INFLUENCE OF INITIAL STANCE CONFIGURATION ON GAIT INITIATION

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
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This work is dedicated to Caleb.

ACKNOWLEDGMENTS

I wish to thank my moms and pops for providing me with a good upbringing. My brothers deserve recognition for toughening me up and continually motivating me. I also thank my many mentors for guiding me through my education.

TABLE OF CONTENTS

LIST OF FIGURES

Abstract of Thesis Presented to the Graduate School
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Gait initiation (GI) is the a task of daily living in which the body is propelled forward from a position of stable, static balance to a continuously unstable position requiring dynamic control of balance. GI requires execution of a system of complex and coordinated postural adjustments, termed Anticipator Postural Adjustments (APA), in order to maintain balance and prevent a fall from occurring. Falling and the fear of falling in elderly individuals and people with Parkinson's disease cause these individuals to scale down the APA magnitudes during GI, resulting in slower initiation of gait. Eventually, festination occurs and shuffling steps predominate gait, raising new dangers of falling (i.e. tripping) and causing disability. One potential therapeutic strategy was evaluated in which the initial starting position of the feet was staggered in the anterior and posterior directions, creating both a forward and backward staggered stance. Three groups, healthy young (HY), healthy old (HO), and Parkinson's disease (PD), consisting of twelve subjects each, initiated gait from three stance positions: back, normal, and forward. Ground reaction forces and motion analysis data were collected for five trails from each stance condition. Significant effects across stance condition were found for center of mass velocity, loading of the swing limb (corresponding to APA), and propulsive force generated by the stance limb. No significant differences were found for APA duration across stance conditions. A backward

staggered starting stance appears to enable individuals from all groups to initiate gait more quickly and with greater final velocity than a normal stance, while maintaining the duration of normal postural adjustments. It is speculated that individuals are therefore able to scale the magnitude of force production within the same time frame during tasks requiring postural stability. Furthermore, posteriorly staggering the swing limb appears to counteract the impeding effects of PD when initiating gait, allowing those individuals to initiate gait as a healthy older population normally would. This effect is maintained in the elderly population compared to the young initiating gait from a normal stance.

CHAPTER 1
INTRODUCTION

This study will examine the relationship between foot placement configuration and the ability to initiate gait in healthy young, healthy elderly, and individuals with Parkinson's disease (PD). Characteristics of the ground reaction forces acting on the limbs prior to and during the first steps of gait initiation will be compared across the groups. It is proposed that modifying the starting orientation of the feet will elicit modifications to the motor program for initiating gait, potentially creating a strategy that will enhance the ability to meet the weight shifting demands of the task. Thereby, a therapeutic intervention may be realized that will alleviate, in part, some difficulties most individuals with Parkinson's disease experience when attempting to initiate forward movement.

Parkinson's Disease

Parkinson's disease (PD) is a progressive neurodegenerative hypokinetic movement disorder. Often idiopathic, the development of PD symptoms is attributed to neuronal degeneration in the substantia nigra. The loss of these dopamine-producing neurons of the basal ganglia elicits an enduring decline in the coordination of motor function. Prevalence of PD is estimated at 1.5 million Americans, with a cumulative yearly incidence of 70,000, leading to $25 billion a year in associated health care costs (Scheife et al., 2000). Additionally, the disease afflicts nearly twice as many men as women. Functionally speaking, the most disabling aspect of PD involves the motor impairments inherent in the disease's symptoms. The constitutive motor symptoms of PD include bradykinesia, resting tremor and/or rigidity, as well as postural instability (including gait instability).

Manifestation of PD primary motor symptoms originates in the dysfunctional basal ganglia. Lesions within the basal ganglia cause uninhibited hyperactivity of an indirect pathway leading to an abnormal presentation of normal impulses. In other words, PD symptoms are not the lack of a given command, but rather an unsuppressed exaggeration of a normal command. A cardinal symptom of PD is bradykinesia, or slowed movement. Bradykinesia results from inefficient communication between the frontal lobe, basal ganglia, and cerebellum during the planning, initiating, and execution of movement. The inability to generate movements at normal or even functional speeds is an important source of disability in PD. Decreased movement speed not only limits an individual's ability to perform tasks of daily living (i.e. gait initiation), it also predisposes an individual to an increased likelihood of injury due to an inability to generate adequate recovery or evasive reflexes. One of the most functionally challenging tasks for individuals with PD is the process of initiating gait, in that it requires the posturally demanding transition from static (standing) balance to dynamic (stepping) balance.

Gait Initiation

Gait initiation (GI) is the transition from quiet stance to steady state of gait. GI represents a challenge to the body's postural control system as it marks the transition from the relatively stable, static balance of standing to the coordination of dynamic balance control during gait. During quiet stance the body is not perfectly still, rather balance is maintained through small fluctuations of the location of the body's center of mass (CoM). Control of the CoM is achieved by shifts in the body's center of pressure (CoP) – the net ground reaction force under the base of support. These coupled movements of the CoM and CoP create a region that represents the limits of an individual's standing balance; movement of the CoM outside the given limits would result in a loss of balance and the resultant adjustment of the base of support (i.e. taking a step). In order to initiate gait, it is necessary to coordinate a planned shift of the CoM outside the established base of support to generate forward motion, all the while maintaining balance.

Conventionally, gait initiation is composed of two main phases: the postural phase and the propulsive phase. The postural phase, which is the initial component of GI, creates movements of the CoM that establish stability to allow for single limb support. Once these postural preparations for single limb support have occurred, the propulsive phase of GI commences, creating the forward-directed momentum of the CoM that enables forward stepping. Examination of the postural and propulsive phases of GI can be used as a diagnostic tool to evaluate GI performance and pinpoint potential deficits in task performance. By examining the ground reaction forces beneath each limb, characteristics of the postural and propulsive phases can be compared across populations, providing insight into the cause and manifestation of disability.

Characteristics of gait are dramatically different in those with Parkinson's disease compared to the healthy population. Generally, PD gait is slow, consisting of short strides with shuffling steps and less arm swing. These characteristics of PD gait are manifestations of the inability to properly control balance and posture. *Ergo*, during GI, individuals with PD tend to minimize the separation of the CoM from the CoP as a means to reduce the destabilizing effect inherent in the task. This results in slowed, less deliberate execution of the movements that lead to the initiation of gait, resulting in slower and shorter stepping. For individuals with PD, it is typically seen that they reduce the initial loading of their swing limb, subsequently unload the limb slower, and generate markedly reduced forward-directed force with their stance limb, all of which culminate in both a posturally less demanding strategy to execute the task, but also a resultant decrease in task performance. The challenging paradigm then presents itself; how do individuals with PD, who must minimize changes to their posture due to an inability to correctively adapt them, successfully perform a task of daily living, GI, which is dependent upon postural manipulations?

Compared to the healthy population, individuals with PD tend to scale down the magnitudes of postural shifts, as evident by reduced loading and unloading of the swing limb, thus minimizing the postural demands of the task. If it were possible to lessen the postural demands during GI, i.e. reduce the initial loading and unloading of the swing limb, while maintaining the ultimate goal of generating forward motion, then a therapeutic strategy could be realized. One study examining the effects of widening the initial stance in PD and healthy controls found a wider stance modified GI by demanding greater postural CoP movements, leading to increased step length and step velocity in both groups (Rocchi et al., 2006). If an initial stance configuration could be realized that maintains or improves GI performance while concurrently reducing the demands of the postural component of the task, GI performance, and thus level of independence, in the patient population could be increased.

Purpose

The challenges initiating gait in those with Parkinson's disease have been duly documented. It is understood that the fear of falling, stemming from inherent postural instability and the dysfunctional balance system itself, leads to deficits in GI performance. It is contended that by altering the initial stance conditions, the process of initiating gait can be modified to reduce the challenges faced by the body's postural control systems. While mediolateral stance modifications have been shown to alter GI (Rocchi et al., 2006), the effect of altering stance in the anterior-posterior direction have yet to be evaluated. Thus, the purpose of this study is to examine the effects of an anteriorly and posteriorly staggered stance on the initiation of gait.

Hypotheses

It should be assumed that gait initiation from a normal stance will follow the group differences found by the previous research summarized in this report; a progressive down-scaling of the GRFs associated with the postural and propulsive components of GI will exist among young, healthy elderly, and PD. Specifically, the swing limb back condition will cause greater loading of the swing limb prior to GI, causing less initial loading of the limb, but enabling more dynamic unloading of the limb while transitioning into single-limb support. Conversely, the swing limb forward condition will effectively unload the swing limb during quiet stance, reducing the need to initially load the swing limb yet reducing the propulsive drive capability of the stance limb. In this manner, the back condition will create more robust postural adjustments than the normal or forward conditions, allowing for improvements in the functional outcome of forward motion seen from normal stance.

CHAPTER 2
LITERATURE REVIEW

This chapter will serve to provide the reader with an overview of the Parkinson's disease and gait initiation literature relevant to this thesis. An overview of the key characteristics and treatments of Parkinson's disease will immediately follow. Then, a synopsis of healthy gait initiation, specifically center of mass and center of pressure relationships as well as ground reaction force profiles, will be presented. Subsequently, a similar summary of the age-induced changes to gait initiation and the related research involving the healthy elderly population will be presented. A final set of characteristics will concentrate on the research focused on the Parkinson's disease population and effects of the disease on the individuals' ability to initiate gait. While not a direct measure of this study, the center of mass and center or pressure interactions are summarized in this chapter to better explain the characteristics of gait initiation relevant to this study. The final sections will highlight the recent, yet sparse, body of research evaluating the effects of stance conditions, and other intervention studies, on gait initiation. Collectively, the research presented in this literature review will provide a sound rationale for the research of this thesis.

Parkinson's Disease

Parkinson disease (PD), or idiopathic parkinsonism, is a chronic progressive disease of the motor component of the central nervous system (CNS), characterized by rigidity, tremor, and bradykinesia (Goodman & Boissonnault, 1998). PD is often termed a disorder of the basal ganglia, yet more specifically the organic basis of Parkinson's disease is the degeneration of substantia nigra inputs to the straitum (Bear et al., 2001). For individuals afflicted by PD all aspects of movement are affected, including initiation, alteration of direction, and the ability to stop a movement once it has begun (Umphred, 1995). Additionally it involves both voluntary and involuntary movements (Klockgether, 2004). One of the most serious complications of gait disturbances in PD is falling, which is likely the result of decompensated postural instability and gait dysrhythmicity (Balash et al., 2005). Though difficult to gain an accurate account of the incidence of PD, estimates include 1.5 – 2 million Americans (Twelves et al., 2003; Park et al., 2005; Zhang et al., 2005), with the vast majority of cases occurring between 50 and 79 years of age (Goodman & Boissonnault, 1998).

Bradykinesia, slowness in movement, has been described as the key impairment leading to functional limitations in PD patients (Mak & Hui-Chan, 2002). It has been reported that 94% of PD patients suffer from bradykinesia (Shrag et al, 2002). In persons with PD, bradykinesia is characterized by the decreased ability to initiate and perform purposeful movement (Umphred, 1995). The underlying cause of this is believed to be inappropriate scaling of the agonist electromyographic burst that is required to accelerate the limb (Klockgether, 2004). This can be caused by difficulty in coordination and activation, as well as decreased muscle strength (Fredericks & Saladin, 1996). The end result of the bradykinesia is that the PD patients simply cannot produce movement forces as quickly, accurately, or smoothly as normal healthy adults do (Fredericks & Saladin, 1996).

In most cases of PD, tremor is found to be the initial symptom to be noticed (Shrag et al, 2002). About 70% of PD patients experience these involuntary rhythmic movements at rest, which are most noticeable in the distal extremities and most evident following movement (Fredericks & Saladin, 1996). The tremor is produced peripherally by alternate activation of the agonist and antagonist muscles, which is centrally caused by abnormal synchronous oscillating neuronal activity within the basal ganglia (Klockgether, 2004). Tremor is often exacerbated with tension or exertion, called action tremor (Brown et al., 1997), but will be reduced during sleeping

(Goodman & Boissonnault, 1998). Additionally, the resting tremor of the upper extremity can be suppressed by outstretching the arms and by voluntary actions (Klockgether, 2004). Therefore, tremor may not be necessarily disabling, however many patients suffer considerably from the tremor in part because the tremor stigmatizes them as PD patients (Klockgether, 2004).

Muscular rigidity, another cardinal feature of PD, is defined as an increased resistance of a joint to passive movement throughout the range of motion (Klockgether, 2004). Patients describe muscular rigidity as a feeling of stiffness and a reduced ability to relax limb muscles, as such it is considered to only minimally contribute to the impairment experienced by PD patients (Klockgether, 2004). This can occur as a result of either an increase in muscle tone or an inability to relax (Fredericks & Saladin, 1996). The rigidity in PD patients has been characterized as either "lead pipe", which is constant throughout the range of motion, or "cogwheel", which is a combination of lead-pipe rigidity and tremor (Umphred, 1995). Rigidity is also associated with the development of postural instability, which affects about 16% of PD patients and is a central contributor to falling (Bartolic et al., 2005). While most patients experience all of these symptoms, they are often classified based on the dominant feature. For example, patients can be classified as tremor dominant or gait instability dominant.

Healthy Gait Initiation

In the healthy population, gait initiation (GI) is an activity of daily living that is scarcely recognized as a challenging task. A healthy neuromuscular system efficiently coordinates the sequence of integrated movements, providing the liberty to take the initiation of gait for granted. Due to the difficulties that arise in GI with age and/or disease, and the consequent desire to understand the cause of such challenges, it is logical to first provide a reference profile by examining the healthy, functional execution of the task.

Center of Pressure and Center of Mass Profiles

Standing balance, a prerequisite to GI, in healthy individuals is maintained by controlling the body's center of mass (CoM) so that it is constrained within a base of support. The CoM is the point on the body that moves in the same way that a single particle would move if subjected to the same external force, or the point at which the weight of the body can be considered to act (Martin, et al., 2002). Control of the CoM is maintained by corrective shifts in the center of pressure (CoP), under direction of the central nervous system (Hass et al., 2008; Martin et al., 2002). The CoP is the central point of pressure exerted on the feet in contact with the ground and is the point where upon the ground reaction forces (GRF) act on the body. During quiet stance, the CoM and CoP are constantly fluctuating within a region of stability, moving in a coupled fashion. Translations of the CoP in the anterior-posterior (A/P) direction are largely influenced by net ankle moments associated with postural control, whereas the mediolateral (M/L) translations are largely influenced by hip control (Winter.et al., 1996; Martin et al., 2002). Deviations of the CoM away from the base of support represent instability, and if of large enough magnitude, the cause of loss of balance.

During GI, uncoupling the CoM from the CoP is required in order to initiate movement. By purposefully destabilizing the body, a forward fall is simulated and by catching that fall with an anteriorly placed stepping limb, the process of gait is initiated. The pattern of CoP movement that elicits the movement of the CoM, and thus motion, has been extensively reported as prototypical and is illustrated in figure 2-1 (Brunt et al., 1991; Elble et al., 1994; Mann et al., 1979; Polcyn et al., 1998). During bilaterally symmetrical quiet stance, the CoP and CoM are located at relatively the same point, evenly between the two feet (Brunt et al., 1991). The first movement of the CoP is towards the eventual swing limb and posteriorly (Elble et al., 1994; Mann et al., 1979). Subsequently, the CoP moves slightly anteriorly, though directly towards and beneath the stance limb, corresponding to toe-off of the swing limb and the beginning of single limb support (Brunt et al., 1991; Mann et al., 1979). These initial movements of the CoP are created in order to generate momentum of the CoM that is necessary to successfully drive the body towards the stance limb in a stable fashion that will enable single limb support. Once the weight of the body is removed from the swing limb, it can be lifted and allowed to take a step forward. The final path of the CoP is an anterior translation entirely within the stance limb, which terminates with toe-off of the stance limb (Mann et al., 1979). This displacement of the CoP creates forward momentum of the CoM that drives the body forward into motion.

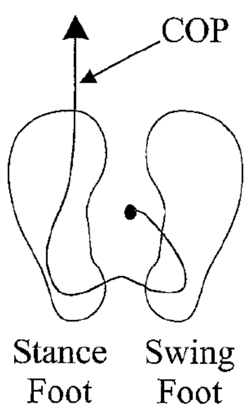

Figure 2-1. Schematic representation of a typical trajectory of the CoP under the feet of a healthy individual during gait initiation (adopted from Polcyn et al., 1998)

Ground Reaction Force Profiles

During normal quiet stance, the vertical GRF (F_z) is divided relatively symmetrically between the two feet. During gait initiation, there is initially an increased loading of the swing limb (Fig. 2-2: F_z; swpk1), corresponding to the shift in CoP location towards the limb (Nissan & Whittle, 1990). Concurrently, the stance limb reaches a minimum vertical force (Fig 2-2: F_z; stpk1), before rapidly increasing as weight is transferred to the stance limb (Brunt et al., 1991). A second peak in the vertical GRF (to an amount slightly greater than body weight) occurs under the stance limb at the point of swing limb toe off (Fig. 2-2: F_z; stpk2), representing the acceptance of total body weight for single limb support (Brunt et al., 1991; Nissan & Whittle, 1990). A third, and final vertical GRF peak is seen corresponding to the point of swing limb heel strike (Fig. 2-2: F_z; stpk3), followed immediately by a decrease in vertical GRF as the stance limb lifts from the ground (Brunt et al., 1991; Nissan & Whittle, 1990).

The anterior-posterior GRF (F_x) represent the propulsive (anteriorly directed) and braking (posteriorly directed) forces applied through the feet. During normal quiet stance, A/P GRF are equal to zero, since no forward or backward movement is occurring. As gait is initiated, both limbs are utilized to generate an anteriorly directed force, creating momentum in the forward direction (Brunt et al., 1991; Nissan & Whittle, 1990). While the swing limb generates a small amount of anteriorly directed force (5% of body weight) just prior to toe off (Fig. 2-2: F_x; swpk1), the stance limb generates a significantly greater amount of propulsive force, contributing as the primary generator of whole-body forward momentum (Brunt et al., 1991). This production of forward motion occurs because of a peak stance limb anteriorly directed force (roughly 25% of body weight) at the point of swing limb heel strike (Fig. 2-2: F_x; stpk2), whereas a smaller peak in anterior force occurs in this limb at the point of swing limb toe off (Fig. 2-2: F_x; stpk1), to the magnitude of about 16% of body weight, corresponding to single limb support (Brunt et al., 1991).

While A/P forces are the determinant of forward motion during GI, M/L GRF are created and modulated to maintain balance and prevent falling. During normal quiet standing the mediolateral GRF fluctuate close to zero, maintaining side-to-side balance (Nissan & Whittle, 1990). During GI, this trend persists until the swing limb begins to accept more weight prior to toe-off, whereby a lateral force towards the swing limb is generated by both limbs (Brunt et al., 1991). A smooth transition into a lateral force in the direction of the stance limb occurs subsequently and persists until toe off, generating the momentum necessary to drive the CoM towards the stance limb in preparation for single limb support (Brunt et al. 1991). M/L directed forces during single limb support are then generated to maintain balance (Nissan & Whittle, 1990).

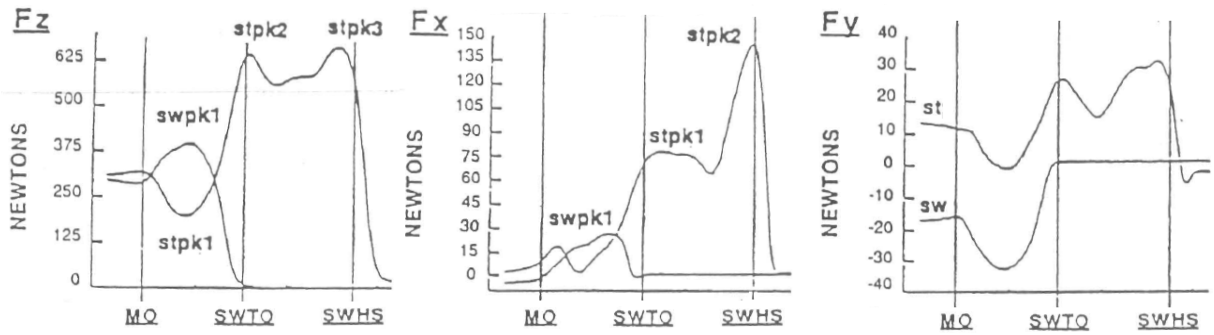

Figure 2-2. Representative vertical (F_z), anterior-posterior (F_x), and mediolateral (F_y) forces during gait initiation. MO: movement onset; SWTO: swing toe-off; SWHS: swing heel-strike; sw: swing limb; st: stance limb. An upward deflection of F_x indicates an anteriorly directed force (adopted from Brunt et al., 1991)

Gait Initiation in the Elderly

Many falls in the elderly occur during transitions such as initiating or terminating gait and changing direction, which makes the initiation of gait a precarious task for elderly individuals (Polcyn et al., 1998). For instance, many elderly persons fall when walking only a short distance (implying that the transition periods are a posturally demanding portion of the task), and/or during the activities when the CoM is mildly shifted from the base of support (Polcyn et al., 1998). Furthermore, the modifications to the GI motor program that cause deficits in performance are caused, at least in part, by changes within the central nervous system that are inherent in the normal aging process (Polcyn et al., 1998). However, it appears that healthy older adults use the same motor program as healthy young adults to initiate gait, with only subtle impairments to movement performance, including CoM – CoP interactions and/or modified strategies (i.e. step length and movement duration) (Polcyn et al., 1998).

Center of Pressure and Center of Mass Profiles

The relationship between the center of mass and center of pressure is an important indicator of GI performance. Older adults exhibit typical modifications to their CoP profiles during GI that lead to subsequent deficits in functional outcomes of the task (i.e. gait speed and step length). It has been repeatedly shown that older adults generate a reduced A/P CoP displacement prior to swing limb toe-off, which results in diminished forward momentum generation (Halliday et al., 1998; Polcyn et al., 1998; Rogers et al., 2001). Differences in the displacement of the CoP in the M/L direction, representing the weight shift that enables single limb support, are less pronounced between elderly and young individuals. Several studies have reported no significant differences between young and elderly CoP displacements in the M/L direction during GI, indicating that the capacity to generate momentum in the frontal plane is preserved with aging to a greater extent than in the sagittal plane (Halliday et al., 1998; Rogers et al., 2001).

Ground Reaction Force Profiles

Compared to young adults, elderly individuals stand with a stooped posture that anteriorly shifts their CoM as a means to increase their postural stability (Blaszczyk et al., 2000; Henriksson & Hirschfeld, 2005; Patchay et al., 2002).   Furthermore, it has been shown that elderly individuals tend to exhibit a limb loading asymmetry during quiet standing, which may serve as a compensatory mechanism to generate forward momentum by reducing the need to load the swing limb (Blaszczyk et al., 2000; Henriksson & Hirschfeld, 2005).

Henriksson found that during GI, the peak propulsive force exerted by both the swing and stance legs tended to be less, but peaked earlier in the gait cycle for elderly as compared to the young adults (Henriksson & Hirschfeld, 2005). This study also found a significantly greater increase in peak vertical force from baseline (standing body weight) in the elderly, and this force peaked earlier in the elderly whereas in the young it peaked closer to the push-off of the stance leg (Henriksson & Hirschfeld, 2005). The same findings were duplicated in a second study examining weight transfer differences between elderly and young in various tasks, including GI (Jonsson et al., 2007). The earlier occurrence of peak forces that characterize elderly GI are the cause of the previously described reductions in CoP displacement, showing that the magnitude of postural adjustments required to initiate gait are reduced by shortening the duration of their corresponding postural shifts, an effect inherent in the aging neuromuscular system.

Gait Initiation in Parkinson's Disease

Parkinsonian gait is characterized by general slowness, small shuffling steps with short strides, and reduced arm swing (Rosin et al., 1997). PD patients tend to walk more slowly than do age-matched controls without neurological impairment, and show a tendency for retropulsion and propulsion (Martin et al., 2002). The PD patients often present festinating gait (taking increasingly shorter and faster steps), as if attempting to catch-up with their CoM, until the feet fail to clear the ground surface and shuffling occurs (Martin et al., 2002). The decreased gait performance represents one of the major determinants for independence and quality of life for patients with PD (Rosin et al., 1997; Stewart et al., 2008). Furthermore, GI is critical to independent function and is generally more problematic for individuals in the advanced stages of PD, who often experience freezing during gait initiation (Martin et al., 2002). GI freezing, which can appear even under absence of all other symptoms of PD (Halliday et al., 1998), is a type of motor block, and Giladi found that of those PD patients with motor blocks, 86% of them had motor blocks during GI (Giladi et al., 1992).

Center of Pressure and Center of Mass Profiles

Generally, during GI individuals with PD produce CoM/CoP trends similar, yet exacerbated, to those previously described in the elderly population (Figure 2-3). Prior to initiation, PD patients stand with their CoP significantly further ahead of their ankle joint than elderly or young subjects (Halliday et al., 1998). In an attempt to preserve stability, individuals with PD tend to minimize the distance between the CoM and CoP during movement, including GI (Halliday et al., 1998; Hass et al., 2008; Hass et al., 2005; Martin et al., 2002). Initially, and indeed throughout GI, the mean CoM-CoP distance is largest in young healthy subjects, followed by older subjects without PD, and smallest (up to 46% reductions from healthy subjects) in subjects with PD (Martin et al., 2002). Specifically, at the point of maximum posterior CoP shift, the A/P displacements of CoP moved significantly less in the PD compared to elderly (Halliday et al., 1998; Hass et al., 2008), which was previously reported by Crenna, who showed the most severe patients had only a 0.8 cm posterior movement of the CoP (Crenna et al., 1990). Furthermore, individuals with PD showed less underlying coordination during GI compared to elderly adults transitioning to frailty, as measured by the smoothness of the CoP displacement (Hass et al., 2008). These data suggest that PD patients are less willing to move through large CoM-CoP displacements during GI, which likely reflects a need to preserve postural stability due to impairments in postural control mechanisms (Hass et al., 2008). Furthermore, it was found that even in individuals with relatively early PD, they would systematically limit the inherently destabilizing CoM-CoP separation throughout GI, reflecting a need to control stability, an inability to generate momentum, or a combination of the two (Martin et al., 2002). Interestingly, Hass found that the severity of PD has an effect on the CoM-CoP interaction during the locomotor component of GI, but not during the postural phase (Hass et al., 2005). This finding suggests that as the disease progresses, the dynamic balance control systems may become more affected than the static balance control systems (Hass et al., 2005).

Ground Reaction Force Profiles

The ability to generate propulsive forces is decreased in PD patients. In PD patients, the forward impulse that the first swing foot left the ground with was significantly smaller than in healthy elderly patients, which corresponded to a significantly slower velocity at stance toe-off (Halliday et al., 1998). As suspected due to decreased propulsive force generation, PD subjects had significantly lower loading of the swing foot at the point of maximum posterior CoP shift compared to healthy older adults (56% vs. 64% of body weight) (Halliday et al., 1998). Crenna also found that propulsive forces were decreased as a function of clinical severity, particularly the horizontal component (Crenna et al, 1990). Gantchev reported similar findings in that the horizontal propulsive force was markedly decreased in PD patients during GI (Gantchev et al, 1996; 2000). Furthermore, the PD patients took significantly longer than elderly patients to unload their swing limb (Halliday et al., 1998). These GRF characteristics of PD gait are the result of less dynamic control of postural stability, restricting individuals to slower, less forceful movements that cause slower, disabled GI.

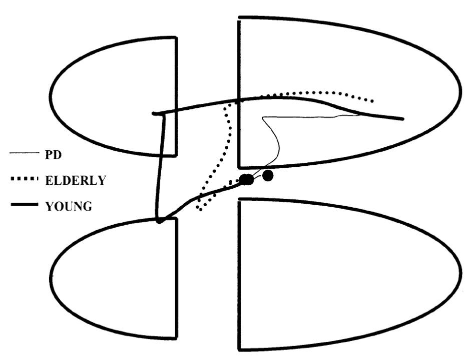

Figure 2-3. Representative CoP trajectory during GI in young, elderly, and PD subjects (adopted from Halliday et al., 1998)

Interventions to Improve Gait Initiation

Though important for functional recovery and increased independence, few studies have attempted to improve GI performance in elderly or PD populations through means of intervention. In a study examining the effects of Tai Chi training on the postural control ability of the elderly, Hass found improvements in coordination during GI (Hass et al., 2004). The 48-week intervention resulted in improvements to the CoP trajectory during the early stages of GI, leading to improvements in the generation of forward momentum (Hass et al., 2004). Specifically, the initial movement of the CoP posteriorly was increased, and the lateral movement towards the stance limb was smoother in the elderly participating in the training compared to those without training (Hass et al., 2004).

A second intervention study done with PD individuals utilized a moderately intense progressive resistance-training program in attempt to elicit modifications to improve their GI performance (Hass & Buckley, 2008). Similar to Tai Chi training in the elderly, the 10-week resistance-training program lead to a greater posterior displacement of the CoP, leading to an increased stepping velocity, during GI (Hass & Buckley, 2008). These intervention studies indicate the impairments in GI that arise from postural deficits inherent with age and PD are not entirely irreversible, and can be improved upon with various methods of training. Furthermore, the similarity in findings for both interventions suggests a specific component, the initial posterior movement of the CoP, is susceptible to both protective constraint (which leads to impaired GI), but also training to reverse the regression.

Another study attempting to elicit modifications to the postural CoP shifts as a means of therapy for the PD population applied a lateral assist to individuals with Parkinson's during GI (Mille et al., 2007). These authors also found the PD subjects to have prolonged duration of the postural CoP shifts and duration of the first step, compared to elderly controls. When lateral assist was applied to the subjects' pelvis, the resulting time to step onset and duration of CoP shifts decreased (resembling the control's baseline values), and the speed of the first step became faster (Mille et al., 2007). Another study attempted to alter GI in individuals with PD by examining changes in ankle control while patients moved their fingers prior to and after performing the task (Hiraoka et al., 2008). The study found that for PD patients who experienced disturbances in ankle control during GI, finger movement that preceded the task improved ankle control (Hiraoka et al., 2008). These findings suggest that individuals with PD have the capability to initiate gait similar to healthy individuals, but require assistance and/or strategies not normally utilized.

Gait Initiation from Altered Stance

Previous research on gait initiation from unconventional starting stance is scarce. A single study has focused on this paradigm, evaluating the effects of narrow vs. wide stance on GI in the healthy elderly and Parkinson's populations (Rocchi et al., 2006). The wide stance was associated with a larger backward and lateral CoP displacement compared to the narrow condition, however the duration of this postural CoP shift was unaffected by stance width (though the duration was longer in PD then in healthy elderly) (Rocchi et al., 2006). Furthermore, the PD subjects were able to increase the size of their backward and lateral CoP shift in the wide condition, however differences in the magnitude of these shifts compared to healthy subjects suggest they had greater difficulty initiating a step from the wide condition (Rocchi et al., 2006). Also, step length and velocity were shown to increase for both groups when stepping from a wide stance compared to the narrow stance (Rocchi et al., 2006). Thus, it appears that manipulating stance conditions can alter the way in which PD patients initiate gait.

CHAPTER 3
METHODS

Participants

A control group consisting of healthy young subjects (HY, N=12) was utilized to evaluate the normal and expected initiation of gait in response to the stance modifications. Second, an elderly group consisting of healthy older adults (HO, N=12) was used to evaluate the alterations in GI that are inherent with the natural aging process. Finally, a Parkinson's disease group (PD, N=12) consisting of elderly individuals with Parkinson's disease was utilized to evaluate the disease related changes in initiating gait from modified stance conditions. Since the vast majority of individuals with PD are elderly, using a three group model it is possible to separately identify the differences in GI performance from altered anterior-posterior stance that are due to the aging process from those caused by the disease. In this respect, disease-specific conclusions can be made and will lead to a better understanding of the disease and potential of this noninvasive nonpharmacological intervention.

Inclusion Criteria

All subjects were able to independently ambulate. Furthermore, the healthy young subjects were between the ages of 18 and 40 years old. Healthy elderly subjects were age (within one year) and gender matched to the Parkinson's disease subjects. Individuals in the PD group were limited to those clinically diagnosed with idiopathic Parkinson's disease with mild to moderate severity (Hoehn and Yahr disability rating 2-4), and a score of 1 or 2 on UPDRS questions 14 and/or 29. Furthermore, PD subjects were required to exhibit stable Parkinsonian motor symptoms without significant fluctuations throughout their medication cycle. PD subjects were between 50 and 75 years of age and were tested while on medication.

Exclusion Criteria

Individuals were excluded if they reported having a history of significant cardiovascular, musculoskeletal, vestibular or other neurological disorders, if they used an assistive walking device, if they had any orthopedic disturbances of the lower extremities, or were concurrently participating in another experimental study.

Measures

The following equipment was used to evaluate the kinematic and kinetic parameters of GI for each subject during the experimental trails. A Bertec forceplate (model 4060-10, Colubmus, Ohio) was used to measure ground reaction forces (GRF) and center of pressure (CoP) displacements under a single limb prior to and during the first step of GI at a collection rate of 1200 Hz. The subject's motion was captured using a Vicon motion analysis system (Vicon, Oxford, UK), including ten MX20 digital cameras collecting at 120 Hz, to provide kinematic data during the trials. Anthropometrics required for subject reconstruction in the Vicon Plug in Gait model were consistently measured by the same investigator and included: height, weight, leg lengths, foot lengths, ankle widths, knee widths, elbow widths, wrist widths, hand thickness, and shoulder offsets. Using 13 mm diameter retro-reflective markers placed over bony landmarks of the body, the subject's full body was reconstructed based on a linked rigid segment model. Markers were bilaterally placed in accordance with the plug in gait marker set.

From the collected data, specific outcome measures were examined. Limb loading asymmetry (the difference in vertical GRF under each limb) during quiet stance preceding the start signal was measured to evaluate stance and group differences. Anterior-posterior and vertical shifts in the GRF between the two lower limbs across stance conditions were evaluated as a measure of propulsion and task demand, respectively. Full body CoM velocity and CoM sway were calculated from kinematic data as measures of overall task performance and stance stability, respectively.

Protocol

Subject Preparation

Subjects participated in a single data collection session which began by reviewing and signing the informed consent document. Each subject wore a tight fitting, sleeveless shirt, a pair of athletic shorts that extended no further than mid-thigh, and was barefoot during the testing session. After the subject was prepared with reflective markers, their preferred swing limb was determined by asking them to initiate gait from a neutral standing position five times and noting the limb that initiated swing most frequently. Subsequently, subjects were instructed to stand in a natural, comfortable standing position with their feet oriented with bilateral symmetry while their heel marker to heel marker stance width was measured. This stance width was used for each subsequent trial.

Stance Condition Orientation

Being constrained by the use of only a single forceplate, the stance limb and swing limb were evaluated independently so that for every stance condition, in reference to the forceplate, there was a “swing limb off” and a “swing limb on” set of trials. Furthermore, maintaining accurate and consistent foot placement across trials for each stance condition was imperative to the experiment and was ensured through the use of floor markings. The evaluated stance conditions were in reference to the placement of the swing foot and will include “normal”, “forward”, and “back”, see figure 3-1. The “normal” stance was maintained with an inter-heel marker distance equal to the subject’s stance width and without any anterior or posterior shift of the feet. The “forward” stance was marked as an anterior (in the direction of eventual motion) displacement from the even condition of the limb off the forceplate, equal to one-half of the subject's foot length. The "back" stance was marked as a posterior displacement from the even condition of the limb off the forceplate, equal to one-half of the subject's foot length. In this manner, the stance width was held constant. Finally, the floor markings for each stance condition were duplicated to either side of the forceplate due to the "stance on" and "stance off" constraint, creating the following six foot placements and corresponding experimental conditions: swing-on forward, swing-on even, swing-on back, swing-off forward, swing-off even, and swing-off back.

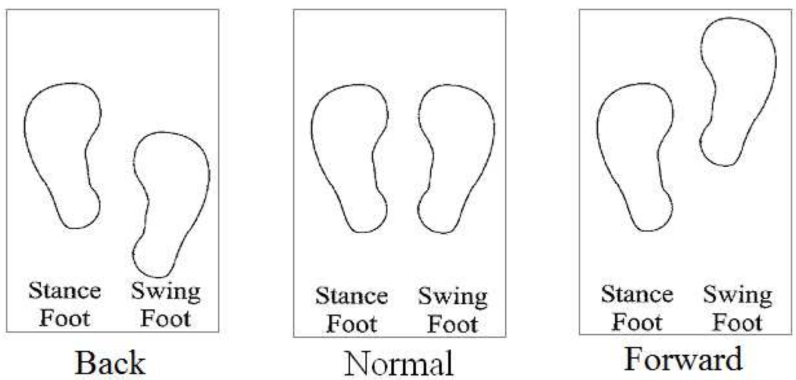

Figure 3-1. Diagram of subject's foot placement for each stance condition

Experimental Procedures

Experimental trials consisted of approximately two seconds of quiet stance prior to the signal to initiate gait and the following three steps. Stance conditions were randomly selected and performed in a block method; all trials of one condition were completed before randomly selecting the next condition. Before the trial was started, proper foot placement was assured and subjects were instructed to "stand comfortably, look straight ahead, and upon hearing the signal pause a moment then begin walking straight forward to the end of the walkway." Five trials of each stance condition were performed, creating a data set consisting of 30 total trials.

Statistical Analysis

The independent variables of this study were stance condition: forward, normal, and behind; and group: PD, HO, and HY. The eight dependent variables included: swing limb loading (average vertical GRF during quiet stance preceding GI); peak swing limb loading (difference between average loading during quiet stance and maximum); peak stance limb propulsive force generation (difference between average anteriorly-directed force during quiet stance and maximum); APA duration (time between deviation of swing limb average vertical GRF during quiet stance to maximum); CoM velocity at swing toe-off (V_1), swing heel-strike (V_2), and stance heel-strike (V_3); and CoM standard deviation in the M/L direction during quiet stance. Group differences for GRF variables (quiet stance swing limb loading, peak swing limb, stance propulsive force, and APA duration) were evaluated using a 3 x 3 (stance x group) MANOVA, a second 3 x 3 (stance x group) MANOVA was used to compare differences among CoM variables (velocity at three time points and standard deviation in M/L direction). Follow up univariate ANOVA's were performed when appropriate. Significant group differences and position differences were further evaluated using independent and dependent t-tests for post-hoc testing. Statistical significance was set at 0.05.

CHAPTER 4
RESULTS

Demographic Data

Three groups of twelve subjects each comprised the study population. The healthy young subjects consisted of 6 males and 6 females [mean (SD), age: 24.3 (4.1) years; mass: 71.9 (11.8) kg; height: 170.4 (11.1) cm]. The healthy older adults consisted of 9 males and 3 females [mean (SD), age: 68.8 (6.8) years; mass: 81.0 (20.4) kg; height: 174.9 (9.5) cm]. The Parkinson's disease group consisted of 11 males and 1 female [mean (SD), age: 70.1 (7.3) years; mass: 89.2 (16.9) kg; height: 168.0 (6.0) cm]. The average age of onset for the PD subjects was 64 (6.1) years old and the average time since onset was 6.1 (4.4) years.

The Global MANOVA for the ground reaction force data revealed significant main effects for Group ($F=4.25$, $p<0.001$) and Position ($F=24.27$, $p<0.001$). No significant Group x Position Interaction was identified at the MANOVA level ($F=0.945$, $p>0.05$). Similarly for the COM variables, the global MANOVA identified a significant Group main effect ($F=4.67$, $P<0.001$) and a significant Position main effect ($F=34.17$, $p<0.001$). A significant interaction was not observed $F= 1.22$; $P>0.05$).

Effects of Stance Condition

Univariate analyses revealed significant position effects for both variables related to swing limb loading, stance limb propulsive force generation, CoM velocity at all time points, and the standard deviation of the CoM trajectory in the mediolateral plane (Figures 4-2 – 4-7). A significant increase in swing limb loading during the APA period was seen from back to normal and normal to forward stance conditions ($p<.001$). Propulsive force generated by the stance limb was determined to be significantly greater in the back relative to the normal and forward conditions ($p<.001$), but propulsive force was similar between the normal and forward conditions ($p=.21$).

CoM velocity was largely affected by the initial stance condition, as the back condition produced the greatest velocity at each time point (Figures 4-4 – 4-6). At toe off of the swing limb (V_1), significant differences were seen across each stance condition ($p<.001$). At heel strike of the swing limb (V_2), CoM velocity remained significantly greater in the back vs. normal conditions and forward conditions and normal vs. forward conditions ($p<.001$). Finally, at the instance of stance limb heel strike (V_3), CoM velocity was significantly greater during the back condition compared to forward and normal (back vs. normal: $p=.016$; back vs. forward: $p<.001$) but similar from normal and forward conditions ($p=.12$). The standard deviation of the CoM in the mediolateral direction during quiet stance showed a significant increase in both the forward (46%) and back (40%) conditions relative to the normal stance ($p<.001$), but not when comparing the forward to back conditions ($p=.591$).

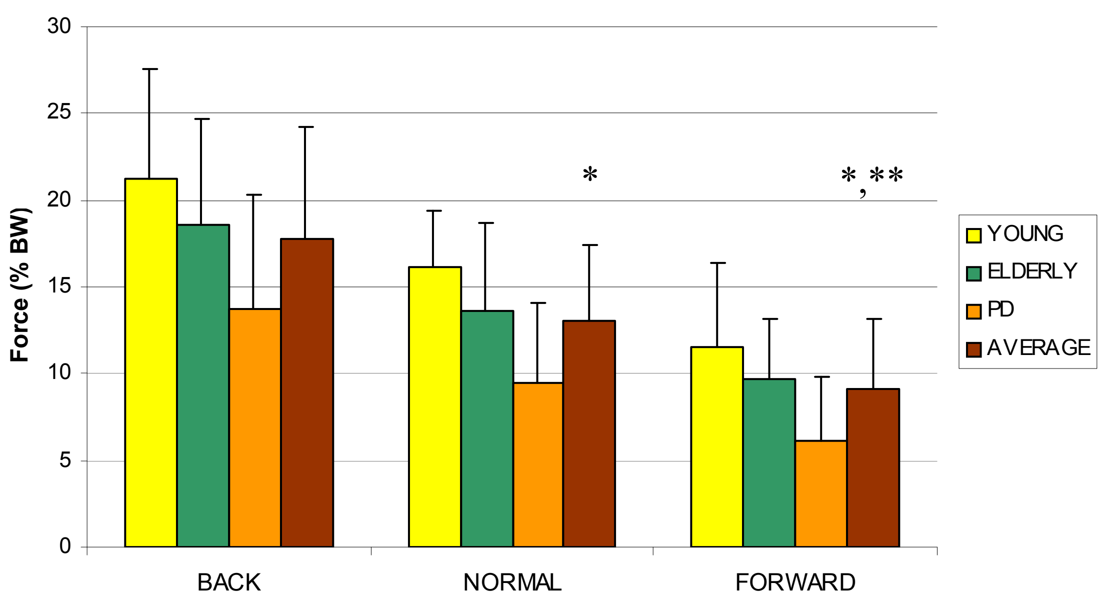

Figure 4-1. Maximum swing limb loading from baseline for each group across stance conditions
* significantly different than Back **significantly different than Normal

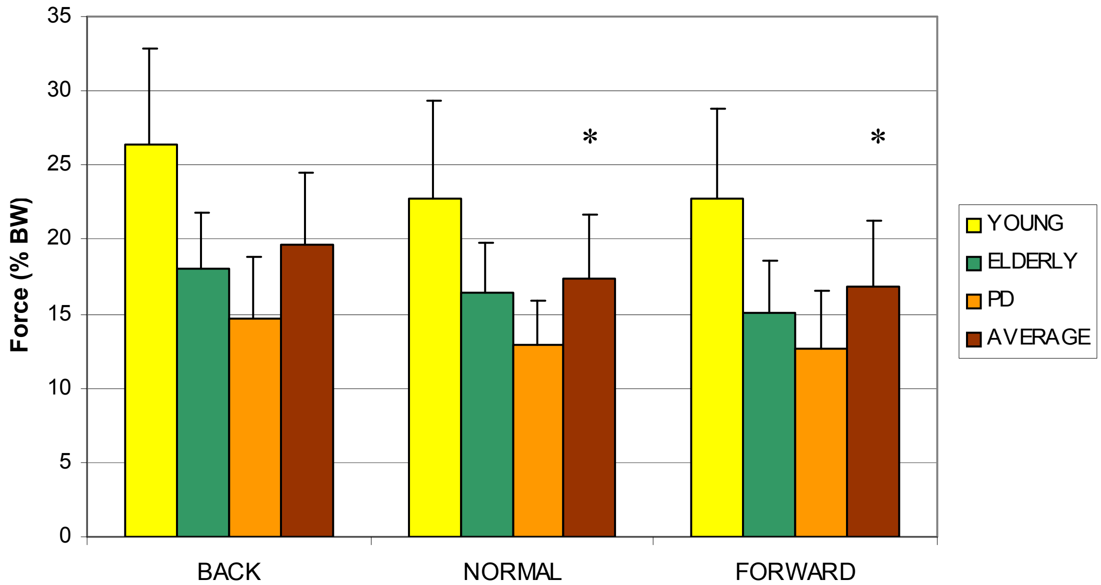

Figure 4-2. Maximum propulsive force generated from baseline by stance limb for each group across stance condition * significantly different than Back

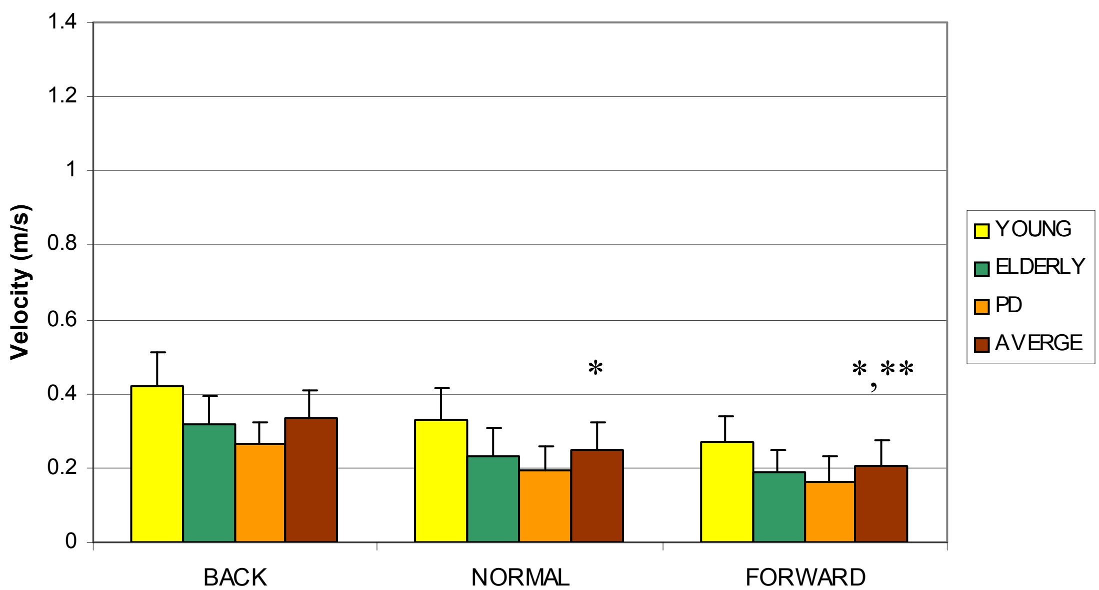

Figure 4-3. CoM velocity at swing toe off (V_1) for each group across stance conditions *significantly different than Back **significantly different than Normal

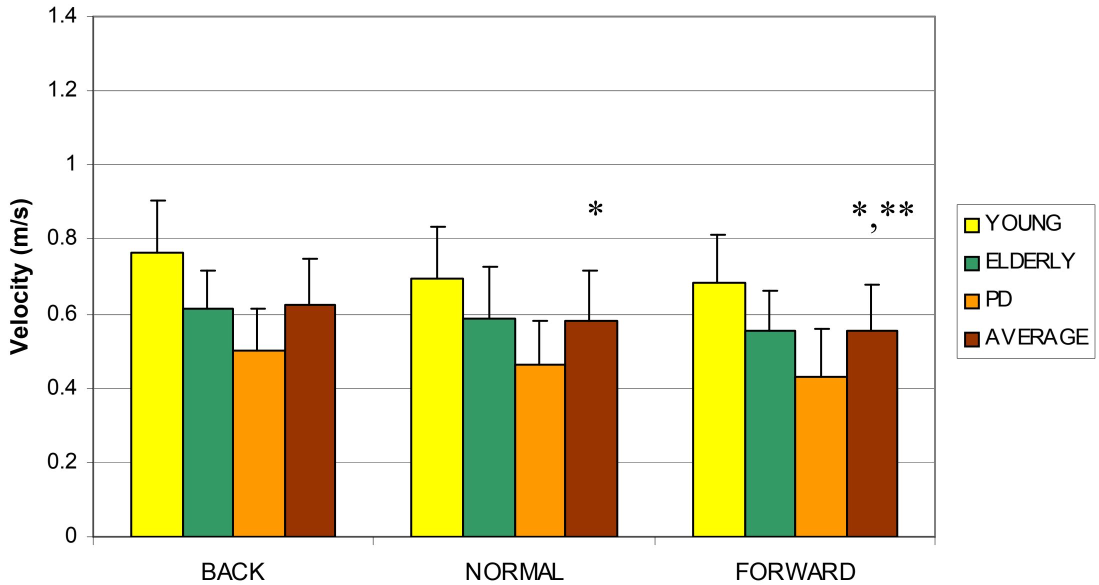

Figure 4-4. CoM velocity at swing heel strike (V_2) for each group across stance conditions
*significantly different than Back **significantly different than Normal

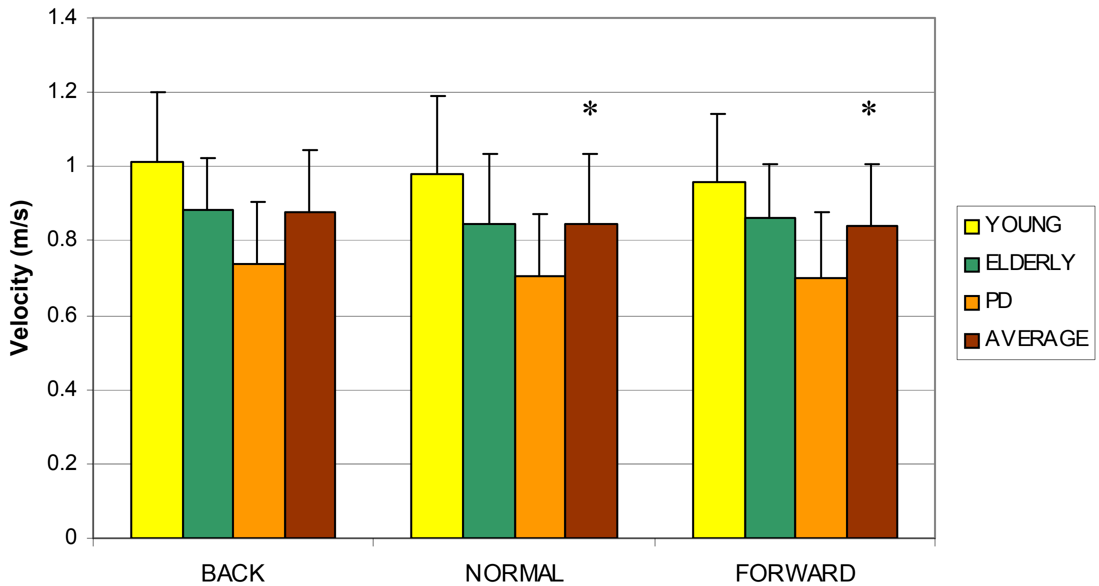

Figure 4-5. CoM velocity at stance heel strike (V_3) for each group across stance conditions
*significantly different than Back

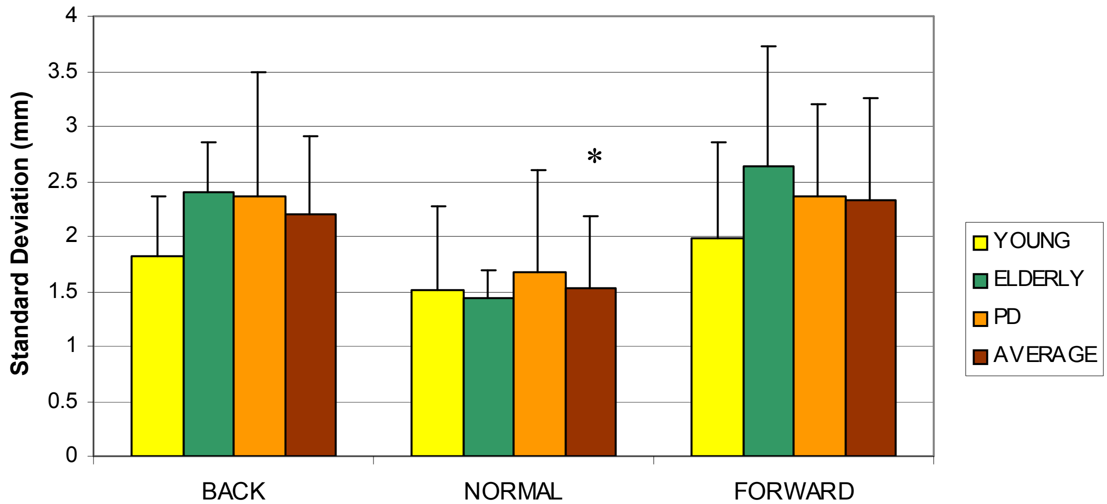

Figure 4-6. Standard deviation of the CoM position in the medial-lateral direction during quiet stance for each group across stance conditions *significantly different than Back

Group Effects

The results from the Univariate testing revealed significant group main effects for swing limb loading, stance limb propulsive force generation, APA duration, and CoM velocity (consistent effect at each time point), (Figures 4-8 – 4-13). Swing limb loading during the APA period was significantly lower in the PD group (HO: $p=.017$; HY: $p<.001$), but similar in the HY and HO groups. The HY group produced significantly greater stance limb propulsive force than either the PD or HO groups ($p<.001$), while the PD and HO groups produced similar values ($p=.104$). APA duration was significantly lower in the HY group compared to the PD group ($p=.011$), but was statistically similar between PD and HO ($p=.13$) and HO and HY ($p=.265$) groups. At all time points, CoM velocity was significantly greater in the HY group compared to the HO and PD groups (HY vs. HO: V_1, $p<.001$, V_2, $p=.003$, V_3, $p=.018$; HY vs. PD: V_1, $p<.001$, V_2, $p<.001$, V_3, $p<.001$). The PD and HO groups were not statistically different at any time point

($V_{1,}$ p=.587, $V_{2,}$ p=.062, V_3 p=.153). There was no significant difference in the standard deviation of the CoM in the medio-lateral direction across groups.

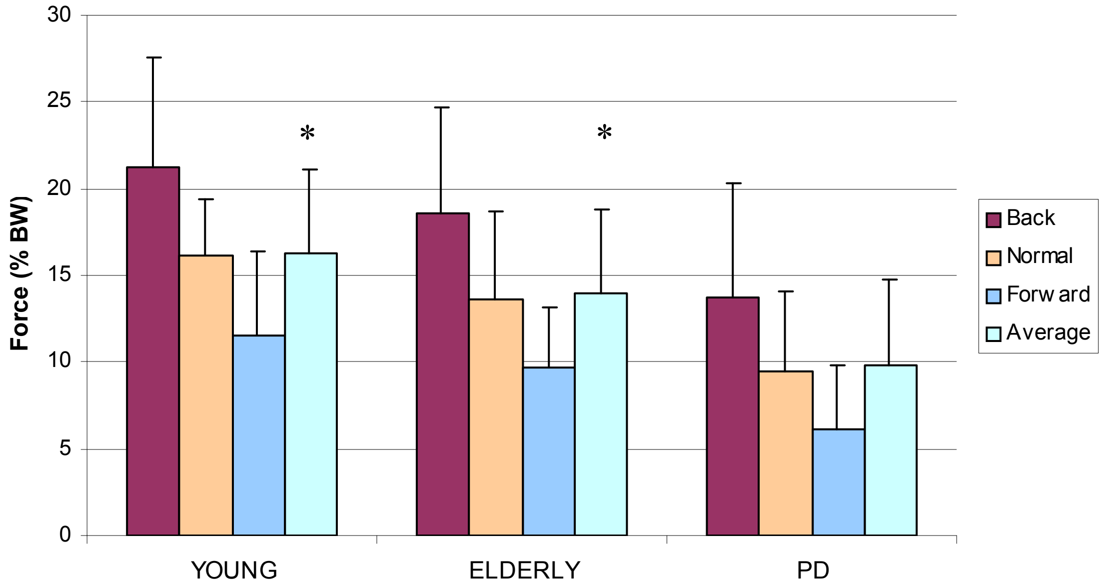

Figure 4-7. Maximum swing limb loading from baseline for each stance condition across subject groups. *significantly different than PD

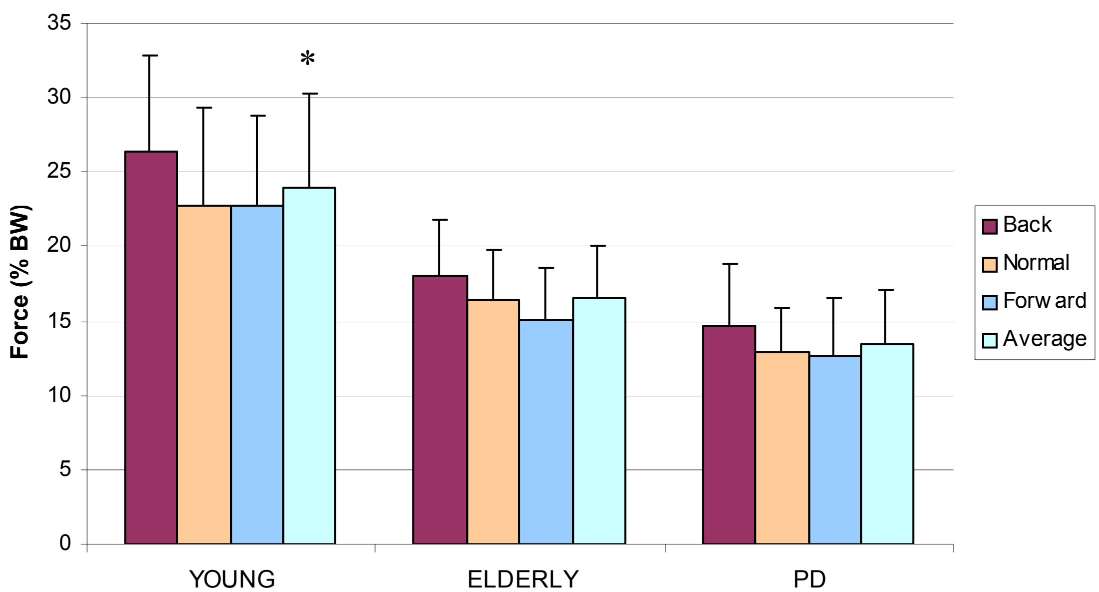

Figure 4-8. Maximum propulsive force generated from baseline by stance limb for each stance condition across subject groups. *significantly different than PD

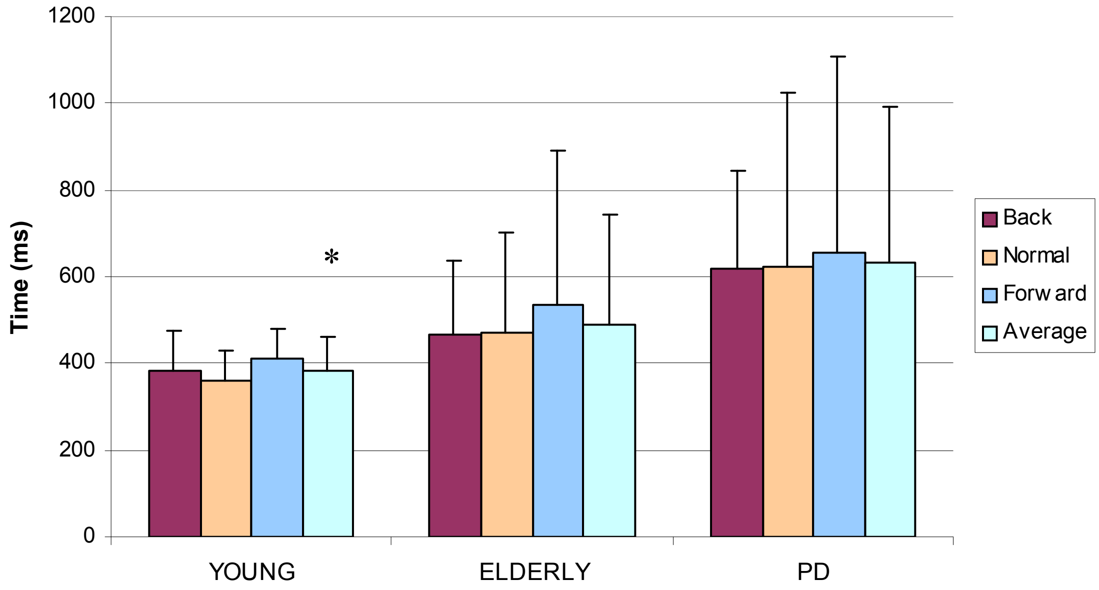

Figure 4-9. Duration of the APA for each stance condition across subject groups *significantly different than PD

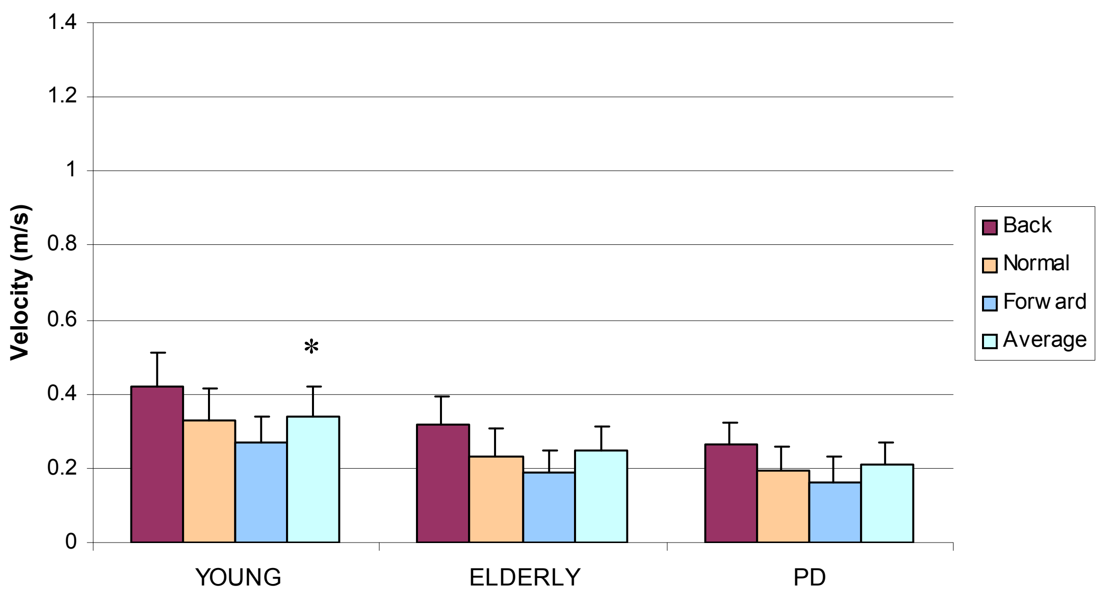

Figure 4-10. CoM velocity at swing toe off (V_1) for each stance condition across subject groups *significantly different than PD

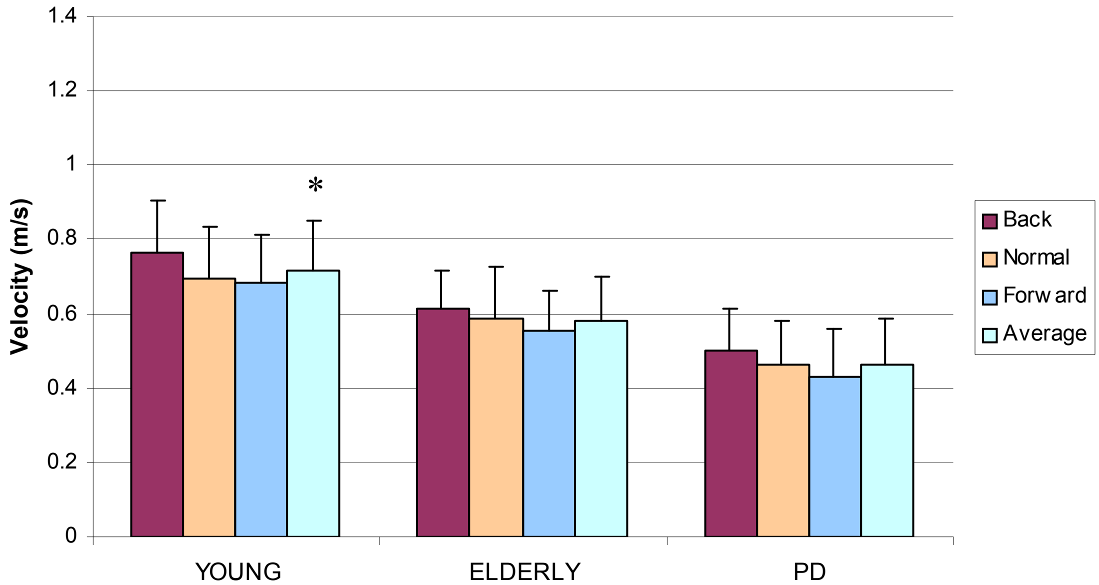

Figure 4-11. CoM velocity at swing heel strike (V_2) for each stance condition across subject groups *significantly different than PD

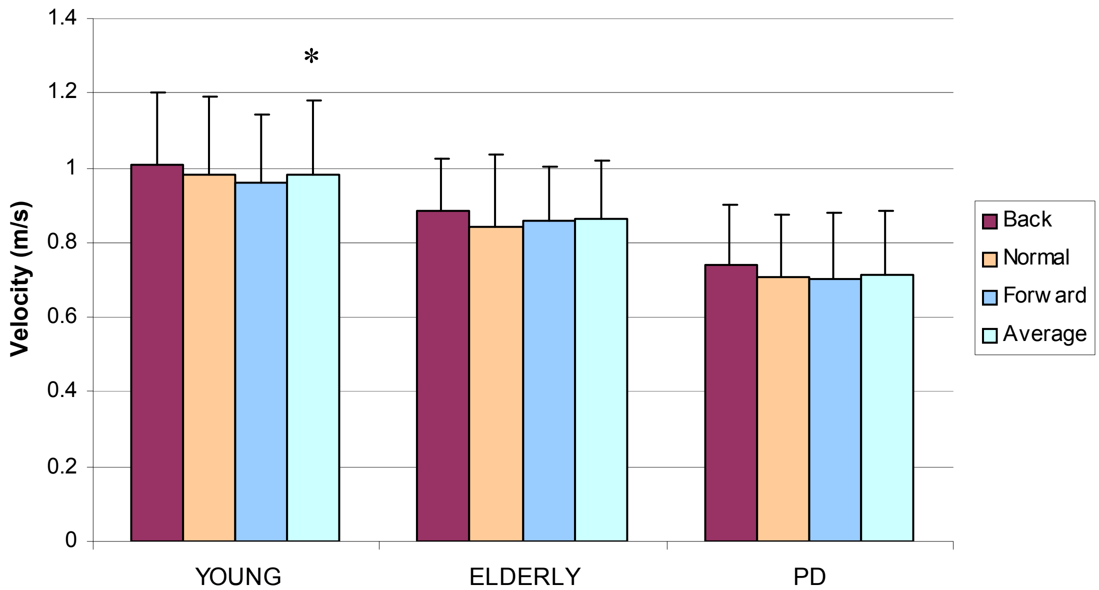

Figure 4-12. CoM velocity at stance heel strike (V_3) for each stance condition across subject groups *significantly different than PD

CHAPTER 5
DISCUSSION

Older adults and persons with Parkinson's disease, when compared to young adults, exhibit difficulties during gait initiation including longer duration APAs, reduced force development and speed. The purpose of this study was to evaluate whether modifying the initial positioning of the swing limb may positively influence gait initiation performance. The results of the study suggest that significant improvements in performance can be achieved by placing the initial swing limb posterior.

Mediolateral weight shifting is a crucial component of an efficient gait initiation pattern. Older adults and individuals with PD have significant difficulty initiating the APAs that lead to weighting of the swing limb (Massion J, 1992). During quiet standing with the swing limb translated backwards ½ foot length, participants stood with significantly more loading under that limb. Once the participants began the initiation process, this posterior position facilitated a significantly greater loading of the swing limb. 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 gait initiation (Brunt et al., 2002; Cordo and Nashner, 1981). Rocchi and colleagues have also shown that manipulating initial stance conditions, in this case a wider stance, leads to a greater loading of the swing leg during gait initiation (Rocchi et al., 2006). Because stance width was the same among our conditions, the greater weight shift was likely due to a greater effectiveness of the APA. Further, we observed that the duration of the APA did not change across condition, thus the participants were able to produce a greater force magnitude within the same amount of time. While these results are promising, one may be hesitant to recommend the staggered position if there was a significant threat to postural stability. The back stance condition did indeed cause significantly greater oscillations in the mediolateral position of the CoM during quiet stance than the normal condition, however the magnitude was such that the participants did not subjectively report any differences in their sense of stability across the conditions. Thus, while statistically different it is appears the back position does not influence participants feeling of being stable.

Swing limb positioning also influenced center of mass velocities throughout the initiation and stepping process. Indeed CoM velocity was greatest at every time point (toe off of the swing limb (V_1), heel strike of the swing limb (V_2), and heel strike of the stance limb (V_3)) when initiating gait from the posterior translated swing limb. It is well known that older adults and persons with PD exhibit slowing of the stepping response but it appears this may be remedied by altering initial foot placement. CoM speed increased on average by 34%, 8.5%, and 2.8% from a back stance relative to a normal stance at the three time points of interest (V_1, V_2, V_3, respectively). Rocchi has also shown that a wider stance width is also capable of improving stepping velocity in young, old, and PD (Rocchi et al., 2006). However, they reported that individuals with PD had much more difficulty initiating a step from a wide stance, thus reducing the potential efficacy of this strategy. Mille and colleagues in two separate studies have shown that a lateral assist force delivered to the hip timed with gait initiation can improve initiation performance including velocity of the first step (Mille et al., 2007; Mille et al., 2009). Similar improvements in gait initiation performance were realized in the current study when initiating gait from the back stance, which is a more practical and feasible method of improving performance than a robotically controlled lateral assist. Furthermore, the range of values reported for APA durations by Mille are consistent with the results of the current study, indicating similar postural adjustments in response to both methods of assistance (Mille et al., 2007; Mille et al., 2009).

The insight into the possible origins of this improved gait speed can be gained when examining the forces corresponding to preloading of the swing limb during quiet stance, peak swing limb loading (generation of M/L momentum) and subsequent stance limb propulsive force generation (forward-directed momentum). The magnitude of each of these forces was greater in the back condition compared to either other condition and for all subjects. The values obtained for peak swing limb loading and stance limb propulsive force when initiating gait from the normal condition are consistent with values reported in previous studies (Halliday et al., 1998; Brunt et al., 1995). In the back condition during quiet stance, participants stood with more force under their swing limb and were able to further load the limb when generating M/L momentum. Peak swing limb loading corresponds to the body's activity during the postural components of the GI process. Because no differences were identified in APA duration across stance condition, the back condition represents a situation that enables individuals to perform the postural phase of GI with greater efficiency. This efficiency is presumably propagated into the propulsive phase of GI, as significantly greater propulsive force was created when initiating from the back condition compared to either other condition (2.3% BW greater than normal, 2.9% BW greater than forward). The back condition appears to enable subjects to perform more dynamic APAs, leading to more rapid and faster CoM movement.

It is speculated that the back condition exhibits its beneficial properties due to the biomechanical advantages awarded by the spatial orientation of the body. The extended position of the limb coming into swing places a stretch on the flexor muscles of the limb, creating a more rapid rate of force production and corresponding limb velocity (which translates into CoM velocity) (Lewek et al., 2007). Furthermore, the back position allows the 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. Finally, a recent paper examining spinal excitability has shown that increases in joint extension correspond to increased descending spinal excitability (Hyngstrom, 2007). Hyngstrom proposes that this increased excitability acts to deactivate extensor muscles during late stance via reciprocal inhibition, enabling more robust swing onset. During the back stance condition both the ankle and hip joints are extended to a greater degree than a normal stance, thus swing may be facilitated.

The forward stance condition elicited modifications to the GI process that were either opposite the effects of the back condition, or were indifferent from the normal stance. Particularly, CoM velocity at V_1 and V_2 was significantly slower when initiating gait from the forward condition compared to normal, and not different at V_3. Peak swing limb loading was significantly less when subjects started with the limb forward and stance limb propulsive force was unchanged in the forward relative to the normal condition. Standard deviation of the CoM in the M/L direction was also significantly greater in the forward condition compared to the normal condition. These findings indicate an overall disadvantage to initiating gait with the swing limb forward, as less robust postural adjustments appear to occur during the APA period, which leads to slower gait initiation.

Group Comparisons

As expected, the healthy young adults were able to initiate gait more robustly, with greater velocity at all time points, greater stance limb propulsive force generation, and shorter APA durations than the healthy old or PD individuals (which were not significantly different from one another). The PD group began walking with significantly decreased peak swing limb loading than the HO or HY groups (which were not significantly different from one another), likely a result of the protective mechanisms utilized to minimize postural shift that are characteristic of the disease. It is obvious that the stereotypical deficits in GI extensively reported in the PD population persist in the findings of the current study. Interestingly, although the absolute performance of GI across conditions was diminished in the PD group compared to the HO group, the differences were not significant (except in the peak swing limb loading measure), indicating similar performance of the tasks by each group. The lack of further significant differences across groups is indicative of the commonality of changes induced by the altered stance, supporting the notion that the effects of stance condition are a result of common modifications to the GI program, independent of the individual.

The PD group, when initiating gait from a back stance, were able to perform the task in a statistically indifferent manner as the elderly group initiating normal gait. This suggests that a backward stance configuration compensates for the GI disturbances caused by PD. Furthermore, the elderly group demonstrated a similar effect of a back stance, performing GI in the same manner as the young group initiating gait from a normal stance. It is proposed that the back stance elicits alterations to the GI program that are able to counteract the deleterious effects of disease or aging.

Limitations

The constraint of using only a single force platform during data collections prevented simultaneous measurement of GRFs beneath both the swing and stance limb for a given trial. While trials were duplicated using the same stance position to obtain both swing limb and stance limb force data, it is possible that differences arose between these trials that are not evident in the results. Another potential confound is the use of subject selected stance widths, which although remaining consistent across stance conditions, could have an overall effect on the measures of stability and APA durations if significant differences between subjects were realized. Also, there is inherent variability in the method used to calculate CoM and therefore velocity measurements and CoM SD measures may vary. Finally, a larger group sample size would increase the fidelity of outcome measures, potentially allowing significant differences to arise in those measures reported to be insignificantly different across position.

Future Directions

An obvious addition to the body of knowledge obtained from this study would be to examine the detailed CoP-CoM interactions during GI from the altered stance conditions. Utilizing a second force platform during data collections would allow for comprehensive CoP profiles to be collected, along with providing same-trial measures of GRFs under both the swing and stance limb. Further, examining the EMG characteristics of the major muscles contributing to GI would provide a valuable analysis of the underlying neuromechanical properties affected by modified stance.

One of the most interesting findings of the current study, and a point that warrants further investigation, is the lack of differences found in APA duration across different stance conditions. That is, despite a different base of support and different loading of the limbs in the altered stance conditions, the body is able to make the necessary postural adjustments to initiate gait without taking more (or less) time. It is proposed that APAs during GI, while stereotypical for a given position, have the ability to adapt to the spatial orientation of the body while being executed in an end-point directed fashion. In other words, for a task the body is in a given starting position and understands the desired ending position, and is inherently able to generate the movements to reach the end point most efficiently.

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BIOGRAPHICAL SKETCH

Elan was born in Colorado Springs, CO in July of 1986. He attended high school there as an International Baccalaureate scholar. His childhood passion of playing football in the street lead him to pursue a university education in Health & Exercise Science at Colorado State University. As a Hughes Undergraduate Scholar, he became involved in a clinical biomechanics laboratory at CSU, developing and leading many research projects. In 2007, he graduated with honors and then began his graduate education at the University of Florida. He has had a multi-faceted involvement with sports throughout his life, ranging from player to official, equipment manager, athletic trainer and coach.