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The Influence of Plantar Cutaneous Stimulation on a Functional Test of Gait in Parkinson's Disease

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THE INFLUENCE OF PLANTAR CUTANEOUS STIMULATION ON A FUNCTIONAL TEST OF GAIT IN PARKINSON'S DISEASE

by

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THESIS

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ABSTRACT

Although possible deficits in proprioception have been implicated as a cause of gait impairments in individuals with Parkinson's disease (PD), little research has been done to investigate improving this possible deficit as a method to influence mobility. The overall purpose of the current thesis was to investigate the influence of increased plantar stimulation on stability and gait impairments. This study also investigated the contribution of attention to locomotion in PD. The two studies comprising this thesis addressed the possible influence of the ribbed insoles in the initial response of PD participants as well as the long-term use of the insole.

The first study focused on developing a task to assess the influence of the facilitatory insoles on gait for individuals with PD compared to healthy control participants. For the purpose of evaluating the facilitatory insoles in a functionally relevant task participants performed a modified "Timed Up and Go" task with an additional secondary motor task. The secondary task of carrying a tray with glasses demonstrated that attention plays a large role in the production and maintenance of gait as gait deficits became more pronounced. However, the facilitatory insoles also influenced gait parameters which demonstrated that the possible deficits in proprioception contribute to the gait impairments in PD. The initial response to the insoles, in the first study, did not improve gait parameters, which suggests that PD participants may need more time to adjust to the increased plantar stimulation.

The second study investigated the influence of the facilitatory insoles when they are worn for a longer period of time. Participants wore either the facilitatory insoles or blank insoles while completing the PD Sensory Attention Focussed Exercise (PD SAFEx) rehabilitation program. Results demonstrated that when the facilitatory insoles are worn long-term, they can benefit the turning and straight-line walking in individuals with PD. PD participants became more confident in their ability to turn as they exerted less control over their centre of mass. Participants also displayed a decreased base of support and time spent in double limb support without negatively affecting lateral stability. These improvements suggest that the facilitatory insoles, when worn long-term, allow for a more normalized pattern of gait for individuals with PD.

The TUG task used in this thesis proved to be a good measure to evaluate changes in stability and gait parameters in PD participants. Long-term use of the facilitatory insoles demonstrated improvements in stability and gait deficits during difficult aspects of gait such as turning. This suggests that the facilitatory insoles would be a simple and effective intervention to use, however further investigation should occur to ensure that the improvements will continue when facilitatory insoles are used on a daily basis. As well, investigation into the long-term use of other types of cutaneous stimulation such as vibratory insoles would be beneficial for the PD population.

List of Abbreviations

PD – Parkinson's disease
COM – Centre of Mass
BOS – Base of Support
TUG – Timed Up and Go
TrayWG – Tray with Glasses
UPDRS – Unified Parkinson's Disease Rating Scale
FI Group – Facilitatory Insole Group
BI Group – Blank Insole Group
TMS – Transcranial Magnetic Stimulation
PET – Positron Emission Tomography
EEG – Electroencephalography
GRF – Ground Reaction Forces
COP – Centre of Pressure

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Wow. I didn't actually think I would get to this point. And now I get to thank everyone who helped me get here.

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CHAPTER 1

INTRODUCTION

Parkinson's disease and Its Complications

While there are many symptoms of Parkinson's disease (PD), including bradykinesia, rigidity of muscles, tremor (Kaji & Murase, 2001), postural instability and gait impairments may be the most debilitating since they can lead to falling and ultimately, limit independence. Ashburn and colleagues, in a community-based study, found that 64% of PD patients had experienced a fall in the past 12 months and approximately 50% experienced falls repeatedly (Ashburn, Stack, Pickering, & Ward, 2001). Similarly, Bloem and colleagues found that during a six month period, 50.8% of PD patients fell at least once and 25.4% of PD patients had recurring falls. Bloem et al. also determined that PD participants had a nine-fold risk increase in reoccurring falls compared to healthy elderly individuals (Bloem, Grimbergen, Cramer, Willemsen, & Zwinderman, 2001). This predisposition is also demonstrated in everyday activities where individuals with more progressive PD employ strategies, such as standing on tips of toes while performing reaching tasks, that predispose them to falls (Stack, Ashburn, & Jupp, 2005).

The most common method of counteracting the symptoms experienced by individuals with PD is through medication. Schaafsma et al. (2003) studied the relationship between levodopa therapy and falls in individuals with PD and found that levodopa significantly reduced stride time variability which has been found to increase in people with PD that fall on a frequent basis (Schaafsma et al., 2003). From this study and others, it is clear that pharmacotherapy has a positive effect, however, the effects of these medications can wear off over time and have negative side-effects such as night time or early morning deteriorations, and medication induced dyskinesias (Guttman, Kish, & Furukawa, 2003; Johnson, 2007). Thus, it is important to investigate other possible interventions as possible treatments of this disease. A significant avenue to explore is the role of the sensory system in individuals with Parksinon's disease which has been implicated as a reason for postural instability and motor impairments (Bloem, 1992; Haas, Buhlmann, Turbanski, & Schmidtbleicher, 2006). Thus, it is necessary to determine if any intervention using this system could be employed to counteract the effects of the dysfunctional basal ganglia in PD patients.

A Deeper Look at the Effects of PD: Postural Instability and Gait Impairments

Postural sway is a well studied area of research that allows for investigation into the effects of PD on postural stability. In a study conducted by Beuter et al. (2008), they had participants withdraw from dopaminergic medication for an average of 16 hours prior to participation to evaluate postural sway with the assumption that the basal ganglia are no longer able to influence motor control. It was found PD patients exhibited mild changes in postural sway in the early stages of PD while OFF dopaminergic medication. The authors suggested that the basal ganglia or dopaminergic circuits play a role in maintenance and execution of postural control. Similarly, Contin et al. (1996) tested the effects of medication and disease severity on postural sway. A significant effect was found as individuals in OFF medication state exhibited higher postural sway scores than healthy, age-matched controls in both eyes open and eyes closed conditions.

Similarly, when investigating the effect of surface displacements on postural response patterns, individuals with PD have also been suggested to being posturally inflexible. Individuals with PD were less able to recover their balance once their centre of mass (COM) passed out of their base of support (BOS). This study reported individuals with PD having smaller limits of stability in which they operate, as demonstrated by a stiffer posture which they find to be more stable. This postural adaptation leads individuals with PD to walk with short, shuffling steps as they are more easily able to keep their COM within their stability limits. When confronted with a perturbation, PD participants respond with inadequate responses to correct their posture. The authors concluded that PD participants were unable to correct their posture in response to situational changes and levodopa medication was unable to improve this ability to adapt (Horak, Nutt, & Nashner, 1992). Therefore, individuals with PD demonstrate increased postural sway and an inability to adapt motor programs in response situational disturbances, which leads to postural instability.

In addition to the postural instability experienced, gait impairments are also a central cause of falls in individuals with PD (Bloem et al., 2001). Individuals with PD normally display a decrease in stride length and gait speed during straight line walking, which are considered to be manifestations of hypokinesia (Morris, Iansek, Matyas, & Summers, 1996; Rogers, 1996). Step-to-step variability is another common characteristic of gait observed in individuals with PD but more likely the result of testing times during the medication cycle and not hypokineisa (Morris et al., 1996).

Another area of gait that is compromised in individuals with PD is gait initiation. Gait initiation is a difficult aspect of gait as it places considerable demand on postural control to transition from a steady stance to a dynamic situation of walking, and requires the COM to move away from the centre of the BOS. It also requires the BOS to become narrower when walking begins (Martin et al., 2002). In general, individuals with PD exhibit a decreased step length and velocity when initiating gait (from standing to walking) compared to participants (Martin et al., 2002; Rosin, Topka, & Dichgans, 1997; Vaugoyeau, Viallet, Mesure, & Massion, 2003). In addition, there is agreement that PD participants spend more time in the postural phase compared to the locomotor phase of gait initiation (Rosin et al., 1997; Vaugoyeau et al., 2003), as well as exhibiting a smaller centre of pressure to COM distance during the locomotor phase (Hass, Waddell, Fleming, Juncos, & Gregor, 2005). The author of these studies concluded that individuals with PD appear to emphasize postural stability by ensuring that they remain stable rather than generating forward momentum to initiate their gait (Hass et al., 2005; Hass, Waddell, Wolf, Juncos, & Gregor, 2008; Martin et al., 2002; Rosin et al., 1997; Vaugoyeau et al., 2003). Therefore, individuals with PD are more concerned with remaining stable than being efficient in gait initiation, as the latter poses a significant threat to their stability.

Turning is also a difficult task for more than 50% of individuals with PD and falls commonly occur during turning (Bloem et al., 2001). Turning has been evaluated in several different ways to determine how individuals with PD turn differently than their healthy, age-matched peers. In a study by Mak et al. (2008), while evaluating PD participant's ability to turn suddenly, the onset time of response in body segments and the step width of the subsequent steps were measured while completing the turn. It was found that individuals with PD had later onset times for foot displacement and larger intervals of time between body COM and lateral foot displacement. Similarly, Huxham and colleagues evaluated spatiotemporal characteristics of turning and found that individuals with PD did not turn as much as their peers when instructed to turn 60° or 120°. PD participants also used more steps to complete the turn as they severely reduced their stride length and showed significant temporal differences that suggest the timing control is impaired (Huxham, Baker, Morris, & Iansek, 2008). From these studies, it is clear that turning, in addition to normal walking and initiating gait, is a difficult aspect of everyday movement that can severely limit individuals with PD.

Interventions to Counteract Gait Impairments

The gait deficits observed during straight line walking, gait initiation and turning pose a significant problem to the stability of individuals with PD. Previous studies have addressed walking (Frazzitta, Maestri, Uccellini, Bertotti, & Abelli, 2009; Herman, Giladi, Gruendlinger, & Hausdorff, 2007; Pohl, Rockstroh, Ruckriem, Mrass, & Mehrholz, 2003; Protas et al., 2005) and gait initiation (Jobges et al., 2004) impairments through various interventions. For example, Protas et al. (2005) had PD participants undergo gait training that included forward, backward and sideways walking on a treadmill. After eight weeks of training, they found an improvement in measures such as velocity, and balance. Similarly, Jobges et al. (2004) trained compensatory stepping in reaction to a perturbation in individuals with PD and found that compensatory step length, and step time improved as well as during voluntary gait initiation. It is not surprising that when individuals with PD undergo gait training, improvements in their gait are observed. However, these improvements require a significant amount of time spent in intensive training as well as access to trainers and equipment in order to receive the benefits.

Therefore, it is important to investigate less intensive and less expensive methods of counteracting the gait deficiencies observed.

Other interventions to counteract the common gait impairments found in individuals with PD involve external sensory cues. Verbal cues that instruct participants to "take a big step" (Behrman, Teitelbaum, & Cauraugh, 1998) and auditory cues such as a beep (Thaut, 1996) have been found to be beneficial for gait parameters such as stride length, velocity and cadence. Auditory cues were also used to improve the time to turn 180° in individuals with freezing of gait (Nieuwboer et al., 2009). Visual cues, such as step targets, have received the greatest consideration as a method to enhance motor performance during postural control (Vaugoyeau, Viel, Assaiante, Amblard, & Azulay, 2007) and gait (Almeida et al., 2005; Keijsers, Admiraal, Cools, Bloem, & Gielen, 2005; Lewis, Byblow, & Walt, 2000; Morris, Iansek, Matyas, & Summers, 1994; Morris et al., 1996) studies. However, using visual cues to overcome gait deficits require visual cues to be available at all times and it may not be possible to place horizontal lines everywhere that an individual may walk. More importantly, visual cues such as ground lines require individuals to constantly attend to the lines in order to improve gait parameters, and this may not be safe as the individuals are no longer paying attention to their surroundings.

In addition to the lack of practical applicability of visual cues, the efficacy of visual feedback declines as individuals with PD age. This was demonstrated in a study where PD participants were required to point to a remembered target in complete darkness and with a light attached to their index finger. Results of this study indicated that in addition to large constant and variable errors in both conditions of PD participants compared to healthy control participants, they showed an increase in the variable error difference between the two conditions as a function of severity. The authors concluded that the use of visual feedback as a way to bypass the defective basal ganglia is no longer helpful as the disease progresses in severity (Keijsers et al., 2005). Similarly, in a study investigating the effect of age on postural control, it was found that vision plays a very important role in the maintenance of postural control in older adults. However, vision operates slowly so that if an older individual loses their balance and is relying on visually-guided postural reflexes, a fall may not be avoidable (Hytonen, Pyykko, Aalto, & Starck, 1993). Therefore, it is of great importance to explore alternative methods to visual cues in order to maintain or improve daily function for individuals with PD.

Furthermore, instead of finding methods to bypass the defective basal ganglia by way of visual or auditory cues, this study will explore a potential underlying cause of the postural instability and gait deficiencies experienced by investigating the proprioceptive deficits observed in individuals with PD.

Causes of Postural Instability and Gait Impairments: An Implication towards Proprioception

Many sources have been identified as to the cause of the movement performance deficits in PD, including abnormal postural strategies (Beckley, Bloem, van Dijk, Roos, & Remler, 1991; Horak et al., 1992) and postural reflexes (Traub, Rothwell, & Marsden, 1980); gait abnormalities (Morris et al., 1996; Rogers, 1996) and reduced muscular strength (Horak, Schupert, Mirka, A., 1989). Yet another factor has been suggested as a cause for postural instability. Specifically involving the proprioceptors and the integration of kinaesthetic information, it has been suggested that individuals with PD may have a proprioceptive deficit (Bloem, 1992). This idea has been confirmed by several studies that investigated proprioceptive impairments found in individuals with PD (Jobst, Melnick, Byl, Dowling, & Aminoff, 1997; Klockgether & Dichgans, 1994; Konczak, Krawczewski, Tuite, & Maschke, 2007; Moore, 1987; Zia, Cody, & O'Boyle, 2000). For example, it was found that when compared to healthy controls, PD patients were less able to locate a target outside their body without vision yet performed just as well as healthy controls on all other sensory evaluations (Jobst et al., 1997). Similarly, it was found that peripheral afferent feedback is significantly impaired in people with PD. This was clearly demonstrated when PD patients consistently underestimated the movement targets when vision was not available compared to age-matched controls (Klockgether & Dichgans, 1994). Using muscle vibration, PD patients demonstrated reduced movement errors during voluntary wrist and ankle movements supporting the notion that a general impairment of proprioceptive inputs (Khudados, Cody, & O'Boyle, 1999; Rickards & Cody, 1997).

Proprioceptive deficits have also been found to affect postural control in PD. In a study conducted by Vaugoyeau et al. (2007), the somatosensory system was isolated by manipulating the vestibular system with undetectable sinusoidal oscillations and the visual system with the individual's eyes closed. They found that when PD participants were relying on the cutaneous sensory sources for information, they were unable to maintain the vertical posture of the head and trunk. These results demonstrate that although the somatosensory system has been found to provide enough information to control posture in healthy individuals, it is not enough for individuals with PD (Vaugoyeau et al., 2007). Similarly, the proprioceptive deficits have also been found to affect various temporal parameters of gait such as time spent in double limb support, When participants closed their eyes and were relying primarily on proprioceptive inputs to guide their walking, PD participants spent more time in double limb support (Almeida et al., 2005). Since these proprioceptive deficits exist in individuals with PD and can lead to postural instability and gait impairments, it is important to conduct further research to understand how proprioceptive feedback can modulate postural control and gait.

However, it is not definitively known if the difficulty lies in defective sensory receptors, the transmission of the sensory information or in the central processing of the sensory input. Studies have found a sensory impairment of two-point discrimination and static joint position sense which would implicate defective sensory receptors (Schneider, Diamond, & Markham, 1987; Zia et al., 2000). As well, Pratorius et al. (2003) conducted a study investigating the sensitivity of the sole of the foot in individuals with PD. They found that PD patients have significantly higher thresholds of sensitivity, and thus PD patients require an amplified stimulus to overcome the increased threshold. They also found that relationship between severity and threshold where the more severely affected patient, the more increased the sensitivity threshold (Pratorius, Kimmeskamp, & Milani, 2003). In accordance with this, Dietz et al. (1998) found that individuals with PD exhibit reduced load sensitivity and therefore, an increased threshold in the lower leg receptors which may also contribute to the movement deficits found in PD. If the deficit lies solely in the sensory receptors themselves, then an increase in stimulus intensity should be able to overcome the defective sensory receptors that may be responsible for the proprioceptive deficit, as suggested in previous research (Demirci, Grill, McShane, & Hallett, 1997; Jobst et al., 1997). However, it is also possible that a greater stimulus actually may not do anything to improve receptor function or it does influence the sensory receptors but in a negative fashion that adds to the impairments observed.

Despite the previous studies that suggest the impairment lies in the sensory receptors themselves, the majority of research findings strongly lean toward the notion that the proprioceptive impairment is of a central processing deficit as proposed by Delwaide (1993) and Seiss et al. (2003) both found evidence that muscle spindle sensitivity is normal in individuals with PD and led to the conclusion that the proprioceptive impairment is in the central processing of the sensory information.

However, it has not been determined which area of the central nervous system is responsible for the "central processing impairment" theory. Cortical areas such as the supplementary motor area (SMA) have been implicated as a possible location for the proprioceptive impairment because the effect of dopamineric medication on step length and step accuracy varied across participants. The authors reasoned that the effect of medication should have been relatively equivalent across participants, if the basal ganglia are primarily responsible for the proprioceptive-motor deficit (Jacobs & Horak, 2006). Likewise, in a study by Mongeon et al. (2009), the variability between PD participants in the accuracy of a reaching task due to dopaminergic medication also led the authors to conclude that the dysfunction of the basal ganglia due to loss of dopamine is not responsible for the impaired processing of proprioceptive information. Thus, it is possible that the sensory processing impairment found in individuals with PD lies within higher brain structures, such as the supplementary motor area.

Yet the majority of the research indicates that the deficit lies in subcortical areas. For example, the impairment may lie at the spinal level, as PD patients have significantly reduced level of intracortical inhibition during static and passive conditions, as subjects performed flexion and extension movements of the wrist (Lewis & Byblow, 2002). However, most of the research has implicated the dysfunctional basal ganglia as the location for the proprioceptive processing impairment (Almeida et al., 2005; Demirci et al., 1997; Konczak et al., 2007; Labyt et al., 2003; Maschke, Gomez, Tuite, & Konczak, 2003; Schrader et al., 2008; Tamburin et al., 2003; Valkovic, Krafczyk, & Botzel, 2006). Maschke et al. (2003) investigated the contributions of the cerebellum and the basal ganglia to sensory processing by comparing individuals with PD to participants with cerebellar degeneration. They found that only PD participants, but not participants with cerebellar deficits, demonstrated a kinaesthetic impairment and this impairment was correlated to the severity of the disease. The authors concluded that an intact cerebro-basal ganglia loop is needed for kinaesthesia awareness and individuals with PD are lacking this intact loop. This has been corroborated with evidence from TMS studies which found a lack of motor evoked potentials induced by muscle vibration in the forearm in PD (compared to a group of healthy and Multiple System Atrophy participants). The authors suggested that this may demonstrate reduced excitability of the intracortical inhibitory pathways which reflects a change in the processing of proprioceptive information (Schrader et al., 2008; Tamburin et al., 2003). Positron emission tomography scans have also identified a reduced activation of the basal ganglia in individuals with PD (in contrast to healthy controls) when continuous vibration was applied to the index finger (Boecker et al., 1999).

Researchers have theorized that the basal ganglia may play a role in sensorimotor integration whereby sensory input is integrated to determine a motor command or program (Abbruzzese & Berardelli, 2003). Schneider et al. (1986) also suggested that the basal ganglia assesses and directs sensory inputs when transmitting the message to other areas of the brain (Schneider, Diamond, & Markham, 1986). Since the basal ganglia are no longer able to "gate" sensory inputs appropriately, the processing deficit has manifested itself various ways such as the scaling of motor output (Demirci et al., 1997; Labyt et al., 2003; Tamburin et al., 2003; Valkovic et al., 2006) and a possible delay of motor programming (Labyt et al., 2003). For example, Demirci (1997) found that PD patients perceive distances to be shorter than they actually are when they are using only proprioception to guide them, thus exhibiting a proprioceptive deficit. Yet in addition to this deficit, it is suggested that individuals with PD have reduced corollary discharge or "efference copy", where PD patients think they are reaching a target, but are actually undershooting the target as they are unable to recognize a discrepancy between their intended movement and the actual movement itself. The error is only recognized when PD patients are able to visually see the error in their results. Thus, there is an in ability to appropriately scale motor responses due to the abnormal sensory information being sent from the basal ganglia (Demirci et al., 1997). Similarly, Labyt et al. (2003) found that there is a delay in the response pattern in the regions contralateral to which side the movement was being performed during EEG recordings for individuals with PD. They attributed this delay to the inability of the basal ganglia to deliver correct sensory information to cortical areas (Labyt et al., 2003). Both of these deficits provide a possible cause for the movement deficits observed in PD. The over-all reduced sensory input to influence the original motor command, and the mismatch of the reduced efferency copy and peripheral feedback may lead to hypokinetic movements such as reduced step length

(Demirci et al., 1997). Similarly, the bradykinetic movements may be a product of the delay in motor programming due to the abnormal sensory input from the basal ganglia to the motor cortices.

From these past studies, it is clear that the majority of research investigating the underlying cause of the proprioceptive deficit believe the impairment lies in the central processing of sensory information, and more specifically in the basal ganglia. If this theory is correct, then it may be possible to improve the amount of sensory information being received by the basal ganglia, which in turn, can increase the amount of sensory information the basal ganglia sends to the various cortical areas that use the sensory information to guide movement. Thus, the focus of this study is to determine if increased sensory stimulation is able to influence the various postural and gait impairments found in individuals with PD. If the impairment is due to reduced sensory information being sent and therefore received by central structures, then providing increased sensory stimulation should be able to overcome the sensorimotor integration deficit. To underline the importance of this investigation, Almeida et al. (2005) examined the influence of visual and proprioceptive inputs while moving toward a target. They found that individuals with PD significantly increased the time spent in double limb support when relying primarily on proprioception to guide them. The authors suggested that PD subjects might have been attempting to improve the amount of sensory feedback sampling, so as to improve their proprioceptive information being provided as they walked. These results demonstrate the importance of improving the sample of sensory feedback which may be necessary for individuals with PD to overcome their proprioceptive impairments. A possible method of providing increased sensory stimulation and proprioceptive sampling for PD patients during locomotion is by way of mechanical facilitation of the plantar surface of the foot.

Sensory Receptors and Mechanical Facilitation

Peripheral afferents, such as mechanoreceptors and proprioceptors provide important information to allow for modulation of gait. Specifically, recent research has shown that mechanoreceptors play an important role in postural control and gait. In a study by Johansson et al. (1980), mechanoreceptors were found to be able to detect position, force, velocity and acceleration of a mechanical disturbance to the skin in healthy adults. Mechanoreceptors have also been found to play a significant role in postural control when looking specifically at plantar cutaneous mechanoreceptors. Perry et al. (2000) investigated the effect of balance perturbations when the foot soles of healthy young adults had been hypothermically anaesthetized. They found there was a direction specific effect of perturbation when the feet were cooled. For example, when individuals were forced to take a backward step, the degree to which the COM moved toward the posterior edge of the BOS increased when the feet were cooled. From this, the authors suggested that plantar cutaneous mechanoreceptors provide information that senses the relationship between the COM and the limits of stability of the BOS allowing for an internal awareness of a person's stability limits (Perry, McIlroy, & Maki, 2000). Similarly, Meyer et al. (2004) suggested that plantar cutaneous afferents provide feedback such as production of ankle torque, information on weight transfer and limb loading as well as characteristics of the support surface. This has been demonstrated in a study where individuals with peripheral neuropathy demonstrated impaired balance, as evidenced by increased postural sway in the anterior-posterior directions (Simmons, Richardson, & Pozos, 1997).

The importance of sensory feedback from mechanoreceptors is also observed during gait in healthy individuals. A study investigated the relationship between tactile sensitivity and centre of pressure (COP) while walking found that individuals with a higher sensitivity to stimulation on the heel had higher peak pressures on the heel just prior to the push-off phase of gait. Thus, the individuals that had an increased sensitivity in the heel moved their centre of pressure to that area. The authors concluded that sensory feedback from the feet plays an integral role in dynamic foot placement and during foot contact (Nurse & Nigg, 1999).

It has also been found that mechanoreceptors located in the feet interact with proprioceptors in the leg, even those in the upper leg. Duysens et al. (2008) found that vibration to the soles of the feet elicited stretch reflexes in muscle throughout the leg. It was demonstrated that mechanical facilitation, by way of vibration, can evoke a response from the proprioceptors, which can in turn affect the gait of an individual. This is reasonable to expect as various types of sensory receptors work together to provide accurate feedback to the central nervous system during locomotion. Thus, it is possible that mechanical facilitation of the plantar surface may be able to increase the sensory stimulation received to overcome the proprioceptive deficits that impair gait in individuals with PD.

To our knowledge, there have only been three studies that investigated the use of cutaneous cues to gait parameters in individuals with PD. In a study by Burleigh-Jacobs et al. (1997), the effect of extraneous cues (by way of a pulse on the hand or earlobe) on anticipatory postural adjustments of individuals with PD was investigated. They used centre of pressure (COP) and ground reaction forces (GRF) to measure various temporal and kinematic variables. It was found that the cutaneous cue improved step initiation, velocity and reaction times, similar to the effect of levodopa administration, when PD participants underwent a backward surface translation. The authors suggested that the external cue may have been a replacement for a dopaminergic influence on voluntary movement governed by central processes (Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997). Similarly, Dibble et al. (2004) used auditory and cutaneous cues during a gait initiation task under temporal constraints. They measured three types of variables: 1) temporal variables including reaction time latency, double limb and single limb support durations; 2) COP variables including lateral and posterior COP displacement and velocity; 3) kinematic variables including step length, and velocity of the swing limb. While these results are in agreement with the previous study, it was found that the sensory cues had a negative effect on displacement of the body and swing limb while initiating gait. However, the authors concluded that the cutaneous cue may have had this effect because it is not typically used as a "go" signal to initiate movement, unlike auditory cues. The authors suggested that individuals with PD may require training with cutaneous cues to achieve the same benefits as other sensory cues (Dibble et al., 2004). Another study, which is most closely linked to the current study, used insoles that had vibration devices inserted at the heel and metatarsal pads so that when pressure is placed on the insoles such as when the foot is in contact with the ground, vibration is induced to enhance proprioceptive stimulation. Results demonstrated that when the vibration insoles were worn, walking speed and stride length increased as well as stride to stride variability improved for individuals with PD (Novak & Novak, 2006). Although these results are quite remarkable, due to the nature of the device, participants were unable to be blinded to the presence of the vibratory insole, which may have made participants aware of the intervention and consequently, changed their gait parameters. As well, this study only measured straight-line walking and did not focus on other aspects of gait, such as turning, that are difficult for individuals with PD. Similarly, this study used stride to stride variability to glean results for stability, but did not use any actual stability measures. Thus, this present study will address the effects of cutaneous cues not only on gait initiation but other aspects of human gait, such as turning. As well, the lateral stability margin will be evaluated with regards to the facilitatory insoles in order to give a direct measure of stability.

In the current study, mechanical facilitation will be provided by way of a facilitatory shoe insole that has raised ridge near the perimeter of the sole (Maki, Perry & McIlroy, 2001). The notion of the ridge is to provide increased stimulation of the receptors near the edge of the foot when the COM nears the BOS. The use of this ridge was developed after participants consistently indicated that they predominantly felt stimulation around the edge of their feet during a weight transfer task. These insoles were then tested in a balance-testing situation where participants were required to react to an external perturbation (Maki, Perry, Norrie, & McIlroy, 1999). The facilitatory insoles reduced the amount of steps necessary to recover from the perturbation in healthy, older adults. The long-term use of the facilitatory insole was then evaluated in a healthy, older population. It was found that after twelve weeks of consistently wearing the facilitatory insoles, lateral stability improved while participants walked over uneven terrain as well as reducing the fall rate of falls in elderly participants. These changes reduced the likelihood that the COM would venture outside the BOS, thus reducing the likelihood of a fall occurring (Perry, Radtke, McIlroy, Fernie, & Maki, 2008).

From these results, it was thought that the facilitatory insoles would provide the increased sensory stimulation necessary to influence gait impairments in PD. We conducted a pilot study using these facilitatory insoles in individuals with PD. This study required PD participants and healthy, age-matched controls to walk in a straight line wearing the facilitatory insoles compared to walking without the insoles. The results demonstrated muscle activation timing of the tibialis anterior became more normalized to healthy participants during heel strike phase of gait while wearing the facilitatory insoles, which allowed for a normal heel-to-toe pattern of gait. In conjunction with this, there was anecdotal evidence from the participants that they felt they could benefit from these insoles. However, no other noteworthy improvements in gait parameters such as velocity and step length were displayed (Jenkins et al., 2009). It is possible that these insoles may only have an effect on gait parameters when the individual's balance is being disturbed. Therefore, it is essential to investigate the possible effect of these facilitatory insoles on the gait of individuals with PD when their sense of balance is being tested such as in instance of gait initiation, turning and fast paced gait.

A Balance-Disturbing Situation: The Timed Up-and-Go Task

The Timed Up-and-Go (TUG) task requires individuals to stand up from a chair, walk to a designated spot at a distance of three metres, turn around at that spot, walk back to the chair and sit down. This entire process is timed and total duration of the activity is the common measure. The TUG task is a clinical tool that allows for assessment of mobility and balance, commonly used to assess older individuals (Hall, Williams, Senior, Goldswain, & Criddle, 2000; Podsiadlo & Richardson, 1991) and also has been found to be a good predictor of falls in older adults (Shumway-Cook, Brauer, & Woollacott, 2000). The TUG task has also been used widely in special populations such as PD (Brusse, Zimdars, Zalewski, & Steffen, 2005; Matinolli et al., 2009; Sage & Almeida, 2009; Stack, Jupp, & Ashburn, 2004) and has been found to be highly correlated with the Unified Parkinson's Disease Rating Scale (UPDRS), an assessment to determine disease severity (Martinez-Martin, Fontan, Frades Payo, & Petidier, 2000). Morris et al. (2001) evaluated the TUG test and found it to be a reliable and valid measurement tool to detect changes in performance according to dopaminergic medication use as well as differences in performance between individuals with PD and those without PD.

The TUG task will be used in the current study to evaluate the effectiveness of the facilitatory insole. This task was chosen as it incorporates various phases of gait that are challenging to individuals with PD as well as being functionally relevant to every day movements. However, in previous research, the TUG task has never been broken down into the separate phases of gait initiation, straight-line walking and turning. The current study will separate the modified TUG task into these phases in analysis and compare the results to previous research that has focussed independently on the three areas of gait initiation, turning and walking.

The Role of Attention

In previous research, individuals with PD have been found to have difficulty multi-tasking. Cognitive and motor tasks have been found to have a detrimental effect on postural stability, evidenced by an increase in centre of pressure movement during stance (Marchese, Bove, & Abbruzzese, 2003). This also occurs when given a cognitive task to complete concurrently with walking, PD participants have been shown to increase their gait variability which indicates less stability (Hausdorff, Balash, & Giladi, 2003). This effect has also been demonstrated with a secondary motor task while walking, where they give greater priority to the secondary task and not to their walking. For example, when given a tray with glasses on it, individuals with PD will attend to the tray with glasses and marked declines in velocity and stride length are observed (Bond & Morris, 2000). The authors of these studies suggest that individuals with PD have reduced attentional capacities and therefore, cannot attend to both tasks and perform them properly (Bond & Morris, 2000; Hausdorff et al., 2003; Marchese et al., 2003). Furthering this idea, Bloem found that PD participants prioritize incorrectly and put more attention on the concurrent task (whether cognitive or motor) or try to attend to both equally, which ultimately leads to instability (Bloem, Grimbergen, van Dijk, & Munneke, 2006). From these studies, it is clear that individuals with PD have difficulty attending to multiple tasks and as a consequence, their gait and stability suffer. However, this field of research has yet to use a secondary task paradigm, whether it is cognitive or motor, to evaluate if the cause of gait deficits observed are truly attentional or if an underlying cause such as a proprioceptive deficit is to blame.

The current study will use a secondary motor task of carrying a tray with glasses to address whether the possible improvements found in gait parameters while performing the modified TUG task, are due to the facilitatory insoles drawing the individuals attention to their feet, or whether the improvements can be attributed to the increased proprioceptive stimulation provided by the facilitatory insoles. Presumably, if improvements in gait are found when the task is at its most complex (carrying the tray with glasses), then the improvements are not due to attention but rather the improved proprioceptive input.

Thesis Objectives

Postural instability and gait impairments pose a significant threat to the daily lives of individuals with PD. Various interventions, such as gait training and visual cues, have been shown to be beneficial in improving these deficits, however these studies are disregarding a very possible and significant underlying cause. The purpose of the current thesis is to determine whether proprioception is a possible cause of postural instability and gait impairments in PD as well as to develop a possible intervention to be used by individuals with PD to counteract gait impairments. This will be determined in the following three chapters by evaluating the effectiveness of a balance enhancing insole, which increases plantar stimulation and thus proprioceptive input, on individuals with PD while their balance is being tested during a modified TUG task.

The first chapter focuses on the initial effect of the facilitatory insoles on PD and healthy control participants. Since previous research has shown improvements in gait parameters due to increased mechanical stimulation in individuals with PD (Burleigh-Jacobs et al., 1997; Dibble et al., 2004; Novak & Novak, 2006), it is expected that these facilitatory insoles will also improve the stability and gait impairments in individuals with PD. The influence of the facilitatory insoles will be evaluated during a modified

TUG task that provides aspects of gait that are difficult for individuals with PD, and are also encountered in everyday life. The purpose of this study is: 1) to determine whether the modified TUG task is an appropriate task to challenge the gait of healthy control and PD , thus allowing the facilitatory insoles to influence lateral stability. If a detrioration in gait and stability parameters are found in both populations during the various conditions of the modified TUG task, then the task would appear to have challenged the gait of the participants. Following this, if a change is observed in these same measures when the facilitatory insoles are worn, this would indicate that the modified TUG task is able to measure these changes and thus, is able to effectively evaluate the influence of the facilitatory insole; 2) to determine whether the facilitatory insoles are able to influence specific measures pertaining to gait initiation, turning and walking; 3) to develop which measures to use to effectively assess the influence of the facilitatory insoles over a six week time period; and 4) to address the role of attention and proprioception in the possible changes in gait due to the facilitatory insoles.

The second study introduces the facilitatory insoles into a six-week exercise rehabilitation program for individuals with PD. Various studies have shown the effectiveness of training to improve various gait parameters for individuals with PD. Similarly, the facilitatory insoles were effective for elderly individuals when studied over a twelve week period. It is expected that the facilitatory insoles will continue to demonstrate beneficial effects, or even have added benefits, on stability and gait parameters when used over a long-term period. Thus, the purpose of the second study is to allow for an evaluation of the effectiveness of the facilitatory insoles as a longitudinal intervention in the PD population, using the measures established in the first study.

Finally, the last chapter summarizes the results from both studies and provides a synthesis of the results to evaluate: 1) the effectiveness of the facilitatory insoles when first encountered and long-term use; 2) whether the proprioceptive deficits are a possible cause for the gait impairments found in individuals; and 3) whether the proprioceptive deficit lies in the sensory receptors or is an impairment in central processing of the sensory information.

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CHAPTER 2

USING A DUAL TASK TO EVALUATE THE INFLUENCE OF A FACILITATORY INSOLE ON GAIT IN PARKINSON'S DISEASE

Abstract

Previous research has suggested that the possible deficits in proprioception may contribute to the stability and gait impairments found in PD. The purpose of this study was to determine whether augmenting proprioceptive feedback of the plantar surface by way of a facilitatory insole can influence stability and gait measures in this population. This study also addressed the role of attention and proprioception on gait within this population. Fifteen PD participants and fifteen healthy controls completed a modified Timed-Up and Go (TUG) task which required them to rise from a chair, walk to a marked spot three metres away, turn around and walk back. Individuals completed this task under three conditions: 1) no tray; 2) empty tray; 3) tray with glasses. The task was completed with and without the facilitatory insoles. Each of the conditions was randomized and a total of thirty trials were completed. Main measures included step length, velocity, base of support, time to turn, and lateral stability margin which were collected by a pressure sensitive carpet and motion capture system. PD participants took more time to turn during the TrayWG condition compared to healthy controls ($p<.0001$). Similarly, PD participants demonstrated a trend where their minimum COM-BOS margin increased during the TrayWG condition ($F(2,22)= 2.64$; $p<.0938$). During the walk back aspect of the modified TUG task, PD participants demonstrated an increase in BOS during the TrayWG condition while wearing the facilitatory insoles ($p<.0222$) and a significant difference in the COM-BOS margin range where the COM-BOS margin range increased

during the TrayWG condition ($p<.0436$). Results demonstrated that the secondary motor task of carrying a tray with glasses resulted in even more pronounced gait deficits in PD participants during the turn, as well as an increase in the COM movement during the walk back which suggests that attention plays a key role in the control and maintenance of gait parameters. However, proprioception also contributes to gait as PD participants demonstrated an increase in their BOS during the TrayWG condition while wearing the facilitatory insoles. Participants might have been attempting to improve their stability because the facilitatory insoles were a novel stimulus. The modified TUG task and measures used in this study were successful in identifying the influence of the facilitatory insoles, which warrants further investigation using this task to determine the influence of long-term use of the facilitatory insoles on gait and stability impairments in PD.

Introduction

Individuals with PD commonly demonstrate gait deficits that include short, shuffling steps with increased step-to-step variability (Hausdorff, Cudkowicz, Firtion, Wei, & Goldberger, 1998; Morris et al., 1996; Rogers, 1996). Some studies have suggested that a key factor contributing to gait impairments are due to attention where gait and postural stability deficits have been found when individuals with PD are presented with a secondary cognitive (Hausdorff et al., 2003; Marchese et al., 2003) or motor (Bond & Morris, 2000) task. For example, individuals with PD demonstrated an even greater stride length and velocity deficit when attending to a tray with glasses while walking, which suggests that attention plays an important role in the production and maintenance of gait (Bond & Morris, 2000). An argument could be made that the tray with glasses blocked vision of the limbs and this is why gait deficits were even more pronounced during this condition. However, these same gait deficits were not found when participant's carried just a tray. This suggests that vision is not required to guide movement of the lower limbs. As such, impaired proprioception in individuals with PD may also be implicated as an underlying cause of stability and gait impairments. To illustrate this, previous research has argued that individuals with PD demonstrate hypometric movements, such as shorter compensatory steps, due to abnormal proprioceptive-motor integration (Jacobs & Horak, 2006; Khudados et al., 1999). Similarly, Almeida et al. (2005) found that when relying primarily on proprioceptive feedback, PD participants demonstrated an increase in their step-to-step variability and amount of time spent in double limb support. Although these studies hint to the involvement of proprioception in gait deficits, the extent to which it is involved is still unclear. The present study will address both proprioceptive and attentional factors in order to investigate the possible proprioceptive deficits as an underlying cause of stability and gait impairments in PD.

Almeida et al. (2005) suggested that deficits including increased gait variability and time spent in double support may be a compensatory adaptation that allows individuals with PD to augment the amount of sensory feedback being provided as they walk. If this is true, then perhaps by improving proprioceptive sampling, postural and gait deficits might be improved in individuals with PD. Cutaneous stimulation, as a way to improve sensory feedback, has been investigated in some studies involving compensatory stepping where a vibrational pulse was delivered to the hand or earlobe. Both studies demonstrated improvements in gait initiation parameters (Burleigh-Jacobs, Horak, Nutt, & Obeso, 1997; Dibble et al., 2004). These results support further investigation into other forms of cutaenous stimulation to improve stability and gait. For instance, plantar cutaneous receptors have been found to contribute important information in healthy adults during compensatory stepping (Perry et al., 2000) and gait (Eils et al., 2004; Perry, Santos, & Patla, 2001). As such, increased stimulation of the plantar cutaneous receptors should be investigated in PD. Indeed, Novak et al. (2006) investigated the effect of plantar stimulation on gait by way of a pressure-sensitive vibratory insole that induced vibrations when feet were in contact with the ground. They found that velocity, stride length and stride-to-stride variability improved when the vibration insoles were worn. This study demonstrated that with increased plantar stimulation, PD participants were able to overcome the proprioceptive deficits to improve their gait. However, this study only evaluated the vibratory insoles during straight-line walking, not during other aspects of gait that have been found to be difficult for individuals with PD. Similarly, this study only used stride variability as the indicator for improved stability. This leaves a need to investigate the effect of plantar stimulation on other aspects of gait such as turning and to use more specific measures to evaluate stability.

The cutaneous stimulation to be explored in the current study will be provided by a patented facilitatory insole that provides mechanical stimulation to the edges of the feet, or perimeter of the base of support (BOS) (Figure 1) (Maki, Perry & McIlroy, 2001). When a person is leaning, and therefore their COM is nearing their BOS, the raised ridge provides additional feedback as to where the edge of the BOS is located. These facilitatory insoles have been found to reduce the amount of stepping needed to recover from a forward step perturbation as well as to reduce the degree to which the centre of pressure (COP) approached the posterior BOS limit for healthy older adults (Maki, Perry, Norrie, & McIlroy, 1999). As well, the long-term use of the insoles was evaluated to determine whether improvements would be maintained after a twelve week period. The results verified that the facilitatory insole increased the lateral stability margin while walking over uneven terrain in healthy, older adults. Thus, the insoles stabilized the participants while their balance was being perturbed and they did not habituate to these insoles after twelve weeks of wear (Perry, Radtke, McIlroy, Fernie, & Maki, 2008).

The facilitatory insoles have been found to be effective in walking environments that challenge balance such as walking over uneven terrain. It is important test the participants balance in a functionally challenging task that requires individuals to perform tasks encountered in everyday life. The Timed Up and Go (TUG) test is a clinical tool that allows for assessment of mobility and balance, commonly used to assess older individuals (Hall, Williams, Senior, Goldswain, & Criddle, 2000; Podsiadlo & Richardson, 1991)). The TUG test has been used widely in special populations such as PD (Brusse, Zimdars, Zalewski, & Steffen, 2005; Matinolli et al., 2009; Sage & Almeida, 2009; Stack, Jupp, & Ashburn, 2004) and has been found to highly correlate with the Unified Parkinson's Disease Rating Scale (UPDRS) (Martinez-Martin, Fontan, Frades Payo, & Petidier, 2000). The TUG test was chosen for the current study as it incorporates some difficult aspects of movement for individuals with PD, such as gait initiation (Hass, Waddell, Fleming, Juncos, & Gregor, 2005; Martin et al., 2002; Rosin, Topka, & Dichgans, 1997; Vaugoyeau, Viallet, Mesure, & Massion, 2003), turning (Huxham, Baker, Morris, & Iansek, 2008a, 2008b; Mak, Patla, & Hui-Chan, 2008) and fast paced walking. It was expected that the modified TUG task will put both healthy and PD participants in a balance-challenging situation and that the facilitatory insoles will improve the stability of both populations. We also hypothesized that due to the increased plantar stimulation to improve proprioceptive feedback, improvements in gait parameters will be observed, especially in difficult aspects of gait such as turning and gait initiation. In addition to the TUG task, a secondary motor task of carrying a tray with glasses will be used. No previous research, that we are aware of, has used a secondary task to evaluate other possible causes of postural instability and gait impairments. Therefore, the secondary motor task of carrying a tray with glasses will be used in the current study to investigate attention as a possible cause for gait impairments. However, if the insoles result in any changes to gait then the changes observed may be more related to augmentation of the proprioceptive feedback provided by the facilitatory insoles and not due to the attention that the insoles might be drawing to the participant's gait. It was expected that the improvement in stability and gait parameters would be evident during the tray with glasses condition, as to demonstrate that proprioception, perhaps in replacement or in addition to attention, is a cause for the gait impairments commonly observed in PD.

Therefore, the purpose of this study is to: 1) determine whether the modified TUG task is able to detect influences of facilitatory insoles on gait initiation, turning and straight-line walking in PD and healthy elderly participants; and 2) investigate the role of attention in stability and gait impairments.

Methodology

Participants

Fifteen (9 males and 6 female; mean age = 67.06 years; age range 48-84) individuals previously diagnosed with Parkinson's disease were recruited from a patient database at the Movement Disorders Research and Rehabilitation Centre at Wilfrid Laurier University, Canada. Fifteen (5 males and 10 females; mean age = 66.46 years; age range 56-78) healthy controls were recruited independently (Table 1). All participants gave informed consent and the study was approved by the ethics committee at Wilfrid Laurier University which is in accordance with the ethical standards put forth by the Tri Council Policy in Canada. All participants were able stand and walk independent of any assistive devices. All participants were free from any primary sensory disorders, neurological disease other than PD, joint replacement or disease and significant visual impairment. PD participants reported to the laboratory while ON their dopaminergic medication. Although there are differences between various dopaminergic medication, they generally begin to work immediately (within fifteen minutes) and peak dopamine levels are maintained for approximately two hours. Participants performed the required tasks in this study during this optimal dose period so they would be at their highest functioning level. PD participants were evaluated using the motor examination section of the Unified Parkinson's Disease Rating Scale to determine severity of their disease. All subjects underwent a sensory evaluation using monofilaments (Semmes-Weinstein, North Coast Medical Inc., Morgan Hill, CA, U.S.A.) to determine sensory thresholds of the plantar surface of the right and left feet at four locations including great toe, head of first metatarsal, head of fifth metatarsal and the centre of the heel. Participants were asked to close their eyes and indicate when they felt pressure applied to the plantar surfaces at the one of the four locations. The lowest gage of monofilament indicated by the participants was recorded.

Equipment

All participants completed the modified TUG task on a data-collecting, pressure-sensitive carpet (GAITRite®, CIR Systems, Inc., Clifton, NJ, USA). This device collects data by capturing the geometry and relative arrangement of each footfall as a function of time and relays temporal and spatial parameters such as velocity, step length, double limb support, stride length and base of support (BOS).

Whole body kinematics, to measure the stability margin, were tracked using a wireless optoelectronic recording system (OptoTrak; Northern Digital Inc., Waterloo, Ontario, Canada) at a sampling frequency of 60 Hz. Participants were set up with a twenty one infrared light emitting diodes (IREDs) placed on the following landmarks: 5th metatarsal of right and left feet (which indicated the edge of the BOS for each foot), left and right anterior talofibular joint, left and right patella, left and right anterior superior iliac spine, zyphoid process, left and right acromion, left and right lateral epicondyle of the humerus and left and right styloid process of the ulna. Three markers were also located on the forehead, stabilized by the inside structure of a hard hat to prevent movement of the markers. Two markers were also placed on the posterior side of the left and right acromion, as well as one marker placed on T12. These markers were to be used in place the left and right acromion markers placed anteriorly and the zyphoid process marker, respectively, as signals from these markers went missing due to the set up of cameras and nature of the task to be performed. The markers located on the legs, trunk and head provided data for the cente of mass (COM) to be calculated and analyzed.

The set up of the modified TUG equipment consisted of a standard chair (Allseating Ltd., Model # 3307) with arm rests placed at the beginning of the twelve foot GAITRite® mat, facing the direction of the mat. Three metres away from the chair, along the runway of the mat was a counter that provided the turn-around point for participants, as well as a place for the tray to rest. The tray was placed behind a curtain structure that allowed the tray to be hidden from participants, yet could be pulled through the curtain when the participants were completing the task (Figure 2). The purpose of the curtain was to hide the tray from the participants as to deter the participants from planning their turn around and walk back movements as they approached the counter. This was in order to compare the approach to the counter with the walk back aspect of the test to ascertain the effect of the tray and tray with glasses conditions. A table was also located beside the chair where the participants started and ended the trial, to allow the participants to place the tray on the table before they sat down to complete the trial.

The dual task paradigm used a tray carrying task while walking. The tray was plain, flat and plastic. It measured 36 x 25.5 cm and weighed 0.27 kg. On the tray were three crosses, placed in a triangular formation to mark the positioning of the glasses. The two crosses at the top were 12 cm from the edge of the tray and the third cross was 18 cm from the edge of the tray (Figure 3). The glasses used were identical, clear, empty, plastic wine glasses and weighed 0.09 kg. The glasses were 205 mm in height, with a base of 80 mm.

Procedure

PD participants were evaluated using the UPDRS testing to determine severity of their disease. Sensory threshold testing was then completed using the Semmes-Weinstein monofilaments on four locations of the plantar surface including the great toe, base of the first metatarsal, base of the fifth metatarsal and centre of the heel.

Each participant was then fitted with walking shoes (Rockport World Tour Classic Model) with either a blank or patented ribbed shoe insole (Maki, Perry & McIlroy, 2001). The order was completed in a randomised fashion, so that half of the participants completed the blank insole condition initially, followed by the facilitatory insole condition.

Participants performed the modified TUG task with blank and facilitatory insoles with three randomized conditions: 1) normal TUG task (No Tray); 2) TUG task while carrying an empty tray (Tray); 3) TUG task while carrying a tray with empty glasses on it (TrayWG). Participants were instructed to sit in the chair located at the beginning of the GaitRite® mat. Participants were instructed to rise from the chair, walk to the three metre mark, and look behind the curtain to see whether a tray or tray with glasses was sitting behind the curtain. If there was no tray, the participants were instructed to turn 180 degrees, walk back to the chair and sit down. If a tray or tray with glasses was present, the participants were instructed to pick up the tray by the lateral edges and slid the tray through the curtain. Once the tray was free from the curtain, the participants were to turn 180 degrees to their left, walk back to the chair, place the tray on the table and sit down in the chair. The participants were instructed to complete the modified TUG task as quickly as they could, but when the glasses were present, participants were to complete the task as fast as they could without tipping the glasses over. This was to ensure that the individuals were attending to the tray with glasses task. Each participant performed five trials of each condition with both blank and facilitatory insoles, for a total of thirty trials. Trials were discarded from analysis if the individual dropped all three glasses at any point during the trial for the TrayWG condition. If individuals dropped one or two glasses, the trials were kept in the analysis because the secondary task would still be effective if at least one glass was present.

Analysis

Data was retrieved from the GAITRite® mat and trials were divided into approach toward the counter, turn around and walk back. Gait initiation data were retrieved by taking the footfalls from stand up from the chair to the first step after the individual stood up. Measures used for gait initiation included: sit-to-walk time which was the time to from the onset of GAITRite sensor activation to the heel strike of the first step (also identified as the first sensor activated by heel contact); length of the first step taken after stand up from the chair. Footfalls from after stand up to the last footfall in front of the counter were considered the approach phase. Footfalls that were included in the turn occurred after the individual had stopped at the counter and started their 180 degree turn. The turn ended when the first footfall that was in the direction of the chair began. Measures used for the turn included time-to-turn and number of steps to turn. Footfalls that were included in the walk back phase of the task included the first footfall in the direction of the chair after the turn until the footfall that preceded the turn around to sit in the chair. The measures used for the approach and the walk back phases included velocity, step length, stride length, double support time, and base of support.

Using data from the OptoTrak system, three COM-BOS measurements were measured (Figure 4). The COM was calculated using a segmental model with data from the head, trunk and leg markers. The edge of the BOS was calculated using the markers located on the 5th metatarsal on each foot. The minimum stability margin is the smallest distance that the COM approached the edge of the lateral BOS during a footfall. If there is a significant increase in this variable, it could indicate greater stability because the COM is better controlled to ensure that it does not approach the edge of the BOS. The maximum stability margin is the greatest distance the COM withdrew from the edge of the BOS during a footfall. If this significantly increases, the individual's COM is farther away from the edge of the BOS could indicate greater stability. However, it could also indicate less stability if the COM deviates too far from the edge of the lateral BOS, it is closer to the edge of the BOS for the other foot. The COM-BOS range is the difference between the minimum COM-BOS margin and the maximum COM-BOS margin. This variable gives an idea of the COM excursions throughout a footfall. If an increase in the COM-BOS range is observed, it could indicate less control of the COM, which is allowing for greater COM excursions during the footfall. Thus, it is helpful to consider the maximum COM-BOS margin in concert with the COM-BOS range. Due to the nature of the task, the data for some participants was incomplete so some trials were discarded (see Appendix A for percentage of missing trials for each condition and other analysis results). Since the number of trials differed from participant to participant for each condition, three of the five trials were analyzed for each participant. The highest and lowest trials were discarded to allow for the three trials with median values for the variables to be analyzed for each condition. Also, some participants had to be dropped from analysis all together due to insufficient data.

Statistical analysis tests were performed using Statistica. Independent t-tests were performed to determine any differences among the PD and Control group for age, height, and UPDRS score. The dependent measures were compared across conditions (with-in subject) and between groups (PD and control) using a repeated measures ANOVA. A Tukey HSD post-hoc test was performed for analysis of all significant findings.

Results

Sensory Threshold

Analysis of sensory threshold data revealed a main effect of group where PD demonstrated a significantly higher sensory threshold than healthy controls for all locations on both feet ($F(1,28) = 7.46$; $p < .0108$) (Figure 2).

Gait Initiation

PD participants demonstrated a decreased step length of the first step taken after standing up from the chair compared to controls ($F(1, 17) = 9.53$; $p < .0067$) (Figure 3). PD participants also demonstrated a significantly increased sit-to-walk time compared to healthy controls ($F(1,16) = 7.40$; $p < .0151$).

Approach to Counter

PD participants demonstrated a decreased step length ($F(1, 15) = 5.64$; $p < .0314$) and velocity ($F(1,16) = 5.15$; $p < .0374$) compared to healthy controls in the approach to the counter. There were no significant differences between any of the tray conditions or the insole conditions for either of the groups.

Turn

PD participants exhibited an increased number of steps to turn ($F(1,19) = 17.38$; $p < .0005$) and time-to-turn ($F(1,16) = 13.89$; $p < .0018$) compared to healthy controls. These main effects were superceded by a significant two-way interaction of condition and group for the number of steps to turn measure ($F(2,38) = 3.47$; $p < .0411$). Post hoc analysis revealed that PD participants took more steps to turn during the TrayWG condition compared to the No Tray ($p<.0001$) and healthy controls in all conditions, and was even more evident in the TrayWG condition ($p<.0001$). This two way interaction was also mirrored in the time-to-turn variable ($F(2,38) = 7.87$; $p<.0014$). Post hoc analysis revealed that PD participants took more time-to-turn during the TrayWG condition compared to the No Tray and Tray conditions ($p<.0001$) and compared to healthy controls in all conditions but especially in the TrayWG condition ($p<.0001$) (Figure 4).

Stability Margin during Turn

Although not significant, PD participants demonstrated a trend where their minimum COM-BOS margin increased during the TrayWG condition ($F(2,22)= 2.64$; $p<.0938$) (Figure 5),however no significant difference or trend was found between the blank insole and facilitatory insole conditions.

Walk Back from Counter

PD participants demonstrated a decreased step length ($F(1,12) = 9.74$; $p<.0088$) and velocity ($F(1,11) = 25.14$; $p<.0004$) compared to healthy controls yet no interaction effects between insole or tray conditions were found. Similarly, no main effects or interaction effects for variables such as double support time or stride length. No main effect was found for the BOS variable, however a three-way interaction between group, tray and insole conditions was demonstrated where PD participants demonstrated an increase in BOS during the TrayWG condition while wearing the facilitatory insoles

(F(2,32) = 4.30; p<.0222) (Figure 6). Post hoc analysis revealed that PD participants demonstrated an increase in BOS during the TrayWG condition while wearing the facilitatory insoles compared to the Tray (p<.0336) and No Tray (p<.0379) and compared to the healthy controls during the TrayWG conditions while wearing the facilitatory insoles (p<.0001).

Stability Margin during Walk Back

PD participants also demonstrated a trend where their maximum COM-BOS increased during the TrayWG condition (F(2,10)=3.43: p<.0732) and a significant difference in the COM-BOS margin range where the COM-BOS margin range increased during the TrayWG condition (F(2,10)=4.35; p<.0436) (Figure 7).

Discussion

This purpose of this study was to determine whether augmenting sensory feedback by way of a facilitatory insole could influence stability and gait parameters in individuals with PD. This study also sought to develop a functionally relevant task that could measure changes in gait to allow for an evaluation of the influence of facilitatory insoles on stability and gait parameters. A secondary task was also used to determine the contribution of attention to gait and stability impairments in individuals with PD.

Does mechanical facilitation improve gait parameters?

A main objective of the current study was to address whether mechanical facilitation, by way of the facilitatory insoles, could improve various gait parameters deficits observed in the PD population. Indeed, an effect of the facilitatory insoles was found during the walk back phase of the modified TUG task. PD participants demonstrated an increased BOS during the TrayWG condition while wearing the facilitatory insoles, whereas healthy controls did not change their BOS regardless of condition and insole type. This increased BOS may have been an attempt to improve stability in response to the facilitatory insole. However, this reaction is not what was expected as improvements due to the insoles were hypothesized. Previous research that demonstrated improved gait parameters used a vibration stimulus to improve sensory feedback. This study found improvements in step length, velocity and step variability (Burleigh-Jacobs et al., 1997; Dibble et al., 2004; Novak & Novak, 2006). These improvements were expected in the present study as well, however this did not occur. Perhaps the facilitatory insoles used in the present study do not provide similar amount of stimulation that vibration does, and thus, do not provide enough stimulation in order to improve the sensory feedback and influence gait parameters. Similarly, since the facilitatory insoles provide mechanical pressure that stimulates the Merkel discs and Ruffini endings, whereas vibration stimulates the Meissner's corpuscles and Pacinian (Germann, 2005). Thus, the facilitatory insoles may also not provide the same type of stimulation as a vibrational stimulus does, which could account for the difference in results. It is also possible that different ascending pathways are used to send information to the central nervous system. For example, the vibratory insoles use the dorsal column-medial lamniscal pathway to send information to the somatosensory cortex whereas the facilitatory insoles might send information via the spinothalamic tract. In addition to this, PD participants in the current study demonstrated an increased sensory threshold compared to the healthy control participants so they required an even greater stimulus to overcome the sensory receptor deficit, and then to also provide enough sensory feedback to improve gait parameters. The facilitatory insoles appear to provide enough sensory feedback to influence various parameters such as BOS but not enough to actually improve these parameters.

It is also possible that the facilitatory insoles acted as another distracter, in addition to the tray with glasses condition. Since the facilitatory insoles are a novel stimulation, it appears that the insoles influenced the PD participants react in such a way that actually led to their gait becoming more unstable. It is possible that more time spent with the facilitatory insoles is needed to allow individuals with PD time to adjust to the increased sensory stimulation provided by the facilitatory insoles. Since improvements in lateral stability due to these facilitatory insoles were found after twelve weeks of wear in healthy elderly participants (Perry et al., 2008), it is important to investigate whether long-term use of mechanical facilitation can improve stability and gait parameters when PD.

Does the modified TUG task challenge gait?

The Timed-Up and Go (TUG) task was chosen in the present study as it is a well used and documented test of mobility, but also because it incorporates difficult aspects of gait for elderly individuals such as initiation, turning and fast walking. The modified TUG task was able to draw out the gait deficits normally observed in individuals with PD, as the PD participants demonstrated a decreased step length and velocity in the approach and walk back aspects of the modified TUG task. These deficits were even more pronounced in the gait initiation phase of the modified TUG task as PD participants demonstrated a decreased first step length of 20 cm during gait initation. This result is even greater than the 10 cm and 16 cm difference in step length found in previous research that evaluated initiation of gait in the PD population (Halliday, 1998; Buckley, 2008). PD participants also demonstrated an increased number of steps to turn, as well as an increased time-to-turn compared to their healthy counterparts. These results are in agreement with previous research that has demonstrated gait impairments in walking (Morris, 1994; Rogers, 1996), gait initiation (Vaugoyeau, 2003; Rosin, 1997; Martin, 2002; Haliday, 1998; Buckley, 2008) and turning (Bloem, 2001; Mak, 2008; Huxham, 2008). Since the modified TUG task was able to draw out gait deficits in PD participants, this allows for a situation where the insoles are able to influence stability and gait parameters. Thus, it appears that the modified TUG task is a good measure to evaluate the potential influence of the facilitatory insoles in individuals with PD.

How does the secondary attention task influence gait?

The modified TUG task with the incorporated secondary motor task of carrying a tray with glasses was successful in drawing out further gait deficits found in individuals with PD, where they demonstrated an increased time-to-turn and number of steps to turn during the TrayWG condition. A possible explanation to account for these changes may be due to PD participants not having vision of their legs during the TrayWG condition as it has been found that vision is consistently used by this population to overcome their proprioceptive deficit (Jacobs & Horak, 2006). If the PD participants demonstrated further gait deficits in the current study due to loss of vision of their legs, then we would have expected to observe these gait deficits during the Tray condition, since vision was occluded in this condition as well. However, this did not occur, thus vision of limbs does not appear to play an important role during gait. To account for the gait deficits observed during the TrayWG condition, the role of attention must be addressed. In previous research, it has been found that when individuals with PD were required to carry a tray with glasses, their stride length and velocity severely decreased because they were attending to the glasses to ensure they remain upright. The authors suggested this might occur due to limited attentional resource capacity in that individuals with PD are unable to attend to both motor tasks equally, thus performance on one task suffers (Bond & Morris, 2000). It has also been suggested that when walking and presented with a secondary task, either motor or cognitive, individuals with PD tend to prioritize the secondary task over their walking, and their walking deficits become even greater (Bloem, Grimbergen, van Dijk, & Munneke, 2006). This current study agrees and extends the previous research as PD participants demonstrated an increased time-to-turn and number of steps to turn during the TrayWG condition, where the healthy control participants did not demonstrate any changes due to the TrayWG task. Since the PD participants were attending to the glasses, they slowed down their turn and took more steps to complete their turn, which in effect made their turn more stable as evidenced by an increase in their minimum lateral stability margin. From these results, it is clear that the individuals with PD have difficulty maintaining normal turn dynamics when a secondary motor task requires attention in addition to their walking. It should be kept in mind that holding a tray could place additional constraints (such as lack of arm swing) on normal walking mechanics. However, this is unlikely since there were differences between the tray and tray with glasses conditions such as a decrease in step length and velocity.

In addition to the influence of the secondary task on turning, the effect carrying a tray with glasses appeared to manifest itself in the walk back phase of the modified TUG task. When carrying the tray with glasses, PD participants demonstrated an increase in the COM-BOS range. It is possible that these results indicate an improvement in the stability of the PD participants as older adults tend to limit the displacement and velocity of their COM when put in situations that pose a postural threat, such as being on a high platform. This research proposed that the central nervous system applies a tighter control on posture in fearful situations to ensure that a greater margin of stability, and thus safety, is maintained to ensure that the COM does not fall outside of its BOS (Adkin, Frank, Carpenter, & Peysar, 2000, 2002; Brown, 1997; Carpenter, Frank, Adkin, Paton, & Allum, 2004). From this research, it would be expected that participants would exhibit a greater control over their COM during the TrayWG condition, which would be evidenced by an increase in the minimum COM-BOS stability margin. However, the opposite trend was observed which may indicate that PD participants did not consider the TrayWG condition a threat to their stability and actually allowed their COM greater freedom during that condition. Yet, it is unlikely that the PD participants became more confident in their stability and did not require greater control over their COM during the TrayWG condition compared to the condition that only required them to perform the normal modified TUG task that did not include a secondary motor task. It is more likely that these results indicate that their walking became less stable when carrying the tray with glasses. It appears that the PD participants prioritized the secondary task of carrying the tray with glasses and their stability of their walking and turning parameters were compromised.

However, PD participants also demonstrated an increased BOS while wearing the facilitatory insoles, which indicates that attention is not the only contributing factor to the gait impairments observed. This effect was found specifically during the TrayWG condition..It appears as though when PD participants wore the facilitatory insoles, and received increased plantar stimulation, the BOS was influenced even when participants were attending to the TrayWG. This suggests that augmentation of proprioception was also capable of influencing gait parameters even when attention might have been expected to solely influence gait parameters. Thus, the role of attention may not be as imperative as had previously been thought and proprioception is an underlying cause of gait and stability impairments.

There are some limitations to this study that should be addressed. Due to the length of the carpet and the nature of the task, we were unable to collect enough footfalls to adequately calculate gait variability measures. Since gait variability can be used to indicate stability, this would have been beneficial data to have in order to corroborate the lateral stability measure. As well, due to equipment restraints, kinematic data was not ideal and some participants either had to be dropped from analysis altogether, or for specific parts of analysis. Thus, it is possible that more participant data could have possibly led to significant findings for the maximum and minimum stability margin data.

Unfortunately, this study was unable to replicate previous findings of the effect of a secondary motor task for gait parameters such as step length. Previous research found a decrease in stride length and velocity when PD participants completed a normal walking task while carrying a tray with glasses (Bond & Morris, 2000). These same results were expected for the current study yet this did not occur as PD participants did not shown any further gait deficits, when carrying the TrayWG on the walk back. It is possible that we were unable to replicate previous findings due to a difference in walkway length. The walk back length in the current study was only three metres, whereas in the previous research that found effects of the TrayWG condition during straight-line walking had a walkway length of fifteen metres. Therefore, the distance covered in the present study may not have been long enough to capture the effect of the TrayWG condition.

Another limitation in the present study reflects that no significant differences were found in the control group for any variables or conditions in modified TUG task when the facilitatory insoles were worn. Thus, we were not able to replicate Perry's (2008) findings for the population using the modified TUG task. The task may not have been challenging enough for the healthy control participants, even though the task requires difficult aspects of gait. The difference in ages used in the studies may account for this as the healthy participants in the current study ranged from 56-78 years of age, whereas in Perry's study, the age range was much smaller, from 65-75 years of age. Since the current study had a large range of ages, especially in the younger ages, the majority of healthy control participants may not have found the task challenging enough, thus their stability was not perturbed allowing for the facilitatory insoles to influence their gait. It is also possible that a difference in sensory thresholds exists between the healthy control participants in the current study and those in previous study (Perry et al., 2008). A difference in sensory thresholds would determine whether the insoles could be felt and thus, be influential to stability measures.

Although this task was not challenging enough for the healthy control participants, they are able to be challenged in a task such as uneven terrain. Since this is the case, it is important to note that potentially greater results could be found for the PD participants if they completed a task that was even more challenging than the modified TUG task. Nevertheless, the modified TUG task was able to challenge the PD participant's stability and gait during the turn and walk back phases of the task. Changes in gait due to the facilitatory insoles were also observed which suggests that the modified TUG task is a useful measure to assess potential changes in stability and gait measures in individuals with PD.

This study has extended previous research that suggests that attention does play an important role in the execution and maintenance of gait. However, PD participants also demonstrated changes in BOS measure due to the facilitatory insoles. Therefore, enhanced sensory feedback to the plantar surface was also able to influence gait parameters which suggests that proprioceptive impairments are an underlying cause of the stability and gait impairments observed in PD. It is important to continue to investigate the influence of augmenting sensory feedback by way of the facilitatory insole, such as long-term use, as a possible method to improve the mobility of individuals with PD.

Table 1. Participant characteristics including age, gender, height and UPDRS score. Tabled values represent means with SDs in parentheses.

	Healthy Controls	PD
Sample Size	15	15
Gender	5 males; 10 females	9 males; 6 females
Age	66.46 (5.98)	67.06 (11.27)
Height	168.15 (8.81)	168.83 (8.42)
UPDRS Motor Score	Not Applicable	28.27 (6.73)

UPDRS, Unified Parkinson's Disease Rating Scale

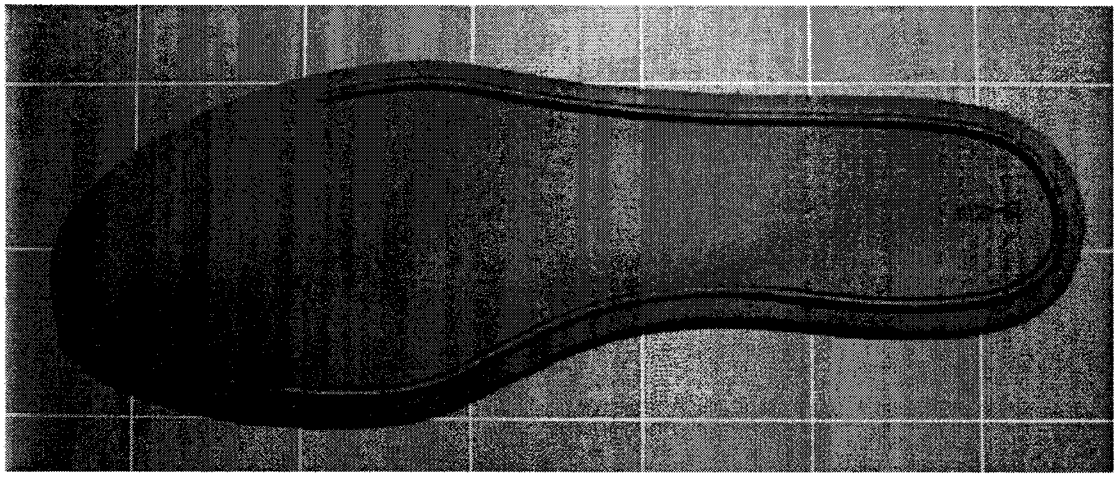

Figure 1. The facilitatory insole to be evaluated in current study.

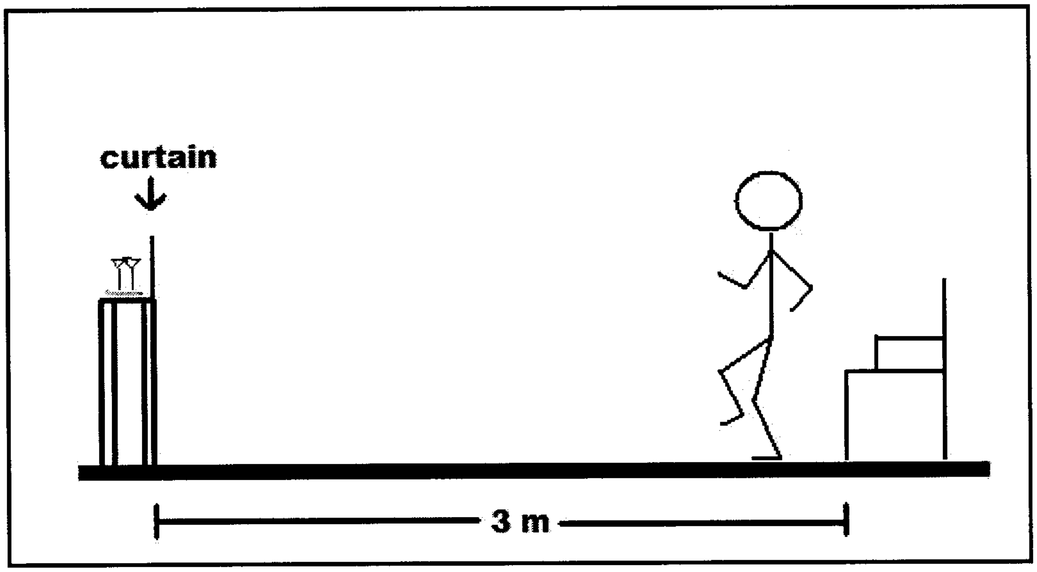

Figure 2. Experimental set up.

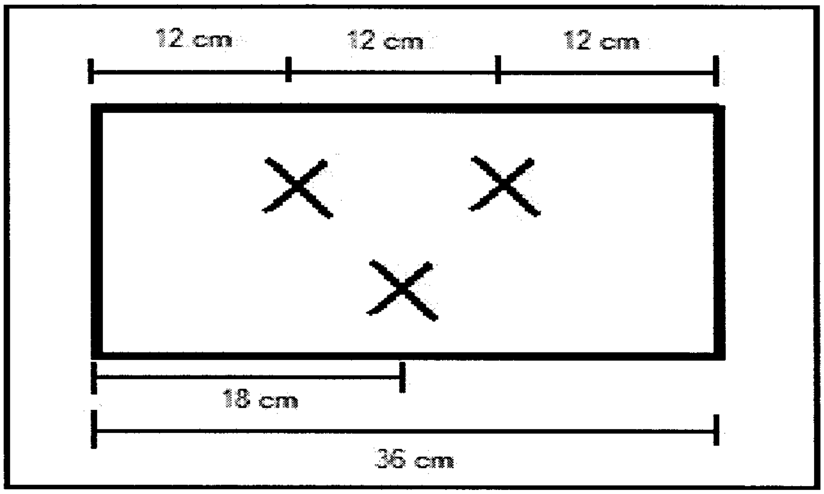

Figure 3. Dimensions of the tray used. X's indicate placement of the glasses.

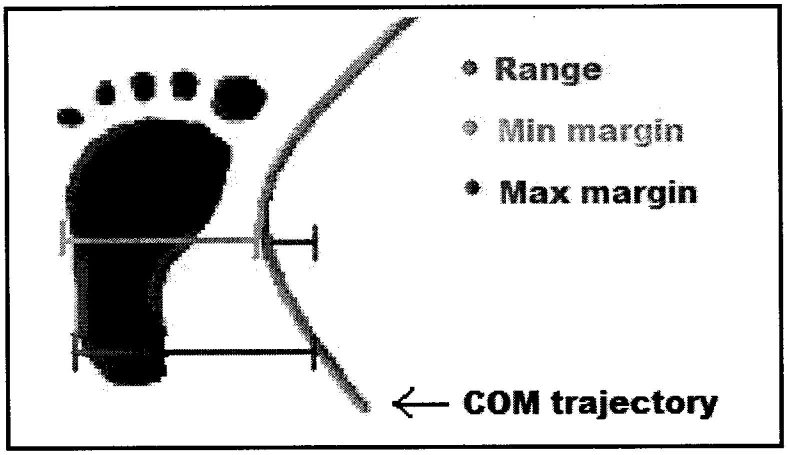

Figure 4. Stability margin measures.

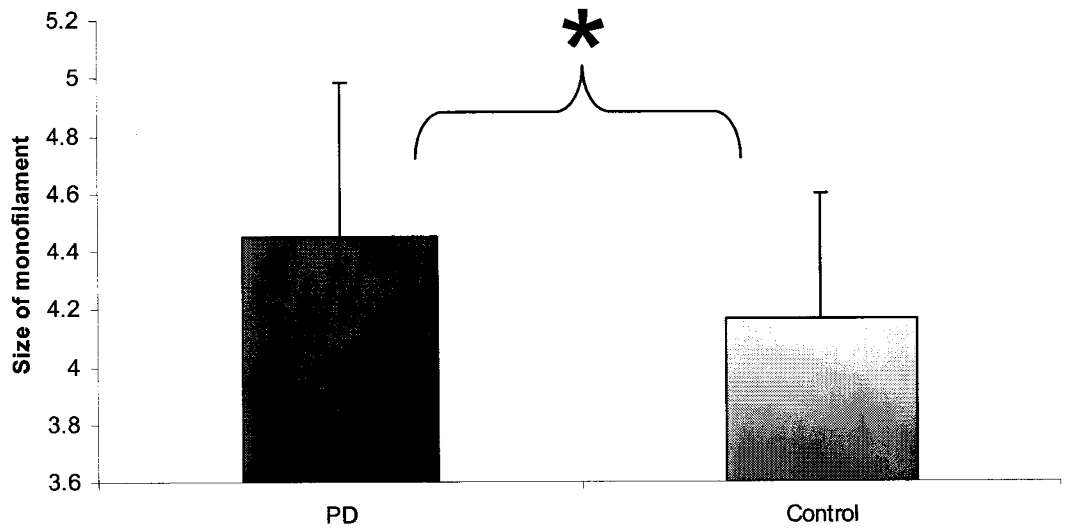

Figure 5. PD demonstrated a significantly higher sensory threshold than healthy controls for all locations on both feet (F(1,28) =7.46; p<.0108).

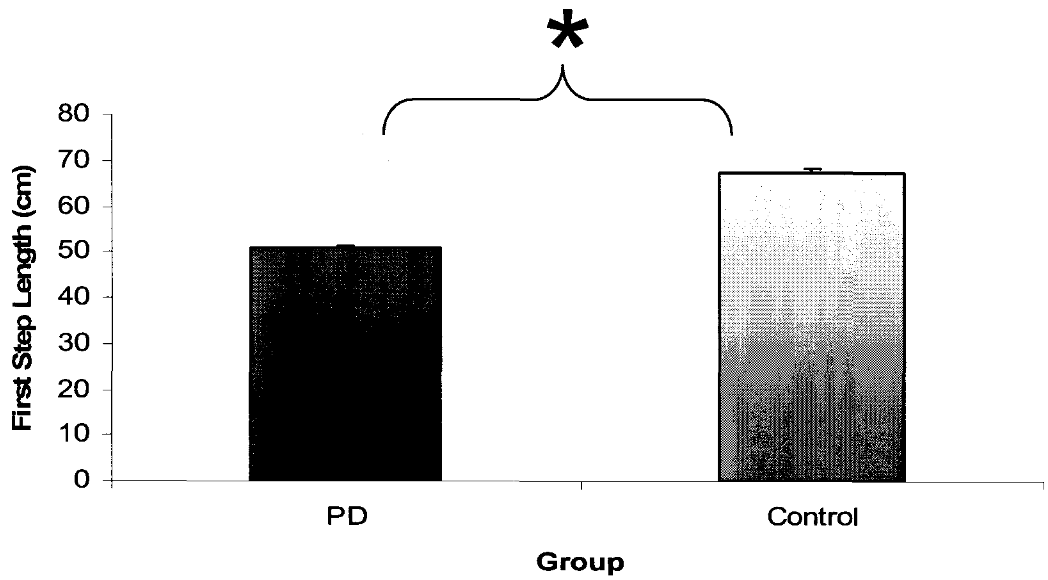

Figure 6. PD participants demonstrated a decreased step length of the first step taken after standing up from the chair compared to controls ($F(1, 17) = 9.53$; $p<.0067$).

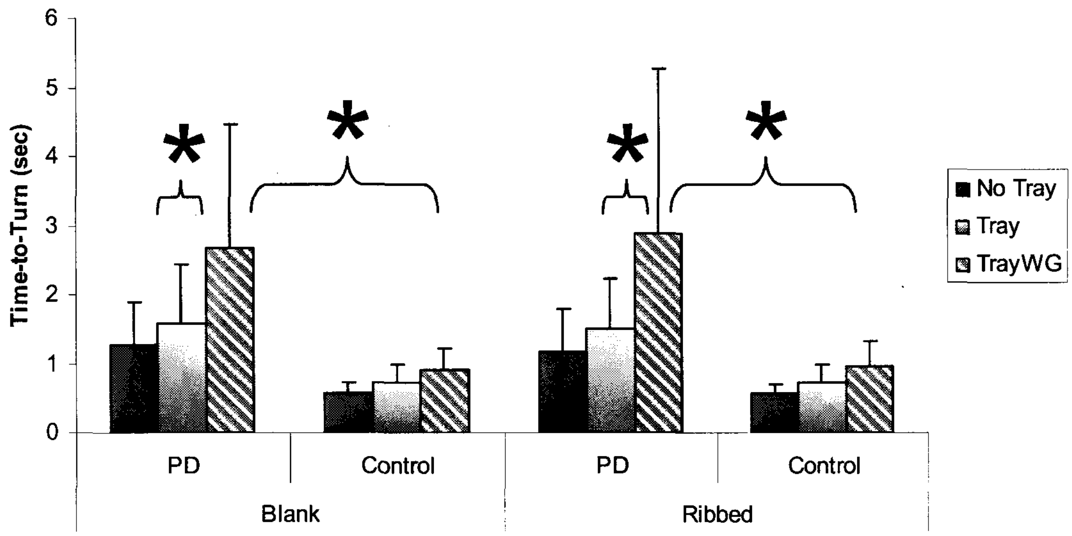

Figure 7. A significant interaction effect was found (F(2,38) = 7.87; p<.0014) where PD participants took more time-to-turn during the TrayWG condition compared to the No Tray and Tray conditions (p<.0001) and compared to healthy controls in all conditions but especially in the TrayWG condition (p<.0001).

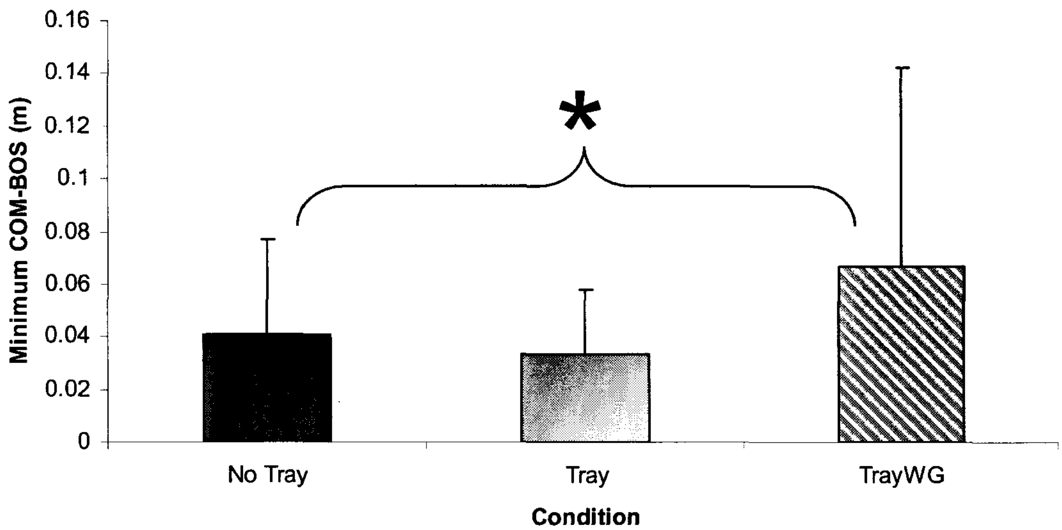

Figure 8. PD participants demonstrated a non-significant trend where their minimum COM-BOS margin increased during the TrayWG condition ($F(2,22)= 2.64$; $p<.0938$).

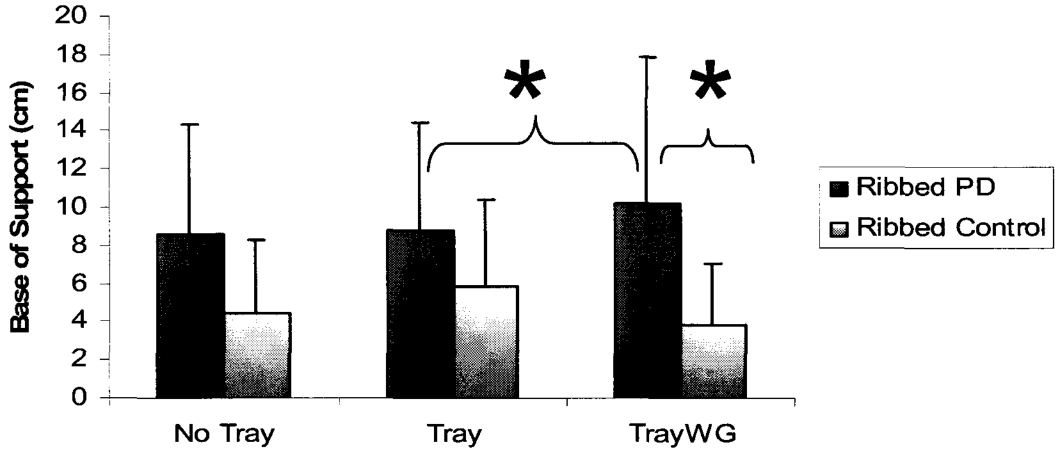

Figure 9. A significant interaction was found (F(2,32) = 4.30; p<.0222) where PD participants demonstrated an increase in BOS during the TrayWG condition while wearing the facilitatory insoles compared to the Tray (p<.0336) and No Tray (p<.0379) conditions (p<.0336) and compared to the healthy controls during the TrayWG conditions while wearing the facilitatory insoles (p<.0001).

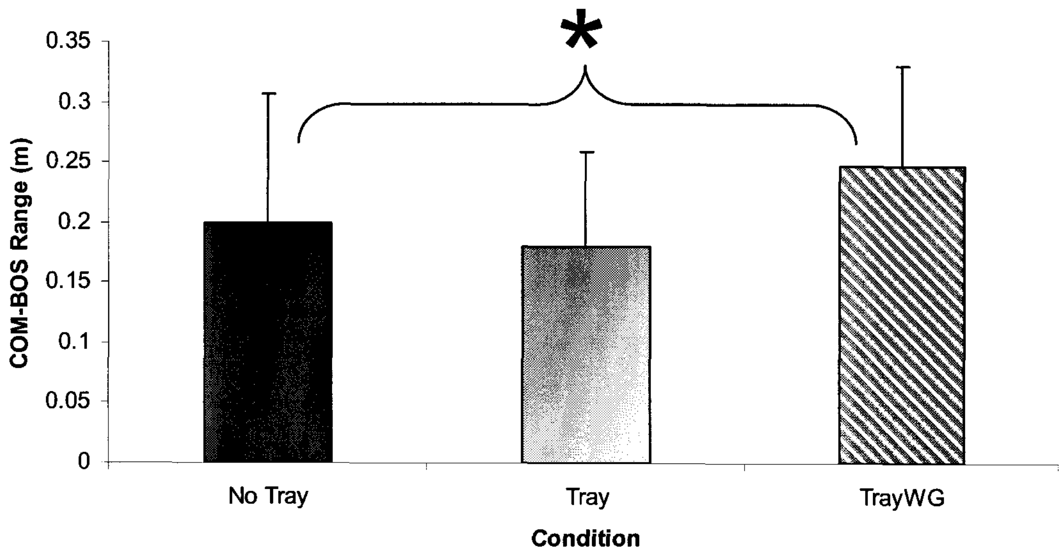

Figure 10. PD participants a significant increase in the COM-BOS range during the TrayWG condition (F(2,10)=4.35; p<.0436).

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CHAPTER 3

EVALUATION OF THE LONG TERM USE OF ENHANCED SENSORY FEEDBACK ON GAIT IN PARKINSON'S DISEASE

Abstract

Previous research has demonstrated that augmenting proprioceptive feedback via cutaneous stimulation can influence gait parameters. The purpose of this study was to determine whether enhancing proprioceptive feedback through the use of a facilitatory insole can improve stability and gait impairments in PD. This was achieved by introducing the facilitatory insoles into a rehabilitation program that focuses on improving individual's awareness of sensory feedback. It is possible that the facilitatory insoles may be an inexpensive and simple intervention to counteract gait deficits in the PD population. Eighteen PD participants were divided into two groups, one of which wore facilitatory insoles for six weeks during the PD SAFEx rehabilitation program, while the other wore blank insoles. Both pre and post assessment testing periods required participants to complete a modified Timed-Up and Go (TUG) task which required them to rise from a chair, walk to a marked spot three metres away, turn around and walk back. Individuals completed this task under three conditions: 1) no tray; 2) empty tray; 3) tray with glasses. The task was completed with and without the facilitatory insoles. Each of these conditions was randomized and a total of thirty trials were completed. Main measures included step length, velocity, base of support, time-to-turn, double support time and lateral stability margin which were collected a pressure sensitive carpet and motion capture system. The Facilitatory Insole group significantly increased their

stability margin range while turning during the post-assessment compared to their pre-assessment period as well as compared to the Blank Insole group ($p<.0024$). Facilitatory Insole group significantly decreased their base of support during walk back aspect during the post-assessment period compared to the Blank Insole group ($p<.0376$). Similarly, the Facilitatory Insole group significantly decreased their double support time while wearing the facilitatory insoles during the post-assessment compared to their pre-assessment period ($p<.0262$). The facilitatory insoles, when worn for six weeks, appear to improve turning as PD participants do not require tighter control over their centre of mass which suggests increased confidence in their ability to complete a turn. Straight-line walking also showed improvements in base of support and double support time variables as a result of long-term use of the facilitatory insoles. Enhanced cutaneous stimulation provides a possible intervention to improve stability and gait impairments in PD.

Introduction

Individuals with Parkinson's disease often suffer from postural instability and deficits during gait. Various interventions including gait training have been evaluated for their effectiveness to counteract these impairments. For example, Pohl et al. (2003) investigated treadmill training on gait parameters and found improvements in stride length and velocity. These improvements are certainly important; however they required intensive training and resources. Furthermore, these types of interventions do not address the underlying causes for the gait impairments.

One possible source of the postural stability and gait deficits involves the proprioceptive system. A growing body of evidence has supported the existence of proprioceptive deficits (Jobst et al., 1997; Klockgether & Dichgans, 1994; Konczak et al., 2007; Moore, 1987; Zia et al., 2000), which follows logically as the basal ganglia have been found to "gate" sensory inputs and influence the control of movement (Schneider et al., 1987). Almeida and colleagues (2005) found that when individuals with PD are relying primarily on proprioceptive information to guide themselves toward a target, their step variability and time spent in double limb support increased significantly. The authors reasoned that these changes in gait parameters may occur because individuals with PD are trying to improve their sampling of proprioceptive information from their environment (Almeida et al., 2005). PD may adapt their gait to gain more sensory information from their surroundings because their proprioceptive system appears to be impaired. This adaptation may be necessary as postural instability and gait impairments are generally less responsive to dopaminergic medication than other symptoms (Almeida

& Hyson, 2008). Thus, it is important to investigate possible interventions that may augment the sensory feedback to counteract the proprioceptive impairment. If the proprioceptive impairment is improved, this may allow individuals with PD to better control parameters of gait and function in their daily lives.

Proprioceptors, such as muscle spindles, have been found to contribute to locomotion (Sorensen, Hollands, & Patla, 2002), while mechanoreceptors (specifically plantar cutaneous receptors) provide information that is crucial for the control of posture such as ankle torque, weight transfer and support surface characteristics (Meyer, Oddsson, & De Luca, 2004). Similarly, Perry and colleagues suggested that the plantar cutaneous receptors are able to sense the relationship between the centre of mass (COM) and the individuals base of support (BOS) during compensatory stepping (Perry et al., 2000). This information may also be important during gait to ensure that the COM does not go outside of the lateral edge of the BOS in order to avoid a fall. It is clear that these sensory receptors provide the cortex with information regarding body position during locomotion. To further express the relationship between proprioceptors and mechanoreceptors, Duysens and colleagues (2008) found that by applying vibrational stimulation to the plantar sole, muscle stretch reflexes were observed in the upper and lower leg (Duysens, Beerepoot, Veltink, Weerdesteyn, & Smits-Engelsman, 2008). These results emphasize the possibility of mechanically stimulating the plantar cutaneous receptors to improve sensory feedback. This increased stimulation may be able to overcome the proprioceptive deficit found in individuals with PD and counteract stability and gait impairments that predispose these individuals to falls.

Previous research has shown that augmenting sensory feedback of the plantar surface by way of vibratory insoles has improved gait parameters such as stride length, velocity and stride-to-stride variability during straight-line walking (Novak & Novak, 2006). Their study demonstrates that mechanical stimulation is a viable method to influence gait parameters in the PD population. Using this idea, we evaluated the use of facilitatory insoles, which have raised up ridges along the outer aspects of the foot, on lateral stability and gait deficits in individuals with PD. Participants performed a Timed-Up and Go (TUG) task while performing a secondary motor task of carrying a tray or a tray with glasses. The TUG task was chosen as it incorporates difficult aspects of gait such as initiation, turning and a fast walking pace and a secondary motor task was used to address the role of attention in gait deficits. PD participants demonstrated an increased base of support (BOS) when wearing the facilitatory insoles, which suggested that PD participants were attempting to improve stability. This might have occurred because the facilitatory insoles were a novel stimulation to which PD participants were not accustomed (van Oostveen, 2009). Therefore it is important to determine if the facilitatory insoles are able to improve stability and gait parameters when worn over a long term period. This is also necessary because long-term use of direct plantar stimulation to improve gait parameters in PD has never, to our knowledge, been investigated. Thus, the current study chose to integrate the facilitatory insoles into the second half of a twelve-week rehabilitation program.

The PD Sensory Attention Focussed Exercise (PD SAFEx) program has been found to be effective in improving PD symptoms and improved performance in the TUG task (Sage, 2009; Sage & Almeida, In Press). This program was chosen as the method to introduce the facilitatory insoles over a six-week period for several reasons. First, the main goal of the PD SAFEx program is to focus the participants attention on their sensory feedback (particularly proprioception) while exercising. This provides a situation where the augmented feedback being derived from the cutaneous receptors could be enhanced further as participants attend to their sensory feedback. Secondly, this program requires participants to be active while wearing the facilitatory insoles as well as providing a situation that challenges balance and co-ordination, which will allows the facilitatory insoles to be influential. Using the insoles during an exercise program also ensures that the two groups were evaluated based on a controlled access to the insoles as the only variable being manipulated.

This study sought to determine if long-term use of the facilitatory insoles is beneficial Specifically, we hoped to observe improvements in parameters such as step length, velocity, base of support and lateral stability margin that would allow individuals with PD a more efficient but stable gait. It is important to determine whether the facilitatory insoles are of benefit as they would be simple to implement because they are a non-invasive and inexpensive intervention that may counteract the postural and gait impairments found in individuals with PD.

Methodology

Participants

From January 2009 to April 2009, thirty individuals previously diagnosed with Parkinson's disease were recruited from the patient database at the Movement Disorders

Research and Rehabilitation Centre at Wilfrid Laurier University, Canada. These thirty participants participated in a twelve week PD SAFEx program at the Movement Disorders Research and Rehabilitation Centre at Wilfrid Laurier University, Waterloo, Canada. The main purpose of the PD SAFEx program is focus participants attention on sensory awareness while exercising. The exercise program includes thirty minutes of non-aerobic walking exercises and thirty minutes of sensory attention exercises that include stretching. All thirty participants were then invited to participate in the current study; however some were excluded based upon attendance rate and the use of an orthotic in everyday wear. Thus, eighteen participants were included in this study and completed the remaining half of the program that consisted of six weeks of exercises. Group assignments were assigned to group based on their Posture and Gait (PG) score, which includes last five items of the UPDRS motor score. This method has been used in previous research where these items are clinical indicators of posture and gait (Sage & Almeida, 2009). Each group was assigned a participant of an approximately equal PG score to ensure that the groups were evenly distributed. The Facilitatory Insole (FI) group included nine individuals (7 males and 2 females; mean age = 72.55; mean PG score = 4.833) and the Blank Insole (BI) group included nine individuals (4 males and 5 females; mean age = 66; mean PG score = 4.667) (Table 1).

Each participant underwent a pre-test to determine baseline values before the treatment was administered to the participants of the PD SAFEx program. This required participants with the ability to stand and walk independent from any assistive devices. All participants were free from any known sensory disorder, additional neurological disease (other than PD), and significant visual impairment. All participants reported to the laboratory ON dopaminergic medication which begins to work immediately and optimal doseage lasts for approximately two hours before wearing off occurs. Participants participated in this study during this optimal dose period so they could perform at their highest functioning level. All participants were evaluated using the motor examination section of the Unified Parkinson's Disease Rating Scale to determine severity of their disease progression. All subjects underwent a sensory evaluation using monofilaments (Semmes-Weinstein, North Coast Medical Inc., Morgan Hill, CA, U.S.A.) to determine sensory thresholds of the plantar surface of the right and left feet at four locations including great toe, head of first metatarsal, head of fifth metatarsal and the centre of the heel.

Equipment

All participants completed the pre-test and post-test assessments on a data-collecting, pressure-sensitive carpet (GAITRite®, CIR Systems, Inc., Clifton, NJ, USA). This device calculates temporal and spatial parameters such as velocity, step length, double limb support, stride length, base of support and step to step variability.

Whole body kinematics were tracked using a wireless optoelectronic recording system (OptoTrak; Northern Digital Inc., Waterloo, Ontario, Canada) at a sampling frequency of 60 Hz. Participants were set up with a twenty one infrared light emitting diodes (IREDs) placed on the following landmarks: 5th metatarsal of right and left feet (which provided the location for the edge of the BOS), left and right anterior talofibular joint, left and right patella, left and right anterior superior iliac spine, zyphoid process, left and right acromion, left and right lateral epicondyle of the humerus and left and right styloid process of the ulna. Three markers were also located on the forehead, stabilized by the inside structure of a hard hat to prevent movement of the markers. Two markers were also placed on the posterior side of the left and right acromion, as well as one marker placed on T12. These markers were to be used in place the left and right acromion markers placed anteriorly and the zyphoid process marker, respectively, as signals from these markers went missing due to the set up of cameras and nature of the task to be performed. The markers located on the head, trunk and legs of the participants provided the data to calculate the COM during the task.

The set up of the modified TUG equipment consisted of a standard chair with arm rests placed at the beginning of the twelve foot GAITRite® mat, facing the direction of the mat. Three metres away from the chair, along the runway of the mat was a cart that provided the turn-around point for participants, as well as a counter-like surface where the tray could rest. The tray was placed behind a curtain structure that allowed the tray to be hidden from participants, yet could be pulled through the curtain when the participants were completing the task. The purpose of the curtain was to hide the tray from the participants as to deter the participants from planning their movements as they approached the counter.

The dual task paradigm used a tray carrying task while walking. The tray was plain, flat and plastic. It measured 36 x 25.5 cm and weighed 0.27 kg. On the tray were three crosses, placed in a triangular formation to mark the positioning of the glasses. The two crosses at the top were 12 cm from the edge of the tray and the third cross was 18 cm from the edge of the tray. The glasses used were identical, clear, empty, plastic wine glasses and weighed 0.09 kg. The glasses were 205 mm in height, with a base of 80 mm.

Procedure

All participants underwent a pre-test assessment before completing the second half of twelve week PD SAFEx program. Participants, after completing six weeks of the PD SAFEx program, then underwent the post-test assessment. The pre-test and post-test assessments procedures did not differ from each other and were identical to previously used methodology (van Oostveen, 2009) except for two differences. The first difference is that the length of the approach and walk back was extended from 3 metres to 3.5 metres. The second change to the procedure was the removal of the chair after the participant had stood up to start each trial. This change required participants to walk off the end of the mat after the walk back phase of the task, instead of sitting back down in the chair. Both of these changes allow for calculation of the step-to-step variability measure during the approach and walk back which was not available in the first study due to insufficient footfalls.

After the pre-test assessment was completed, the facilitatory insoles were introduced into the PD SAFEx program for six weeks. Participants received either blank insoles (regular shoe insoles) or the facilitatory insoles to wear for six weeks during the PD SAFEx program. Each participant had an area reserved in the changeroom for their specific insoles as to ensure that knowledge of the insole differences were unknown to participants as well as to ensure that the insoles were not taken home and worn by the participants. Attendance was recorded for the six weeks to ensure that the participants were wearing the insoles for the allocated amount of time. Post-test assessments were carried out after six weeks where both groups of participants completed the modified modified TUG task with blank and facilitatory insoles.

Analysis

Data retrieved from the GAITRite® mat were divided into approach toward the counter, turn around and walk back. Gait initiation data were retrieved by taking the footfalls from stand up from the chair to the first step after the individual stood up. Measures used for gait initiation included: sit-to-stand time which measured the time required to go from a seated position to the heel strike of the first step as well as length of the first step taken after stand up from the chair. Footfalls from after stand up to the last footfall in front of the counter were considered the approach phase. Footfalls that were included in the turn occurred after the individual had stopped at the counter and started their 180 degree turn. The turn ended when the first footfall that was in the direction of the chair began. Measures used for the turn included time-to-turn and number of steps to turn. Footfalls that were included in the walk back phase of the task included the first footfall in the direction of the chair after the turn until the last footfall collected. The measures used for the approach and the walk back phases included velocity, step length, stride length, step-to-step variability, double support time, and base of support.

Using data from the OptoTrak system, three COM-BOS measurements were calculated. The COM was calculated using a segmental model with data from the head, trunk and leg markers. The edge of the BOS was calculated using the marker located on the 5^{th} metatarsal on each foot. The minimum stability margin is the smallest distance that the COM approached the edge of the BOS during a footfall. If there is a significant increase in this variable, it indicates greater stability as greater control is applied to the COM to ensure that it does not approach the edge of the BOS. The maximum stability margin is the greatest distance the COM withdrew from the edge of the BOS during a footfall. If this significantly increases, the individual's COM is farther away from the edge of the BOS could indicate greater stability. However, it could also indicate less stability if the COM deviated farther from the edge of the BOS than normal. This deviation would bring the COM closer to the edge of the BOS for the other foot. The COM-BOS range is the difference between the minimum COM-BOS margin and the maximum COM-BOS margin. This variable gives an idea of the COM excursions throughout a footfall. If an increase in the COM-BOS range is observed, it could indicate less control of the COM, which is allowing for greater COM excursions during the footfall. It is helpful to consider the maximum COM-BOS margin in concert with the COM-BOS range. Due to the nature of the task, the data for some participants was incomplete so some trials were discarded (see Appendix A for percentage of missing trials for each condition). Since the number of trials differed from participant to participant for each condition, three of the five trials were analyzed for each participant. The highest and lowest trials were discarded to allow for the three trials with median values for the variables to be analyzed for each condition. Also, some participants had to be dropped from analysis all together due to insufficient data.

Statistical analysis tests were performed using Statistica. Independent t-tests were performed to determine any differences among the RI and BI groups for age, height, UPDRS motor score and sensory threshold. The dependent measures were compared across test periods (pre and post assessments), across conditions (with-in subject) and between groups (RI group and BI group) using a repeated measures ANOVA. A Tukey HSD post-hoc test was performed for analysis of all significant findings.

Results

Participant Demographics

There was no significant difference between the FI and BI groups with regards to UPDRS motor score at the pre-assessment period or the post-assessment period. Groups also did not differ in regards to sensory threshold as there were no significant differences between pre and post assessments. Similarly, groups did not differ in height or attendance rate for the PD SAFEx program. Independent t-tests revealed that there was a significant difference between the age of FI group ($M = 72.56$, $SD = 3.24$) and BI group ($M=66$, $SD = 4.71$); $t(16) = 3.29$, $p=0.002$) where the FI group was significantly older than the BI group (Table 1).

Gait Initiation

There were no significant differences between pre and post assessments for either group for gait initiation parameters such as sit-to-walk time, first step length or kinematic measures. Similarly, there were no differences between the FI and BI groups for gait initiation parameters between pre or post assessment values.

Turn

A significant effect of condition was found where all participants, regardless of group, increased the time required to turn during the TrayWG condition during the pre-assessment ($F(2,12) = 44.64$; $p<.00005$) and post-assessment ($F(2, 16) = 12.42$; $p<.0006$)(Figure 1). This effect was also found in the number of steps required to turn during the pre-assessment ($F(2,14) = 16.39$; $p<.0002$) and post-assessment ($F(2,24) = 50.29$; $p<.00003$). However, there were no significant differences between the groups or between testing periods found for either time-to-turn or number of steps to turn variable.

Stability Margin during Turn

A significant difference was found between groups where the FI group significantly increased their COM-BOS range during the post assessment ($F(1,2) = 38.84$; $p<.0024$) (Figure 5). Post hoc analysis revealed a difference between groups where the FI group significantly increased their COM-BOS range post-assessment compared to their pre-assessment period ($p<.003$) as well as compared to the BI group pre assessment ($p<.001$) and post assessment ($p<.0003$) periods. A similar effect was found for maximum COM-BOS margin where the FI group significantly increased their maximum COM-BOS margin during the post assessment period ($F(1,2) = 12.79$; $p<.0183$). Post hoc analysis revealed a difference between groups where the FI group significantly increased their COM-BOS range post-assessment compared to their pre-assessment period ($p<.006$) as well as compared to the BI group pre assessment ($p<.001$) and post assessment ($p<.001$) periods.

Approach and Walk Back

There were no significant differences found for any variables between groups regarding the approach for the pre-assessment period. Although there were no difference between groups for the walk back phase of the modified TUG task during the pre-assessment period, there was an effect of condition found where all participants decreased their velocity ($F(2,18) = 15.13$; $p<.0001$) (Figure 2) and step length ($F(2,16) = 80.41$; $p<.0004$) and increased their double support time ($F(2,16) = 9.54$; $p<.0019$) during the TrayWG condition. The effect of the TrayWG condition was also found during the post-assessment period where all participants demonstrated a decreased velocity $F(2,18) = 9.92$; $p<.0012$) and step length ($F(2,18) = 14.60$; $p<.0002$).

A significant interaction was found between groups and testing periods for the BOS variable ($F(1,2) = 25.14$; $p<.0376$) (Figure 3) where the FI group significantly decreased their BOS during the post-assessment period compared to the BI group. Post hoc analysis revealed that the FI group significantly decreased their BOS during the post-assessment period compared to the BI group whether they were wearing the blank insoles ($p<.01$) or the facilitatory insoles ($p<.0088$).

A significant interaction was found between groups and testing periods for the double support time variable ($F(1,2) = 16.86$; $p<.0262$)(Figure 4). Post hoc analysis revealed a difference between groups where the FI group significantly increased the time spend in double support in the post-assessment while wearing the blank insoles compared to their pre-assessment period with blank insoles ($p<.035$) as well as compared to the BI group across both assessment periods and both insoles worn. The FI group also demonstrated a decrease in DS time during the post-assessment period while wearing the facilitatory insoles compared to the blank insole condition ($p<.012$) and showed a non-significant trend compared to the BI group ($p<.071$).

Discussion

Research on improving plantar stimulation, and perhaps influencing proprioceptive feedback, as a possible intervention has not received much attention, even though proprioceptive deficits have been implicated for the presentation of postural and gait impairments in individuals with PD. The purpose of this study was to determine if individuals with PD would benefit from long-term use of increased stimulation to the plantar surface. As such, the insoles were introduced into the PD SAFEx program, a program that challenges balance and coordination while focussing on proprioceptive feedback the participants are receiving from their own body.

In previous research, the PD SAFEx program used the TUG task as a functional task measure and found that the total time to complete the normal TUG task (without the tray carrying task) was improved in individuals that participated in the twelve-week program. In addition to this, participants of the PD SAFEx program also showed a trend of decreasing time spent in double limb support. The authors suggested that the program not only allows for improvements in symptoms severity, but also in movement control (Sage & Almeida, 2009). The results of the current study demonstrate that the facilitatory insoles, when used in conjunction with the PD SAFEx program, show additional benefits to certain aspects of gait such as turning and straight line walking. After wearing the facilitatory insoles for six weeks, the Facilitatory Insole group demonstrated a greater

COM-BOS range during the turn. At first glance, it would be expected that a decrease in range of COM excursion would be of greater benefit as it would demonstrate greater stability. However, in previous research, it has been found that when older adults and individuals with PD are in situations of postural threat, they respond by tightening the control on posture, to ensure that the COM does not approach the BOS (Adkin et al., 2000, 2002; L. F. Brown, JS., 1997; Carpenter et al., 2004). Since turning is a difficult task that would pose a postural threat to individuals with PD, it might be expected that participants would tighten the control over the excursions of the COM during the turn to ensure that it did not approach the edge of the BOS and allowing for maximum stability. However, this was not observed and the Facilitatory Insole group actually decreased control over their COM during the turn which allowed for more COM excursions. This may suggest that the Facilitatory Insole group has become more confident in their ability to complete a turn while remaining stable, and are no longer as concerned with applying greater control over their COM during a difficult aspect of gait. Thus it appears as though the facilitatory insoles have improved the PD participant's confidence in turning when they were worn for an extended period of time.

Along with the improvements during the turn, BOS and double limb support time improved from use of the facilitatory insoles during the walk back phase of the modified TUG task. The Facilitatory Insole group showed a marked decline in their BOS after wearing the facilitatory insoles for six weeks while participating in the PD SAFEx program. Since there was a change in the BOS measure, it could be expected that the stability margin would be influenced as well. Yet there was no significant difference in stability for the Facilitatory Insole group from pre to post assessment periods. This suggests that the location of the COM relative to the edge of the BOS did not change, even though the BOS for this group was reduced. Therefore, the stability of the participants did not suffer due to this change in their BOS. In addition, it appears as though the facilitatory insoles allowed the BOS variable to return to a near-normal value. The average BOS value while wearing the facilitatory insoles during the pre-assessment testing period for the Facilitatory Insole group was 11.43 cm. This value changed to 6.79cm in during post-assessment. This reduced value is comparable to healthy control participant data collected in a previous pilot study where the average BOS value for healthy control participants during normal walking was reported at 5.36cm (van Oostveen, 2009). Thus, the facilitatory insoles allowed for individuals with PD to return to a more normalized gait pattern in terms of their BOS, without negatively affecting their stability.

The facilitatory insoles also influenced the time spent in double limb support measure during the walk back aspect of the modified TUG task. During post-assessment, the Facilitatory Insole group increased their time spent in double limb support while completing the modified TUG task with the blank insoles. Almeida suggested that due to their proprioceptive deficit, individuals with PD increase their time spent in double limb support to improve their proprioceptive sampling (Almeida et al., 2005). If this is indeed the case, then it is possible that the Facilitatory Insole group may have been attempting to improve the sensory feedback they were receiving by increasing the time spent with both feet on the ground, when the facilitatory insoles are absent. When they completed the modified TUG task while wearing the facilitatory insoles they significantly decreased their double limb support time compared to when wearing the blank insoles. Similarly, although non-significant, they also demonstrated a trend toward decreased time spent in double limb support compared to the BI group. These results suggest that when the Facilitatory Insole group performed the modified TUG task with the facilitatory insoles in place, the insoles provided the necessary increase in stimulation to improve sensory feedback and they were able to spend less time in double limb support.

In addition to improving the proprioceptive sampling, the insoles may have a positive influence in the confidence of PD participants to perform the modified TUG task. Recent research has investigated the influence of postural threat on gait for older adults and individuals with PD and found that PD participants increased the amount of time they spent in double limb support when in a posturally threatening situation (L. A. Brown, Gage, Polych, Sleik, & Winder, 2002; Duarte Caetano, 2009). Thus, it is also possible that the Facilitatory Insole group spent less time in double limb support after six weeks of wearing the facilitatory insoles because they no longer found the modified TUG task a threat to their posture. Therefore, it appears as though when the facilitatory insoles are worn for a six week period, they improve the sampling of proprioceptive sampling the participants are receiving which allow for a more mechanically efficient gait as well as lessening the postural threat that a situation may place on an individual.

When reviewing these results, it is important to note that although the Facilitatory Insole group was found to be significantly older than the Blank Insole group, there was no difference in sensory threshold between the two groups. Thus, a difference in sensory receptor sensitivity due to age should not be considered when results of the study are being interpreted. It is also important to note that all subjects in this study participated in six weeks of the PD SAFEx program prior to the introduction of the facilitatory insoles.

Similarly, most of these participants have also participated in a previous 12-week session of the PD SAFEx program. The PD SAFEx intervention has resulted in improved motor symptoms assessed using the UPDRS, as well as improved timed performance on the TUG task (Sage & Almeida, 2009). These results may suggest that participants in the PD SAFEx program are able to complete the modified TUG and manage a secondary motor task better than individuals that have not participated in the exercise program. Thus, the results in the current study may be an underestimation of the possible benefits the facilitatory insoles could have on the general PD population.

Previous research conducted to improve stability in individuals with PD has focussed on balance training interventions and the measures used in these studies are quite varied. This makes comparison between previous work and the current study quite difficult. For example, after a ten week balance and strength training intervention, participants demonstrated a decrease in body sway during destabilizing test conditions such as eyes closed (Hirsch, Toole, Maitland, & Rider, 2003). Based on these results, the current study should have demonstrated a decrease in the COM-BOS range (which is a similar measure to body sway) when the facilitatory insoles were worn. Yet this was not found, and this may be due to a difference in the type of stability measured. The current study was interested in stability while an individual is walking, whereas the previous study measured participants in a static situation. These differences make it difficult to compare between these specific studies. However, another study used a dynamic gait index which rates performance on tasks that included turning, pivoting and various types of walking tasks (Cakit, Saracoglu, Genc, Erdem, & Inan, 2007). This measure may better mirror the dynamic stability the current study intended to quantify and indeed, improvements were found after eight weeks of gait and balance training. These improvements reflect the improved stability of participants during various gait tasks including turning. The current study also found improvements in turning and gait due to long-term use of the facilitatory insoles. Since improvements in dynamic stability where found in both studies, this may suggests that the facilitatory insoles are able to improve dynamic stability during gait in a similar manner to a balance and gait training intervention. Although the PD SAFEx program has been found to improve UPDRS and PG scores, no improvements have been found in gait parameters such as double limb support time or BOS (Sage & Almeida, 2009). During the current study, improvements in gait were observed when the facilitatory insoles were used in conjunction with the PD SAFEx program suggesting that the improvements found in BOS and time spent in double limb support are due to the facilitatory insoles.

Although the insoles seem to have a beneficial effect on turning and straight-line walking, this study does have limitations that need to be addressed. The number of participants was low due to poor attendance, sickness or inability to perform the modified TUG task. As well, the scheduling of participants for their pre and post assessment scheduling was not controlled for in terms of when participants were tested during their medication cycle. For example, although participants performed both the pre and post assessments while ON medication to be at optimal functioning, the time at which they performed during their drug cycle was not necessarily the same between assessment periods. Therefore, participants in either group may have been able to perform better depending on when they had taken their medication for each testing period. Group bias is another limitation that needs to be addressed. Although group assignments were completely confidential, the Blank Insole group may have realized they were not wearing the insoles being tested for effectiveness, which could have affected their performance in the post-assessment period.

Despite the limitations, this study provides evidence that mechanical facilitation to the plantar cutaneous surface, by way of a facilitatory insole, allowed for an improvement in gait. After wearing the facilitatory insoles for six weeks, individuals with PD appeared to be more confident when completing difficult aspects of gait such as turning and did not require tighter control over their COM because they may no longer perceive the task as threatening. This improvement in COM movement while turning may also have a significant implication for the common presentation of rigidity in individuals with PD. Rigidity has been found to negatively affect functional tasks such as reaching (Schenkman, Morey, & Kuchibhatla, 2000) and locomotion (Franzen et al., 2009). Although no study, to our knowledge, has investigated the affect of rigidity on COM movement, it is certainly possible to suggest that a relationship does exist. Therefore, the improvement in COM movement while wearing the facilitatory insoles may also have a beneficial effect on the symptom of rigidity, however this requires further investigation.

Long-term use of the facilitatory insoles also improved straight-line walking, which was evidenced by a decrease in the BOS, as well as a decrease in time spent with both limbs in contact with the ground. These improvements did not negatively affect the stability of the Facilitatory Insole group and suggests that they allowed for a mechanically efficient and normalized pattern of gait. Thus, the facilitatory insoles, by way of improving the proprioceptive feedback the individuals are receiving, are able to benefit individuals with PD when worn on a long-term basis. These results are remarkable as this intervention is an inexpensive, non-invasive and easy method to implement in the daily lives of individuals with PD. Future research should focus on determining whether the benefits received from the facilitatory insoles extend over a longer period of time and whether greater benefits may occur with additional time spent with the facilitatory insoles.

Table 1. Mean (± standard deviation) of participant characteristics of both RI and BI groups.

Group	Gender	Age	Pre-Test PG Score	Post-Test PG Score	Pre-Test UPDRS Motor Score	Post-Test UPDRS Motor Score	Percentage of classes attended (%)
Facilitatory insole	7 Male; 2 Female	72.56 (3.24)	4.83 (2.73)	4.5 (2.96)	27	26.55	91.5
Blank Insole	4 Male; 5 Female	66 (4.71)	4.67 (2.4)	4 (2.46)	25.44	23.5	90.2

UPDRS, Unified Parkinson's Disease Rating Scale

PG, Posture and Gait score

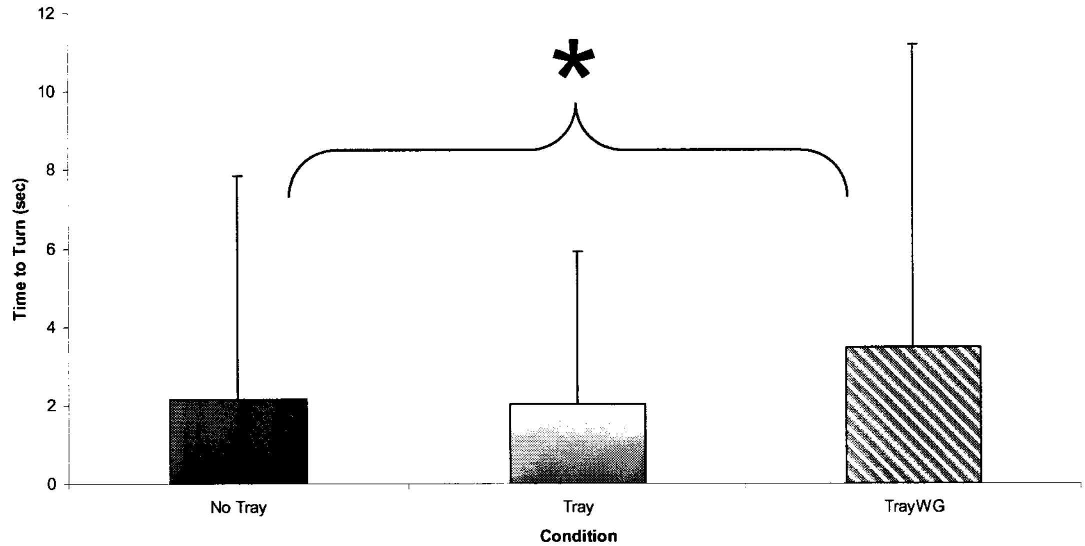

Figure 1. All participants increased the time-to-turn during the TrayWG condition during the pre-assessment ($F(2,12) = 44.64$; $p<.0000$).

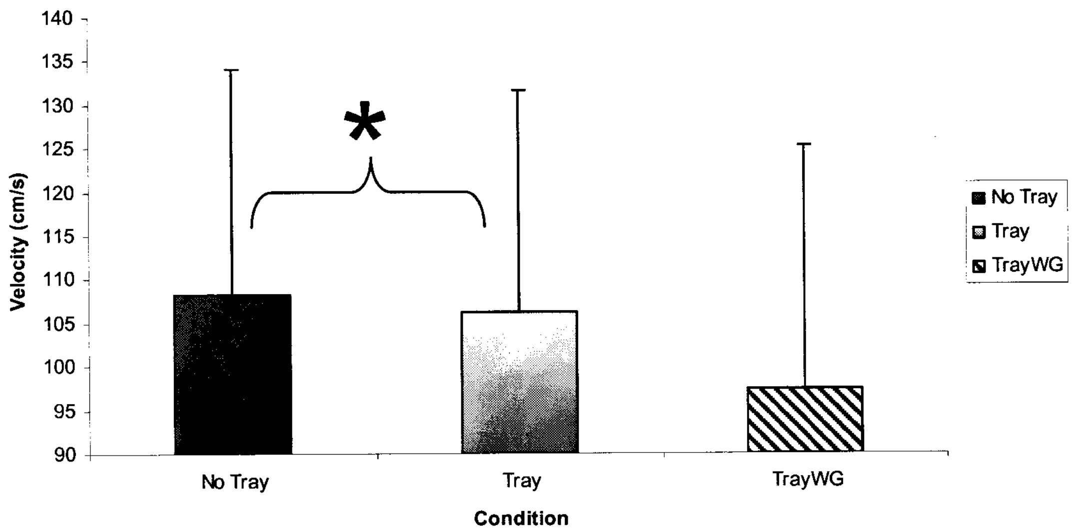

Figure 2. All participants decreased their velocity on the walk back during the TrayWG condition ($F(2,18) = 15.13$; $p<.0001$).

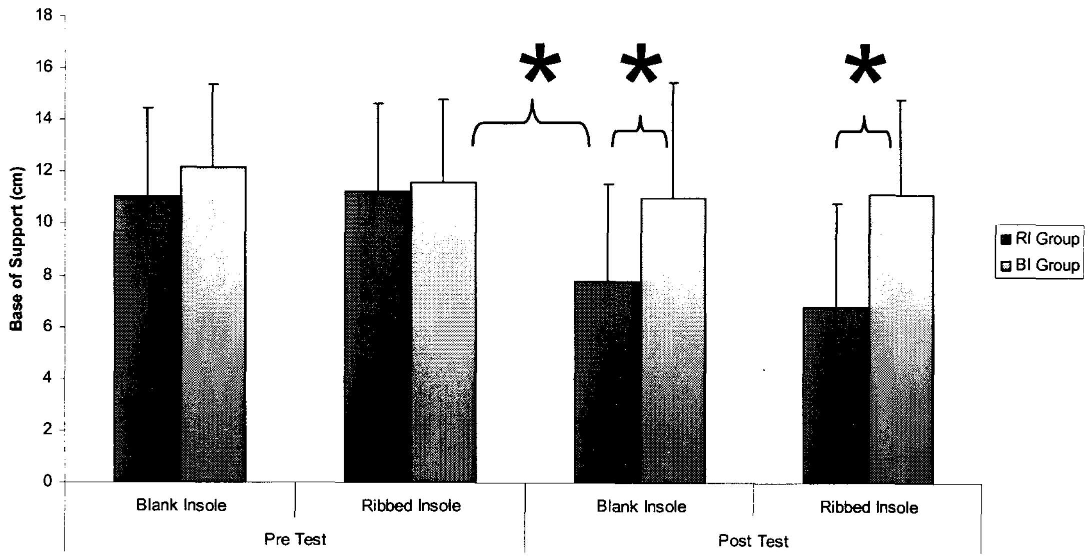

Figure 3. RI group significantly decreased their BOS during the post-assessment period compared to the BI group ($F(1,2) = 25.14$; $p<.0376$).

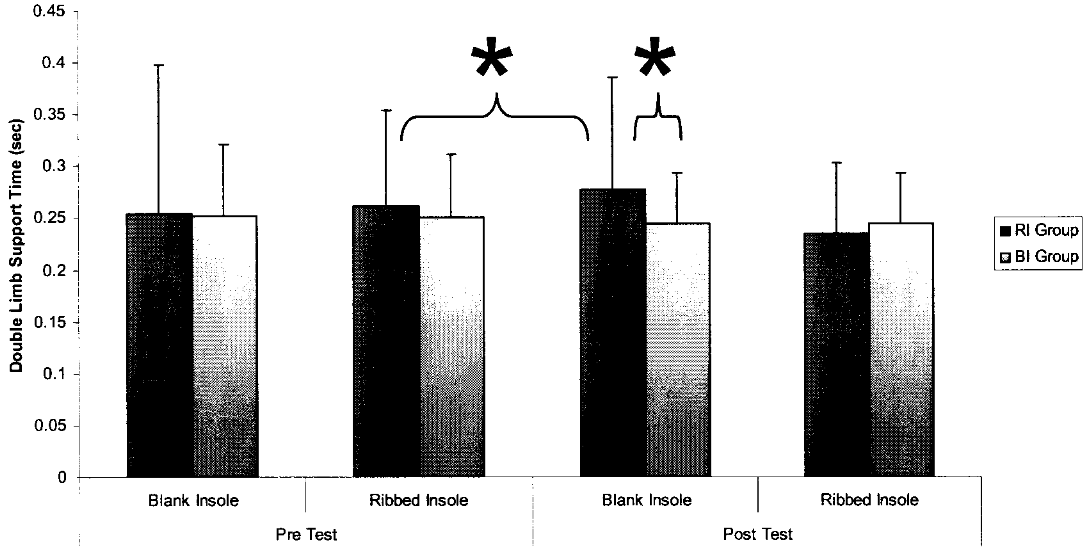

Figure 4. A significant interaction where the RI group significantly increased the time spend in double support in the post-assessment (F(1,2) = 16.86; p<.0262). RI group significantly increased the time spend in double support in the post-assessment while wearing the blank insoles compared to their pre-assessment period with blank insoles (p<.035) as well as compared to the BI group across both assessment periods and both insoles worn. The RI group also demonstrated a decrease in DS time during the post-assessment period while wearing the facilitatory insoles compared to the blank insole condition (p<.012) and showed a non-significant trend compared to the BI group (p<.071).

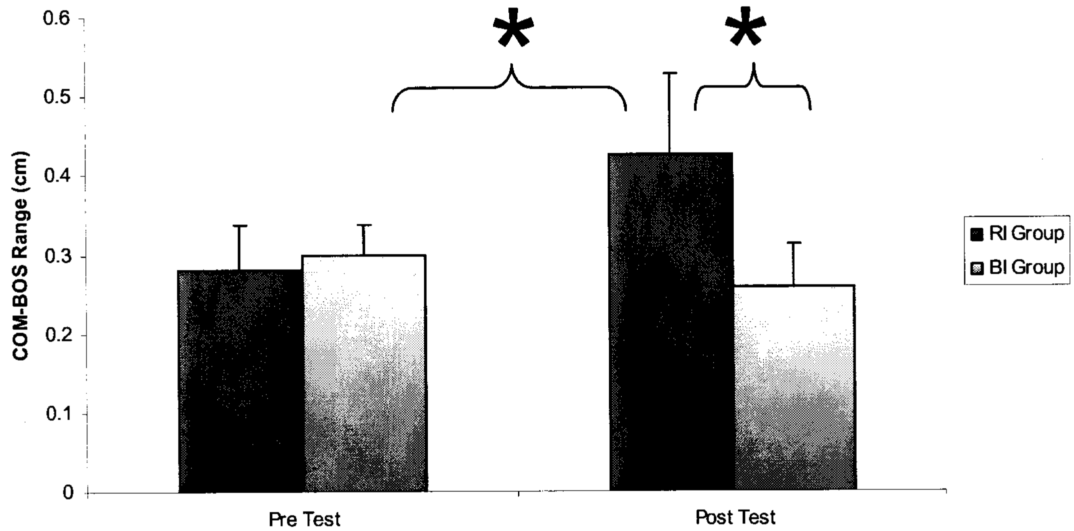

Figure 5. A significant difference was found between groups where the RI group significantly increased their COM-BOS range during the post assessment ($F(1,2) = 38.84$; $p<.0024$).

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CHAPTER 4

GENERAL DISCUSSION

Overall Objectives

Postural instability and gait impairments can be some of the most harmful symptoms experienced by individuals with PD as they can lead to falls (Bloem et al., 2001), and so it is important to investigate interventions that could improve these observed deficits. The overall objective of the current thesis was to investigate the influence of mechanical facilitation, by way of a facilitatory insole, on the stability and gait impairments of individuals with PD. An underlying theme of this thesis was to explore how possible deficits to proprioception might contribute difficulties in postural stability and gait present in this population.

This was accomplished in two parts where the first study addressed the initial exposure to the facilitatory insoles by comparing individuals with PD to a age-matched population. In addition to addressing the influence of the facilitatory insoles, the first study sought to determine a protocol and task that could measure changes in stability and gait in both the healthy and PD populations. The protocol that was evaluated was called the modified Timed Up and Go (TUG) task which was separated into the approach, turn and walk back aspects of the task. The first study also investigated the role of attention as it pertains to the gait deficits observed in PD. The second study addressed the influence of long-term use of mechanical facilitation by comparing two groups of individuals with PD, one of which worn the insoles during the PD SAFEx exercise rehabilitation program for six weeks. This study also sought to determine whether the facilitatory insoles would be beneficial as an intervention for individuals with PD.

The Timed Up and Go task: A balance challenging situation

In previous research, the facilitatory insoles used in the current thesis, were found to be effective when older adults were tested using inclined platforms to simulate uneven terrain, where their lateral stability margin improved when the facilitatory insoles were worn (Perry et al., 2008). In order to investigate the possible benefits these insoles may have for the PD population, the task they were required to perform needed to incorporate aspects of gait that are challenging. The Timed Up and Go task was chosen because it involves difficult aspects of gait such as initiation, turning and fast paced walking which are challenges that individuals face in their everyday life. It is also a well-documented tool that has been used to assess mobility in a clinical population such as PD (Morris, Morris, & Iansek, 2001; Sage & Almeida, 2009; Stack et al., 2004). By dividing the TUG task into four sections, the current study succeeded in evaluating four aspects of gait including gait initiation, approach to the target, turn and walk back. These divisions were necessary for this study because each aspect of gait had various and differing measures to assess possible improvements in gait. As well, it was possible that the facilitatory insoles may influence each aspect of the task differently, for instance, the insoles may only be beneficial in initiating gait and not in turns.

Although the task used in the current study was different from previous insole studies that evaluated the influence of the facilitatory insoles over uneven terrain (Perry et al., 2008), it was important to use a similar measure to evaluate whether the modified

TUG task was effective in allowing the facilitatory insoles to be influential. Thus, the lateral stability margin was a central measure used in the current study. In addition to the TUG task, a secondary motor task of carrying a tray or a tray with glasses was used to address the role of attention but also to add to the complexity, and difficulty of the task to ensure that it was challenging.

The modified TUG task was successful in challenging gait and stability of the PD participants. The task was able to draw out the hallmark gait deficits observed in individuals with PD during straight-line walking, which has been found in previous research (Morris et al., 1996). A decrease in step length and velocity were observed in the approach and walk back aspects on the modified TUG task in the first study as well as an increased number of steps to turn and time-to-turn. These deficits in PD participants were then exacerbated when the task was made more difficult with the addition of the tray with glasses condition. In addition to the gait deficits observed, changes in stability during various conditions were observed for the PD participants in both studies, which suggest that the modified TUG task was able to influence the stability of the PD participants. This allowed for the possibility of the facilitatory insoles to influence the stability and gait deficits. Indeed, the modified TUG task was also able to measure changes in gait parameters and stability when the facilitatory insoles were worn. For example, in the first study, an increased in the BOS was observed when facilitatory insoles were worn. Thus, the modified TUG task was able to challenge the stability and gait in the PD population and also evaluate the efficacy of the facilitatory insoles which lends credibility to the modified TUG task as a useful measure to assess potential changes in stability and gait in individuals with PD.

In contrast, it appears as though the modified TUG task may not have been an appropriate task to use to challenge the stability and gait for the healthy, older adults. It was expected that healthy older adult participants would demonstrate a decline in their stability with the added task of carrying a tray with glasses, compared to the conditions of carrying a tray or not carrying anything. Similarly, an improvement in stability was expected when the facilitatory insoles were worn, especially during the most difficult task of carrying a tray with glasses. However, no changes were observed in any of the conditions, and regardless of which insoles were worn for the control participants. This suggests that the modified TUG task may not have been enough to perturb the stability of the control participants, and thus, did not provide a situation where the facilitatory insoles could improve stability. This lack of results could be due to the greater age range of participants in the current study compared to previous research. It is also possible that the task used in the previous study directly perturbed the lateral stability in participants, whereas the modified TUG task used in the current thesis challenged the overall stability and gait of participants while they performed a functionally relevant task. In the healthy, older adult population, this may not have been enough to challenge the lateral stability specifically, and thus, no changes were observed.

Although the modified TUG task did not challenge the healthy older adults, it was successful in doing so for the PD participants. Since this thesis was interested in the influence of the facilitatory insoles in the PD population, the modified TUG task is still considered an appropriate measure to use to evaluate changes in gait and stability parameters in PD.

Attention or Proprioception: A Cause for Gait Impairments

Recent research has demonstrated that when individuals with PD are attending to their gait, they are able to improve gait parameters. For example, when individuals are given a visual cue such as a horizontal line on the ground, they are able to increase their stride length, velocity and double support time. Likewise, if they are instructed to focus on a mental image of walking with an increased stride length, these gait parameters also improve (Morris et al., 1996). Consequently, if given a secondary task to complete while walking, the gait deficits return and are even more pronounced (Hausdorff et al., 2003; Morris et al., 1996). From these studies, it is clear that attention can play a key role to benefit or negatively effect gait parameters in individuals with PD. However, possible deficits in proprioception have also been found to influence gait. The current study used a secondary task of carrying a tray with glasses to determine the extent to which attention and proprioception influence gait. It was thought that if improvements in gait and stability were observed due to the facilitatory insoles, then it could be argued that the improvements occurred because the facilitatory insoles drew the individual's attention to their walking. By introducing a secondary task for the participants to attend to, and if changes in gait are still observed, then they would be due solely to the influence of the facilitatory insole and not attention. In the first study, participants with PD showed an increased time-to-turn and number of steps to turn when carrying a tray with glasses compared to the healthy control participants in the first study. All participants in the second study also responded the same way to the TrayWG condition as they exhibited the same deficits when turning. Gait deficits due to the TrayWG were also evident in the walk back aspect of the modified TUG task where all participants demonstrated a decreased step length, velocity and increase in double limb support time during the pre-assessment testing. These results extend and confirm the previous notion that these more pronounced gait deficits occur when individuals are given an attention demanding task (Bond & Morris, 2000). However, it is also important to consider whether the tray acts solely as an attention demanding task or if the tray causes overall mechanical constraints on the participants while they were walking. Since arm swing normally counteracts the COM shift that occurs when a step is taken, COM might be disturbed without arm swing in conditions when a tray is present. It is also possible that the additional weight of the tray places extra motor demands that cannot be compensated for in individuals with PD. Thus, the tray carrying task may present an additional motor challenge that could account for the changes in gait observed in the PD participants. However, this is not likely because identical results would have been observed in both the tray and tray with glasses conditions. The fact that gait impairments were only observed in the TrayWG condition suggests that when glasses are added to the task, they place an additional demand on participants that is more likely attentional in nature.

Although it is clear that attention contributes to gait impairments in PD, proprioception also plays a role. In the first study, PD participants increased their BOS while wearing the facilitatory insoles during the TrayWG condition. Based on the hypothesis, since a change in gait was observed during the TrayWG condition when the facilitatory insoles were worn, these changes must be due to the facilitatory insoles influencing sensory feedback and not due to attention being drawn to the participants gait because of the facilitatory insoles. This suggests that proprioception does play a critical role in influencing gait parameters in PD.

Results from the second study also point to proprioception as a clear contributor to gait deficits. Even though participants still demonstrated gait deficits in step length and velocity due to the TrayWG condition, improvements were demonstrated across all of the tray conditions in the post-assessment period. Attention clearly plays a large role in some gait deficits, but by providing increased plantar stimulation to augment sensory feedback, the facilitatory insoles were able to improve other gait parameters. As a result, proprioception appears to be an underlying influence of gait parameters. This distinction is important because although attentional strategies are effective in counteracting gait impairments, they become useless when the individual is required to attend to something else. More importantly, using attentional strategies to improve gait parameters does not address the underlying cause of the deficits but instead bypasses the issue altogether. Thus, it is important to explore potential roots of the impairments, such as the proprioceptive deficits, so that interventions can be developed to counteract the debilitating side effects of stability and gait impairments.

Facilitatory insoles as an Intervention

The main purpose of this thesis was to investigate the influence of a facilitatory insole as a possible intervention to counteract the postural stability and gait impairments found in individuals with PD. Previous research has found not only an improvement in the compensatory stepping reactions of younger adults, but also improvements in the lateral stability involving healthy, older adult population when the facilitatory insole was used (Maki et al., 1999; Perry et al., 2008). Thus, it was hypothesized that by providing increased plantar stimulation by way of the facilitatory insoles, PD participants would be able to overcome the proprioceptive deficits that may be responsible for the stability and gait impairments commonly encountered in this population. Both studies required participants to complete the modified TUG task which was analyzed in sections including gait initiation, approach to the curtain, turn around and walk back from the curtain.

Gait Initiation

Analysis of gait initiation in this thesis included time required to move from a seated position to foot contact of the first step, the length of the first step taken after standing up from the chair as well as stability margin data. In the first study, PD participants demonstrated a marked decrease in step length and an increase in the time to rise from a seat position to taking the first step compared to control participants, which supports previous literature (Buckley, Pitsikoulis, & Hass, 2008; Hass et al., 2005; Martin et al., 2002; Rosin et al., 1997; Vaugoyeau et al., 2003). However, the insoles did not have an effect of gait initiation in either study. Previous studies that used cutaneous stimulation by way of vibration demonstrate improved step length and step time during gait initiation (Burleigh-Jacobs et al., 1997; Dibble et al., 2004). In these studies, it appears as though the cutaneous cue acted as a cue for participants to react to initiate gait. This type of cutaneous cue may have acted similarly to the reaction of a racehorse to an electric shock, to which the horse comes out of the gate much faster and with more force when electric shock is present. Participants in the previous studies may have reacted similarly to the cutaneous cue as it resulted in a greater production of force (Burleigh-Jacobs et al., 1997) and increased COP displacement and velocity (Dibble et al., 2004). However, the cutaneous stimulation in the present studies differs in that the facilitatory insoles were consistently worn throughout the testing period and therefore, did not act as a 'go' signal to cue the participants to initiate gait. It is also possible that the facilitatory insoles used in the current study stimulate a different ascending pathway to send sensory information to the central nervous system. Regardless of how the facilitatory insoles differ from other cutaneous stimulation, no improvements similar to previous studies were found. This suggests that PD participants may need a cue or a greater stimulus to improve gait initiation and the facilitatory insole is not able to supply this type of stimulation.

There was also no difference between the lateral stability of the PD participants and healthy controls in the first study with regards to gait initiation. The second study also showed no significant differences between either of the groups between pre and post assessments for any measures nor did either study show any difference when the facilitatory insoles were worn. This may be due to the possibility that when rising from a chair and initiating gait, lateral stability is not as important as anterior-posterior stability. A study by Inkster et al. found that when completing a sit-to-walk task, PD participants demonstrated an exaggerated displacement of COM forward during the preparation phase to stand up (Inkster & Eng, 2004). These results make sense; however, there was no mention of the lateral motion of the COM. Similarly, most studies that investigate gait initiation use a centre of pressure (COP) or a COP-COM separation measure and do not measure COM independently. This measure was not used in the current study because the stability margin data was more important as it allowed evaluation of the influence of the facilitatory insoles compared to previous studies that have used these insoles (Perry et al., 2008). Nonetheless, lateral COM movement does not seem to be an important measure in previous research of gait initiation, it is possible that no changes in lateral stability during gait initiation were observed because lateral motion of the COM is negligible when performing a sit-to-walk movement. Thus, the insoles could not improve the lateral stability in participants because it simply may not matter.

From these results, it appears as though mechanical facilitation by way of the facilitatory insoles is not enough to influence lateral stability measures because laterally stability may not play a role in gait initiation. The facilitatory insoles may also not provide the correct type of stimulation necessary to improve gait initiation parameters similar to previous research.

Approach

Common gait deficits in PD participants are observed during straight-line walking. These gait deficits include a decrease in stride length, gait speed and step-to-step variability compared to healthy counterparts (Hausdorff et al., 1998; Morris et al., 1996). The results of the first study also found these deficits in PD participants where a decrease step length and velocity were observed. Since these common deficits were found, it is clear that the PD participants in this study provide a good representation of the general PD population. However, no differences in gait or stability parameters were found during the approach when the facilitatory insoles were worn, in either study. This is not surprising as the approach only requires participants to walk forward towards the curtain, and most participants only took four or five steps to do so. This aspect of the task is similar to a pilot study we conducted with the facilitatory insoles that required only straight-line walking (Jenkins et al., 2009). In that study, no noteworthy changes in gait parameters were found either. Since the approach aspect is quite simple, it is possible that this part of the task was not challenging enough to the participant's stability, thus the facilitatory insoles did not have an opportunity to influence these measures. Therefore, the facilitatory insoles did not influence straight-line walking when their gait is not challenged by something such as secondary motor task.

Turn

In a prospective assessment of falls in PD, it was found that falls occurred most often when individuals were turning (Bloem et al., 2001). Turning provides an extremely difficult aspect of everyday life that can perturb an individual's stability and this provides a situation in which the facilitatory insoles may be of great benefit. Previous research investigating turns in the PD population found that they tend to increase time taken to complete a turn as well as the number of steps taken while turning (Crenna et al., 2007; Huxham et al., 2008). The current thesis is in agreement with these past studies as PD participants, in the first study, demonstrated an increased time-to-turn and number of steps to turn compared to their healthy counterparts. Thus, it appears as though PD participants recognize turning as a difficult aspect of gait, and tend to slow down, and be more cautious as they complete the turn. It is also possible that they may slow down their turns to increase the sensory feedback they are receiving, in order to guide their movement during the turn.

These gait deficits became even more pronounced when PD participants were presented with the TrayWG where an even greater increase in time-to-turn and number of steps to turn was observed. In the first study, this exaggerated time-to-turn and number of steps to turn in response also may have lead to an increase in the lateral stability of PD participants, regardless of which insole was worn. These results suggest that PD participants consider turning a postural threat and in order to remain stable, slow down and take more steps, which allows their COM to remain in the centre of their BOS. Since most individuals complete many turns throughout their day, it is likely that PD participants consistently slow down when completing their turns and this becomes a normal strategy when turning. It is possible that this strategy has become so innate that the turn is already at its most stable; therefore the facilitatory insoles have no room to influence the turning strategy or stability measures.

Conversely, PD participants may have changed their turning strategy when more time was spent wearing the facilitatory insoles as differences in turn measures were observed in the second study. Previous research has demonstrated that when older adults and individuals with PD are placed in situations of high postural threat, they limit the displacement and velocity of their COM (Adkin et al., 2000, 2002; Brown, 1997; Carpenter et al., 2004). The opposite response was observed in the turning of participants who wore the facilitatory insoles for six weeks. Although they still slowed down when turning with the TrayWG which suggests that attention has a large influence on gait parameters, they also demonstrated an overall increase the COM-BOS range and maximum COM-BOS margin. These results suggest that the Facilitatory Insole group no longer considers turning a postural threat and are able to allow their COM to move more freely when turning, which suggests that they have adjusted their turning strategy and become more confident in their ability to complete a turn. Therefore, it appears as though the facilitatory insoles have improved turning in PD participants who have worn them over a longer period of time.

Walk Back

Similar to the approach, the walk back aspect of the modified TUG task required participants to walk from the curtain back to the starting position. Thus, PD participants demonstrated the common gait deficits when compared to healthy, older adult population in the first study. However, the walk back phase of the modified TUG differed from the approach in that participants were required to carry a tray or a tray with glasses for some trials. This allowed the task to become more complex as to perturb the balance and gait in order to allow for the facilitatory insoles to be influential. In the first study, it appears as though the PD participants, when carrying the TrayWG, became unstable. Furthermore, when the facilitatory insoles are worn, PD participants widened their BOS. Maki found that, despite the expectation that a wider BOS is indicative of greater stability, an increased BOS is actually predictive of falls (Maki, 1997). Unfortunately, it appears as though the facilitatory insoles did not improve gait and stability parameters, but instead may act as a detriment when they are first encountered. This may be occurring because the facilitatory insoles are a novel stimulus, which caused the PD participants to respond in a negative fashion.

The tray with glasses condition influenced gait parameters in the second study, which suggests that attention still played a large role in gait. However, the Facilitatory Insole group showed an improvement in their BOS, where they demonstrated a narrower BOS across all conditions. Since there was no change in lateral stability, this demonstrates that the distance of the COM relative to the BOS did not change. Thus, the narrower BOS did not negatively influence the stability of the PD participants, which suggests that the narrower BOS is beneficial to the gait of individuals with PD. In addition, this improvement allowed the BOS variable to return to a value similar to that of healthy, older adults. The facilitatory insoles allowed for individuals with PD to return to a more normalized gait pattern, without negatively affecting their stability.

Another improvement in gait was also found as the Facilitatory Insole group decreased the amount of time spent in double limb when wearing the facilitatory insole. Since double limb support time has been found to be associated with falling in older adults (Maki, 1997), a decrease in double limb support time due to the facilitatory insoles is a significant benefit. This result follows the hypothesis put forth by Almeida et al. (2005) where individuals with PD appear to adapt their gait in order to improve the sensory feedback needed to guide movement. The insoles provided the improved sensory feedback needed by individuals with PD and no longer need to spend more time in double limb support. The changes in BOS and double limb support variables demonstrate that the facilitatory insoles allowed PD participants to return to a more normalized pattern of gait, which may reduce the risk of falling.

Although interventions such as gait and balance training have improved various gait and stability parameters, they require a great amount of time and resources in order to be effective. The facilitatory insoles may represent an easier method to counteract the debilitating gait impairments as they are inexpensive in terms of time and finances. More importantly, instead of bypassing the issue, they tackle an underlying cause of the impairments. This allows for greater knowledge of the disease in order to improve the lives of those affected by PD.

Where does the proprioceptive deficit lie?

Although attention can clearly influence gait in individuals with PD, proprioception also plays an important role. From previous research, it is apparent that individuals with PD demonstrate a proprioceptive deficit. However, it is uncertain as to where the deficit lies within the sensory system. Some studies suggest that the deficit is located in the sensory receptors, such as plantar mechanoreceptors (Pratorius et al., 2003) or lower leg proprioceptors (Dietz & Colombo, 1998). The current thesis also found an increase in the sensory threshold of the PD participants compared to the participants. Perhaps PD participants require some form of greater mechanical stimulation to be of benefit. However, if the deficit was solely in the sensory receptor themselves, the system would just require an increase in stimulus intensity to overcome this increased threshold. If an analogy can be used, the increased plantar stimulation provided by the facilitatory insoles would be like flipping a light switch. Every time the feet contact the ground, the facilitatory insoles provide increased stimulation that would augment the existing proprioceptive information to the central nervous system (including the basal ganglia and motor cortices) to be processed and improvements in gait would be observed automatically. From this, we would expect to see improve stability and gait parameters in the first study, however, this did not occur. Changes in both stability and gait parameters were observed in the first study; however, these changes were not improvements. This suggests that the increased stimulus was able to overcome the increased sensory threshold in the receptors and send sensory information to the central nervous system. Yet this "new" sensory information did not improve or fix the deficits. Therefore, it appears as though the deficit is not within the sensory receptors themselves but lies in the integration and processing of the proprioceptive information by the central nervous system.

The idea that the deficit lies within the central processing of the sensory information is also mirrored in the second study. Improvements were observed in some gait parameters but deficits in step length and velocity, still existed after long-term use of the facilitatory insole. These results are troubling as the plantar stimulation using vibrational insoles improved stride length, velocity and step to step variability in previous research (Novak & Novak, 2006). Since "flipping the light switch" did not lead to instantaneous improvements in gait and stability in the first study, perhaps improving sensory feedback is similar to a volume control instead. If the amount of stimulus is increased, such as using vibration, this may improve the ability of the central nervous system (including the basal ganglia) to integrate the sensory information to allow for better movement control and consequently, improve gait parameters. This idea may account for why some improvements were observed when the facilitatory insoles were worn for six weeks but were unable to improve specific gait parameters such as step length and velocity. Participants spent more time with the facilitatory insoles and some improvements were observed, so perhaps "turning up the volume" by increasing the time spent with the facilitatory insoles or introducing a greater stimulus, such as vibration. This may be necessary in order to improve the integration and processing of the sensory information within the central nervous system.

Another theory has been suggested that might account for the lack of improvement in gait parameters, such as stride length and velocity. Unlike the BOS variable that seems to be influenced by the proprioceptive system, previous research has suggested that gait variables such as stride length are preset and not necessarily regulated by proprioceptive inputs. Morris and colleagues (1996) postulated that the stride length deficits observed in individuals with PD are due to problems related to the interaction of the defective basal ganglia with the supplementary motor area (SMA). They suggested that the basal ganglia interact with the SMA for learned movements, such as walking. Since the basal ganglia are abnormal in PD, they appear to disturb the motor sequence and the performance of that motor sequence. From this, the authors reasoned that step length is preset by these cortical structures (Morris et al., 1996). This idea emerges in the current research as the increased plantar stimulation provided by the facilitatory insoles did not influence gait parameters such as step length or velocity. Thus, the facilitatory insoles were unable to influence the motor sequence that is preset by the basal ganglia and SMA and consequently, could not improve the stride length of PD participants.

However, it is also possible that the stimulation provided by the facilitatory insoles used in the current study differs from previous research that used vibrational devices (Burleigh-Jacobs et al., 1997; Dibble et al., 2004; Duysens et al., 2008; Novak & Novak, 2006). The raised ridges that placed mechanical pressure stimulates the Merkel discs and Ruffini endings, whereas vibration stimulates the Meissner's corpuscles and Pacinian corpuscles found superficially and deep in the skin, respectively (Germann, 2005). Thus, a possible reason that the insoles did not improve various aspects of gait, specifically gait initiation measures as well as stride length and velocity, could reflect the difference in which sensory receptors were stimulated by the insoles.

Regardless of why gait parameters such as step length did not improve, it is clear the mechanical stimulation by way of the facilitatory insole was able to overcome the increased sensory threshold in PD participants and influence stability and various gait parameters such as BOS and double support time. However, the stimulation provided by the facilitatory insoles was not enough to overcome all gait deficits, which strongly suggests that the proprioceptive deficit lies somewhere in the processing of the sensory information within the central nervous system.

Future directions

Developing new interventions to counteract the stability and gait deficits experienced by individuals with PD is of great importance. Although various strategies, such as gait training or visual cues, have been found to be advantageous, they require intensive training and lack efficacy in everyday life, respectively. These interventions also try to solve the problem with out addressing the potential causes of the very gait impairments they are attempting to improve. Using mechanical facilitation allows for an investigation into the proprioceptive deficit observed in individuals with PD and provides a potential method to counter this deficit.

In order to evaluate the effectiveness of the facilitatory insole, the modified TUG task was used to provide a situation that perturbed stability and gait. Although unsuccessful in doing so for healthy, elderly participants, the modified TUG task was certainly effective in drawing out gait and stability deficits in the PD participants.

Therefore, the modified TUG task was useful in assessing gait and stability parameters in a clinical population.

Even though the facilitatory insoles did not appear to benefit individuals when they are worn initially, individuals with PD benefited from the long term use of the insoles. This was evident in the stability and gait improvements found in the turning and walk back phases of the modified TUG task. These results are promising as the facilitatory insoles as an intervention are an inexpensive, non-invasive and non-time consuming method of counteracting the stability and gait impairments in individuals with PD.

It is important to continue the investigation into whether mechanical facilitation, by way of the facilitatory insoles or other means, is an effective way to improve the gait and stability deficits in the PD population. Future research should continue to evaluate the benefits received from the facilitatory insoles over an extended period of time and whether greater benefits may occur with this additional time spent with the insoles. Similarly, since benefits have also been demonstrated with use of the vibrational stimulus, it may be advantageous to use this type of stimulus in various situations. This could include using a continuous vibrational stimulus to improve gait initiation, instead of as a cue to initiate gait. As well, it may be valuable to use a vibrational stimulus in conjunction with a secondary task to pursue the role of attention and proprioception with regards to gait in individuals with PD.

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APPENDIX A

Due to the nature of the task, the data for some participants was incomplete so some trials were discarded. Since the number of trials differed from participant to participant for each condition (see Table 1 and 2 for percentage of missing trials for the first and second study, respectively), we chose to analyze three of the five trials for each participant. The highest and lowest trials were discarded to allow for the three trials with median values for the variables to be analyzed for each condition. Also, some participants had to be dropped from analysis all together due to insufficient data.

Other options for analysis were explored, however these options did not show any significant effects for the measures investigated. Below are examples of ANOVA tables for the various options explored.

Table 1. Percentage of missing trials for stability margin data for first study.

Healthy Controls	Blank Insole			Facilitatory insole		
	No Tray	Tray	TrayWG	No Tray	Tray	TrayWG
Approach	3.85	9.23	6.15	4.62	7.69	0.77
Turn	5.71	8.57	8.57	5.71	5.71	11.43
Walk Back	9.09	12.73	7.27	5.45	7.27	9.09
PD						
Approach	12.31	8.46	12.31	11.54	10.77	20.38
Turn	13.85	9.23	13.85	15.38	12.31	21.54
Walk Back	11.54	6.15	17.69	11.54	9.23	23.85

Tray WG, Tray with glasses condition

Table 2. Percentage of missing trials for stability margin data for second study.

Group	Blank Insole Group											
Period	**Pre-Assessment**						**Post-Assessment**					
Condition	Blank Insole			Facilitatory insole			Blank Insole			Facilitatory insole		
	No Tray	Tray	TrayWG	No Tray	Tray	TrayWG	No Tray	Tray	TrayWG	No Tray	Tray	TrayWG
Approach	3.57	5.71	7.86	10.71	8.57	7.14	12.22	11.67	16.67	11.67	16.67	17.22
Turn	20.00	13.33	33.33	16.67	20.00	23.33	8.57	14.29	20.00	20.00	25.71	42.86
WB	26.00	16.00	32.00	18.00	26.00	56.00	31.11	25.56	37.78	38.89	38.89	37.78
Group	**Facilitatory Insole group**											
Period	**Pre-Assessment Period**						**Post-Assessment Period**					
Condition	Blank Insole			Facilitatory insole			Blank Insole			Facilitatory insole		
	No Tray	Tray	TrayWG	No Tray	Tray	TrayWG	No Tray	Tray	TrayWG	No Tray	Tray	TrayWG
Approach	19.44	16.11	12.78	10.00	12.22	11.11	18.13	16.25	13.75	18.13	14.38	15.63
Turn	37.50	30.00	40.00	25.00	30.00	25.00	24.00	20.00	32.00	24.00	20.00	32.00
WB	48.57	34.29	48.57	41.43	38.57	45.71	38.33	33.33	25.00	28.33	35.00	40.00

Tray WG, Tray with glasses condition

GP, Gait and Posture score

ANOVA TABLES FOR VARIOUS METHODS OF ANALYSIS OF STABILITY MARGIN DATA

1) Using the mean across trials to fill in missing values

Example: Minimum stability margin during walk back

Summary of all Effects; design: (adstudy.sta)
1- INSOLE, 2-CONDITIO, 3-FOOTFALL, 4-TRIAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.000344	9	.000605	.567986	.470316
2	2	.000093	18	.000513	.181168	.835797
3	1	.004286	9	.003882	1.104160	.320750
4	2	.000046	18	.000235	.195883	.823838
12	2	.000892	18	.000396	2.253125	.133883
13	1	.000070	9	.000571	.123214	.733651
23	2	.000536	18	.000335	1.599776	.229357
14	2	.000718	18	.000211	.410260	.155482
24	4	.000241	36	.000270	.892113	.478644
34	2	.000106	18	.000216	.491636	.619602
123	2	.000222	18	.000610	.364767	.699375
124	4	.000320	36	.000260	1.231109	.314962
134	2	.000419	18	.000250	1.678869	.214514
234	4	.000310	36	.000243	1.273445	.298427
1234	4	.000306	36	.000158	1.930658	.126426

2) Collapsing across trials to avoid missing data

Example: COM-BOS range during walk back

Summary of all Effects; design: (adstudy.sta)
1-INSOLE, 2-CONDITIO, 3-FOOTFALL, 4-TRIAL

	df Effect	MS Effect	df Error	MS Error	F	p-level
1	1	.001185	8	.006808	.174039	.687517
2	2	.014834	16	.008738	1.697658	.214479
3	1	.109458	8	.039087	2.800389	.132778
4	2	.006770	16	.003340	2.027067	.164183
12	2	.004556	16	.007379	.617505	.551655
13	1	.020490	8	.014733	1.390773	.272155
23	2	.039116	16	.015685	2.493938	.114081
14	2	.000572	16	.007009	.081651	.921975
24	4	.005108	32	.004262	1.198494	.330508
34	2	.003530	16	.004381	.805861	.464029
123	2	.002557	16	.009598	.266376	.769482
124	4	.008989	32	.007242	1.241206	.313295
134	2	.017931	16	.008768	2.045005	.161852
234	4	.003079	32	.001669	1.844377	.144622
1234	4	.000725	32	.003519	.206131	.933133