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GAIT INITIATION IN OLDER ADULTS WITH POSTURAL INSTABILITY

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Abstract

Background—This study examined changes in the translation of the center of pressure during forward and lateral (90 degrees to the side) gait initiation in two populations of older adults with postural instability.

Methods—Twenty-eight older adults transitioning to frailty and 16 persons with Parkinson's disease in the "on medication state" were evaluated during initiation trials. Displacements, velocities, and smoothness of the center of pressure trace were calculated and compared.

Findings—Both groups produced movements of the center of pressure that on average were reduced compared to healthy populations. Adults transitioning to frailty were able to scale the output of the motor program so forces that propel the body in the intended direction of movement were maximized as evidenced by movements of the center of pressure. The adults transitioning to frailty produced patterns of center of pressure trajectories that were more similar to healthy adults where as individuals with Parkinson's disease produced trajectories that were counterproductive to producing efficient gait initiation in both the forward and lateral direction.

Interpretation—These findings suggest that persons with Parkinson's disease even when in the medicated state exhibit inefficient postural adjustments during both forward and lateral gait initiation and that these postural adjustments are more susceptible to deterioration from the complex interaction of central and peripheral changes associated with Parkinson's disease than to aging alone.

Keywords

Parkinson's disease; Transitioning to frailty; initiating gait; locomotion; posture; Parkinsonism

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Individuals diagnosed with Parkinson's disease (PD) and older adults transitioning to frailty are two specific populations of older adults that are highly susceptible to falls, are known to possess significant fear of falling, and demonstrate disturbances in postural stability and gait abnormalities (Kressig et al., 2004, Wolf et al., 2003, Adkin et al., 2003, Morris et al., 2001, Hass et al., 2004). Adults transitioning to frailty can be defined as those persons not meeting the criteria for either frail or vigorous based on Speechley and Tinetti's (Speechley and Tinetti, 1991) classification scheme of ten attributes of frail or vigorous adults. Using this classification criteria (Speechley and Tinetti, 1991), Kressig et al. (Kressig et al., 2004) observed that the spatial and temporal features of gait in this population are characterized by reduced gait velocity and stride lengths and greater variability (greater standard deviations in spatiotemporal parameters) compared to robust older adults. Similarly, Hass and colleagues (Hass et al., 2004) observed that adults transitioning to frailty produced anticipatory postural adjustments during gait initiation that were smaller and less forceful than those reported previously for older adults (Halliday et al., 1998, Martin et al., 2002). Persons with PD are also known to exhibit performance decrements during both straight line walking and gait initiation. Compared to healthy older adults, these patients demonstrate reduced gait speed, stride length, abnormal force regulation, and excessive variability during locomotion and reduced magnitudes of center of pressure (COP) displacements during gait initiation (Morris et al., 2001, Halliday et al., 1998, Gantchev et al., 1996, Martin et al., 2002). Thus, both of these populations have demonstrable problems with postural stability during locomotion and during transitions between states of equilibrium, such as gait initiation.

Gait initiation is a functional task representing one of the first voluntary destabilizing behaviors observed in the development of a locomotor pattern as the whole body center of mass (COM) transitions from a large to small base of support. This task represents a challenge to the postural control system due to the volitional transition from a condition of relatively static stable support to one of continuously unstable posture during locomotion (Jian et al., 1993, Martin et al., 2002, Polcyn et al., 1998, Halliday et al., 1998, Chang and Krebs, 1999) and one that has been shown to be a sensitive indicator of balance dysfunction (Chang and Krebs, 1999). Indeed, gait initiation has been studied to provide insight into dynamic postural control and the changes that occur in the control system with advancing age and disability (Halliday et al., 1998, Martin et al., 2002, Mbourou et al., 2003, Michel and Do, 2002, Patchay et al., 2002, Fiolkowski et al., 2002, Sasaki et al., 2001). Of note, however, is that studies utilizing gait initiation to study postural control have been limited to straight ahead walking. The fact that the effects of changing direction during gait initiation has been given little attention is surprising considering: many older adults report falling when directing motion laterally; impairments in lateral stability are an important aspect of balance dysfunction and falls (Rogers and Mille, 2003) and older adults and patient populations are known to have difficulty turning and moving laterally. Indeed, in persons with PD twenty percent of falls are directed laterally and the predominance of sway abnormalities is observed in the mediolateral direction (Bloem, 2003 and 2004). Further, changing direction during the initiation of gait is a common skill performed daily such as when walking away from the kitchen sink or after selecting groceries from the grocery aisle.

To date, multi-directional gait initiation and direct comparisons between transitionally frail older adults and persons with PD, whose postural and locomotor performance are both degraded, have not been performed. We suggest that the examination of differences in postural control within these two fall prone populations during forward and lateral gait initiation is valuable for several reasons. First, acquiring more information regarding postural control during functional tasks in these groups could add to our understanding of dynamic postural stability in fall prone older populations. An understanding of performance during multidirectional gait initiation may provide insight as to why changing direction has been associated with an increased incidence of falls in older adult populations. Second, these direct

comparisons would provide valuable information regarding the degradation in postural control that is observed in elderly or diseased populations and could help partition which decrements result from increasing frailty, alone, or from the motor dysfunction associated with neurodegeneration. These two groups have also been observed to have similar gait performance with differences in magnitude in stride length, velocity, and cadence between groups averaging <5%. Thus, differences in the performance during gait initiation may be telling in regards to sequencing of postural and locomotor actions. Last, the observed data will be valuable in identifying important variables of interest to be evaluated for intervention-related changes in postural control over time.

Given that gait initiation is a destabilizing activity for older adults and that the COP represents the response of the central nervous system during postural adjustments, the purpose of this study was to examine potential differences in the translation of the COP during gait initiation in older adults transitioning to frailty and those with PD.

Methods

Participants

Twenty-eight older adults ((mean (SD), age: 80.2 (6.1) yrs; mass: 65.7 (12.1) kg; height: 162.3 (10.2) cm)), defined as transitioning to frailty based on criteria proposed by Speechley and Tinetti, were recruited for this investigation from 20 congregate living facilities in the metropolitan Atlanta area. For each of Speechley and Tinetti's 10 attributes including: age, gait/balance, walking for exercise, other physical activity, depression, use of sedatives, near vision, upper extremity strength, lower extremity strength, lower extremity disability, participants were classified as transitioning to frailty if they did not meet the criteria for being either vigorous (> 3 vigorous and < 2 frail attributes) or frail (<1 vigorous and >4 frail attributes). The attributes distinguish robust (vigorous), frail, and transitionally frail older adults with the latter two categories containing people with falls' histories or who are prone to falling. All participants transitioning to frailty had experienced falls in the past year but were capable of unassisted ambulation. They had no untreated medical conditions. In addition to the adults transitioning to frailty, sixteen ambulatory individuals with idiopathic PD ((mean (SD), age: 66.6 (6.4) yrs; mass: 79.1 (15.4) kg; height: 174.7 (8.1) cm)) were recruited from the Movement Disorders clinics at the University School of Medicine. Additional Parkinson's specific attributes can be found in Table 1. All PD patients were being treated with stable doses of antiparkinsonian medications and were tested while clinically "on", within 1–1.5 hours of taking their antiparkinsonian medications. The following are a list of the antiparkinsonian drugs taken by the participants: bztropine, entacapone, fluoxetine, Klonopin, pramipexole, quetiapine, Requip, ropinirole, selegiline, Sinemet, Sinemet CR, Stalevo, Symmetrel, and trihexyphenidyl. Approximately, twenty percent of the patients were taking one antiparkinsonian drug, 50% were taking two drugs, 20% were taking three drugs, and 10% were taking four drugs. At the time of testing the PD patients did not exhibit dyskinesia, dystonia, or other signs of involuntary movement. The participant groups were matched for over ground self-selected gait speed and stride length. Gait speed averaged 1.15 (0.14) m/s and 1.17 (0.20) m/s for the adults transitioning to frailty and PD participants, respectively. Stride length averaged 75% of body height for both groups. All participants provided separate written informed consent prior to participating in the study as approved by the Universities' Institutional Review Boards.

Instrumentation

Ground reaction forces were collected using a multi-component force platform (Kistler Instruments Corp, Amherst, NY). The platform was mounted flush with the surface of a level 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 300 Hz (Peak Performance Technologies, Englewood, CO). Force platform data were subsequently used to calculate the instantaneous COP and the dependent variables of interest using Labview coding written in the Center for Human Movement Studies.

Experimental Protocol

Even though the vast majority of gait and gait initiation studies in older adults and those with PD have focused on straight ahead motion, the ability to turn is an integral part of functional locomotion. Turning is also associated with increased risk of falling in older adults (Thigpen et al., 2000) and is a potent source of freezing episodes that are common precursors to falls in patients with PD (Giladi et al., 1992). Thus, participants in this investigation performed both forward and lateral directed gait initiations. In the lateral conditions, the participant began walking by stepping 90 degrees to the side of the instructed leg (Figure 1).

Participants were instructed to begin each trial standing quietly on the force platform in a relaxed posture with weight equally distributed between their two feet. Initial positioning of the feet was self-selected. Acquisition of force platform data was triggered just prior to the participants receiving a verbal cue to begin walking. In response to the cue, the participants initiated walking and continued walking for several steps. The cue also triggered an electronic event marker that identified the beginning of the task. For each participant, one to two practice trials were allowed to ensure participants understood the task and exhibited consistent performance. The practice trials were followed immediately by three data collection trials for each limb performed at a self-selected pace. Thus, a total of 12 gait initiation trials, including 6 forward trials (three starting with the left foot and three with the right foot) followed by 6 lateral trials (three going to the left stepping with the left foot and three going to the right stepping with the right foot) were analyzed for each participant.

Landmarks and Periods Identified in the Gait Initiation Cycle

The COP pattern was divided into three periods by identifying two landmark events (see exemplar trace, Figure 2, of a participant initiating gait with the left leg in the forward and lateral directions). The first section (S1) began with the initiation command and ended with the COP located in its most posterior and lateral position toward the initial swing limb (Landmark 1). The second section (S2) was characterized by a lateral translation of the COP towards the stance limb ending at Landmark 2 which was defined as the point at which the COP shifts from lateral to anterior motion. The third section (S3) extended from Landmark 2 until toe off of the initial stance limb as the COP translated anteriorly. During these three phases of gait initiation, five dependent variables were computed: a) displacement of the COP in the X direction; b) displacement of the COP in the Y direction; c) average velocity of the COP in the X direction; d) average velocity of the COP in the Y direction; and e) smoothness - defined as the integral of the 3rd time derivative squared of the COP trace in the X and Y directions (Hreljac, 2000). In this case, smaller calculated values represent greater smoothness and control. These dependent variables were evaluated because of their relationship to the generation of momentum and their association with compensatory strategies and movement coordination (Geladi and Breniere, 2000).

Data Analyses

Descriptive statistics (Mean and *SD*) were calculated for age, height, and weight. Measures of central tendency and variability were calculated for the variables of interest. Data from gait initiation trials beginning with the left and right legs were compared within the transitionally frail group to determine if differences existed. Further, data from the most affected and less affected side of the PD patients determined during neurological evaluation were compared. No

significant differences were observed between either right or left legs or between the most affected and less affected sides in the patients with PD. Therefore, data from the right and left legs were averaged and data from the both legs were averaged prior to statistical analyses designed to compare groups and directions.

The primary hypotheses were that differences exist in the dependent variables between the two experimental groups during the three COP trace sections. Therefore, three separate multivariate analyses of variance (MANOVA) were used to test for overall group differences while controlling for type I error. Comparisons between groups were carried out on the forward and lateral directed gait initiation trials, separately. An α -priori alpha level of 0.05 was set for all statistical tests. Follow-up tests on separate univariate ANOVAs were conducted when appropriate (Schutz and Gessaroli, 1987). Bonferroni adjustments were used during follow-up testing. All statistical tests were performed using SPSS 11.0 for Windows (Chicago, Illinois).

Results

Forward Directed Gait Initiation

A significant main effects for Group (Hotelling's $T=2.5$, $F(5,38)=18.5$, $p<0.001$) for the five variables in the S1 region of the COP curve was found (MANOVA). Follow-up univariate testing revealed that the patients with PD produced significantly less posterior COP displacement ($p=0.041$) but significantly greater mediolateral displacement ($p=0.016$) compared to the transitionally frail participants (Figure 3, left column). In addition, the PD patients moved the COP more rapidly in both the posterior and mediolateral directions ($p<0.001$) (Figure 3). The calculated smoothness values were over twice as smooth for the adults transition to frailty compared to the patients with PD ($p<0.001$).

The MANOVA also indicated a significant between Group effect (Hotelling's $T=4.5$, $F(5,38)=34.4$, $p<0.001$) in the S2 region of the COP curve. Follow-up univariate testing indicated that similar to the observations in the S1 period; the PD patients produced significantly greater COP velocity in the posterior ($p=0.009$) and mediolateral direction ($p<0.001$) and significantly less smooth COP movements ($p<0.001$) compared to the transitioning to frailty participants (Figure 4, left column).

During the S3 portion of the COP trajectory, the MANOVA suggested a significant main effects for Group (Hotelling's $T=21.9$, $F(5,38)=214.17$, $p<0.001$). Follow-up univariate testing indicated that the PD patients produced greater velocity of the COP in the mediolateral and anterior direction ($p<0.001$) (Figure 5, left column).

Lateral Directed Gait Initiation

A significant main effects for Group (Hotelling's $T=4.25$, $F(5,38)=32.27$, $p<0.001$) was identified (MANOVA) for the five variables in the S1 region of the COP curve. However, the only variable that was significantly different between groups during univariate testing was the posterior displacement of the COP, where the PD patients produced significantly greater displacement ($p=0.048$) (Figure 3, right column).

During the S2 portion of the COP curve, the MANOVA again revealed a significant Group effect (Hotelling's $T=19.59$, $F(5,38)=148.95$, $p<0.001$). The PD patients produced greater COP displacement and velocity in the anterioroposterior direction ($P<0.001$) and significantly less displacement and velocity in the mediolateral direction ($p<0.001$) compared to the participants transitioning to frailty (Figure 4, right column).

The MANOVA also identified a significant Group effect (Hotelling's $T=0.76$, $F(5,38)=5.98$, $p=0.001$) during the S3 period. The PD patients produced significantly less displacement and

velocity in the anteroposterior directions compared to their counterparts ($p < 0.001$) and significantly greater COP velocity in the mediolateral direction ($p < 0.001$) (Figure 5). In addition, compared to the adults transitioning to frailty, the PD patients produced significantly smoother COP movements ($p = 0.002$) (Figure 5, right column).

In summary, PD patients produced COP displacements that were greater than those produced by the individuals transitioning to frailty but the directionality of these displacements were not consistent with effective movement strategies. For example, greater swing side displacements during forward directed and greater anterior-posterior displacements during lateral directed gait initiation were observed. These displacements are not appropriate for generating momentum in the intended direction of movement. PD patients also produced COP trajectories that were significantly less smooth except during S3 of the lateral directed trials.

Discussion

Forward-oriented Gait Initiation

Posterior movement of the COP during the S1 period generates the forward momentum needed to initiate gait (Polcyn et al., 1998). Cross sectional analysis of gait initiation has revealed that with advancing age and disability there is a reduction in the magnitude of the posterior COP displacement during the postural phase (S1 and into S2) (Martin et al., 2002, Patchay et al., 2002, Hass et al., 2004, Halliday et al., 1998, Gantchev et al., 1996, Dibble et al., 2004). While both groups produced COP movements that were smaller and possessed reduced velocity than those previously reported for healthy older adults, the individuals transitioning to frailty shifted their COP backwards significantly more than the patients with PD (3.2 cm versus a 2.7 cm) despite being older. These data suggest that the control mechanism used to move the COP posteriorly (Vaugoyeau et al., 2003) may be more susceptible to deterioration from the complex interaction of central and peripheral changes associated with dopamine depletion than to aging alone. Reductions in the posterior displacement of the COP have been attributed to the deterioration of centrally mediated anticipatory postural adjustments (Polcyn et al., 1998). Both Polcyn and colleagues (Polcyn et al., 1998) and Mickelborough et al. (Mickelborough et al., 2004) observed that the soleus and gastrocnemius muscles remain active as the tibialis anterior becomes engaged in older adults during gait initiation, thereby limiting posterior COP excursions. Similarly, Gantchev et al. (Gantchev et al., 1996) and Halliday et al. (1998) observed improper / inefficient tibialis anterior activation in PD patients which may also reduce the posterior COP excursions. During similar forward oriented tasks, persons with Parkinson's disease showed reduced magnitudes and delayed timing of the postural and voluntary components of the motor task (Frank et al., 2000). The present findings of reduced posterior displacement might suggest that PD patients are less able to fully deactivate previously activated muscles due to an inability to gate or scale serial and simultaneous motor actions leading to low levels of force for anticipatory postural adjustments (Frank et al., 2000).

The initial movement of the COP laterally towards the swing limb functions to propel the body COM towards the stance limb (Polcyn et al., 1998). Previous studies have reported that the displacement of the COP towards the swing limb is greater in healthy age matched older adults (ranging: 2.9–4.5 cm) compared to individuals with PD (1.8–2.5 cm) (Halliday et al., 1998, Dibble et al., 2004, Martin et al., 2002). In the present study, contrary to our original hypothesis, the COP displaced significantly greater towards the swing limb in the PD compared to the adults transitioning to frailty (3.7cm vs. 2.5 cm, respectively). A potential explanation for greater mediolateral displacement is that patients with PD may have decoupled the generation of forward from stance side momentum (Gantchev et al., 1996, Gantchev et al., 2000). Due to an inability to generate forward momentum via appropriate tibialis-soleus interactions, the PD patients may place greater emphasis on the mediolateral weight transfer so that the forces are enhanced which subsequently move the COM closer to the stance leg prior to taking a step.

Once the stance limb is fully loaded, the patients simply pick up/step with their swing limb. A secondary explanation may be related to the freely chosen stance width. Differences in stance width might explain the reduction in COP excursion (Rocchi et al., 2006). However, during analyses of frontal plane video data, the stance width for both groups did not differ and was roughly shoulder width apart for both participant groups (24.2 cm measured from center of heel to center of heel). Thus, it is likely the differences in COP excursions are attributable to motor performance rather than initial foot positioning.

During the S2 portion of the movement, the COP quickly moves towards the stance limb, in an effort to accelerate the COM forward and start to accelerate it away from the stance limb (Jian et al., 1993). Winter and colleagues (Winter et al., 2003) suggest that medial-lateral displacement of the COP is controlled by the coordinated action of the hip abd/adductor muscles. The 9.4 cm COP displacement along the medial-lateral axis during S2 in the transitioning to frailty group and the 10.5 cm displacement in the PD group are similar to the values in older adults and those with PD reported elsewhere (Martin et al., 2002). The patients with PD generated greater velocity in the posterior and stance side directions compared to their counterparts. The increased velocity in the posterior direction during S2 may be a compensation for the reduced ability of the PD participants to move the COP posterior during S1 or a manifestation of a delayed activation of the motor plan to initiate gait. Previously, Hass and colleagues have observed an increased velocity in the posterior direction during S2 in older adults as they become more disabled (Hass et al., 2004).

The trajectory of the COP during the S3 section is similar to that of the stance phase during forward walking. The persons with Parkinson's disease produced greater COP velocities compared to the transitioning to frailty group. Brenière and coworkers (Brenière et al., 1987) reported that backward COP shift during S1 co-varies with the progression velocity at the end of the first step. Despite the reduced posterior displacement during S1, the PD group had greater velocity of the COP during S3. This greater velocity that was unrelated to performance during the S1 phase suggests that the persons with PD do not rely solely on the COP shift mechanism to generate forward velocity.

Movement smoothness is often used to assess motor performance in both healthy and disabled subjects (Puniello et al., 2000, Platz et al., 1994, Rohrer et al., 2002, Hreljac, 2000). The mean-squared jerk value during the movement has been reported as an index of smoothness with the assumption that minimizing this value is indicative of improved movement control (Platz et al., 1994, Puniello et al., 2000, Hass et al., 2004). The adults transitioning to frailty demonstrated smoothness values of the COP trace during S1 and S2 that were 2 times smaller than those exhibited by the PD group, suggesting better coordination of body movement during these phases of the gait initiation task. The observed differences in movement smoothness between the two groups may be related to the akinesia, bradykinesia, and tremor/movement discontinuities associated with PD. We have observed that Unified Parkinson Disease Rating Scale motor scores and Hoehn and Yahr disability ratings significantly and negatively correlate with gait initiation performance. In particular, smoothness appears to be most affected at times when motor programs are initiated or switched between, i.e. S1 and S2. These are common times where poverty of movement is observed in this population. In addition greater coordination and better movement control in the non-PD participants when body weight is moving to a smaller single limb base of support is likely contributory smaller values.

Lateral-oriented Gait Initiation

Though previous investigations have evaluated diagonal stepping (Vaugoyeau et al., 2003) and lateral deviated gait due to galvanic stimulation (Bent et al., 2004), we were unable to find reports describing laterally directed gait initiation where the foot turns 90 degrees from the facing direction. During this task the COP moves posterior and towards the initial swing limb,

though the magnitude of the displacement during the S1 section is reduced in the lateral trials particularly in the posterior direction. This finding is not surprising since forward momentum (in the direction the individual is facing in stance) is not as relevant in lateral directed initiation and thus the magnitude of the posterior COP displacement should be reduced. Conversely, momentum generation in the intended direction of movement (lateral) should be enhanced via appropriate scale of muscle forces. Comparatively, the individuals in the transitioning to frailty group appear to retain a greater ability to scale their motor output to enhance force production to propel the body in the intended direction of movement. This finding was also reported by Vaugoyeau (Vaugoyeau et al., 2003) and Tonolli et al. (Tonolli et al., 2000) who observed small amplitude postural adjustments and reduced forces during a lateral and diagonal stepping among persons with PD. To explain these observations, Vaugoyeau and colleagues (Vaugoyeau et al., 2003) suggested that PD patients may produce minimal postural adjustments as a result of deficits in the ability to generate propulsive forces or as an attempt to simplify the motor act.

Conversely, during the S2 phase, the participants with PD produced greater anteroposterior and reduced mediolateral COP displacements and velocities. This movement pattern appears counter productive as increasing the forward (from the perspective of the initial stance direction) velocity of the COP would not aide in propelling the COM in the lateral direction. Our results are in agreement with Tonolli et al (Tonolli et al., 2000) who reported a smaller amplitude of the COP displacement towards the support limb during a lateral step in patients with PD. Kirker et al. (Kirker et al., 2000) suggest that the unloading of the swing limb is accompanied by increased activity of the stance leg gluteus medius and swing leg adductors. The reduction in the ability to shift weight in the mediolateral direction during gait initiation for patients with PD may be a result of the known alterations in proximal musculature strength (Lawrence and Kuypers, 1968) and the muscles surrounding the hip in particular (Inkster et al., 2003).

The group of individuals with PD exhibited less displacement in the forward direction and more in the lateral direction when compared to the group of individuals transitioning to frailty during the S3 phase. This behavior is likely a compensation for the alterations in COP displacement observed in S2. These two findings may result from the failure of the COM to progress as far over the foot during these trials and the participant's stance limb pushing the COM towards the intended direction of movement.

Several limitations of this study must be considered. The first is the absence of measurements related to the movement of the COM. Though movement of the COM during gait initiation is dependent upon manipulation of the COP, direct recordings of COM location would help delineate whether patients attempt to constrain COM movement so as to maintain stability. Further, control parameters such as the relationship between the COP and COM may have provided greater information regarding differences in dynamic balance control in these two populations. The magnitude of the separation between the COP and COM, referred to as the COP-COM moment arm, relates to the subject's tolerance of dynamic unsteadiness, generation of forward momentum, and is a valid tool for discriminating unsteady older adults from healthy older adults or those with balance dysfunction (Inkster et al., 2003). Last, electromyographic recordings would have been beneficial in helping to explain differences in the COP displacements between the populations of interests. Despite the limitations, the methods we used were powerful enough to demonstrate differences between the subjects with PD and those without the disease.

Summary

Transitionally frail older adults and patients with PD were studied during a functionally related task because they have similar deficits in locomotor control, exhibit postural instability, and

are susceptible to falls when turning or changing direction. In general, the older adults transitioning to frailty produced larger and more coordinated movement of the COP in a directionally appropriate manner during lateral and forward directed gait initiation. In addition, they were able to scale the output of the gait initiation motor program so that forces were maximized to propel the body in the intended direction of movement. Conversely, the PD patients appear to have limitations that reduce anticipatory postural forces and secondarily exhibit movement patterns that maintain stability. For example, during the S1 portion of forward directed gait initiation, the older adults transitioning to frailty produced greater posterior displacement of the COP while the PD group produced greater mediolateral displacement. These findings suggest that PD patients may be placing greater emphasis on postural stability than on generating forward momentum. The smoothness of the COP displacement, i.e. underlying coordination, was consistently better in the transitioning to frailty group suggesting this measure may be more affected by the PD disease process than by aging alone. Rehabilitation strategies aimed at specifically improving COP displacements in both the posterior and lateral directions may be beneficial for improving postural stability during transitions from large to small base of supports in these populations.

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Figure 1.

Participant performing the lateral directed gait initiation trial. The sequence of movement progresses from left to right in the figure. The participant begins each trial standing quietly facing forward. Following the cue, the participant begins walking by lifting the instructed leg and steps in the lateral direction ($\sim 90^\circ$). The participant then continues walking for several steps in the intended direction of movement.

Figure 2.

Exemplar record of an overhead view of the path of the COP during forward (left panel) and lateral (right panel) oriented gait initiation when stepping with the left foot. Landmark 1 and Landmark 2 were identified separating the COP trace into the defined sections S1, S2, and S3.

Figure 3.

Dependent variables (Mean and SE) observed for the TF and PD participants during the S1 period of the COP trace for forward and lateral directed gait initiation. * Significantly different from the performance of the individuals with PD, $p < 0.05$.

Figure 4.

Dependent variables (Mean and SE) observed for the TF and PD participants during the S2 period of the COP trace for forward and lateral directed gait initiation. * Significantly different from the performance of the individuals with PD, $p < 0.05$.

Figure 5.

Dependent variables (Mean and SE) observed for the TF and PD participants during the S3 period of the COP trace for forward and lateral directed gait initiation. * Significantly different from the performance of the individuals with PD, $p < 0.05$.

Table 1
Disease Related Characteristics of the participants with Parkinson's disease

	H&Y	UPDRS			UPDRS		
	Score	Total	Motor	Posture	Gait	Stability	
Mean (SD)	2.4 (0.4)	40.0 (2.7)	21.7(1.4)	1.2 (0.2)	0.9 (0.1)	0.8 (0.1)	
Range	1.5–3.0	13.5–58.5	11–32.5	0–2	0–2	0–2	