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Gait Initiation in Parkinson's Disease: The Manipulation of Cue Expectancy in a Dual Task Paradigm

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A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science

GAIT INITIATION IN PARKINSON'S DISEASE: THE MANIPULATION OF CUE EXPECTANCY IN A DUAL TASK PARADIGM

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ABSTRACT

Introduction. This study examined movements of the center of pressure (CoP) during forward gait initiation, in Parkinson disease (PD) patients and healthy controls, in a dual task paradigm with manipulations of cue expectancy. **Methods.** The CoP trajectory was divided into three periods and, prior to testing, subjects were given instructions as to whether they would receive the cue to initiate gait. The secondary task was a numerical recitation. **Results.** PD patients demonstrated significantly reduced CoP movements and greater variability in the timing of the vocalizations compared to healthy controls. Both groups demonstrated significant increases in CoP movements when uncertain and significant increases in counting cadence when dual tasking. **Conclusions.** PD patients constrained their CoP movements more than healthy controls, reflecting a need to control stability, and uncertainty in task timing cues reflected increases in CoP movements during gait initiation in both PD patients and healthy controls.

Key Words: Gait initiation, Parkinson's disease, dual task, cue expectancy, center of pressure

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ABBREVIATION AND SYMBOLS

PD	Parkinson's disease
HOC	Healthy age-matched controls
CoP	Center of pressure
CoM	Center of mass
CoP-CoM	Distance between center of pressure and center of mass
COPL	Center of pressure length
SAS	Startling auditory stimulus
UPDRS	Unified Parkinson's Disease Rating scale
APAs	Anticipatory postural adjustments
TMS	Transcranial magnetic stimulation
EMG	Electromyography
DT	Dual task
NDT	Non-dual task
L1	Release
L2	Unload
S1	Period 1 of center of pressure trace
S2	Period 2 of center of pressure trace
S3	Period 3 of center of pressure trace
RMS	Root mean square
X	Medial-lateral
Y	Anterior-posterior
Z	Vertical
Ms	Milliseconds
Cm	Centimeters
MANOVA	Multivariate analysis of variance
ANOVA	Analysis of variance

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1. INTRODUCTION

In daily living, people are frequently required to perform more than one task at a time (dual task performance). Dual tasking involves the simultaneous execution of a primary task (the major focus of attention) and a secondary task (the lesser focus of attention; O'Shea et al., 2002). For example, people commonly carry on a conversation while walking, read a magazine while exercising at the gym, or listen to music while walking the dog. In some populations, focusing attention on the performance of one task results in a deterioration in the performance of the other task. Specifically, this has been identified as a common issue for individuals with Parkinson's disease (PD; Camicioli et al., 1998; Bond and Morris, 2000; O'Shea et al., 2002; Marchese et al., 2003; Galletiy and Brauer, 2005; Holmes et al., 2010).

A common progressive neurodegenerative disorder, PD is characterized by a large number of motor and non-motor symptoms that can impact on function to a variable degree. There are four clinical features of PD: tremor at rest, rigidity, bradykinesia (or akinesia) and postural instability (Jankovic, 2008) which lead to motor disorder that impairs the individual's balance and posture, limiting mobility, and leading to health problems as a result of immobility and falls.

The performance of multiple tasks simultaneously is a frequent and debilitating problem in PD patients. Many people with PD find that when they focus attention on one task, the performance on another becomes troublesome. The difficulties experienced in the simultaneous performance of two or more tasks have led to the development of numerous theories on human information processing, two of which are the bottleneck

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theory and the capacity-sharing theory. The bottleneck theory proposes that only one task can be processed at a time (i.e., the processing of the second task will be delayed until the processor is free from processing the first task; Yogev et al., 2008). The capacity-sharing model proposes that individuals have a certain amount of attentional capacity, and that the allocation of attentional resources while performing two or more attention-demanding tasks will cause a decreased performance of one or both tasks when they exceed this capacity (Yogev et al., 2008).

Gait disturbances (O'Shea et al., 2002; Galletly and Brauer, 2005) and postural instability (Holmes et al., 2010) have shown to increase in PD patients during the performance of a secondary task. O'Shea and colleagues (2002) examined the effect of motor versus cognitive secondary tasks during gait in 15 people with Parkinson's disease and 15 age and sex matched controls. Similarly, Marchese and colleagues (2003) investigated the effect of cognitive and motor tasks on the postural stability of 24 subjects with PD and 20 healthy age matched individuals. Results from both studies indicated that performance of simultaneous motor or cognitive tasks compromise both postural stability and gait in people with PD. These studies have contributed to our understanding of the deleterious effects of different types of dual tasking in populations of PD. However, further research is needed to determine whether these results can be generalized to other complex tasks that challenge the balance control system, such as gait initiation.

Gait initiation, the phase between standing and steady-state locomotion (Breniere, 1991), is a useful task for quantitative analysis of movement performance due to the demands on the maintenance of balance and the generation of momentum (in the forward direction and in the direction of the stance limb; Martin et al., 2002). The stance limb is

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the first leg loaded with the individual's body weight, and the swing limb is the first leg to be lifted to execute the first step during the gait initiation process. The gait initiation motor program generates momentum by manipulating the center of pressure (CoP) under the feet and moving it away from the center of mass (CoM), creating a CoP-CoM distance (Crenna and Frigo, 1991; Halliday et al., 1998; Polcyn et al., 1998; Martin et al., 2002; Hass et al., 2004). Gait initiation involves a sequence of three distinct CoP movements. The first movement is a posterior-lateral shift of the CoP towards the first swing limb, which generates the forward momentum required to initiate gait and the lateral momentum required to propel the body CoM towards the stance limb (Polcyn et al., 1998; Hass et al., 2008). The second movement is a lateral shift of the CoP towards the stance limb, which accelerates the CoM forward and away from the stance limb (Jian et al., 1993; Hass et al., 2004). The third movement is an anterior shift of the CoP along the stance foot, until toe-off, propelling the CoM forward leading into a steady state gait. The ability to create CoP-CoM distances is fundamental in gait initiation and without the separation of the CoP and CoM, gait initiation would not occur (Jian et al., 1993). Previous reports demonstrate that PD patients try to maintain stability by keeping the CoP and CoM as close together as possible, throughout the initiation of gait, and that this effect increases with progression of disease (Martin et al., 2002; Hass et al., 2005). This diminished CoP-CoM distance results in a reduction of momentum generation, which may lead to falls causing hip fractures (Cummings and Nevitt, 1989). Furthermore, individuals with PD demonstrate a reduced gait speed, decreased initial step lengths, and decreased propulsive forces during push off when compared to healthy controls (Gantchev et al., 1996; Halliday et al., 1998; Martin et al., 2002).

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Examining the effects of dual tasking on the initiation of gait, in a population of PD, is particularly important given that gait initiation has been proven a common area of impairment, as well as a safety concern. For example, intersections and cross-walks are caution areas where individuals are required to initiate gait, after being given a cue (light), while also being aware of their surroundings (i.e., pedestrians, cyclists and automobiles). In addition to this dual task paradigm, a manipulation of cue expectancy examined how uncertainty plays a role in the gait initiation process. This methodology has not been previously used but can be related to the startle effect which has been previously demonstrated using a startling auditory stimulus (SAS) in combination with a visual cue during gait initiation (MacKinnon et al., 2007; Queralt et al., 2010).

The multiple purposes of this research were to evaluate group differences in gait initiation, to evaluate the effect of uncertainty on gait initiation parameters, to evaluate the effects of a secondary verbal task on gait initiation performance, and to evaluate the effects of gait initiation on the secondary verbal task. It was hypothesized that PD patients and healthy matched controls will both show deterioration in postural stability while initiating gait under dual task conditions, but that these effects will be greater in the PD patients and when uncertain as to whether they would receive the visual cue. It was also hypothesized that PD patients and healthy matched controls will both show a decreased maximum posterior shift of the CoP while dual tasking, and that these effects will be greater in the PD group and when uncertain about the visual cue. It is further hypothesized that PD patients will experience increased variability on the secondary verbal task during gait initiation compared to healthy controls, and when uncertain about

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the visual cue. The long-term goal of this research is to develop strategies to help people with Parkinson's disease safely manage dual task situations.

2. LITERATURE REVIEW

2.1. Parkinson's Disease

Parkinson's disease (PD) is a common progressive neurodegenerative disorder characterized by a large number of motor and non-motor features that can impact on function to a variable degree. PD occurs throughout the world in all ethnic groups and affects both males and females, being slightly predominant among males (Zhang and Roman, 1993). It has an estimated prevalence of 100 to 200/100,000 in Canada (Parkinson-Society-Canada, 2003) and 31 to 328 per 100,000 people worldwide (Levine et al., 2003); it is the second most common neurodegenerative disease following Alzheimer's disease (Romero and Stelmach, 2003).

2.2. Pathological Features of Parkinson's disease

The pathological features of PD include the degeneration of dopaminergic neurons in the substantia nigra pars compacta coupled with intracytoplasmic inclusions known as Lewy bodies (Olanow and Tatton, 1999). The various pathological mechanisms of PD include oxidative stress (Jenner and Olanow, 1996), mitochondrial dysfunction (Schapira et al., 1990), excitotoxicity (Beal, 1998; Good et al., 1998), neurotrophic factors (Gash et al., 1998), glia immune modulators (Orr et al., 2002), and apoptosis (Mochizuki et al., 1996; Anglade et al., 1997).

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2.3. Clinical Features of Parkinson's disease

There are four clinical features of PD: tremor at rest, rigidity, bradykinesia (or akinesia) and postural instability (Jankovic, 2008). Tremor at rest is the most common and easily recognizable symptom of PD with appearance being variable among patients during the course of the disease. One study reported that 69% of patients with PD had rest tremor at disease onset and that 75% had tremor during the course of their disease (Hughes et al., 1993). However, a prospective study in patients with autopsy-proven disease found that 100% of patients had tremor at some point in their lives (Rajput et al., 1991). Tremor at rest in PD patients is almost always prominent in the distal part of an extremity (i.e., hands) but can also involve the lips, chin, jaw and legs. The associated tremors are often unilateral and occur at frequencies of 4-6 Hz, and tend to disappear with action and during sleep (Jankovic, 2008).

Rigidity is characterized by an increased resistance to passive joint motions, during the full range of motion. Rigidity can occur in both proximal (i.e., neck, shoulders, hips) and distal (i.e., wrists and ankles) joints, resulting in abnormal axial postures. Postural deformities, due to rigidity, can develop late in the disease and include a flexed neck, trunk, elbows and knees (Jankovic, 2008).

Bradykinesia refers to the slowness of movement and is considered the hallmark of basal ganglia disorders, encompassing difficulties with planning, initiating and executing movement and with performing sequential and simultaneous tasks (Berardelli et al., 2001). Other manifestations of bradykinesia include loss of spontaneous movements and gesturing, drooling due to impaired swallowing (Bagheri et al., 1999), monotonic and hypophonic dysarthria, loss of facial expression and decreased blinking,

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and reduced arm swing while walking. Bradykinesia is the most characteristic clinical feature of PD, with an early onset appearing sometimes before there is sufficient cause to request a neurological exam (Jankovic, 2008).

Postural instability (e.g., loss of postural reflexes) is generally a manifestation of the late stages of PD and usually occurs after the onset of other clinical features (Jankovic, 2008). Several other factors can also influence the occurrence of postural instability in PD patients. These include other Parkinsonian symptoms, orthostatic hypotension, age related sensory changes and the ability to integrate visual, vestibular and proprioceptive sensory input (kinesthesia; Bloem, 1992; Bronte-Stewart et al., 2002). The fear of falling can further impair balance control in patients with PD (Adkin et al., 2003) with the frequency of falls being correlated with the severity of the disease (Koller et al., 1989).

The motor symptoms of PD dominate the clinical features, but there are other non-motor impairments as well. These include fatigue, anxiety, sleep disturbance, constipation, bladder and gastrointestinal problems, and sensory symptoms such as pain, restlessness, and burning in affected limbs (Fahn, 2003). There are also behavioural and mental symptoms that are common in PD patients. These include changes in mood such as depression, decreased motivation and apathy, slowness in thinking, and a declining cognition that can progress to dementia (Fahn, 2003).

Due to the diverse profiles and lifestyles of those affected by PD, the accurate measurement of function and disability is important to determine the efficacy of therapeutic intervention and to monitor disease progression. There are a number of rating scales used in the evaluation of motor impairment and disability in PD patients (Ramaker

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et al., 2002; Ebersbach et al., 2006), but only two will be discussed. The Hoehn and Yahr scale is commonly used to compare groups of patients and to provide gross assessment of disease progression, ranging from stage 0 (no signs of disease) to stage 5 (wheelchair bound or bedridden unless assisted). The Unified Parkinson's Disease Rating scale (UPDRS) includes several impairment items (salivation, falling, freezing, tremor, and sensory complains) and demonstrates high internal consistency and inter-rater reliability (Ramaker et al., 2002). The UPDRS has become the most well established scale for assessing disability and impairment (Ramaker et al., 2002; Goetz et al., 2004).

2.4. Etiology of Parkinson's disease

PD is diagnosed upon the presence of at least two of the four clinical features mentioned earlier, and an appropriate response to levodopa medication (Dirette, 2000; Copperman et al., 2002; Lim et al., 2005). PD can develop as early as the age of 30 (Cooperman et al., 2002), however it is most common in older adults (Fahn, 2003).

The specific etiology of PD is still unknown, but epidemiologic studies have indicated that a number of factors may increase the risk of developing PD (Tanner et al., 1990). These include exposures to well water (Koller et al., 1990), pesticides and herbicides (Semchuk et al., 1992), and metals such as manganese and iron (Zayed et al., 1990). Certain occupations have also been associated with the development of PD such as cabinetmakers, carpenters, cleaners, welders, miners, loggers, and foresters (Fall et al., 1999; Tsui et al., 1999; Noonan et al., 2002). The potential role of genetic factors in the etiology of PD have also caused a growing interest (Golbe, 1990), with an alternate

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theory demonstrating that individuals must first carry a susceptibility gene and then be exposed to an environmental toxin in order to develop clinical PD (double hit hypothesis; Olanow et al., 2001).

2.5. Dual Task Interference in Parkinson's disease

The performance of executing multiple tasks simultaneously is a frequent and debilitating problem in PD patients. Numerous theories on human information processing have been proposed to explain why there are dual tasking costs in certain situations. Two of these theories include the bottleneck theory and the capacity-sharing theory. The bottleneck theory proposes that only one task can be processed at a time (i.e., the processing of the second task will be delayed until the processor is free from processing the first task; Yogev et al., 2008). For example, the performance of a calculation problem vocalized during walking might result in a slowed gait or a delayed response to the calculation problem. The capacity-sharing model proposes that attentional resources are limited, and the simultaneous performance of two or more attention-demanding tasks will cause a decreased performance of at least one or both tasks (Yogev et al., 2008). Therefore, the performance of the calculation problem during walking will cause a decrease performance in gait, the calculation problem, or both depending on whether the attentional demands of the two tasks exceed the individual's capacity.

Previous literature has examined the effects of dual task interference on gait disturbances (Bond and Morris, 2000; O'Shea et al., 2002; Galletiy and Brauer, 2005) and postural instability (Marchese et al., 2003; Holmes et al., 2010) in PD patients within dual task paradigms. The results have displayed significant decreases in the performance of

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the primary tasks, demonstrated by increases in gait disturbances and postural instability when PD patients execute multiple tasks simultaneously.

Holmes and colleagues (2010) examined the effects of secondary cognitive tasks of two levels of difficulty on quantitative biomechanical measures of postural control in 12 individuals with PD and 12 age-matched controls. PD patients and matched comparison subjects were evaluated under three conditions during 30s quiet stance: (1) without a secondary task, (2) performing a numerical recitation task (counting from one to five in a looped sequence), (3) generating a monologue (describing a familiar place). Results demonstrated a significant effect of cognitive load on postural stability among both dual tasking conditions. However, tasks of low complexity resulted in an increased excursion of the center-of-pressure across both PD and age-matched controls while showing the reverse on tasks of high complexity with PD patients. This suggests that as the complexity of the secondary cognitive task increases the PD patients may begin to over-constrain their postural adjustments, diminishing the individual's ability to respond to unexpected perturbations of balance.

Marchese and colleagues (2003) also investigated the effect of secondary tasks on postural stability in 24 PD patients and 20 matched controls; however, they implemented both a cognitive secondary task and a simple motor secondary task. Postural sway was measured with eyes open and eyes closed in quiet stance and during the performance of the cognitive calculation task (counting backward aloud in multiplies of three), and the motor thumb opposition task (thumb to the second, third, fourth, and fifth finger of the dominant hand). The concomitant execution of a cognitive or motor task during quiet standing induced a worsening of postural stability in patients with PD, marked by a

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significant increase in CoP area. This study demonstrated that dual task interference on postural control could be observed in PD patients during the performance of both a cognitive secondary task as well as a motor secondary task. These two studies have provided some insight into the impact of dual task interference on postural control in individuals with PD, as related to task complexity and task type, providing implications for strategies which can be used to help reduce the risk of falls in PD. Other studies have expanded into dual task interference while walking in individuals with PD.

Bond and Morris (2000) examined the effects of secondary motor tasks of three levels of difficulty on spatial and temporal parameters of gait in 12 individuals with PD and 12 matched controls. PD patients and matched comparison subjects walked under three conditions along a 10-m walkway: (1) free walking, (2) walking while carrying an empty tray, (3) walking while carrying a tray with four plastic glasses. Subjects did not observe any significant deterioration in gait when carrying a tray while walking compared with free walking. In contrast, PD patients showed a significant reduction in gait velocity and stride length when changing from free walking to walking while carrying a tray with glasses. Therefore, a critical level of motor task complexity was required before walking performance deteriorated in people with PD.

Galletly and Brauer (2005) investigated the effect of the concurrent (motor and cognitive) tasks on gait parameters and used the rate of correct responses of the concurrent tasks as an indicator of complexity. 16 PD patients and 16 matched controls performed two secondary cognitive tasks (count backwards by threes, and list as many words that start with the letters S and F) and a secondary motor task (button press) when seated, walking 10m, and walking over visual cues. Results demonstrated a reduction in

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stride length and gait velocity in PD when performing the secondary calculation and language tasks, but not with the motor task. The complexities of the tasks were calculated (response rate per second x % correct) and they determined that the language task was more complex than the calculation task. Therefore, the effect was not due to task complexity alone.

O'Shea and colleagues (2002) examined the effect of motor versus cognitive secondary tasks during gait in 15 PD patients and 15 matched controls. For the motor task (coin transfer task), the subjects would transfer coins from one pocket on their hip to the other pocket (opposite hip) using their dominant hand. For the cognitive task (digit subtraction task), the subject would be given a randomly generated number between 125-250 and count backwards by threes. Results showed that the performance of simultaneous motor and cognitive tasks compromised gait in PD patients. However, the type of secondary task was not a major determinant of the severity of dual task interference.

These studies have contributed to our understanding of the deleterious effects of different types of dual tasking in populations of PD while standing and walking. However, further research is needed to determine whether these results can be generalized to other complex tasks that challenge the balance control system, such as gait initiation.

2.6. Gait Initiation in Parkinson's disease

There are two demands associated with gait initiation (maintenance of balance and the generation of momentum). These two demands are usually in conflict considering the generation of significant amounts of momentum generally involves moving the CoM

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beyond the base of support (defined by the feet), resulting in instability. However, the CoP-shift mechanism solves this problem in an efficient manner by first shifting the CoP posteriorly, via soleus inhibition and tibialis anterior activation, allowing the individual to generate the initial momentum required without moving the CoM out of the base of support (Crenna and Frigo, 1991; Polcyn et al., 1998; Hass et al., 2004).

Gait initiation involves the sequence of three distinct CoP movements, as mentioned earlier. Previous reports demonstrate that PD patients try to maintain stability by keeping the CoP and CoM as close together as possible, throughout the initiation of gait, and that this effect increases with progression of disease (Martin et al., 2002; Hass et al., 2005). Martin et al. (2002), studied differences in postural stability during gait initiation between patients with early and middle stages of PD, and two other groups of subjects without PD (healthy elderly and healthy young). The distance between the vertical projections of the CoP and the CoM (CoP-CoM distance) was used to reflect postural control during five events in the CoP trajectory to characterize the gait initiation cycle: (1) Most lateral motion of the CoP toward the swing limb; (2) the most posterior position of the CoP under the swing limb; (3) the event after the CoP crosses the midline (during lateral movement towards the stance limb); (4) the shift in CoP from lateral to anterior motion under the stance limb; (5) when the initial stance limb breaks contact with the supporting surface (i.e., toe-off). Results indicated that patients with PD showed significant differences for four of the five events (excluding event 4) in gait initiation, demonstrating a reduced CoP-CoM distance than individuals with no neurologic problems.

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Hass et al., (2005) studied peak CoP-CoM distances during three phases of the CoP trajectory between two groups of PD patients: PD patients with a Hoehn and Yahr disability score of 2.0 or less and PD patients with a Hoehn and Yahr disability score of 2.5 or more. The peak magnitude of the CoP-CoM distance was significantly greater during the end of single-support phase in the PD patients with a score of 2.0 or less compared to PD patients with a score of 2.5 or more. This difference in CoP-CoM distances between the two disabled groups suggest that patients with PD who have impaired postural control produce shorter CoP-CoM distances than do persons without clinically detectable balance impairment.

These findings suggest that patients with PD try to maintain stability by keeping the CoP and CoM close together throughout gait initiation, and that this effect increases with progression of disease. This strategy to maintain stability is utilized because the greater the CoP-CoM distance, the greater the need for active postural control to counteract the increased moment arm for the body-weight vector acting around centers of joint rotation (Hass et al., 2005). However, this decreased CoP-CoM distance also results in a reduction of momentum generation, and it has been suggested that the inability to generate sufficient momentum during gait initiation may cause people to fall (Cummings and Nevitt, 1989). This reduced CoP-CoM distance along with other known decrements to gait initiation exhibited by PD patients, (i.e., reduced gait speed, decreased initial step lengths, and decreased propulsive forces during push off when compared to healthy controls; Gantchev et al., 1996; Halliday et al., 1998; Martin et al., 2002), may prove useful in the development and assessments of interventions to improve ambulation and

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balance in PD. However, research has yet to analyze the affect of dual task interference on gait initiation among PD patients.

2.7. Startle Effect

The startle effect is an involuntary reaction to an unexpected sensory input and is involved in the execution of actions that are typically considered voluntary (Valls-Solé et al., 2008). This phenomenon consists of the involuntary and early activation of prepared motor programs, and has been examined using a visual 'go' cue with the addition of a startling auditory stimulus (SAS) during gait initiation (MacKinnon et al., 2007; Queralt et al., 2010).

Queralt et al., (2010) examined how two motor programs (initiation of gait and following gait phases) respond to an experimental manipulation of the timing of gait initiation. Eight healthy subjects, with no neurologic or motor impairment, were instructed to start walking as soon as possible at the perception of a visual cue that in some interspersed trials was accompanied by a SAS. Temporal characteristics (time of each step and duration of standing & swing phase) and electromyography (EMG) recordings of four muscles (soleus, tibialis anterior, rectus femoris, and biceps femoris) in the leg that initiated gait were collected. In trials with SAS, latency of all gait initiation-related events showed a significant shortening with bursts of EMG activity being higher in amplitude and shorter in duration compared to trials without SAS. The events related to the following gait-pattern were typically unchanged. The fact that all the effects of SAS were limited to gait initiation suggests that startle selectively can affect the neural structures in gait initiation.

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MacKinnon et al., (2007) examined the preparation of anticipatory postural adjustments (APAs) before forward step initiation using a SAS and a transcranial magnetic stimulation (TMS) in combination with a visual 'go' cue. TMS or SAS were delivered before (-100ms), on (0ms), or after (+100ms for TMS, +200ms for SAS) the visual cue to initiate gait. Ground reaction forces and EMG activity (soleus, tibialis anterior, and sternocleidomastoid) were recorded in ten healthy subjects with no neurological or motor impairments. Results demonstrated that SAS-evoked APAs had an increased reaction time, with incidence, magnitude, and duration of the APA increasing as the stimulus timing approached the visual cue. A facilitation of motor-evoked potentials in the initial agonist muscle was observed only when TMS was applied at +100ms. These findings are consistent with a feed-forward mode of neural control whereby the motor sequence is prepared before voluntary movement.

3. METHODS

3.1. Subjects

Fifteen healthy age-matched controls with no history of neurological illness or degenerative condition, and ten PD patients participated in this study. The diagnosis of idiopathic PD has been confirmed by a neurologist specializing in movement disorders, based on established diagnostic criteria (Hughes et al., 1992). A full list of population demographics is presented in Table 1.

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Table 1. Descriptive and clinical characteristics for all subjects

	HOC (n=15)	PD (n=10)
Age (y)	70.4(7.9)	69.4(4.9)
Gender (male/female)	8/7	8/2
Mass (lbs.)	176(28.7)	193.6(34.3)
Height (cm)	172.3(9.2)	174.6(3.8)
Duration of Illness (y)		7.9(3.8)
Hoehn & Yahr Score		2.1(0.2)
Total (motor) UPDRS		24.4(8.4)

Severity of PD was assessed using the motor subscale (section III) of the UPRDS (Fahn et al., 1987) and the Modified Hoehn and Yahr Staging Scale (Jankovic et al., 1990). Subjects were tested during their self-determined peak or "ON" phase of their medication cycle (approximately two hours after taking their usual medications; Gauntlett-Gilbert and Brown, 1998). A full list of PD sex, age, disease and medication characteristics are presented in Table 2.

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Table 2. PD sex, age, disease and medication characteristics

Subject	Gender	Age (y)	Duration of Illness (y)	H&Y Score	UPDRS III	Medication
PD1	M	72	8	2	28	Levodopa: 100mg/day Carbidopa: 25mg/day Mirapex: 0.5mg/day
PD2	M	66	7	2	21	Levodopa: 400mg/day
PD3	F	71	13	2	21	Levodopa: 100mg/day Benzeraside: 25mg/day
PD4	M	79	14	2.5	25	Levodopa: 100mg/day Carbidopa: 25mg/day Mirapex: 1.0mg/day Comtan: 200mg/day
PD5	F	66	6	2	26	Levodopa: 100mg/day Carbidopa: 25mg/day Mirapex: 0.5mg/day
PD6	M	67	9	2	15	Levodopa: 600mg/day
PD7	M	68	5	2	41	Levodopa: 300mg/day Mirapex: 0.125mg/day
PD8	M	61	6	2	12	Levodopa: 300mg/day Mirapex: 0.75mg/day
PD9	M	72	1	2.5	22	Levodopa: 150mg/day
PD10	M	72	10	2	33	Levodopa: 750mg/day Amantadine: 300mg/day Mirapex: 4.5mg/day

Inclusion criteria required that all subjects had to be able to stand unassisted for periods of 3 minutes at a time. Healthy controls additionally needed to be free of any cognitive or physical impairment resulting in gait dysfunction. Exclusion criteria included reported major back or lower limb pathology that may influence standing balance or their ability to initiate gait, if they routinely experienced episodes of freezing, or if they obtained a score higher than a stage 3 on the Modified Hoehn & Yahr scale, as these subjects had (by definition) difficulty standing without assistance, and were considered to present an unacceptable risk of falling. Each subject was given a verbal and paper description of the study, and when comfortable, they provided informed

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consent (Appendix 8.2). The University's Human Ethics Board approved this project (Appendix 8.1).

3.2. Instrumentation

Ground reaction forces were collected using an AMTI force platform.[a] The platform was embedded into the walkway surface and oriented such that the laboratory coordinate system coincided with the *y* axis aligned in the direction of forward progression, *x* axis aligned in the lateral direction and the *z* axis aligned in the vertical direction.

The vibrations from the vocal cords were measured using a miniature (5x8x3 mm) tri-axial accelerometer (BMA140;+/- 4g)[b] secured to the anterior neck about 2 cm above the subject's sternal notch using double-sided adhesive tape.

Force and moments in the 3 principal axes, and neck accelerations in the vertical direction (z) were simultaneously collected at a sample rate of 400Hz using a 16 bit analog to digital converter (DAQPad-6015)[c] and a custom written software program (LabVIEW 8.5).[c] The custom software program was also used to trigger the visual cue using a series of threshold systems.

3.3. Protocol

All testing was conducted in the Interdisciplinary Movement Disorders Laboratory, located in Elborn College at Western University. The testing session took approximately 45 minutes to complete, and involved no risks or discomforts beyond those normally experienced by performing upright standing and walking. Between trials, subjects were allowed rest periods and were offered water to drink at their own convenience.

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In preparation, the miniature neck accelerometer was attached at the start of the testing session with the battery-housing unit placed in a fanny-pack, worn by the subject. The trailing cable was held by a research assistant and did not interfere with the walking trials. Subjects began each trial by standing quietly in a relaxed position on the force platform with hands at their sides, and eyes and head facing forward. On the surface of the force platform, a piece of white Bristol board was fitted under the subject's feet and the location of the ankles (anterior to the medial malleoli) was recorded. This ensured that the subject stood in the same location at the start of each trial. Initial positioning of the feet required the subject to bring their toes to the front edge of the force plate, without going over, with a self-selected stance width. Subjects wore comfortable shoes throughout the trials.

The visual cue to initiate gait was a traffic light, positioned eye level height, about 5 meters in front of the subject. A verbal countdown from three was given to the subject to mark the start of each trial. The red light would be on at the start of each trial and after a range of 21-31 seconds a custom-written software program (LabVIEW 8.5) would trigger the green light. In response to the green light, the subjects began walking and continued for a couple steps; an event marker was created and collected, along with the forceplate and accelerometer data, to identify the timing of the visual cue.

The visual cue (green light) did not light up for all trials. There were two different instructions given to the subject prior to the start of each trial. (1) For this trial you will receive the cue to initiate gait (i.e., the traffic light will turn green). This trial was classified as "Yes". (2) For this trial you may receive the cue to initiate gait (i.e., the traffic light may remain red or may turn green). This trial was classified as "Maybe".

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When the light remained red, the subject remained standing until they were told that the trial was over.

The subjects completed a set of three trials under each instruction twice. Six trials while performing only gait initiation (non-dual task; NDT), and six trials while performing gait initiation and a secondary task simultaneously (dual task; DT). The secondary task was a numerical recitation task and involved cyclically counting from 1-5. The subjects were instructed to count loudly and clearly, at a comfortable steady pace from the start of each trial (during quiet standing) until the termination of each trial (after gait had been initiated). In total, each subject had completed 12 trials (6 DT and 6 NDT).

3.4. Gait Initiation Assessment

Gait initiation was quantitatively assessed in trials when the visual cue was triggered. Gait initiation involves standing with the individual's weight borne equally on both legs, then shifting the weight onto one foot (stance limb) and lifting the other limb (swing limb) to initiate gait. Past investigations of gait initiation have divided the CoP pattern into separate sections by identifying important landmarks (Halliday et al., 1998; Martin et al., 2002; Hass et al., 2004; Hass et al., 2005; Hass et al., 2008).

Two landmarks were identified in this study, as previously defined (Halliday et al., 1998). *Release* (L1), is the point of maximum posterior-lateral displacement of the CoP toward the first swing limb. This point corresponds to the first swing limb heel off. *Unload* (L2), is the point of maximum posterior-lateral displacement of the CoP toward the first stance limb. This point corresponds to toe-off of the first swing limb. The addition of these two landmarks divides the CoP movement pattern into three separate

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periods. The first period (S1) included from the start of gait initiation until L1. The second period (S2) extended from L1 to L2. The third period (S3) extended from L2 until toe-off of the initial stance limb (Hass et al., 2004; Figure 1).

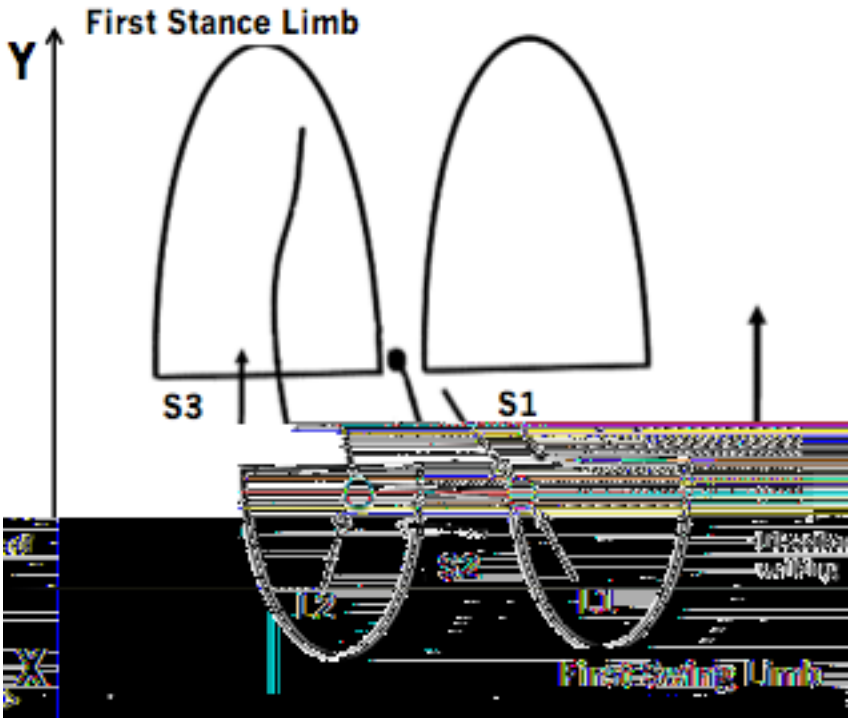

Figure 1. Overhead view of the CoP path during forward gait initiation when stepping with the right foot.

The CoP movements during each of the three sections were assessed and analyzed using a custom-written software program (LabVIEW 8.5). The following six outcome variables were calculated for each section: (1) CoP displacement in the medial-lateral direction (x); (2) CoP displacement in the anterior-posterior direction (y); (3) CoP average velocity in the medial-lateral direction (x); (4) CoP average velocity in the anterior-posterior direction (y); (5) CoP RMS Jerk (Hogan, 1984); (6) CoP Path Length

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(COPL). In addition to the six outcome variables, S1 had an additional measure being the peak anterior-posterior distance of CoP relative to the ankles.

3.5. Secondary Task Assessment

The secondary task (verbal counting) was assessed during DT trials using the neck accelerometer; this approach was adopted over microphone recordings as it excluded environmental noise (Coleman, 1988). During data collection, the vertical accelerations were captured using a custom-written software program (LabVIEW 8.5) from the start of each DT trial until the end of the trial. This included vocalizations made during the stance period (before the visual cue), vocalizations made while initiating gait, and a few steps (3-5) after the visual cue. The measured parameter was the amount of time between each vocalization (Figure 2).

The LabVIEW program, used to collect the data, contained a threshold system that triggered each time the subject vocalized a number. After 21 seconds of counting, a threshold was used to trigger the visual cue. The threshold for the visual cue was randomized (using a Microsoft Excel program) between 1-5 vocalizations after 21 seconds and, when triggered, the green light would turn on. An event marker for the timing of the visual cue was stored along with the accelerometer and force plate signals in the data set.

The raw accelerometer samples were post processed using another custom-written software program (LabVIEW 8.5) for further analysis including being filtered using a bandpass Butterworth filter (3Hz – 45Hz). The filtered data was sent through a threshold system, similar to the one used during data collection, to calculate the timing between

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each vocalization, before and after the visual cue. Two outcome variables were calculated for before the cue (NDT) and after the cue (DT): (1) Average time (ms) between vocalizations; and (2) Pooled standard deviations in time (ms) between vocalizations.

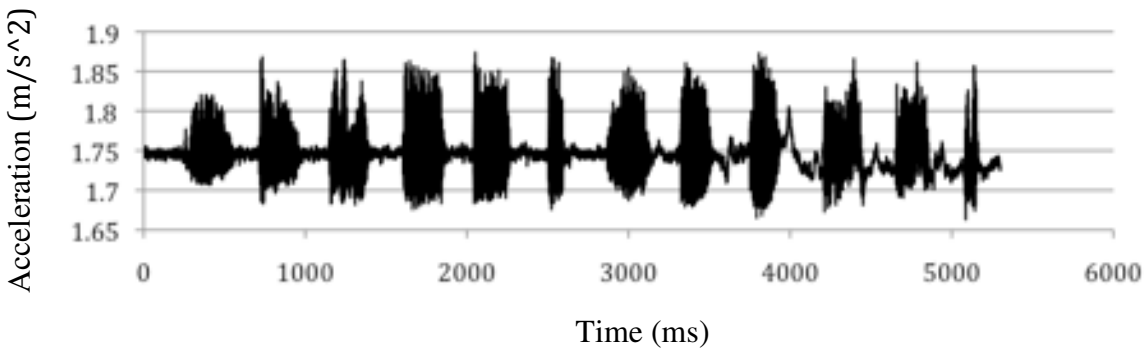

Figure 2. Neck accelerations captured during a series of vocalizations.

3.6. Data Analysis

To evaluate the influence of dual task performance and level of uncertainty on dependent variables during S1, S2, and S3, three separate 2X2X2 (group by dual task condition by instruction) multivariate analysis of variance (MANOVA) were used to test for overall group differences while controlling for type I error. A fourth 2X2X2 MANOVA was used to evaluate the influence of dual task performance by level of uncertainty by group on the S1 peak variable, and a fifth 2X2X2 MANOVA was used to evaluate the influence of dual task performance by level of uncertainty by group on the average time between vocalizations and the pooled standard deviations between vocalizations. Separate analyses of variance (ANOVAs) were then performed for follow-up testing for all MANOVAs, when significant multivariate effects were found. The

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Modified Bonferroni adjustment (Jaccard and Wan, 1996) was used to adjust the overall type I error rate for univariate testing when appropriate. $P < 0.05$ was considered significant for all tests. The software package SPSS v. 15.0 was used for statistical analysis.

4. RESULTS

4.1. S1 Period

The multivariate effect for Group was non-significant (Pillai's Trace = 0.410; $F(6,18) = 2.085$, p=0.106, $\eta 2 = 0.410$) in the S1 period of the CoP curve (MANOVA). However, a Modified Bonferroni correction (Jaccard and Wan, 1996) was implemented for the univariate testing and revealed significant main effects for Group for all six variables. The follow-up univariate testing revealed that the PD patients produced a significantly smaller center of pressure length ($F(1,23) = 8.810$, p=0.007, $\eta 2 = 0.277$), and significantly smaller CoP displacements in both the posterior ($F(1,23) = 10.435$, p=0.004, $\eta 2 = 0.312$) and lateral ($F(1,23) = 6.40$, p=0.019, $\eta 2 = 0.218$) directions compared to the healthy control subjects. Furthermore, PD patients moved their CoP significantly slower in both posterior ($F(1,23) = 9.076$, p=0.006, $\eta 2 = 0.283$) and lateral ($F(1,23) = 6.647$, p=0.017, $\eta 2 = 0.224$) directions with a significantly smoother transition, defined by the RMS jerk ($F(1,23) = 8.103$, p=0.009, $\eta 2 = 0.261$), compared to the healthy control subjects.

The MANOVA also indicated a significant multivariate effect for Instruction (Pillai's Trace = 0.480; $F(6,18) = 2.774$, $p<0.05$, $\eta 2 = 0.480$) in the S1 period of the CoP curve, allowing for univariate analyses of these effects with an alpha of 0.05. Follow-up

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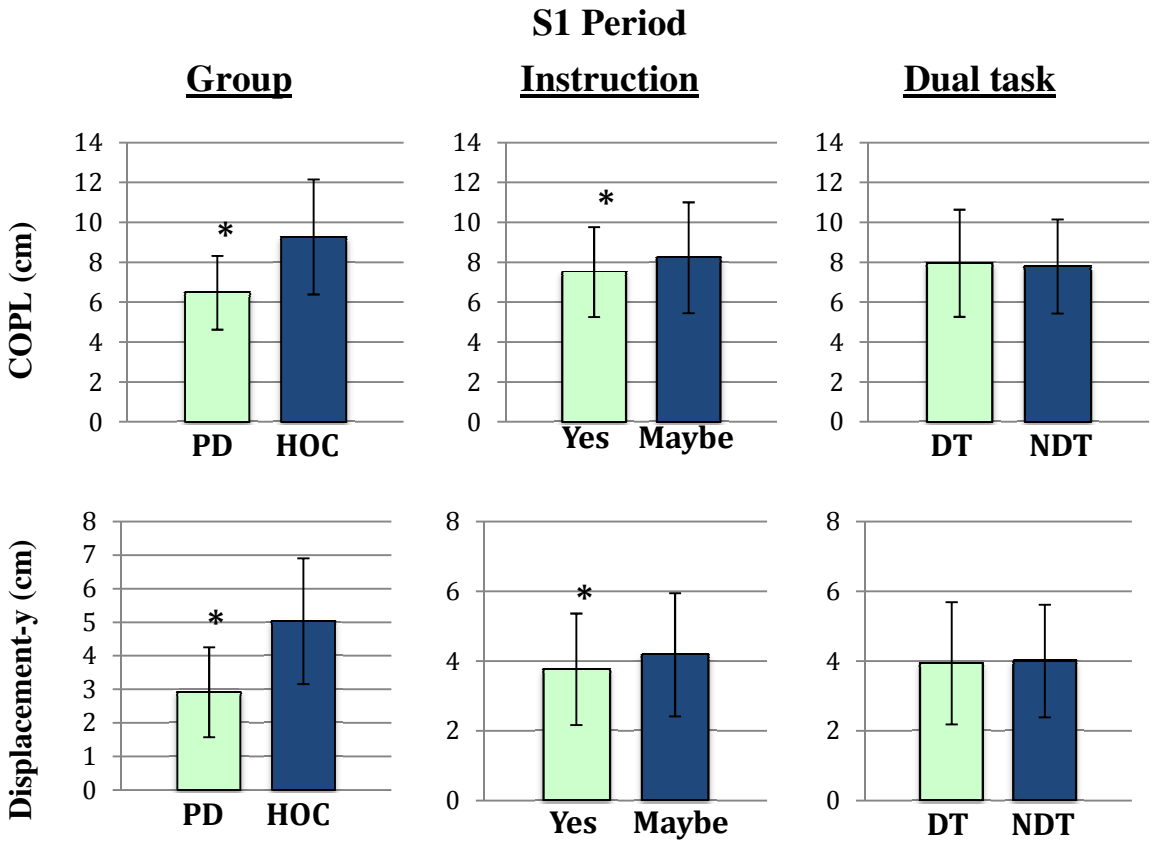
univariate testing revealed that both PD patients and healthy control subjects produced a significantly greater COPL ($F(1,23) = 12.987$, $p<0.05$, $\eta 2 = 0.361$), and significantly greater CoP displacements in both the posterior ($F(1,23) = 8.413$, $p<0.05$, $\eta 2 = 0.268$) and lateral ($F(1,23) = 5.721$, $p<0.05$, $\eta 2 = 0.199$) directions when they were uncertain as to whether they would receive the cue, compared to when they were certain (i.e. the Maybe vs. Yes trials).

There were no significant main effects among Dual Task conditions on gait initiation parameters during the S1 period of the CoP curve in either group. The means and standard deviations for each dependent variable during the S1 period, separated by group, condition and instruction, are presented in Figure 3 with a full list of values presented in Appendix 8.3.1.



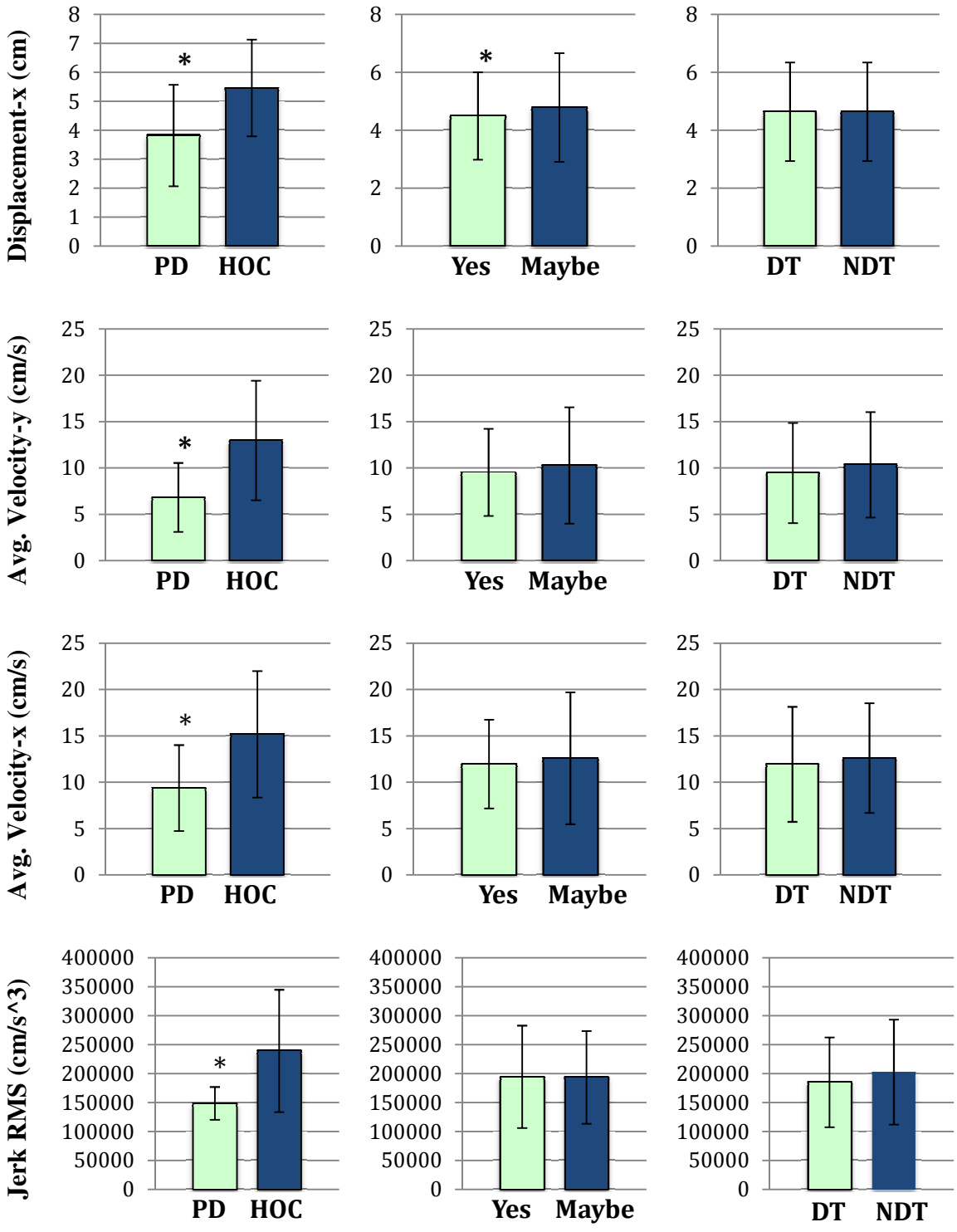


Figure 3. Dependent variables (Mean and SD) observed for PD and HOC subjects during the S1 period of the CoP trajectory for forward gait initiation. *Significant difference between 1) PD & HOC; 2) Yes & Maybe; 3) DT & NDT; ($p<0.05$).

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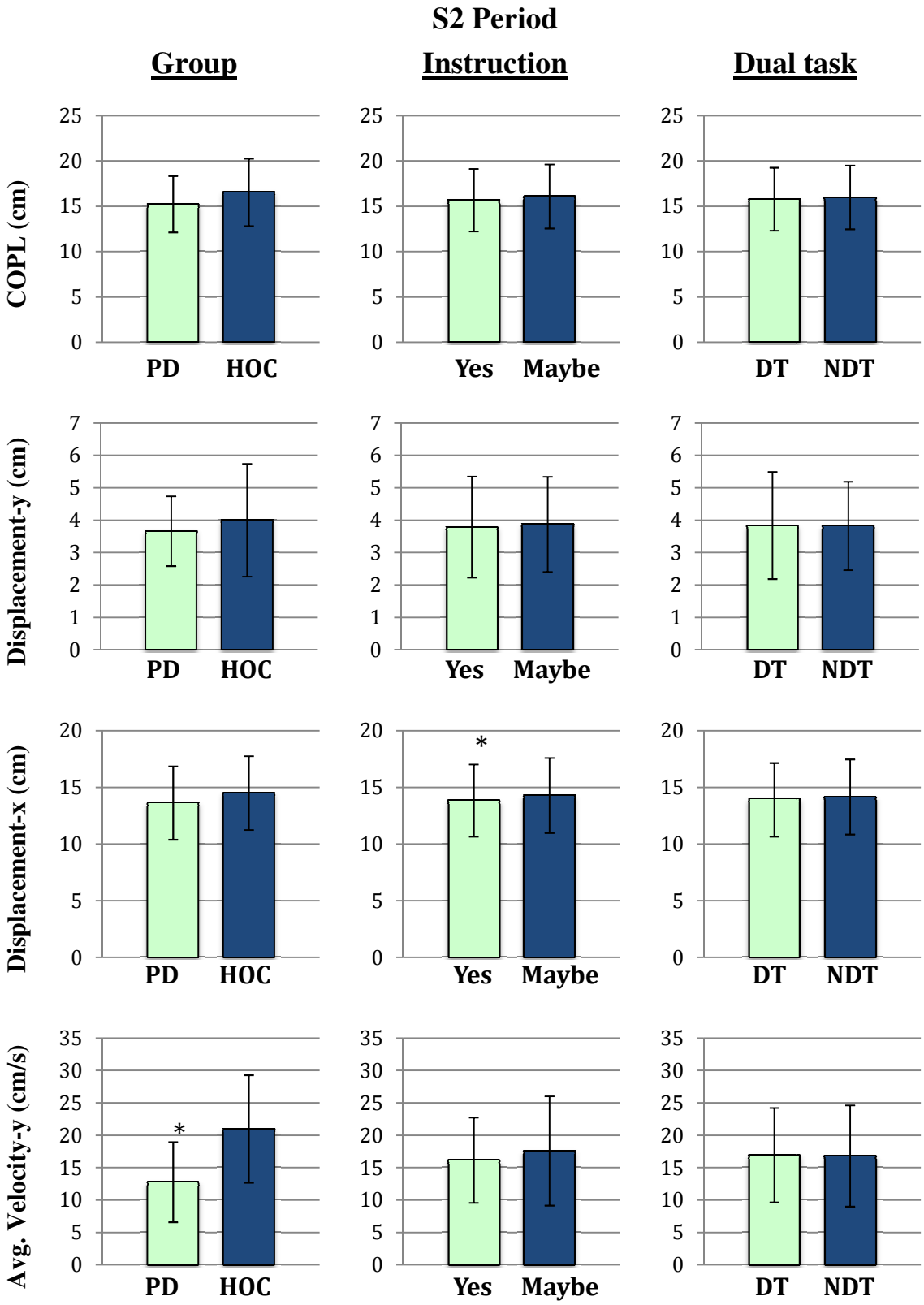
4.2. S2 Period

The MANOVA indicated a significant multivariate effect for Group (Pillai's Trace = 0.509; $F(6,18) = 3.111$, $p<0.05$, $\eta2 = 0.509$) in the S2 period of the CoP curve, allowing for univariate analyses of these effects. Follow-up univariate testing revealed that PD patients produced significantly slower CoP movements in both the anterior-posterior ($F(1,23) = 8.625$, $p<0.05$, $\eta2 = 0.273$) and lateral ($F(1,23) = 7.905$, $p<0.05$, $\eta2 = 0.256$) directions with a significantly smoother transition (defined by the RMS jerk; $F(1,23) = 8.820$, $p<0.05$, $\eta2 = 0.277$), compared to healthy control subjects. The MANOVA also indicated a significant multivariate effect for Instruction (Pillai's Trace = 0.438; $F(6,18) = 2.335$, $p<0.05$, $\eta2 = 0.438$) in the S2 period of the CoP curve, allowing for univariate analyses of these effects. Follow-up univariate testing revealed that both PD patients and healthy control subjects demonstrated a significant increase in CoP displacement ($F(1,23) = 7.250$, $p<0.05$, $\eta2 = 0.240$) and CoP velocity ($F(1,23) = 6.893$, $p<0.05$, $\eta2 = 0.231$) in the lateral direction towards the stance limb when they were uncertain as to whether they would receive the cue, compared to when they were certain (Maybe vs. Yes trials).

There were no significant effects among Dual Task conditions on gait initiation parameters during the S2 period of the CoP curve in either group. The means and standard deviations for each dependent variable during the S2 period, separated by group, condition and instruction, are presented in Figure 4 with a full list of values presented in Appendix 8.3.2.


S2 Period
Group
Instruction
Dual task
COPL (cm)
Displacement-y (cm)
Displacement-x (cm)
Avg. Velocity-y (cm/s)
PD
HOC
Yes
Maybe
DT
NDT
*
*

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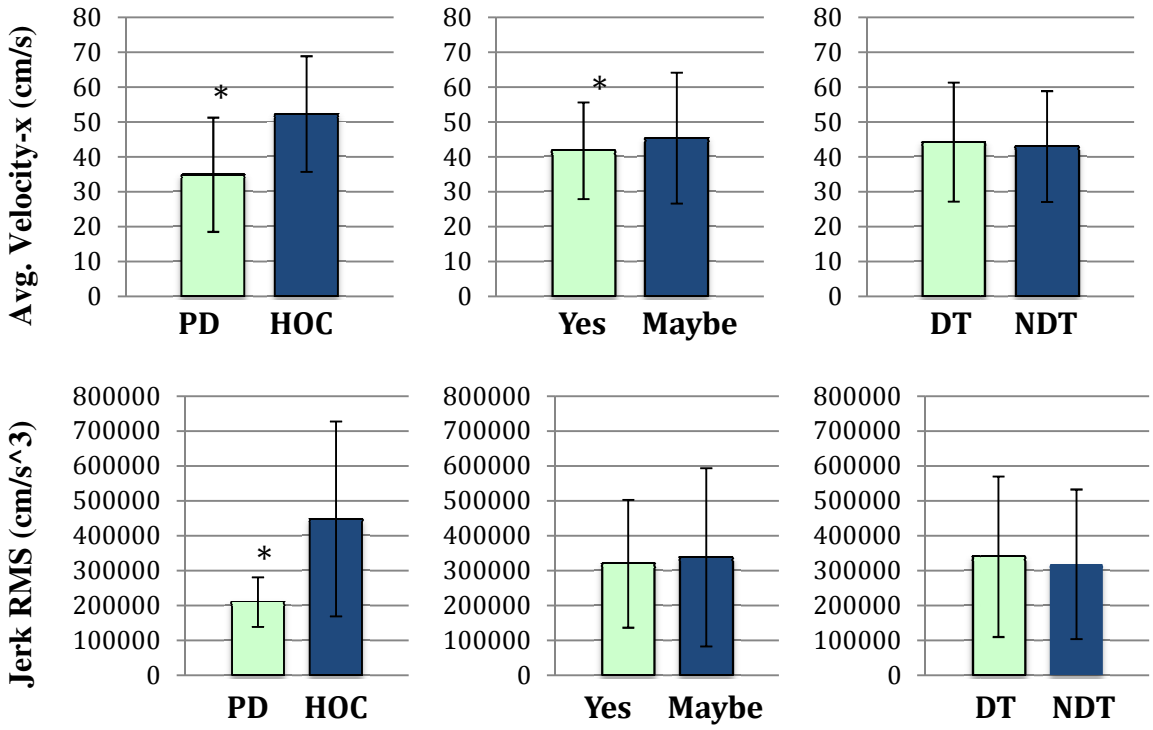

Figure 4. Dependent variables (Mean and SD) observed for PD and HOC subjects during the S2 period of the CoP trajectory for forward gait initiation. *Significant difference between 1) PD & HOC; 2) Yes & Maybe; 3) DT & NDT; ($p<0.05$).

4.3. S3 Period

The MANOVA indicated a significant multivariate effect for Group (Pillai's Trace = 0.494 $F(6,18) = 2.924$, $p<0.05$, $\eta 2 = 0.494$) in the S3 period of the CoP curve, allowing for univariate analyses of these effects. Follow-up univariate testing demonstrated that PD patients produced a significantly smaller CoP displacement ($F(1,23) = 4.255$, $p<0.05$, $\eta 2 = 0.156$), and a significantly slower CoP velocity ($F(1,23) = 4.150$, $p<0.05$, $\eta 2 = 0.153$) in the anterior direction compared to healthy control subjects. In addition, the transition of the CoP was significantly smoother (RMS jerk; $F(1,23) =$

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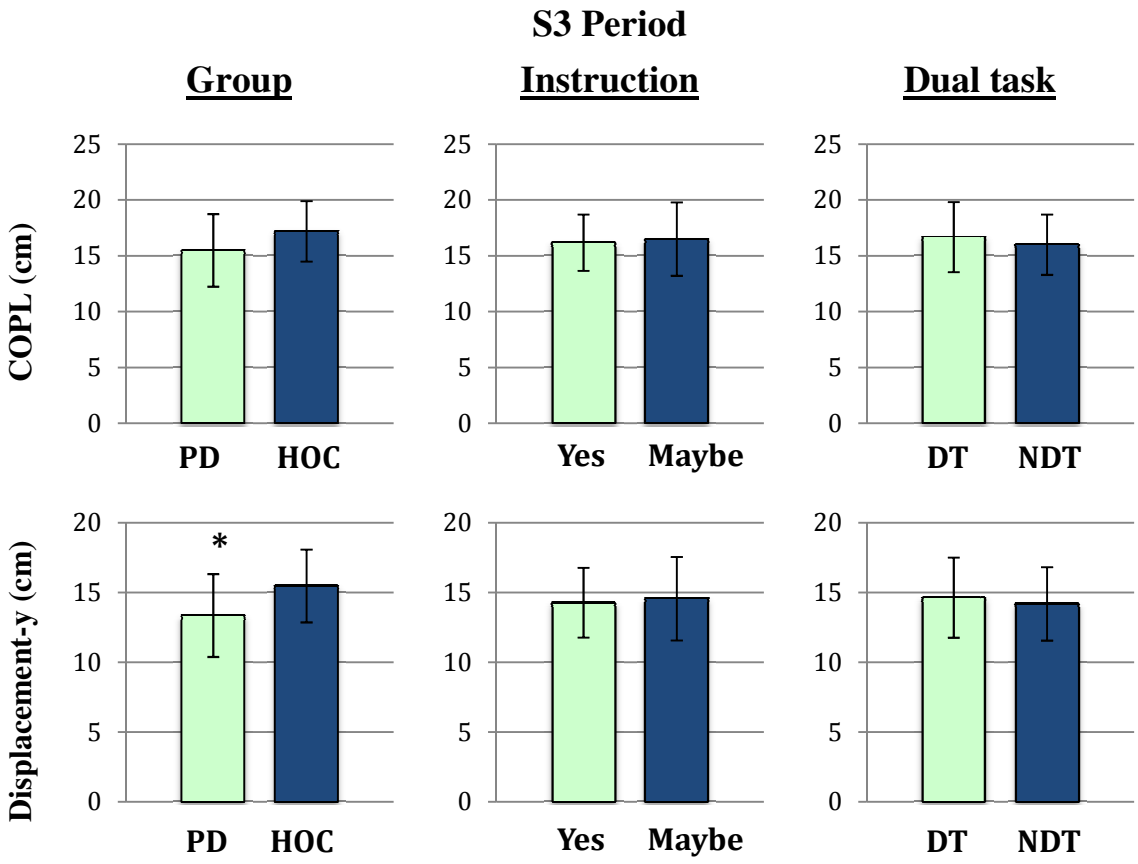
6.316, $p<0.05$, $\eta 2 = 0.215$) in the group of PD patients than in the healthy control subjects.

There were no significant effects among Dual Task conditions or Instructions given on gait initiation parameters during the S3 period of the CoP curve in either group. The means and standard deviations for each dependent variable during the S3 period, separated by group, condition and instruction, are presented in Figure 5 with a full list of values presented in Appendix 8.3.3.



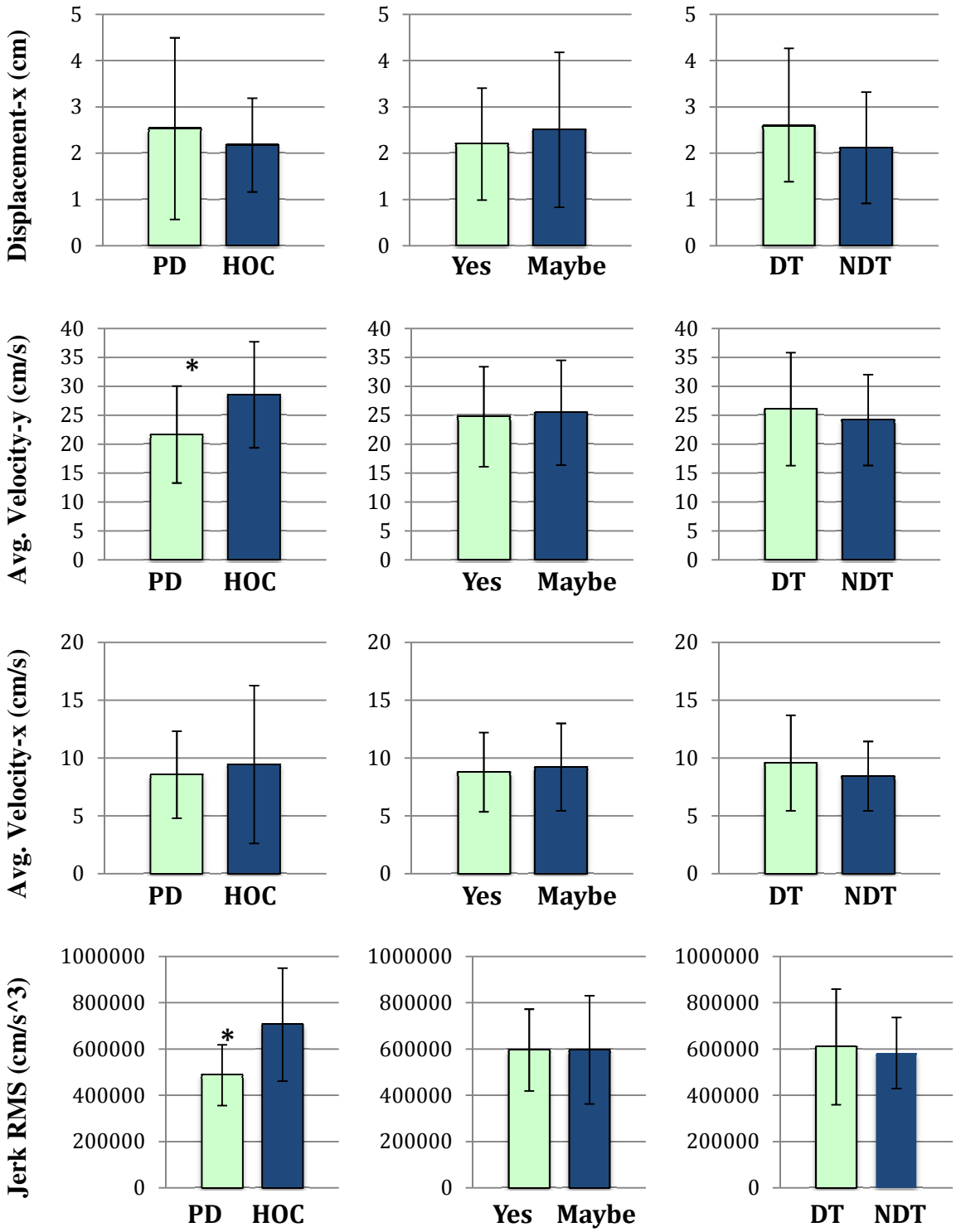


Figure 5. Dependent variables (Mean and SD) observed for PD and HOC subjects during the S3 period of the CoP trajectory for forward gait initiation. *Significant difference between 1) PD & HOC; 2) Yes & Maybe; 3) DT & NDT; ($p<0.05$).

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4.4. S1 Peak

The MANOVA revealed significant main effects for Group ($F(1,23) = 6.450$, $p<0.05$, $\eta 2 = 0.219$) and Instruction ($F(1,23) = 18.803$, $p<0.05$, $\eta 2 = 0.450$), with a significant Dual Task by Group interaction ($F(1,23) = 8.708$, $p<0.05$, $\eta 2 = 0.275$) for the S1 peak variable at the termination of the S1 period. These results from the MANOVA revealed that PD patients demonstrated a significantly diminished posterior shift of the S1 peak, compared to healthy controls, illustrating an inability for PD patients to move the CoP behind their ankles at L1. In addition, the MANOVA also revealed that both the PD patients and healthy controls demonstrated a significant increase in the posterior shift of the S1 peak when they were uncertain as to whether they would receive the cue, compared to when they were certain (i.e. Maybe vs. Yes trials; Figure 6). Follow-up pairwise comparisons of the Dual Task by Group interaction revealed that only the PD patients demonstrated a significant increase in the posterior shift of the S1 peak ($p < 0.05$; 95% CI [-1.201, -0.033]) when dual tasking compared to when not dual tasking (Figure 7). A full list of values are presented in Appendix 8.3.4.

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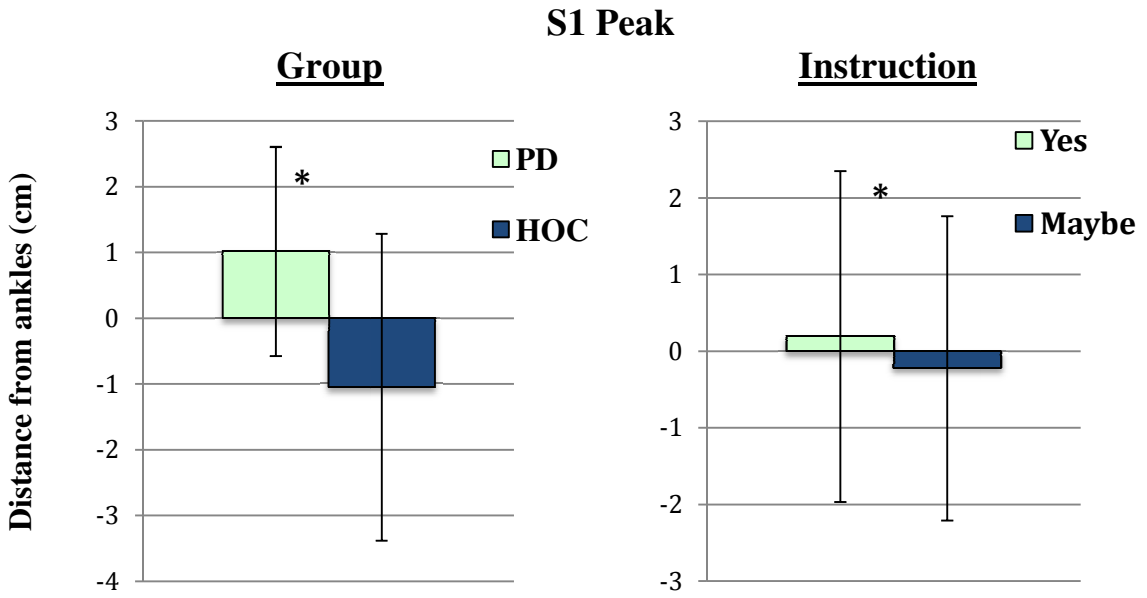

Figure 6. The S1 Peak (Mean and SD) observed for PD and HOC subjects at the termination of S1 period. Ankle location is represented at the y=0. *Significant difference between 1) PD & HOC; 2) Yes & maybe; ($p<0.05$).

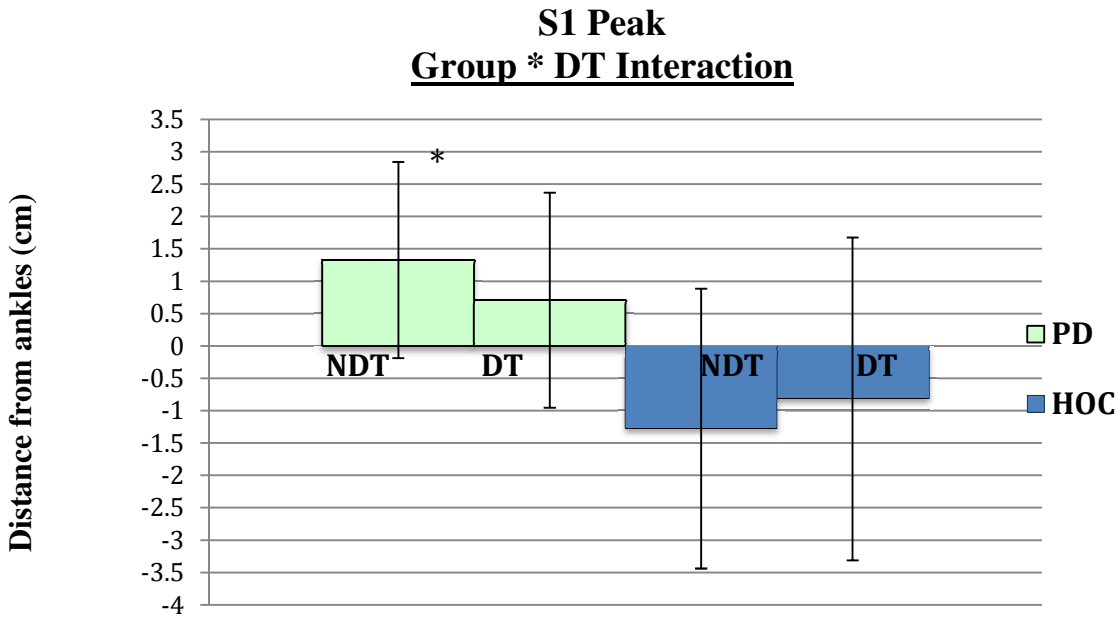

Figure 7. The S1 Peak (Mean and SD) observed for PD and HOC subjects at the termination of S1 period. Ankle location is represented at the y=0. *Significant difference between dual task conditions in PD patients; ($p<0.05$).

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4.5. Vocalizations

There was a significant multivariate effect for Dual Task condition (Pillai's Trace = 0.783; $F(2,21) = 37.954$, $p<0.05$) in the MANOVA, allowing for univariate analyses of these effects. Follow-up univariate testing revealed that both PD patients and healthy control subjects had a significantly higher counting cadence when starting to walk (dual tasking) compared to when standing still (not dual tasking; $F(1,22) = 77.78$, $p<0.05$).

A significant multivariate effect was also found for Group (Pillai's Trace = 0.359; $F(2,21) = 5.869$, $p<0.05$) in the MANOVA, allowing for univariate analyses of these effects. Follow-up univariate testing revealed that PD patients demonstrated significantly more variability in the timing between vocalizations (Pooled standard deviation of the time between vocalizations; $F(1,22) = 6.036$, $p<0.05$) compared to healthy controls who demonstrated a more consistent counting cadence.

There were no significant main effects for Instruction on the secondary task parameters in either subject group. The means and standard deviations for the time between each vocalization, separated by group, condition and instruction, are presented in Figure 8 with a full list of values presented in Appendix 8.4.1.

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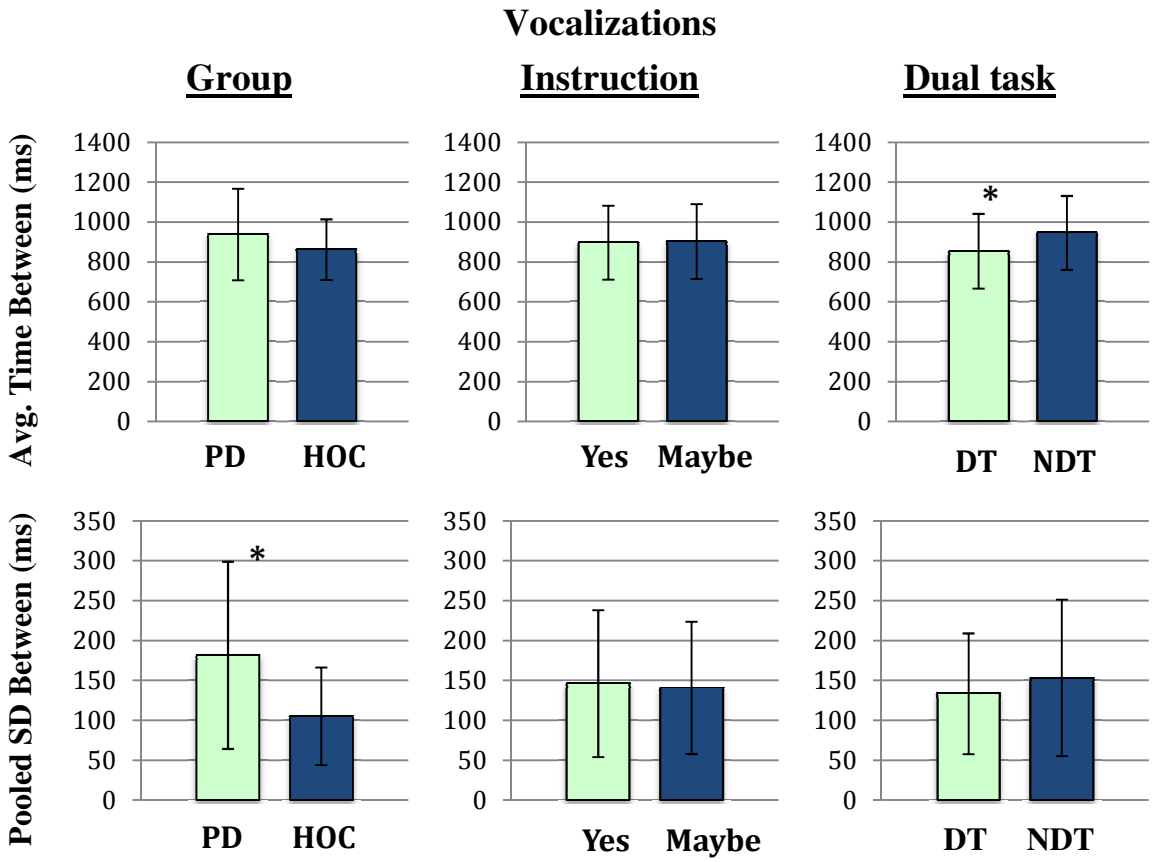

Figure 8. Dependent variables (Mean and SD) observed for PD and HOC subjects for vocalizations made during the numerical recitation task. *Significant difference between 1) PD & HOC; 2) Yes & Maybe; 3) DT & NDT; ($p<0.05$).

5. DISCUSSION

Gait initiation has been acknowledged as a useful task for quantitative analysis of movement performance due to the demands in postural control and momentum generation required (Martin et al., 2002). For this reason, the three periods of the CoP trace were analyzed individually to enable a more detailed interpretation of the mechanics involved in the gait initiation process (Hass et al., 2004; Hass et al., 2008). Using this model, multiple aims were established to evaluate different scenarios and their impact on

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gait initiation performance in a population of PD patients and healthy age-matched controls. The following list of purposes will be expanded in the subsequent sections.

The first purpose was to evaluate group differences in gait initiation, which confirmed previous results demonstrating that PD patients lean significantly further forward, when initiating gait, and that all measures of gait initiation in the PD group were consistent with the slower velocity and restricted CoP movement that has been reported by other researchers (Gantchev et al., 1996; Halliday et al., 1998; Martin et al., 2002; Dibble et al., 2004; Hass et al., 2008).

The second purpose was to evaluate the effect of uncertainty on gait initiation performance by implementing trials with the subject being uncertain to whether they would receive the cue to initiate gait. When subjects were uncertain, both groups demonstrated increases in CoP velocity and displacements during the phase between the onset of CoP movement to the onset of the first swing foot heel off (S1&S2); previous researchers have referred to this as the postural phase (Gantchev et al., 1996; Rosin et al., 1997; Hiraoka et al., 2006). This methodology, using a manipulation of cue expectancy, has not been used before but results can be linked to reports with increases in temporal characteristics of gait initiation and increased EMG activity while examining the startle effect (MacKinnon et al., 2007; Queralt et al., 2010).

The third purpose was to evaluate the effects of a secondary verbal task on gait initiation performance, which demonstrated minimal effects. The only significant effect was an increased posterior shift in the translation of L1 in PD patients when dual tasking compared to when not dual tasking. No research has previously examined the effects of a secondary task on gait initiation, however these results are not consistent with previous

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results finding significant decrements in postural stability (Marchese et al., 2003; Holmes et al., 2010) and gait (Bond and Morris, 2000; O'Shea et al., 2002; Galletiy and Brauer, 2005) while dual tasking.

The fourth purpose was to evaluate the effects of gait initiation on the secondary verbal task, confirming results of previous investigations with a concurrent motor activity having a significant impact on speech performance (Brauer et al., 2002; Ho et al., 2002).

5.1. Differences Between Individuals with PD and Healthy Elderly

As defined earlier, L1 is the point of maximum posterior-lateral displacement of the CoP toward the first swing foot (Halliday et al., 1998). The movement of the CoP toward this landmark is captured in the S1 period and is an important component of gait initiation because this manipulation of the CoP allows the individual to generate the required momentum without moving the CoM out of their base of support (Polcyn et al., 1998; Hass et al., 2004). Previous studies have revealed that PD patients have a reduced magnitude of posterior CoP displacement and CoP velocity during S1 (Gantchev et al., 1996; Halliday et al., 1998; Martin et al., 2002; Dibble et al., 2004; Hass et al., 2008). This trend was observed in the current study with the healthy elderly controls shifting their CoP posteriorly significantly more than PD patients (5.03cm versus 2.92cm), and with a significantly larger CoP velocity (12.97cm/s versus 6.82cm/s). Reduced posterior displacement and velocity of the CoP have been attributed to the deterioration of centrally mediated anticipatory postural adjustments; this is characterized by a reduced inhibition of the soleus and gastrocnemius muscles and an improper and inefficient activation of the tibialis anterior muscle (Gantchev et al., 1996; Halliday et al., 1998;

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Polcyn et al., 1998). These findings of reduced posterior displacement and velocity might suggest that individuals with PD may over-constrain their posture and are less able to efficiently deactivate previously activated muscles (Hass et al., 2008).

The posterior CoP shift towards L1 also demonstrated that PD patients refrained from bringing their CoP behind their ankles. On average, PD patients' L1 location remained 1.02cm anterior to the ankle joint while healthy elderly controls had brought their L1 an average of 1.05cm behind the ankle joint. This significant forward lean can be attributed to the stooped posture adopted by PD patients, causing them to stand more towards their toes (Andrews, 1987; Halliday et al., 1998), or could be due to a need to preserve stability. PD patients display smaller CoP-CoM magnitudes compared to healthy elderly controls (Martin et al., 2002); this is thought to preserve stability during gait initiation in the presence of impairments to their postural control mechanisms.

The lateral movement of the CoP towards L1 generates the momentum required to propel the body's CoM towards the stance limb (Polcyn et al., 1998; Hass et al., 2008). Previous studies have demonstrated that individuals with PD have a decreased lateral displacement and velocity of the CoP toward the swing foot compared to healthy elderly controls (Halliday et al., 1998; Martin et al., 2002; Dibble et al., 2004). This study supports these findings; our healthy elderly control subjects demonstrated a significant increase in lateral CoP displacement (5.46cm versus 3.82cm), and lateral CoP velocity (15.18cm/s versus 9.39cm/s), compared to PD patients. A potential explanation for this finding might be that patients with PD over-constrained their posture in order to maintain stability. Martin et al., (2002) suggested that individuals with PD maintain stability by keeping the CoM and the CoP close together throughout gait initiation. A reduction in the

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CoP displacement would lead to a decrease in the magnitude of the CoM shift toward the stance foot and result in a shorter CoP-CoM distance (Hass et al., 2005).

During S2, the CoP moves toward the stance limb (L2), accelerating the CoM forward and away from the stance limb (Jian et al., 1993; Hass et al., 2004). There were no significant differences between groups in CoP displacements, however we did observe a significant increase in CoP velocity among the healthy elderly group compared to the PD group for both medial-lateral (52.33cm/s versus 34.92cm/s) and anterior-posterior (21cm/s versus 12.8cm/s) directions. These findings are consistent with previous reports (Halliday et al., 1998; Martin et al., 2002) and could be potentially explained by initial decreases in CoP displacements exhibited by PD patients during S1. As the CoM moves towards the stance foot, the CoP must also move in that direction to maintain stability (Martin et al., 2002). The decreased CoP-CoM distance exhibited by PD patients would cause a decrease in CoM acceleration, which in turn would allow more time for the CoP to shift over to the stance limb, requiring a smaller CoP velocity, to maintain stability. Another possible reason may be the result of weaker and inefficient hip muscles in the PD patients, considering that medial-lateral shifts of the CoP are primarily controlled by the hip adductor and abductor muscles (Winter et al., 2003).

S3 is the final segment of gait initiation and represents the CoP movement from L2 to toe-off of the first stance foot. The PD patients demonstrated a significantly smaller anterior CoP displacement (15.48cm versus 13.36cm) and CoP velocity (28.54cm versus 21.68cm) compared to the healthy elderly subjects. Brenière et al., (1987) reported that an increased posterior CoP movement during S1 coincides with an increased progression velocity at the end of the first step. This trend continues in this study as PD patients

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demonstrate a significant decrease in CoP displacement during S1 with a corresponding significant decrease in CoP velocity during S3. The decrease in the anterior CoP displacement could be related to the foot length of the individual, limiting the CoP excursion pathway. However, the PD patients had a larger foot size (from heel to toe) compared to the healthy elderly controls (28.1 versus 27.2 cm); thus it is unlikely that the differences in CoP displacements are related to foot length.

Jerk is a measure of movement smoothness, representing the third time derivative of the center of pressure, with an increased smoothness reflecting a minimized rate of change of acceleration (Hogan, 1984). Movement smoothness has been used to assess motor performance in healthy and disabled populations (Hreljac, 1993; Platz et al., 1994; Hreljac, 2000; Puniello et al., 2000; Hass et al., 2004; Hass et al., 2008). PD patients had demonstrated a significant increase in smoothness of CoP movement during all three segments of gait initiation, as compared to healthy elderly controls. These results are not consistent with previous literature relating to PD and healthy controls (Hass et al., 2008), and may be the result of a reduced CoP-CoM distance observed in previous reports for PD patients (Martin et al., 2002; Hass et al., 2005) or a reduced velocity of the CoP, reflecting an adaptive strategy adopted by the PD patients allowing for a better and slower control of movement (Vaugoyeau et al., 2003).

5.2. Effects of Uncertainty on Gait Initiation

Manipulation of cue expectancy was utilized in this study to examine how uncertainty plays a role in the gait initiation process. To do this, trials were split into two separate groups of probability (Yes and Maybe). With an additional randomized

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probability of the visual cue appearing between 21-31 seconds, it was apparent that this methodology resembled similar outcomes as those examining the startle effect on gait initiation (MacKinnon et al., 2007; Queralt et al., 2010).

In a report studying the effects of startling auditory stimulus (SAS) on gait initiation (Queralt et al., 2010), it was demonstrated that temporal characteristics of gait initiation decreased ("sped-up") when a SAS was presented together with the visual cue to initiate gait. The speeding up of events in gait initiation was accompanied by an increase in amplitude and a decrease in duration of EMG bursts in the tibialis anterior and soleus muscles (MacKinnon et al., 2007; Queralt et al., 2010). Our study expands these findings by demonstrating significant effects in gait initiation performance during the postural phase (i.e., S1 and into S2). During S1, PD patients and healthy elderly controls had a significantly increased COPL, and both posterior and lateral CoP displacements towards L1, ending with a significant posterior shift of the S1 peak in trials of uncertainty compared to trials when they were certain. These results can be attributed to the increased activation of the tibialis anterior and soleus muscles due to the startling effect of being surprised by the appearance of the visual cue in the uncertain trials (MacKinnon et al., 2007; Queralt et al., 2010).

During S2, the PD patients and healthy elderly controls had significantly increased CoP displacements and CoP velocities in the lateral direction, towards the stance foot (L2), in trials of uncertainty compared to trials when they were certain. An explanation for these results could be the increased CoP displacements experienced during S1. As previously stated, the lateral movement of the CoP towards L1 generates the momentum required to propel the body's CoM towards the stance limb (Polcyn et al.,

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1998; Hass et al., 2008). As the displacement of the CoP increases, the moment arm (CoP-CoM distance) by which the ground reaction forces can propel the CoM increases (Hass et al., 2004).With an increase in momentum propelling the CoM towards the stance foot, the CoP must increase velocity and displacement to follow (Martin et al., 2002).

No significant effects of uncertainty occurred during the S3 period, which is not surprising because it is thought that the postural phase is the period during which external cues would have their primary effects (Hiraoka et al., 2006).

5.3. Effects of a Secondary Verbal Task on Gait Initiation

Gait initiation performance did not show any significant effects with the addition of a secondary task in the healthy elderly controls. The only significant effect was in the translation of L1 in PD patients, with an increased posterior shift when dual tasking compared to when not dual tasking. No previous reports have examined the influence of a secondary task on gait initiation in PD patients; however, these results are substantially different from reports finding significant decrements in postural stability in both PD and healthy controls, while dual tasking. For example, previous research has demonstrated increases in COPL and CoP excursions (Marchese et al., 2003; Holmes et al., 2010). Additionally, reports on gait tasks in PD and healthy controls also demonstrated significant decrements when dual tasking, illustrated by reductions in stride length, gait velocity and increased motor errors (cessations and hesitations) in PD patients (Bond and Morris, 2000; O'Shea et al., 2002; Galletiy and Brauer, 2005).

The secondary task utilized in this study was implemented to have only monosyllabic words vocalized. This enabled us to interpret the performance of the

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secondary task continuously and more clearly (throughout the balance, gait initiation, and gait tasks) so that there was no confusion between multiple vibrations, which multisyllabic words would generate. Therefore, these current discrepancies could be attributed to the simplicity of the secondary verbal task that we used in this experiment. Bond & Morris (2000) examined a secondary motor task, with three different levels of difficulty, on gait performance in PD patients and healthy controls (walking alone, walking with an empty tray, walking with a tray carrying glasses). Significant decrements in gait performance only existed in PD patients when they walked while carrying the tray full of glasses, illustrating that a critical level of task complexity was required before walking performance deteriorated in PD patients.

5.4. Effects of Gait Initiation on a Secondary Verbal Task

Both healthy elderly controls and PD patients demonstrated a significant increase in counting speed when starting to walk (dual tasking) as compared to when standing (uni-tasking). At the start of each trial, subjects had been instructed to maintain a steady counting cadence, therefore a significant increase in counting speed could be considered a decrement in the secondary task. These findings can be associated with similar results found in deficits of simple auditory reaction times while performing a gait task (Brauer et al., 2002), and in volumetric and temporal measures of speech while performing a motor distractor task (Ho et al., 2002). To account for these changes in cognitive performance under dual task conditions, it has been suggested that the individual copes with complex situations by prioritizing balance over other concurrent tasks (posture-first principle;

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Bloem et al., 2006). This could explain why there was a dual task effect for only the secondary verbal task.

Across all conditions, PD patients also demonstrated significantly more variability in their counting cadence as compared to the healthy elderly controls. Previous researchers observed that it was hard for PD patients to shift attention between two simultaneous tasks (motor and cognitive), and when the option of pausing was available, it was frequently adopted (Ho et al., 2002). This pattern of inappropriate prolonged pausing was observed frequently in the PD patients of the current experiment, occurring mostly at the end of each count cycle. PD patients would wait for this pause to take a deep breath and then continue counting at an accelerated pace through the cycle, without taking a breath until the next pause. Healthy elderly controls did not experience this pattern; instead they would take short consistent pauses between each word and between cycles, allowing for proper breathing patterns and a steady counting cadence. These patterns reflect previous findings examining articulatory rates and pause times in a standardized reading task demonstrating increased articulation rate and a significantly reduced number of pauses, but with prolonged durations, in PD patients compared to healthy control subjects (Skodda and Schlegel, 2008).

5.5. Limitations

Several limitations of this study must be considered. Our gait initiation parameters focused strictly on the trajectory of the CoP during gait initiation, and though manipulations of the CoP control the CoM, direct measures of the CoM location would have helped clarify whether PD patients constrained CoM movement in order to maintain

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stability (Martin et al., 2002). The additional knowledge of the CoP-CoM distance at a given time may have enhanced our interpretation of the CoP and CoM displacements and provide a better insight into postural control (Hass et al., 2005). For example, we might have been able to evaluate whether PD patients used the CoP-shift mechanism to generate momentum or if they used alternate strategies. Another limitation to this study was the lack of EMG recordings, which would have provided a greater insight to the motor control issues underlying the observed CoP patterns exhibited in the current experiment, and how the influence of uncertainty and dual tasking may have affected EMG activity in selective muscles (e.g. tibialis anterior, soleus, gastrocnemius).

Limitations also existed in the dual task paradigm. Previous to data collection, the methods utilized to implement the secondary task seemed appropriate in using only monosyllabic words in a cyclic pattern. This was to help with data processing and cue triggering, considering the secondary task was measured via accelerations, to keep all words representing one vibration burst. However, the complexity of the secondary task seemed to be too simple as no significant effects were found in gait initiation performance while dual tasking.

5.6. Conclusion

Despite these limitations, the methods used in this study were still considered powerful as they successfully identified significant differences between PD patients and healthy matched controls, and between conditions of uncertainty. Our results demonstrate that PD patients constrained their CoP movements throughout the gait initiation cycle more than healthy elderly control subjects, but that they demonstrated a smoother CoP

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trajectory. The constrained CoP movements may reflect a greater need to control stability, creating a smaller CoP-CoM distance, and an inability to generate substantial momentum. Interestingly, this study also provides evidence that increased activation of tibialis anterior and soleus muscles may occur in situations of uncertainty, as reflected by increases in CoP velocity and displacements, for both healthy elderly controls and patients with PD. These results should be further investigated as they may hold further implications for the prevention of falls in older adults and patients with PD.

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7. SUPPLIERS

a. Advanced Mechanical Technology Inc., 151 California St, Newton, MA 02158.

b. Bosch Sensortec GmbH, Gerhard-Kindler-Strasse 8, 72770 Reutlingen, Germany.

c. National Instruments Corporation, 11500 N MoPac Expwy, Austin, TX 78759-3504.

8. APPENDIX

8.1. Ethics

Research Western

Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Jeffrey Holmes
Review Number: 18166
Review Level: Full Board
Approved Local Adult Participants: 45
Approved Local Minor Participants: 0
Protocol Title: The Effects of a Cognitive Secondary Task on Gait Initiation in Parkinson's disease
Department & Institution: Occupational Therapy,
Sponsor:
Ethics Approval Date: October 28, 2011
Ethics Expiry Date: September 30, 2013

Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
UWO Protocol		
Letter of Information & Consent		
Advertisement		

This is to notify you that the University of Western Ontario Health Sciences Research Ethics Board (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced study on the approval date noted above. The membership of this HSREB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request form.

Member of the HSREB that are named as investigators in research studies, or declare a conflict of interest, do not participate in discussions related to, nor vote on, such studies when they are presented to the HSREB.

The Chair of the HSREB is Dr. Joseph Gilbert. The UWO HSREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

[redacted]

Signature

Ethics Officer to Contact for Further Information

[redacted]

This is an official document. Please retain the original in your files.

The **University** *of* **Western Ontario**
Office of Research Ethics
Support Services Building Room 5150 • London, Ontario • CANADA - N6G 1G9
PH: 519-661-3036 • F: 519-850-2466 • ethics@uwo.ca • www.uwo.ca/research/ethics

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8.2. Letter of Information and Participant Consent

The Effects of a Cognitive Secondary Task on Gait Initiation in Parkinson's Disease

INVESTIGATORS:

Dr. Jeffrey Holmes, PhD
Dr. Jim Dickey, PhD
Dr. Andrew M. Johnson, PhD
Dr. Mary Jenkins, BSc (PT), MD, FRCPC

[redacted]

You are invited to participate in a study of dual-tasking, in which we will evaluate the effects of a repetitive verbal task (count aloud 1 – 5 repeatedly) on an individual's ability to maintain their balance and to start walking from a stationary standing position.

Background

The ability to "dual-task" (i.e., carry out two unrelated activities simultaneously) is an important component of one's ability to effectively carry out activities of daily living. In particular, the ability to perform verbal tasks while standing still or while starting to walk is an integral part of functional locomotion. For example, the ability to carry on a conversation while starting to walk across a road may involve significant mental effort that could impact in some way on one's ability to walk in a consistent and stable fashion.

Inclusion and Exclusion Criteria

We plan to test a total of 45 participants: 15 young adults (aged 18 to 30), 15 individuals aged 40 and older without neurologic impairment, and 15 individuals with a confirmed diagnosis of idiopathic Parkinson's disease. In order to be eligible for participation, you must be free of any neurological (other than Parkinson's disease), inner ear, or orthopedic condition, as well as any medical condition that would impair balance, compromise your ability to stand (unassisted) for periods of 2 or 3 minutes at a time, or compromise your ability to start walking from a stationary standing position (i.e., frequent episodes of freezing).

Description of Research

All testing will take place in the Interdisciplinary Movement Disorders Laboratory, Room 1545 Elborn College, at the University of Western Ontario. The tasks involved will take approximately 45 minutes to complete, and involve no known risks or

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discomforts beyond those normally experienced by you while standing for a duration of no more than 2 or 3 minutes at a time or while starting to walk from a stationary standing position. If you agree to participate, we will collect your height (cm), mass (kg), and birth date. Your birth date will be used solely for the purpose of computing your age in years and will then be discarded.

Testing will consist of 18 trials: 9 trials will involve no secondary task and nine trials will involve performing a numerical recitation task (count aloud 1-5 repeatedly).

For all trials you will be asked to stand on our laboratory forceplate, a device that consists of a plate with embedded electronic force sensors. These sensors feed information to an attached computer, and this information is used to provide us with information concerning your balance and body movement (e.g., how far your body moves in a forward-backward, and side-to-side fashion). You will begin each trial by standing as still as possible on the force plate in a relaxed position with your feet side by side, looking straight ahead at a traffic light positioned directly in front of you. For some trials you will receive a visual cue to start walking (traffic light will turn from red to green), whereas for other trials you will not receive the visual cue (traffic light will remain red). During each trial, we will use a video camera to capture your lower extremities while you are standing, initiating gait, and during the first couple of steps of your walking. To ensure subject confidentiality, the video camera will NOT include your face or head and will be limited to a field of view limited from the belly button down to the feet. All video records will be de-identified and retained indefinitely. To begin each trial you will be provided with one of the following three sets of instructions:

(1) For this trial you will **NOT** receive the cue to start walking (i.e., the traffic light will remain red). We would like you to remain as still as possible until you are told the trial is over.

(2) For this trial you **MAY** receive the cue to start walking. If you receive the cue, (i.e., the stop light turns green), we would like you to start walking as soon as you receive the cue, and to continue to walk the length of the walkway at a self selected comfortable pace. If you do not receive the cue (i.e, the light remains red) we would like you to remain standing as still as possible until you are informed the trial is over.

(3) For this trial you **WILL** receive the cue to start walking (i.e., the stop light will turn green). **When** you receive the cue, we would like you to start walking as soon as possible, and to continue to walk the length of the walkway at a self selected comfortable pace.

For each trial that involves dual tasking (counting from 1-5 repeatedly), you will be instructed to begin the counting first, and then following a 10-15 second delay, will be given the cue to start walking (light turns green) or continue to be presented with the stimulus signaling you to remain still (light remains red). You will complete

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three trials in each of the three conditions under both single (no speech task) and dual task (counting 1-5) conditions for a total of 18 trials. During all trials, an investigator will be positioned directly beside you to ensure safety.

To measure performance on the secondary task, a small sensor (accelerometer) will be attached to your throat with adhesive tape. This sensor feeds information to an attached computer, and this information is used to provide us with information concerning the temporal patterns of your speech. This sensor is not a microphone and therefore the sound of your voice itself will not be recorded.

Potential Benefits

You will not experience any direct benefit from participating in this research project. This study may, however, provide us with valuable information concerning one's ability to carry out more then one task at a time, and may ultimately help us develop strategies such that injuries could be reduced in the future.

Potential Risks or Discomforts

There is a small risk in this study that you may experience a temporary loss of balance while performing the activities used to assess your balance. To minimize your risk of losing your balance and falling during the performance of the balance and walking assessments, an investigator will be positioned directly beside you. There is also some potential for you to feel self-conscious or anxious during the attachment of the accelerometer, as an unfamiliar person (investigator) must touch your throat. There may also be a small amount of discomfort felt when the accelerometer is removed as the tape may gently pull on the skin or hair.

Voluntary Participation and Protection of Information

Your participation in this research project is voluntary. You may refuse to participate, refuse to answer any questions, and you may withdraw your participation at any time with no effect on your future participation in university-sponsored activities, or if applicable, on your academic status, or your future medical care. If you withdraw your participation in the study before the conclusion of data collection, your data will be destroyed. In order to assure complete confidentiality, no identifying information will be attached to the data collected in this study. The only record of your name that will be retained will be on the attached consent form, and this information will be stored in a locked file cabinet, within a locked room, that is (in turn) inside the Interdisciplinary Movement Disorders Laboratory (which remains locked at all times). This information will not be linked, in any way, with the study information. This also means that your data may not be withdrawn from the study after the testing session is concluded, and the

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information is entered into the computer. If the results of this study are published, your name will not be used, and no information that discloses your identity will be released or published without your explicit consent to the disclosure. Electronic data collected during the course of this study will be kept indefinitely. Representatives of the University of Western Ontario Health Sciences Research Ethics Board may contact you or may require access to your study related records to monitor the conduct of the research."

You will not receive remuneration for participation in this study. However if you drove to the experiment today, we will provide you with a parking voucher for your vehicle, or if you took public transit today, we will reimburse you the value of a standard round-trip bus ticket. We will give you a $5 gift card for Tim Horton's as a small token of our appreciation for your time and participation.

You will be asked on the consent form accompanying this letter to indicate if you agree to be contacted about future research opportunities. Your decision to be contacted has no impact on your ability to participate in the present research.

Further Questions

If you have any questions about this research project, please contact the principal investigator, Dr. Jeffrey Holmes, at [redacted], or by email at [redacted] If you are participating in this research as a healthy young or older control participant and have any questions about your rights as a research participant, or the conduct of this study, you may contact the Office of Research Ethics, (519) 661-3036, email: ethics@uwo.ca. If you are participating in this research as a participant with Parkinson's, and have any questions about your rights as a research participant, or the conduct of this study, you may contact Dr. David Hill, Scientific Director, Lawson Health Research Institute at [redacted] You are not waiving any legal rights by signing the attached consent form. This letter is yours to keep.

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The Effects of a Cognitive Secondary Task on Gait Initiation in Parkinson's disease

Please sign this form to indicate that you agree with the following statement:

I have read the Letter of Information, have had the nature of the study explained to me, and I agree to participate. All questions have been answered to my satisfaction.

Participant (Printed Name): _____

Participant (Signature): _____

Person Obtaining Informed Consent (Printed Name):
_____

Person Obtaining Informed Consent (Signature):
_____

Date: _____

I consent to having my name added to a list of potential participants in future research. I may withdraw this consent at any time, by contacting the principal investigator (Dr. Holmes). *Note: this consent has no impact on your ability to participate in the present research.*

Participant (Printed Name): _____

Participant (Signature): _____

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8.3. CoP Means and Standard Deviations for PD and Healthy Controls

8.3.1. S1 Period

Parameter	Condition	Instruction	HOC	PD
CoPL (cm)	NDT	Yes	9.01 (2.82)	6.05 (1.52)
		Maybe	9.40 (2.51)	6.75 (2.01)
	DT	Yes	8.83 (2.23)	6.21 (1.89)
		Maybe	9.89 (3.75)	6.92 (1.93)
Displacement (y) (cm)	NDT	Yes	4.92 (1.83)	2.58 (0.87)
		Maybe	5.35 (1.71)	3.18 (1.67)
	DT	Yes	4.72 (1.87)	2.86 (1.28)
		Maybe	5.14 (2.06)	3.06 (1.41)
Displacement (x) (cm)	NDT	Yes	5.31 (1.43)	3.60 (1.63)
		Maybe	5.69 (1.77)	3.98 (2.02)
	DT	Yes	5.40 (1.44)	3.67 (1.59)
		Maybe	5.45 (1.97)	4.04 (1.73)
Velocity (y) (cm/s)	NDT	Yes	13.58 (6.39)	6.23 (2.33)
		Maybe	13.88 (6.42)	7.68 (5.67)
	DT	Yes	11.42 (4.64)	6.87 (3.18)
		Maybe	13.01 (7.92)	6.52 (2.76)
Velocity (x) (cm/s)	NDT	Yes	15.62 (5.79)	9.26 (4.57)
		Maybe	15.68 (6.47)	9.92 (6.35)
	DT	Yes	14.02 (4.53)	8.99 (3.45)
		Maybe	15.41 (9.49)	9.38 (3.59)
Jerk (cm/s^3)	NDT	Yes	256846.95 (118328.80)	151560 (29409.02)
		Maybe	251914.98 (109203.85)	151080.74 (25986.75)
	DT	Yes	227502.63 (103787.11)	142469.47 (22046.69)
		Maybe	220839.27 (88748.03)	150048.10 (34142.92)

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8.3.2. S2 Period

Parameter	Condition	Instruction	HOC	PD
CoPL (cm)	NDT	Yes	16.45 (3.83)	15.42 (2.99)
		Maybe	16.78 (3.74)	15.25 (3.09)
	DT	Yes	16.44 (3.42)	14.40 (3.31)
		Maybe	16.48 (3.87)	15.82 (3.01)
Displacement (y) (cm)	NDT	Yes	3.89 (1.45)	3.89 (1.01)
		Maybe	3.98 (1.70)	3.55 (0.83)
	DT	Yes	4.18 (2.08)	3.21 (1.17)
		Maybe	3.96 (1.66)	4.01 (1.25)
Displacement (x) (cm)	NDT	Yes	14.37 (3.09)	13.70 (3.46)
		Maybe	14.85 (3.37)	13.72 (3.40)
	DT	Yes	14.32 (3.18)	12.98 (3.07)
		Maybe	14.44 (3.37)	14.12 (3.00)
Velocity (y) (cm/s)	NDT	Yes	20.51 (7.75)	11.47 (4.29)
		Maybe	21.93 (9.52)	13.44 (7.72)
	DT	Yes	20.59 (7.00)	12.16 (5.69)
		Maybe	20.97 (8.78)	14.13 (6.55)
Velocity (x) (cm/s)	NDT	Yes	51.11 (14.15)	31.22 (13.36)
		Maybe	52.96 (15.73)	36.68 (20.39)
	DT	Yes	50.38 (13.45)	34.51 (14.48)
		Maybe	54.87 (21.64)	37.26 (16.33)
Jerk (cm/s^3)	NDT	Yes	418855.31 (236672.73)	210159.39 (78374.21)
		Maybe	445139.41 (297125.62)	199409.55 (63211.58)
	DT	Yes	440549.54 (220317.47)	209989.49 (53067.75)
		Maybe	488058.58 (344240.61)	220669.55 (84539.77)

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8.3.3. S3 Period

Parameter	Condition	Instruction	HOC	PD
CoPL (cm)	NDT	Yes	17.18 (2.38)	14.73 (2.25)
		Maybe	16.92 (2.89)	15.15 (3.24)
	DT	Yes	17.28 (2.87)	15.50 (2.38)
		Maybe	17.38 (2.64)	16.54 (4.59)
Displacement (y) (cm)	NDT	Yes	15.51 (2.16)	12.44 (2.04)
		Maybe	15.28 (2.74)	13.54 (3.50)
	DT	Yes	15.47 (3.04)	13.68 (2.45)
		Maybe	15.64 (2.40)	13.78 (3.58)
Displacement (x) (cm)	NDT	Yes	2.01 (0.82)	2.36 (1.95)
		Maybe	2.16 (1.01)	1.95 (0.97)
	DT	Yes	2.25 (0.97)	2.18 (1.08)
		Maybe	2.29 (1.21)	3.64 (3.08)
Velocity (y) (cm/s)	NDT	Yes	27.64 (7.18)	20.14 (7.16)
		Maybe	27.52 (8.29)	21.35 (8.74)
	DT	Yes	28.87 (10.94)	22.40 (8.03)
		Maybe	30.14 (9.73)	22.81 (9.41)
Velocity (x) (cm/s)	NDT	Yes	9.13 (3.23)	8.43 (3.86)
		Maybe	9.07 (2.98)	7.17 (1.04)
	DT	Yes	9.70 (3.99)	7.95 (2.00)
		Maybe	9.92 (3.72)	10.77 (6.04)
Jerk (cm/s^3)	NDT	Yes	710236.55 (26573.19)	483874.56 (127650.20)
		Maybe	656461.04 (246310.90)	481219.25 (92901.71)
	DT	Yes	712607.45 (280117.51)	476795.28 (107383.22)
		Maybe	741927.18 (304097.64)	506978.32 (179705.75)

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8.3.4. S1 Peak

Parameter	Condition	Instruction	HOC	PD
S1 Peak	NDT	Yes	-1.06 (2.24)	1.66 (1.39)
		Maybe	-1.49 (2.08)	1.00 (1.63)
	DT	Yes	-0.74 (2.62)	0.92 (1.85)
		Maybe	-0.89 (2.36)	0.50 (1.45)

8.4. Vocalization Means and Standard Deviations for PD and Healthy Controls

8.4.1. Time between Vocalizations

Parameter	Condition	Instruction	HOC	PD
Average time between vocalizations (ms)	NDT	Yes	894.54 (150.18)	979.37 (221.19)
		Maybe	910.07 (145.95)	999.67 (240.92)
	DT	Yes	817.12 (162.16)	896.4 (225.0)
		Maybe	825.62 (150.18)	876.07 (230.71)
Pooled SD between vocalizations (ms)	NDT	Yes	107.98 (68.08)	211.52 (137.96)
		Maybe	102.3 (63.11)	192.43 (129.12)
	DT	Yes	104.65 (48.74)	160.65 (115.4)
		Maybe	106.62 (63.29)	162.41 (77.61)

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CURRICULUM VITAE

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Education

2010 – Present M.Sc., Joint Biomechanics Laboratory, The School of Kinesiology, Faculty of Health Sciences, Western University.
Supervisor: Dr. J.P. Dickey.

Thesis: "Gait Initiation in Parkinson's Disease: The Manipulation of Cue Expectancy in a Dual Task Paradigm"

2006 – 2010 Honors B.A., Specialization Kinesiology, Western University.

Teaching Experience

2012 *KIN4450* *Clinical Kinesiology*
Course Description: Theoretical and hands-on (laboratory) approach towards the study of clinical biomechanics. Special emphasis in: Posture and Balance, Gait and Orthopaedic biomechanics.
Roles and Responsibilities: Teaching Assistant. Prepared and demonstrated all lab material and assisted ~ 15 students during a bi-weekly 2 hour laboratory session. Lab tutorials included training in: EMG, goniometers, Kistler force plates, accelerometers, and stress fractures (two-point & three-point bending). Marking responsibilities included bi-weekly lab quizzes, midterm and final. Proctoring responsibilities included midterm and final exam.

2011 KIN2230 *Introductory Exercise Physiology*
Course Description: The physiological basis of muscular exercise and training. The course examined metabolic, cardiorespiratory and muscular adaptations to acute and chronic exercise.
Roles and Responsibilities: Teaching Assistant. Prepared and demonstrated all lab material and assisted ~40 students during a bi-weekly 3-hour laboratory session. Proctoring responsibilities during the midterm exams and final exam. Marking responsibilities included the laboratory final exam.

2011 *KIN3343* *Biomechanical Analysis of Discrete Sports Skills*

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Course Description: A laboratory-oriented, quantitative approach to the study of jumping, striking and throwing patterns incorporated into various sports.
Roles and Responsibilities: Teaching Assistant. Prepared and demonstrated all lab material and assisted ~15 students during a weekly 2 hour laboratory session. Marking responsibilities included monthly lab reports. Proctoring responsibilities included the final exam.

2009 KIN2230 *Introductory Exercise Physiology*
Course Description: The physiological basis of muscular exercise and training. The course examined metabolic, cardiorespiratory and muscular adaptations to acute and chronic exercise.
Roles and Responsibilities: Teaching Assistant. Prepared and demonstrated all lab material and assisted ~40 students during a bi-weekly 3-hour laboratory session. Proctoring responsibilities during the midterm exams and final exam. Marking responsibilities included the laboratory final exam.

Presentations at Conferences

2012 "Proof of Principle: Assembly of an Immersive Virtual Reality Simulation for Lift Trucks"
Poster Presentation at the Ontario Biomechanics Conference, Barrie, ON Canada

2011 "Time-to-Boundary measure of Center of Mass using Individual Functional Bases of Support to measure Postural Control"
Poster Presentation at the University of Ontario Faculty of Health Science Research Day, London, ON

Volunteer Experience

2011-2012 Kinesiology Graduate Board – VP Student Services