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Simple Change in Initial Standing Position Enhances the Initiation of Gait

Elan Dalton¹, Mark Bishop², Mark D. Tillman¹, and Chris J. Hass^{1,3}

¹Department of Applied Physiology and Kinesiology, Center for Exercise Science, University of Florida, Gainesville, FL

²Department of Physical Therapy, University of Florida, Gainesville, FL

³University of Florida Movement Disorders Center, McKnight Brain Institute, University of Florida, Gainesville, FL

Abstract

Purpose—Older adults and individuals with Parkinson’s disease (PD) exhibit impaired gait initiation performance with less effective anticipatory postural adjustments (APA) and less dynamic stepping characteristics. These observations may reflect impaired interactions between the postural and locomotor components of this task. The purpose of this study was to evaluate the effectiveness of altering the stance position of the initial swing limb on improving APA characteristics and stepping performance.

Methods—Three groups (healthy young adults, individuals with PD, and age-matched older adults) of twelve participants initiated gait from three initial stance conditions: Normal, Backward displaced swing limb, and Forward displaced swing limb. Ground reaction forces and whole body kinematics were recorded to characterize the APA and step parameters.

Results—Initiating gait from the Back condition produced more forceful weight shifting ($P < 0.001$), greater propulsive forces ($P < 0.001$), and faster center of mass velocities throughout the stepping phases ($P < 0.05$).

Conclusions—Translating the swing limb ½ foot length backward appears to enhance the interaction between posture and locomotion which may have therapeutic potential for improving gait initiation performance.

Keywords

movement disorders; start hesitation; rehabilitation; gait

Introduction

Initiating walking from quiet standing is a seemingly simple, yet complex task that requires generation of momentum while simultaneously maintaining postural stability. This delicate balance is achieved in part by anticipatory postural adjustments (APA). During quiet stance, the location of the whole body’s center of mass (COM) and the ground reaction force’s center of pressure (COP) are coupled; oscillating about each other in the transverse plane to maintain postural stability (35). During gait initiation (GI) however, the APA purposefully

Corresponding Author: Chris J. Hass, Ph.D., Department of Applied Physiology, University of Florida, Box 118205, Gainesville, FL 32611-8205, Phone:352-392-9575 x 1294; Fax:352-392-5262; cjhass@hhp.ufl.edu.

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uncouple the movement of the COM and COP. Before any appreciable movement of the COM, the COP is shifted posterior and lateral towards the initial stepping limb (swing limb). Whereas the backward movements of the COP results from the bilateral deactivation of the triceps surae musculature coupled with activation of the tibialis anterior, the lateral COP movement is achieved by hip abductor activation and stance limb knee flexion (23). This COP shift increases the components of the ground reaction force (GRF) anteriorly and towards the support limb (stance limb) leading to generation of momentum in those directions (5). Thus, the APA generate the initial momentum needed to begin walking while the COM remains within the base of support (28).

Alterations in APA are considered a major pathophysiological mechanism underlying dysfunctional GI performance in persons with Parkinson's disease (PD) (22, 30, 31). Previous studies suggested that the APA are abnormally prolonged and reduced in amplitude compared to age-matched control subjects (16, 17). This pattern of behavior is associated with increased movement preparation time (24, 25, 30), reduced swing limb loading (14), and less effective uncoupling of the COP and COM (16, 22). Further, there are multiple abnormalities associated with the first step in individuals with PD including reduced propulsive forces (10, 14), reduced step length and velocity, and less forward movement of the COM during single limb support of the stance limb (6, 16, 21).

Though both the postural and stepping components are improved by antiparkinsonian medication (7, 30), even when optimally medicated GI performance remains impaired relative to age-matched controls (6, 17, 22, 30). Thus alternative interventions, such as rehabilitative therapy, play an important role in treating postural instability and gait dysfunction in this population. Unfortunately, external cueing and exercise have been shown to enhance only certain aspects of GI performance (7, 11, 15). Recently, robotic assistance given at the onset of the gait initiation APA was shown to reduce APA duration, produce an earlier step onset, and a faster first step (25). Further, a single session of robotic assisted training provided some therapeutic improvement in APA duration and step onset time (24). While promising, these interventions require external input. One intrinsic strategy that may influence GI behavior is altering the initial stance condition. Rocchi and colleagues (30) have shown that GI performed from a wide stance width was associated with larger COP displacements in groups of participants with and without PD. However, despite the ability to amplify the APA with stance width, individuals with PD had more difficulty initiating from the wide stance. To our knowledge, little is known regarding the influence of manipulating the anteroposterior aspects of the initial stance position.

In this current study, we evaluated the influence of foot positioning on GI by manipulating the position of the swing limb (Figure 1). We hypothesized that a posterior translated swing foot would improve APA and stepping characteristics because the backward translated foot creates lower extremity alignments that more closely match ongoing gait, namely an elongated base of support requiring greater force production to accelerate the COM.

Methods

Twelve persons with idiopathic PD, 12 age-matched healthy older adults (HOA), and 12 healthy young adults (HYA) participated (Table 1). Inclusion criteria for the individuals with PD included diagnosis of idiopathic PD by a movement disorders neurologist, a Modified Hoehn & Yahr stage of II or III and a score of ≤ 1 on UPDRS questions 14 and 29. Scores of ≤ 1 indicate that the participant experiences freezing of gait or start hesitation and slowed walking with increased cadence and short steps. HOA inclusion criteria included lack of a history of PD and within a two-year age match of one of the PD participants of the same gender. HYA were neurologically healthy between the ages of 18-30 years. Exclusion

criteria included use of an assistive walking device or any cardiovascular, musculoskeletal, or vestibular disorders that prohibited the subject from standing and initiating a step independently. Participants provided written informed consent before participating as approved by the University's Institutional Review Board.

GI trials were performed along a 10 m walkway surrounded by an 11 camera motion capture system (Vicon Oxford, U.K.) collecting at 120Hz. GRF and moments were collected at 1200Hz from a force plate (Bertec model 4060-10, Columbus, Ohio) embedded within the walkway surface. Participants were barefoot and wore tight-fitting clothing. Retroreflective markers were placed over bony landmarks according to the Plug-in-Gait marker system. Subjects performed 30 gait initiation trials, 10 trials in each of the three stance conditions (Figure 1). During the Forward and Back conditions, the initial starting position of the swing limb was translated $\frac{1}{2}$ foot length forward or backward, respectively, from normal quiet stance. Within each condition, five trials were conducted with each limb on the force plate. Trials were performed in random block method, balanced across participants, for each of the three stance conditions and limb placements (swing limb or stance limb on the force plate). For example, participants performed 5 trials of a condition and force plate combination (i.e. Back swing limb on force plate) followed by sequential blocks of 5 trials at a different condition-force plate combination (Normal swing limb on force plate, etc). Initial foot positioning for the Normal condition and stance width was self-selected and was subsequently constrained via tracings on the floor for consistency across conditions. The stepping leg during GI was the participant's preferred stepping leg during the Normal condition and this stepping leg was maintained throughout the experiment. Force plate data and kinematics were sampled for the 5 seconds immediately preceding the auditory signal, defined as quiet standing. The participants were instructed "after hearing the auditory signal, pause and then when you are comfortable, walk to the end of the walkway at your natural pace."

Data Analyses

The mean individual values from the experimental trials for each dependent variable during each stance condition were analyzed and compared across group and condition. We evaluated: the average magnitude of swing limb loading during quiet standing (vertical GRF beneath the swing limb as percent of body mass); peak swing limb loading (difference between max and quiet standing average swing limb vertical GRF); peak stance limb propulsive force generation (difference between max and quiet standing average stance limb anteroposterior GRF); APA duration (defined here as the onset of an asymmetric change of the vertical ground reaction force under the swing limb (more than 5%) until maximum swing limb loading. (20)); and the kinematic COM velocity at the instance of swing limb toe-off, swing limb heel-strike, and stance limb heel-strike (Figure 2). The standard deviation of the position of the COM in the frontal plane was used as a surrogate measure of postural stability during quiet standing. In addition participants ranked the three positions in regards to the most stable and easiest from which to start walking.

GRF and COM related variables were evaluated using two separate 2×3 (Group $\times$ Stance Condition) multivariate analysis of variance (MANOVA) with repeated measures to test for differences while controlling for type I error. Statistical significance was set at $p = 0.05$. When the MANOVA detected significance, follow up mixed model univariate ANOVA's were performed as suggested previously (32). When significant Group and Stance condition main effects were observed, univariate contrasts were conducted utilizing Bonferroni adjustments.

Results

All participants completed the experimental trials without incident such as festination, freezing, or loss of balance. The MANOVA evaluating the GRF data revealed main effects for Group ($F(8,62)=4.25$, $P<0.001$) and Position ($F(8,26)=24.25$, $P<0.001$). Similarly for the COM variables, the global MANOVA identified Group ($F(8,62)=4.67$, $P<0.001$) and Position main effects ($F(8,26)=34.17$, $P<0.001$). A significant interaction was not observed for either the GRF ($F(16,54)=0.945$, $P>0.05$) or COM data ($F(16,54)=1.22$; $P>0.05$). Thus, the remainder of the results are focused on the evaluation of Position and Group main effects.

Follow up univariate ANOVAs detected Position effects for both variables related to swing limb loading as well as stance limb propulsive force generation (Figure 3). During the APA period, the participants were able to increase loading onto the swing limb significantly more during the Back compared to the two other conditions (both $P<0.001$). During the Forward condition, swing limb loading was significantly less than that observed in the Normal condition ($P<0.01$). Propulsive force generated by the stance limb was also greater in the Back relative to the Normal and Forward conditions ($P<0.001$). No significant differences in the duration of the APA period among conditions were detected (Back: 488 ± 118 ms; Normal: 485 ± 130 ms; forward 530 ± 124 ms).

Initiating gait with the swing limb initially back led to significantly greater velocity of the COM (relative to both Normal and Forward conditions) when the swing limb left the ground ($P<0.001$) as well at the end of both the first ($P<0.01$) and second step ($P<0.01$) (Figure 4). Conversely, the forward positioned swing limb retarded development of COM velocity (compared to both the Normal and Back conditions) until the end of the second step where it became similar to that observed in the Normal condition ($P=0.12$).

Postural sway as measured by the magnitude of the standard deviation in COM position was significantly larger in both the Forward (2.3 ± 0.3) and Back (2.2 ± 0.2) conditions relative to the Normal (1.7 ± 0.2) stance (both, $P<0.001$). No significant differences were detected between the Forward and Back conditions ($P=0.591$). In spite of these results, the participants' rankings of the conditions based on perceived stability did not show a clear bias (percentage of rankings as the most stable: Forward: 32%; Back: 32%; Normal: 36%). The Back condition was ranked the easiest position from which to start walking by 48% of the participants followed by the Normal (30%) and Forward (22%) conditions.

As mentioned Group main effects were identified for both GRF and COM related variables. Specifically when collapsed across condition, swing limb loading during the APA period was significantly lower in the PD group (Figure 3). As expected, the HYA group produced significantly greater stance limb propulsive force (Figure 3) and lower APA durations than the HOA and PD groups. Similarly, the HYA produced greater COM velocity at all time points ($P<0.02$) than their counterparts (Figure 4). The PD and HOA groups' performances were not different across these variables. There was no significant difference in the standard deviation of the COM position across groups.

Discussion

Regardless of participant group significant improvement in GI performance was observed by simply starting with the swing limb positioned ½ foot length back from normal. The back condition increased the magnitude of swing limb loading without influencing APA duration, suggesting increased ability to scale task performance to postural demands. Further, the magnitude of the propulsive force and resulting COM velocities throughout the stepping phase were significantly enhanced, meaning a more dynamic and faster GI was achieved.

These findings indicate that natural pace GI can be acutely enhanced by manipulating the initial stance position through improved postural and stepping components.

Participants stood with significantly more loading under the initial swing limb when in the Back condition. Once the initiation process began, this position facilitated further swing limb loading. This weight shift and posterior-lateral movement of the COP is a critical component of an efficient GI pattern and serves to uncouple the COP and COM. The ability to separate these 2 by manipulating the COP has major implications on momentum generation and balance control. Previously, Brunt and colleagues have shown that manipulating the initial position of the limb in the sagittal plane can influence sit to stand performance, a task with a similar initial motor response to GI (4). Rocchi and colleagues (30) have also shown that widening initial stance also leads to greater loading of the swing limb. Because stance width was constant throughout our conditions, the greater weight shift was likely due to greater effectiveness of the APA. A potential stability related factor as to why the back condition had a greater swing limb loading relative to normal is that there is a greater tolerance to asymmetrical loading. The asymmetrical loading between the two legs would cause the COM to be driven laterally and forwards, rather than just laterally as in the normal condition. Older adults and persons with Parkinsons may not exhibit large asymmetries of limb loading to avoid destabilizing themselves in the medio-lateral plane during normal stance; the diagonal stance condition would help alleviate this potential problem. Beneficial effects of the Back condition were generally comparable across groups indicating the capacity to improve the postural components of GI by simply altering the starting position. These findings should provide important information for rehabilitation specialist as they indicate that both older adults and those with neurologic impairment can utilize this foot placement strategy.

The duration of APA did not change across conditions, thus participants were able to produce greater forces within the same time period while in the Back condition, translating into a more dynamic initiation of gait. The ability to scale force amplitude while keeping the time to reach peak force relatively constant is consistent with the notion of a pulse height neural control strategy observed by neurologically healthy subjects (12, 13, 26). Previous research has shown that regulation of force time parameters, particularly the rate of development, is significantly impaired in PD (1, 3, 9, 29, 33, 34). Further, impairment in force development has been proposed to be one of the underlying causes of bradykinesia (27). That such a simple strategy as altering initial limb placement improved a consistently important impairment is significant.

The velocity of the COM was greatest at every time point when initiating gait from the Back condition. The greatest influence of altering foot position, however, appears to occur early in the GI process, where the spatiotemporal interactions between the postural and stepping requirements occur. This finding that performance can improve in temporal relation to the switch between the two proposed motor programs governing GI is important because impaired GI performance in PD is associated with changes in the basal ganglia that result in slowing the sequential execution of the postural and stepping components (31).

Rocchi et al.(30) reported that widening stance width leads to improved step velocity. However, individuals with PD had much more difficulty initiating a step from the wide stance, thus reducing the potential efficacy of this strategy. Mille and colleagues in two separate studies of individuals with PD have shown that a lateral assist force delivered to the hip timed with the APA can improve GI performance including velocity of the first step (24, 25). Similar improvements in GI performance were realized in the current study when initiating gait from the Back stance. We propose that altering foot position may be more

practical than a robotically controlled lateral assist in improving performance, and raises future consideration of its effects on PD freezing.

While these results are promising, the Back condition did cause significantly greater oscillations in the mediolateral position of the COM during quiet standing than the Normal condition. The groups, however, didn't report any differences in their sense of stability across the conditions and ranked the Back condition as the easiest from which to start walking by each population of participants. While adopting a, a staggered stance position could be perceived as an added task demanding further postural control, previous work has shown perseverance of stopping ability with mild to moderate PD (2, 8). Thus, we propose that stopping with a slightly staggered stance is potentially no more or less difficult than stopping with a parallel stance. To evaluate the real world application of this technique, we asked 25 ambulatory persons with PD to perform planned gait termination tasks whereby they achieve a stopping position with their feet staggered. All participants (across a range of mild to moderate disease severity) were able to do so without observable loss of stability or an increase in braking time (unpublished data). Thus, we recommend that times when GI performance may be problematic for people with PD such as at a cross walk, stopping with a staggered stance may be an appropriate strategy. Additionally, participants in the present study did not report or exhibit any real difficulty in establishing this starting position likely because of the rather small asymmetry in foot placement (1/2 foot length). At times when planned stopping may be constrained yet efficient GI performance is needed (such as entrance and exit of an elevator), individuals may adjust their feet to achieve the more optimal Back stance condition.

The beneficial properties exhibited by the Back condition are likely due to the biomechanical advantages awarded by the spatial orientation of the body. The more extended position of the swing limb likely places greater stretch on the hip flexor and plantar flexor muscles of the limb, potentially creating a faster rate of force production and corresponding limb velocity (18,19). The Back position may also facilitate the transfer of rotational momentum generated by the swing limb to help carry the COM over the stance limb (pendular dynamics), reducing the amount of energy otherwise required. Certainly, electromyographical analyses of the muscle activation patterns and evaluation of potential changes in corticospinal and spinal excitability are needed to better address the contributing mechanisms.

Concerning the limitations of the study, the constraint of using only a single force platform during data collections prevented simultaneous measurement of forces beneath both swing and stance limbs. While trials were duplicated using the same stance position to obtain both swing limb and stance limb force data as has been done previously (5), differences may have arose between these trials that are not evident in the results. Gait initiation is brought about by a motor program that governs a complex sequence of muscle activation patterns. Thus, future studies investigating differences in starting position should further evaluate changes in muscle activation to help better understand the underlying changes in behavior observed here. A potential confound exists in the use of a constrained stance width across conditions. This was done to isolate the effects of anterior-posterior modifications. Participants may have naturally altered their preferred stance widths in the Forward and Back conditions if allowed, which could potentially modify swing limb loading and stepping behavior (30). A larger group sample size and greater diversity of individuals with PD may increase the fidelity of our findings. Future studies should also investigate the effectiveness of this protocol in individuals with freezing of gait.

In conclusion, placing the swing limb backward 1/2 foot length from the normal stance had significant positive impacts on both the postural and locomotor phases of GI in all

participants. Further, initiating gait from the back condition allowed the persons with PD to initiate gait in a similar fashion as their age matched peers. These findings suggest that altering foot position may be an effective therapy to offset the typically observed deterioration in initiation performance.

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FIGURE 1.

Stance conditions. Back condition, the swing limb was translated 1/2 foot lengths in the posterior direction from the Normal condition. Forward condition, the swing limb was translated 1/2 foot lengths in the anterior direction from the Normal condition.

FIGURE 2. Representative vertical GRF beneath a swing limb during gait initiation. Associated variables are illustrated.

FIGURE 3.

Loading and propulsive ground reaction forces measured during the three stance conditions (Back=black column; Normal=grey column; Forward=white column) for each group and collapsed across participant groups (Average). + Significantly different from Healthy Older Adults (HOA) group; ++ Significantly different from PD group (Group main effects). * Significantly different from Back condition; ** Significantly different from Normal condition (Condition main effects).

FIGURE 4.

Center of Mass (COM) velocities during three time points of the gait initiation process for each group during the three stance conditions (Back=black column; Normal=grey column; Forward=white column) and collapsed across participant groups (Average). + Significantly different from Healthy Older Adults (HOA) group; ++ Significantly different from PD group (group effects). * Significantly different from Back condition; ** Significantly different from Normal condition (condition effects).

TABLE 1

Subject demographic characteristics and disease status. The Mean is provided along with the Standard Error.

Group	Age (yrs)	Mass (kg)	Height (cm)	H&Y Stage	UPDRS Motor	Disease Duration (yrs)
HYA	24±1	71.9±3.4	170.4±3.2	-----	-----	-----
HOA	69±2	81.0±5.8	174.9±2.7	-----	-----	-----
PD	70±2	89.2±4.9	169.0±1.8	2.2±0.4	29±3	8±1

H&Y Stage, Hoehn and Yahr Staging. UPDRS, Unified Parkinson's disease Rating Scale obtained during medicated state. Disease duration reflects the amount of time from diagnosis.