.

Table 1: Clinical Characteristics of the 2 Participant Groups

Group	H&Y Score	UPDRS Total	UPDRS Motor	UPDRS Posture	UPDRS Gait	UPDRS Stability
H&Y ≤2.0						
Mean	1.9±0.0	37.0±2.5	20.0±1.4	1.1±0.2	0.8±0.1	0.4±0.1
Range	1.5–2.0	13.5–51	11–32.5	0–2	0–2	0–2
H&Y ≥2.5						
Mean	2.7±0.0*	42.9±2.8	23.3±1.4	1.3±0.2	0.9±0.1	1.1±0.1*
Range	2.5–3.0	31–58.5	17–29	0–2	0–2	0–2

NOTE. Values are mean ± standard error of the mean.
Abbreviation: UPDRS, Unified Parkinson's Disease Rating Scale.
*Significantly different from H&Y ≤2.0 group.

Results from these investigations suggest that the peak magnitude of the COP-COM distance can be used to discriminate between healthy adults and those with varying degrees of disability. With increased PD severity, there is a concomitant increase in the incidence of postural instability and increased difficulty initiating gait. The purpose of this investigation was to examine the extent to which dynamic balance control as measured by the COP-COM distance during gait initiation is sensitive to disease severity of PD.

METHODS

Forty-three patients with idiopathic PD volunteered to undergo motion analysis during gait-initiation tasks. These patients were recruited from the Movement Disorders Clinics at Emory University School of Medicine. All patients with PD were being treated with stable doses of dopaminomimetics and were tested while clinically "on," or fully responding to their PD medications. At the time of testing, none of the patients exhibited any dyskinesia, dystonia, or other signs of involuntary movement. Patients were stratified into 2 groups based on the Hoehn and Yahr (H&Y) disability score, which heavily favors balance in determining disability. The 2 groups were: H&Y score of 2.0 or less (n=23; age, 61±10y; mass, 83.9±20.1kg; height, 176.6±11.3cm) indicating unilateral or bilateral disease without impairment in balance or H&Y score of 2.5 or higher (n=20; age, 70±9y; mass, 78.9±12.5kg; height, 171.2±5.4cm) indicating mild bilateral disease with recovery on pull test (2.5) or mild to moderate disease with some postural instability, physically independent (3.0). Descriptive clinical scores for both groups of participants are listed table 1. Both groups of participants provided written informed consent before participating in the study as approved by the Georgia Tech and the Emory University Institutional Review Boards.

Gait initiation trials were performed along an 8-m walkway, containing a force platform surrounded by a 6-camera Peak Motus 3D Optical Capture system.[a] Ground reaction forces were collected using a multicomponent force platform[b] mounted flush with the surface of the walkway and oriented so that the laboratory coordinate system coincided with the right posterior corner of the force platform, with the *x* axis aligned in the direction of forward progression. Forces and moments along the 3 principal axes were sampled at 300Hz.[a] Force platform data were subsequently used to calculate the instantaneous COP and the dependent variables of interest using software[c] developed in the Center for Human Movement Studies at Georgia Tech. Kinematic data were collected at 60Hz using a 6-camera, 3-dimensional Optical Capture system.[a] We used an L-shaped calibration frame (4 control points, 1.50×1.00×0.09m) and wand (2 control points, .913m) for 3-dimensional space reconstruction. Within the calibrated volume, the motion capture system was accurate to 2mm. The video cameras and force platform recordings were time synchronized using the Peak Motus video analysis system.

During the testing session, participants wore dark-colored tight-fitting shirts, shorts, and athletic shoes. Passive retroreflective markers were placed over landmarks according to the Helen Hayes marker system. In addition, markers were attached bilaterally to the subject's styloid process of the ulna, lateral epicondyle of the humerus, and the acromion process. The 21 markers were used to construct a simple 9-segment model. Estimates of segment mass centers were based on Dempster's anthropometric data and the calculation of the location of the whole-body COM was calculated using the Peak Performance software.[a] The distance between the vertical projections of the COM in the transverse plane and the COP[8] was calculated using software developed in the Center for Human Movement Studies and is referred to as the COP-COM in this investigation (fig 1).

Experimental Procedure

Participants began each trial standing quietly on the force platform in a relaxed position. Initial positioning of the feet was self-selected. In response to a verbal cue, the participants initiated walking and continued walking for several steps. The verbal cue instructed the participant which limb to use to initiate walking and triggered an electronic event marker that identified the beginning of the movement. For each participant, 1 to 2 practice trials were followed immediately by 3 data-collection trials for each leg performed at a self-selected pace. Thus a total of 6 experimental trials were evaluated for each person. All trials initiated gait in the forward direction.

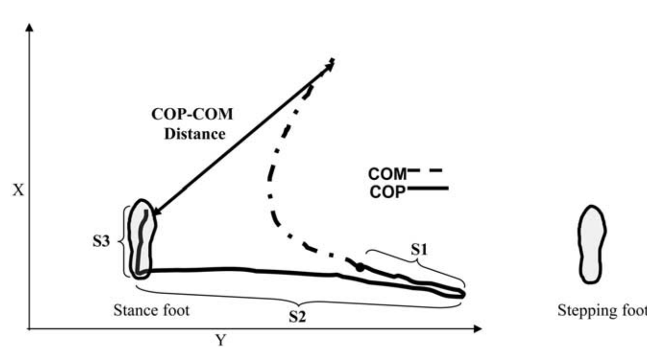

Fig 1. Representative record of an overhead view of the path of the COP and COM during forward-oriented gait initiation when stepping with the right foot. The arrow represents the calculated distance between the COP-COM.

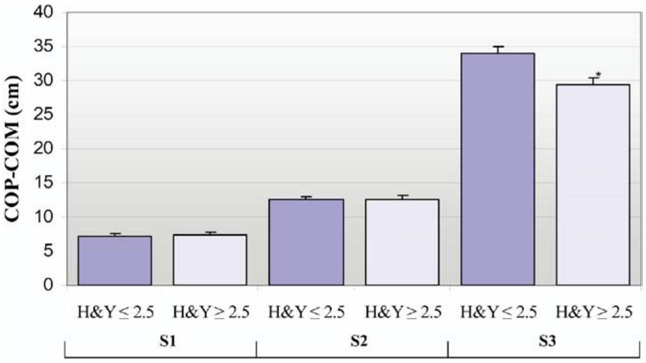

Fig 2. Maximum COP-COM separation values normalized to body height for both experimental groups during the S1, S2, and S3 regions of the COP gait initiation trace. Values are mean plus standard error of the mean. *Significantly different from ≤2.0 group.

The magnitude of the COP-COM distance was evaluated during each of 3 important periods of gait initiation that have been defined previously.[20] Briefly, the S1 period encompasses the uncoupling of the COP and COM as the COP displaces posterior and toward the intended stepping limb. During the subsequent S2 period, the COP moves mediolaterally toward the stance foot. Finally, during the S3 period the COP moves anteriorly under the stance foot (see fig 1). The maximum distance between the COP and COM during each of these time periods was calculated.

Data Analysis

Our primary hypothesis was that differences in the peak magnitude of the COP-COM distance exist between the 2 participant groups during the 3 phases of the COP trajectory. Thus, we used independent *t* tests to compare differences between groups for the peak COP-COM distance during the S1, S2, and S3 periods of the gait initiation cycle. An a priori α level of .05 was used to determine statistical significance. We used descriptive statistics to characterize the participants in each group.

RESULTS

All participants were able to complete the experimental trials without incident or other disruption, such as festination or freezing. Participant's age, H&Y score, and the Unified Parkinson's Disease Rating Scale balance score were the only personal characteristics found to be significantly different between the 2 experimental groups. The H&Y $<$2.0 group was 9 years younger and possessed greater stability than the H&Y $\geq$2.5 group. Because there were no significant differences between groups in height or weight, the experimental COP-COM parameter was not normalized to body dimensions.

For all subjects, the peak COP-COM distance ranged from 7.32$\pm$1.95cm during S1 to 31.65$\pm$4.97cm during S3. The peak COP-COM distance did not differ significantly between the 2 groups during the S1 (P=.65) and S2 (P=.81) gait initiation periods. During S3, the peak COP-COM was 16% greater in the H&Y $\leq$2.0 group than in the H&Y $\geq$2.5 group (P=.004) (fig 2). In all participants, the greatest COP-COM distance occurred at the end of single-support phase and just before initial contact of the first swing limb.

DISCUSSION

Because age- and disease-related declines occur in postural control systems, it is reasonable to expect observable changes in dynamic stability during functional tasks such as gait initiation. Further, changes in dynamic stability should be manifested in altered patterns of COM motion and its coordination with movement of the COP. Results of the present investigation show that the relation between the movement of the COP and the COM provides a means to identify and quantify difficulties in dynamic balance control in PD patients at various stages of the disease. A significant severity-related difference was found in the peak COP-COM distance during the S3 phase of the gait initiation task. The 16% smaller peak COP-COM distance suggests that a conservative strategy may be adopted by the more severely affected patients. By maintaining a shorter distance at the end of the single-support phase, the more advanced patients are able to reduce the mechanical and postural challenge of initiating the locomotor task.[17] Hahn and Chou[17] suggested that a smaller COP-COM distance would reduce the magnitude of muscular strength required because of the smaller moment arms created for the body weight vector acting around centers of joint rotation in the supporting limb. Additionally, Davis et al[21] observed a significant positive association between leg strength and functional reach (an assessment of anteroposterior stability), indicating that strength may influence how far a person can tolerate the movement of the COM in front of the base of support. We compared isokinetic knee extensor strength between the 2 participant groups and observed that the less-affected patients possess significantly greater peak torque (40% greater, P=.027) than their more-affected counterparts. Thus, greater strength may be an important contributor to the greater peak COP-COM observed in the less-advanced patients during this phase of gait initiation.

Martin et al[8] have suggested that shortening the COP-COM distance may also reflect a need to preserve stability because of impairments in postural control and/or an inability to generate adequate momentum using the COP "shift mechanism" during the S1 phase. To evaluate the functional effectiveness of the gait-initiation motor program in generating momentum, we examined the relation between the time integral of the COP displacement and the amount of momentum generated in the forward and stance directions, respectively. The evaluations indicated that both groups generated similar momentum in both the forward (P=.607) and stance (P=.654) directions. Thus, differences in momentum generation are not likely contributors to the observed differences in the peak COP-COM distance. Also, differences in the participant group's self-selected speed of initiation could affect the COP-COM distance. However, differences in speed were not likely to have been causative factors because (1) no differences were observed in the posterior displacement of the COP during S1 (H&Y $\leq$2.0, 2.8cm; H&Y $\geq$2.5, 2.8cm), which is known to be directly related to stepping velocity; (2) the mean velocity of the COP during the locomotor S3 phase was similar between groups (H&Y $\leq$2.0, 1.3m/s; H&Y $\geq$2.5, 1.4m/s); and (3) the mean velocity of the COM was similar (H&Y $\leq$2.0, 1.2m/s; H&Y $\geq$2.5, 1.1m/s).

Postural control during dynamic activities such as initiating gait and locomotion requires the integration of multiple sensory and motor pathways so that the central nervous system can coordinate the anticipatory/postural and intentional/movement components of the task.[22,23] Patients with PD are known to have limitations in proprioception, muscle weakness, and movement speed, and reduced general mobility.[24] It is likely then that some combination of these factors may help explain the observed reduction in the COP-COM distance during this locomotor phase of gait initiation as the disease advances.

In a review of the literature, there seems to be a continuum of values for the peak COP-COM distance that may be related to disability. Data from Jian[19] and Burleigh-Jacobs[25] and colleagues suggest that the peak distance between the COP and COM in healthy young adults is approximately 23cm during gait initiation. Chang and Krebs[16] reported a peak COP-COM distance of 21cm for healthy elderly and about 16cm for older adults with disability. Using a slightly different calculation for the COP-COM, Martin et al[8] observed peak COP-COM distances of 30cm in patients with PD and 32cm in older adults without PD during gait initiation. Nine of the 12 participants in the Martin study would have been in H&Y ≥2.5 group. Thus, the observed similarities in the magnitude of the COP-COM between the less affected patients in the present study and those in Martin (30cm vs 29cm) should be expected. Of interest, the 33-cm COP-COM produced by the H&Y ≤2.0 participants is remarkably similar to the 32.2-cm distance produced by the nonparkinsonian older adults (69y) tested by Martin. In other words, younger less-affected patients with PD (61y) performed similarly to healthy adults who are 8 years older. These findings, in conjunction with previous data, suggest there may be a continuum of performance during gait initiation.[8,9,26-28] With increasing age and disability, the temporal features of gait initiation are slower and more variable while the spatial parameters become smaller and more variable, leading to decreased separation between the COP and COM.

Data presented by Chang and Krebs[16] also show that the COP-COM distance was significantly smaller in the disabled elderly than in the healthy elderly during time periods similar to S1 and S2 identified here. Similarly Martin[8] observed significantly larger COP-COM distances in older adults than in subjects with PD during both of these time periods. These findings imply that people with increased disability limit the separation of the COP and COM during the postural or preparatory phase of gait initiation. Previous research has shown that disabled older adults and patients with PD produce smaller COP displacements compared with aged-matched controls during the S1 phase.[7-9] This reduction in COP displacement leads to a decrease in the displacement of the COM forward and toward the stance limb and results in shorter COP-COM distances. However, evaluation of the COP displacements in the present evaluation revealed that both participant groups produced similar posterior (H&Y ≤2.0, 2.8cm; H&Y ≥2.5, 2.8cm) and lateral (H&Y ≤2.0, 4.4cm; H&Y ≥2.5, 4.2cm) COP displacements. These similarities in COP displacements likely explain the lack of differences observed in COP-COM during the postural or preparatory phases. Thus, the ability to uncouple the COP and COM via shifts of the COP does not seem to be affected by disease progression.

CONCLUSIONS

During gait initiation, there is deliberate uncoupling of the COP and COM to generate forward momentum. However, the greater the separation of the COP and COM, the higher the demands placed on postural control systems. Thus, persons with balance deficiencies may limit the COP-COM distance to enhance control of the movement. Our data indicate that the severity of PD does not affect the interaction of the COP and COM during the postural phases (S1) but rather during the locomotor phase (S3) of gait initiation. The more affected patients, ie, those with an H&Y score greater than 2.5, appear to limit the COP-COM magnitude during the locomotor phase of gait initiation to potentially reduce muscular effort and to enhance stability. Our findings of differences in the peak COP-COM during the locomotor stages but not in the postural stages suggest that dynamic postural control may be more affected than static postural control as they transition from having normal balance to having early balance difficulties. Further, our data indicate that the COP-COM distance measure may provide clinicians with a quantifiable and sensitive indicator of impending difficulties in movement performance in patients with PD.

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