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THE EFFECTS OF ORTHOTICS AND INCREASED PLANTAR SOLE MECHANORECEPTOR ACTIVATION ON TURNING PERFORMANCE IN INDIVIDUALS WITH PARKINSON'S DISEASE

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by

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ABSTRACT

Locomotion and turning are complex movement patterns essential to activities of daily living. Individuals with Parkinson's disease (PD) report difficulties turning, often coupled with impaired balance and increased fear of falling. The purpose of this within-subject study was to determine if orthotics, with and without a textured top cover, can improve gait stability and turning performance within Parkinson's participants. Seven participants with a diagnosis of idiopathic Parkinson's disease, aged 55-80 years old, participated in the study. Participants completed three testing sessions; baseline, 4 weeks post-baseline, and 5 weeks post-baseline. The 'footwear only' and 'footwear + non-textured orthotic' conditions were tested at baseline, 'footwear + non-textured orthotic' and 'footwear + textured orthotic' conditions were testing at 4-weeks, and the 'footwear + textured orthotic' condition was repeated at 5 weeks. Kinematic, kinetic, electromyographical, and video data was collected during a turning task. The turn task consisted of walking towards a pre-determined turn area, and then completing a 180° to static stance. Variables of interest were categorized into three main areas: dynamic stability (COM/BOS ML maximum, minimum, and range), turning performance (turn strategy, step count, step length, step width, and average walking velocity), and average muscle activity of lower limb musculature (tibialis anterior, medial gastrocnemius, and peroneus longus). Results were further subdivided between acute and long-term changes associated with both non-textured and textured orthotics. Long-term orthotic wear and the addition of texture appears to significantly improve dynamic stability, characterized by an increase in the ML maximum and ML range COM/BOS relationship. Significant increases in averaged muscle activity of the ipsilateral tibialis anterior and medial gastrocnemius were noted in the textured orthotic condition, along with significant decreases in ipsilateral peroneus longus. These study results provide two potential treatment options, foot orthotics and textured orthotics, for rehabilitation professionals treating Parkinson's disease individuals.

Keywords: Parkinson's disease, orthotics, somatosensory, mechanoreceptors, balance, turns, falls

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Lastly, to HBO. Thank you for being my rock and unconditional support system. This is for you.

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GLOSSARY OF TERMS

Analysis of Variance (ANOVA)

- inferential statistical analysis method used in analyzing the difference between group means

Balance

- the body's ability to resist linear and angular accelerations (Hamill, Knutzen, & Derrick, 2015a)

Base of Support (BOS)

- specifically during gait, the BOS is defined by the lateral border of one, or both feet, in contact with the ground surface

Biomechanics

- study of motion and the effect of forces on biological systems (Hamill et al., 2015a)

Center of Mass (COM)

- the point about which the distribution of mass sums to zero (Hamill et al., 2015a)

Center of Pressure (COP)

- the point about which the distribution of pressure sums to zero (Hamill et al., 2015a)

COM-BOS Stability Margin

- the degree to which the COM approached the limits of stability defined by the BOS, a larger distance suggests increased stability (Perry, Radtke, McIlroy, Fernie, & Maki, 2008)

Cutaneous Mechanoreceptors

- receptors located in the skin of hands and feet, responsible for tactile sensation (Gardner & Johnson, 2013b)

Force Platform

- an instrument used to sense and record the dynamic ground reaction forces (Hamill et al., 2015a)

Functional Gait Assessment (FGA)

- assessment tool derived from the Dynamic Gait Index, used to assess postural stability in individuals with PD during various walking tasks

Gait

- basic reference to human locomotion. One full gait cycle consists of the period of time between successive ipsilateral heel strikes (Michaud, 1997)

Gastrocnemius

- superficial muscle of the posterior calf, has two prominent bellies (medial and lateral), plantar flexes when the knee is extended and flexes the knee when the foot is dorsiflexed (Marieb, Mallatt, & Wilhelm, 2005)

Ground Reaction Force (GRF)

- a single equivalent force equal to the sum of a distribution of forces applied to a surface (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2014)

Hoehn and Yahr (HY)

- most widely used and universally accepted staging system for overall functional disability in Parkinson's disease (Hoehn & Yahr, 1967)

Kinematics

- area of study that examines the spatial and temporal components of motion (position, velocity, and acceleration) (Hamill et al., 2015a)

Kinetic

- study of forces that act on a system (Hamill et al., 2015a)

Meissner's Corpuscles

- RA1 cutaneous mechanoreceptor, responds to lateral motion and lies close to skin surface (dermal papillae) (Gardner & Johnson, 2013b)

Merkel Cells

- SA1 cutaneous mechanoreceptor, responds to edges and points, and lies on the tips of epidermal sweat ridges (Gardner & Johnson, 2013b)

Monofilament

- Instrument used to test an individual's sensation on the skin, in this experiment, used on the plantar sole of the foot

Orthotics

- An orthopaedic appliance placed in footwear to correct, align, or cushion the foot or lower leg

Pacinian Corpuscles

- RA2 cutaneous mechanoreceptor, responds to vibration and lies in deep dermal tissue (Gardner & Johnson, 2013b)

Parkinson's Disease

- Neurodegenerative disorder involving the degeneration of dopamine-producing cells in the substantia nigra (Anderson, 2015)

Peroneus Longus

- Superficial lateral muscle, plantar flexes and everts the foot (Marieb et al., 2005)

Postural Control

- Our body's equilibrium, or balance, involving active resistance to external forces acting on the body (Macpherson & Horak, 2013)

Postural Sway

- The medio-lateral or antero-posterior movement of the body to remain in a state of equilibrium

Ruffini Endings

- SA2 cutaneous mechanoreceptor, responds to skin stretch and lies in the dermis (Gardner & Johnson, 2013b)

Single Stance

- portion of the gait cycle whereby the body is supported by a single limb

Somatosensory

- bodily system serving three functions: 1) proprioception: sense of oneself, 2) exteroception: sense of direct interaction with the external world, and 3) interoception: sense of internal state of bodily organs (E.P. & Johnson, 2013)

Spin Turn

- a change in walking direction by spinning the body around the stance foot (Hase & Stein, 1999)

Stability

- refers to a state of balance or the ability of a joint to resist dislocation (Hamill et al., 2015a)

Step Turn

- a change in walking direction by shifting body weight from one foot to the other to complete the direction change (Hase & Stein, 1999)

Texture

- tactile surface characteristics. In this experiment, texture is referenced to the material selection on the top cover of the orthotics

Tibialis Anterior

- superficial muscle of the anterior lower leg, prime mover of dorsiflexion (Marieb et al., 2005)

Timed Up and Go (TUG)

- a clinical performance-based screening tool, validated for Parkinson's Disease populations, to evaluate lower extremity function, mobility, and fall risk (Herman, Giladi, & Hausdorff, 2011)

Unified Parkinson's Disease Rating Scale (UPDRS)

- most widely used scale to assess impairment and disability in PD populations (Fahn & Elton, 1987)

Velocity

- vector quantity defined as the time rate of change of position (Hamill, Knutzen, & Derrick, 2015b)

LIST OF ABBREVIATIONS

AP	Antero-posterior
BOS	Base of support
COM	Centre of mass
COP	Centre of pressure
EMG	Electromyography
F	Condition 1 – Footwear only
FGA	Functional Gait Assessment
FO	Condition 2 – Footwear + non-textured orthotic
FOF	Fear of falling
FOT	Condition 3 – Footwear + textured orthotic
HY	Hoehn and Yahr
ML	Medio-lateral
MVC	Maximal voluntary contraction
PD	Parkinson's Disease
TUG	Timed Up and Go
UPDRS	Unified Parkinson's Disease Rating Scale

CHAPTER 1: INTRODUCTION

Parkinson's disease (PD) is a neurodegenerative disorder, characterized by the substantia nigra producing insufficient amounts of dopamine (Przedborski, 2015). This neurotransmitter has a critical role in muscle activation, whereby loss of dopamine results in increased abnormal neuron firing patterns, and impaired control of purposeful movements (Przedborski, 2015). Clinically, impairments to gait and balance are among the most common debilitating symptoms, increasing the fear of falling, and largely decreasing these patient's quality of life (Lindholm, Hagell, Hansson, & Nilsson, 2014). PD gait characteristics are important in understanding the pathophysiological changes within this demographic; however, they provide minimal information on intervention strategies. Understanding these underlying mechanisms of impaired gait can translate into improved treatment options for clinicians, and consequently, have a direct impact on improving quality of life. The relationship between PD gait changes, impaired balance, and fear of falling has been minimally researched (Lindholm et al., 2014). Furthermore, there is a lack of treatment options specifically targeting Parkinsonian gait characteristics. Consequently, this thesis study aims to increase both research and clinical knowledge for this demographic. This study aims to increase plantar foot sole mechanoreceptor activation, with the addition of orthotics and texture under the entire length of the plantar sole of the foot, as a potential treatment option for individuals with Parkinson's disease.

Parkinson's disease (PD) is the second most common neurodegenerative disorder following Alzheimer's disease (Hirtz, Thurman, Mohamed, Chaudhuri, & Zalutsky, 2007). Statistics Canada reports Canadian disease prevalence at an estimated 55,000 adults living in private households and 12,500 residing in long-term residential institutions. Gait impairment is the most common motor characteristic associated with the condition, further complicated by freezing of gait, experienced in 30-60% of PD patients (Nanhoe-Mahabier et al., 2011). The 2014 Canadian Seniors' Falls Report lists balance and gait deficits, neurological disorders, and reduced physical fitness, as the main risk factors contributing to increased falls. This same report suggests that "each year, fall-related hospitalizations account for about

85% of injury hospitalizations for seniors" (Wong, Gilmour, & Ramage-Morin, 2014). Risk factors include Parkinson's disease, lack of muscle strength, and fear of falling (FOF). Consequently, continued research progress in Parkinson's disease, balance, and gait disorders has important implication in clinical rehabilitation. It is quite evident that falls create a large economic burden to our health care system, and have large personal consequences to PD individual's quality of life. If we can increase our understanding of the gait and balance impairments that increase falls, and couple this understanding with the task-specific activities that increase risk factors to falls, we can translate this knowledge towards targeted intervention strategies preventing falls. Since walking and turning are self-reported activities increasing the risk of falls in PD (Ashburn, Stack, Ballinger, Fazakarley, & Fitton, 2008), this thesis has a focus on turning behavior. Sensory augmentation, via foot orthotics with and without texture, are two proposed intervention strategies to decrease fall risks in individuals with Parkinson's disease.

Parkinson's Disease and Motor Symptoms

The clinical phase of Parkinson's disease is defined by the onset of motor symptoms. Tremors, bradykinesia, rigidity, and balance problems are among the most common symptoms of the condition. PD medications offer some symptomatic relief; however, the normalization of motor symptoms is stage dependent. For example, Levadopa, one of the most effective medications for Parkinson's disease, has a wearing-off period prior to a secondary dose. This diminishing effect is most commonly experienced during the mid to late stages of the disease, where motor symptoms re-emerge before the body receives additional medication. Furthermore, as PD progresses, the development of postural instabilities, freezing of gait, loss of balance, and frequent falls increase ambulatory impairments (National Institute of Neurological Disorders, 2015). These secondary complications are drug-resistant, highlighting a need for greater understanding of causes and treatment availability.

Gait Characteristics

The axial impairments of a Parkinsonian gait include a stooped posture, shuffling feet, postural imbalances, and freezing (Carpenter & Bloem, 2011). In comparison to normal walking patterns, a PD gait includes decreased stride length and velocity, with increased cadence, and duration in double limb support time (Morris, Iansek, Matyas, & Summers, 1998). PD patients experiencing walking patterns with freezing of gait (FOG) tend to have additional impairments; including increased stride length variability (Hausdorff et al., 2003), larger asymmetries between lower leg swing times (Plotnik, Giladi, Balash, Peretz, & Hausdorff, 2005), and increased irregularity of inter-limb coordination (Nanhoe-Mahabier et al., 2011). Plantar force research has demonstrated altered force distribution patterns within the PD demographic. A slower load acceptance at heel strike, an earlier forefoot load, reduced amplitude at toe-off (Nieuwboer & De Weerdt, 1998), decreased peak ground reaction forces (GRFs) at initial contact and toe-off, and lower peak power production of lower limb joints (Morris, Huxham, McGinley, Dodd, & Iansek, 2001) have all been previously observed.

Balance and Fear of Falling

Approximately 75% of PD patients are affected by impaired balance, greatly increasing their fall risks in comparison to healthy individuals of the same age (Nilsson, Hariz, Iwarsson, & Hagell, 2012). Balance in the PD literature is commonly reported by functional performance tests (example: Timed Up and Go) and postural sway. Nilsson et al. (2012) reported balance impairments resulting from postal survey results. Participant responses to the Swedish 'Walk-12G' questionnaire, determined that self-reported balance deficits are the largest walking difficulty contributing to fear of falling. Lindholm et al. (2014) replicated these results, highlighting functional balance, dual-task difficulties, and gait speed as the strongest factors increasing fear of falling in PD patients. Ambulatory tasks seem to be the largest contributor to increased falls, including abnormal posture and poor balance (Latt, Lord, Morris, & Fung, 2009). Balance in these previously reported studies (Ashburn et al., 2008; Lindholm et al., 2014; Nilsson et

al., 2012) was defined from results of self-reported questionnaires, diary logs, and performance-based instruments.

The measure of balance, and the mechanisms by which a researcher defines balance improvements, varies study by study. Within the PD literature, balance impairment is commonly quantified by force plate posturography; the measurement of postural sway, through the analysis of center of mass (COM) motion, in relation to the center of pressure (COP) and base of support (BOS) (Stylianou, McVey, Lyons, Pahwa, & Luchies, 2011). Studies in the early 1990's fail to consider the effects of medication and disease severity when reporting the effect of PD on quiet standing postural sway. Consequently, early documentation of postural sway analysis revealed mixed results. Current research attempts to quantify the postural movement strategies of PD patients during static and dynamic conditions, while considering the effects of Levadopa and disease severity, in eyes open and closed conditions. During static stance, in mild to moderate PD (Hoehn-Yahr scale stages 1-3), both the medio-lateral (ML) sway path length and range appear to increase (Stylianou et al., 2011). This sway path direction has been further linked to increased fall risk, an important consideration for the PD community (Maki & McIlroy, 1996). The presence of visual input has a greater effect on postural sway in the antero-posterior (AP) sway path length, area, and range (Stylianou et al., 2011), compared to the ML direction. AP sway is also greater in PD patients compared to healthy age matched controls. It is important to note these results are observed when PD patients are on their medications, and it remains unclear if force plate posturography is an appropriate measure of static balance in studies conducted when patients are off their medication. In the assessment of static balance using an inclinometric device, Matinolli et al. (2007) recorded postural sway data for 60 seconds during normal static standing, in both eyes open and closed conditions (Matinolli et al., 2007). Disease duration and severity, medication, recent fall history, and use of walking aids, were all associated with larger postural sway.

Additional Parkinson's disease research is investigating gait and balance by classifying PD into disease subtypes (postural instability gait difficulty [PIGD] vs. tremor dominant [TD]) (Herman, Weiss,

Brozgol, Giladi, & Hausdorff, 2014), evaluating the influence of freezing of gait (Bloem, Hausdorff, Visser, & Giladi, 2004), and attempting to gain a larger understanding of the influence of the on and off cycle of Levadopa medication (Curtze, Nutt, Carlson-Kuhta, Mancini, & Horak, 2015; Morris et al., 2001). As researchers develop a greater understanding of the contributing factors influencing PD patients' falls and impaired balance, this increased knowledge generation is slowly transferring into clinical practice. There is a gap within current literature to further understand dynamic stability and the potential treatment interventions to facilitate balance improvements. Furthermore, there is a failure to consider balance during specific times within the gait cycle, most importantly, when the body is at a greatest threat to its state of equilibrium. Balance analysis during static stance is an important first step in evaluating the neural complexities of equilibrium, however isolates the experimental results to static stance conditions.

A body is considered balanced when the COM falls within the base of support, as defined by the individual's area of contact on the ground surface. An individual is most vulnerable to balance disturbances during the single support phase of gait, when only one foot is in contact with the ground. The displacement of the COM within the base of support, during this time of the gait cycle, is a strong indicator of stability during dynamic movement (Perry et al., 2008). As the COM approaches the lateral base of support, resulting in a smaller stability margin, small threats to the balance system can result in a fall. If the stability margin is greater, a larger threat is required to increase fall risks. Consequently, an individual is considered more stable, and thus less vulnerable to balance loses, with a larger stability margin (See Figure 1) (Perry et al., 2008). Fall mechanisms are more complex then single stance isolation, however a greater understanding of this stability margin variability in PD can further our knowledge of balance strategies during dynamic movement.

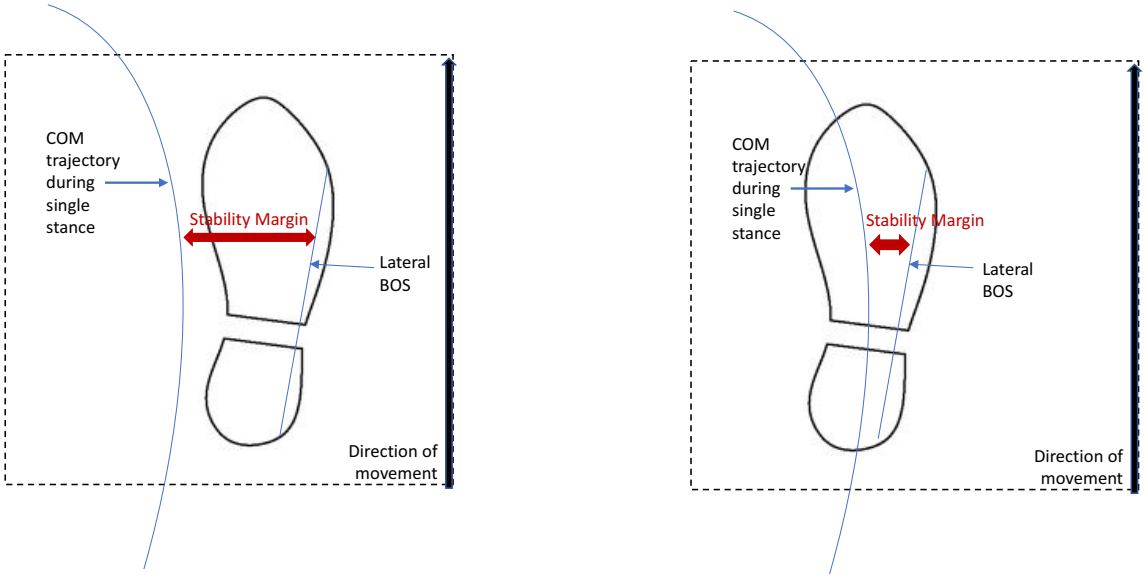

Figure 1: The COM/BOS and lateral stability margin. Larger stability margins (left figure) result in increased stability and less vulnerability to balance impairments. Smaller stability margins (right figure) are less stable and vulnerable to balance impairments. Adapted from Perry et al., 2008.

Turning Performance: A Comparison Between Typical and PD Turning Behavior

Typical Turning Strategies

There are two main turning strategies commonly adopted during human locomotion: a turn step and a spin step. By definition, a turn involves that an individual decelerate forward motion, rotate the body, and step out towards the new direction (Hase & Stein, 1999). Two factors influencing turn strategy adoption include the location or side of the braking foot (the last foot on ground contact prior to initiating the turn) and turn direction. During a spin turn, the ball of the foot serves as a turning axis whereby the body spins around on the stance foot. This strategy is less stable than a step turn as the deceleration of forward momentum and change in turn direction occurs almost simultaneously. Secondly, the complete change of direction occurs in single stance. Spin turns are commonly adopted when the braking foot side and turn direction are the same (example: right braking foot and right turn direction). The step turn utilizes both feet to change direction, each serving as an axis for part of the turn. Step turns are more common when the braking foot side and turn direction oppose each other (example: right braking foot and

left turn direction). Step turns have a wider base of support than spin turns, resulting in a more stable turning strategy (Hase & Stein, 1999). A visual representation of turning strategies is shown in Figure 2. This thesis adopts the spin and step turn definitions described above. Recent literature (Conradsson, Paquette, & Lo, 2017) has adopted a slightly different definition between turns, an important consideration when comparing results between authors.

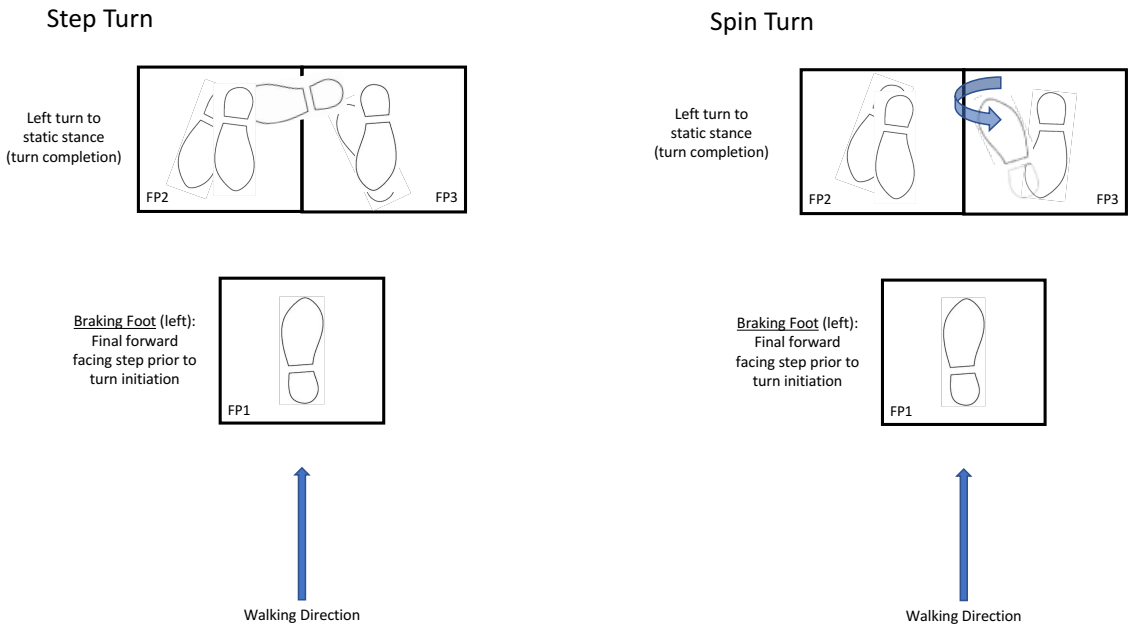

Figure 2: Spin and step strategies. Adapted from Hase & Stein, 1999.

Parkinson's Disease and Turning Performance

Previous turning performance literature has focused on the changes in postural characteristics, axial trunk rotation, and electromyography in patients with PD. During functional tasks, such as making tea in one's kitchen, PD subjects with self-reported difficulties completing turns require more steps to complete the movement compared to PD subjects without self-reported difficulties (Stack, Ashburn, & Jupp, 2006). Trunk rotation has been evaluated under various turning conditions; including velocity changes, cued turning, and dual task performance. Within each turning condition, longer turn times and a decrease in yaw (vertical axis) and roll (longitudinal axis) angular velocity is observed in PD subjects compared to healthy controls (Visser et al., 2007). Crenna et al. (2007) observed similar results when PD subjects were

required to turn 90 degrees and continue ambulation. PD subjects required more steps to complete the turn, decreased velocity approaching the turn, had a prolonged mean duration of turn step, and abnormal timing of head-trunk rotation (Crenna et al., 2007). When turning 180 degrees on the spot, PD subjects have simultaneous movement of the head, trunk, and pelvis, and an increased number of steps and turn time. Interestingly, the absence of a craniocaudal turning strategy was not accompanied by changes in lower limb muscle activation patterns (Hong, Perlmutter, & Earhart, 2009). It is difficult to make further comparisons between these studies as turning characteristics are all unique to each testing condition. The ambulatory movements preceding a turn will have effects on performance ability. Secondly, this literature combines testing on PD subjects during both on and off medication times, an important consideration when interpreting these results. A recent study by Conradsson and associates (2017) investigated PD subjects turning performance both on and off dopaminergic medication. Medicinal intake had no effects on turn strategy adoption and PD participants' turning impairments remained following dopaminergic medication. Conradsson et al. (2017) concluded that the regulation of step width was the most crucial difference between PD participants and healthy controls. PD participants took narrower steps, increased crossover steps during turns, and compromised their ML stability (Conradsson et al., 2017). In this thesis study, the turning variables of interest include turn strategy, step count, and velocity changes between experimental conditions. All subjects were tested during on times of dopaminergic medication.

Balance and Somatosensory Response

The visual, vestibular, and somatosensory systems all contribute to the body's movement control (Eils et al., 2002). Somatosensory receptors, located throughout the body, provide the afferent feedback to the central nervous system required for the performance of human movement. There are four types of receptors responsible for somatic sensation response: 1) cutaneous and subcutaneous mechanoreceptors; 2) thermoreceptors; 3) nociceptors, and 4) muscle and skeletal proprioceptors. In balance control, proprioceptors and mechanoreceptors are most important, responding to muscle length and force changes,

joint angle changes, and skin deformation (Gardner & Johnson, 2013a). The mechanoreceptors in the feet, and the proprioceptors located in our muscles and joints have important roles in the response to postural changes. These specialized receptors play a large role in the neural mechanisms responsible for controlling center of mass motion. When the body experiences an unpredicted disturbance to its state of equilibrium, automatic postural adjustments and muscle activation produce direction-specific forces to maintain balance control (Macpherson & Horak, 2013). Further details on the somatosensory system and its receptors can be found in Appendix A.

In attempts to better understand the role of the somatosensory system in balance control, studies have explored various manipulations at the plantar sole of the foot. These studies focus on manipulating plantar cutaneous mechanoreceptor activity, through either sensory augmentation or down-regulation of their cutaneous response. Down-regulation of plantar foot sole mechanoreceptor activity is experimentally manipulated by placing ice under the foot. When exposed to these conditions, participant's adopt a more cautious walking pattern and observe longer contact times during all phases of gait (Eils et al., 2002). This diminished cutaneous sensation alters plantar pressure distribution patterns, with significant reductions noted under the calcaneus and metatarsals. This decreased calcaneal and forefoot pressure suggests a more cautious walking pattern at initial contact and toe-off. Secondly, during single leg stance, load is shifted to the forefoot earlier under iced conditions. In comparison to normal conditions, there is a larger contact area between foot and ground, consequently increasing contact time and load distribution across the foot (Eils et al., 2002). Perry et al. (2000) explored the specific roles of plantar mechanoreceptors to better understand their role in compensatory stepping reactions. Plantar mechanoreceptors provide important spatial and temporal information to the body. With diminished plantar cutaneous sensation, participants' stepping patterns changed in instances of unpredictable postural perturbations. Compensatory stepping patterns appear to be both direction specific and step phase dependent (Perry, McIlroy, & Maki, 2000). These results suggest that the role of plantar mechanoreceptors contribute to the relationship between the body's base of support and stability limits. Changes in gait kinematics have also been observed, with

significant differences in the hip, knee, and ankle joint angles when plantar cutaneous feedback is down-regulated. Electromyography (EMG) analysis revealed decreases in muscle activity of key lower limb muscles, including the tibialis anterior, peroneus longus, and gastrocnemius (Eils et al., 2004).

In PD patients, the pathogenesis of peripheral neuropathy and the mechanisms inducing peripheral nerve damage remain unclear (Nolano et al., 2008). Secondly, this neuropathy tends to mirror limb asymmetry and PD motor symptomology. Clinically, PD patients demonstrate decreased sensitivity of the plantar sole of the foot and higher monofilament testing thresholds for touch and vibration. The motor and somatosensory system changes in PD patients appear to be correlated, with increased motor impairment resulting in increased plantar sole sensitivity thresholds (Prätorius, Kimmeskamp, & Milani, 2003). Consequently, reduced somatosensory response may be a contributing factor to impaired balance control. If standing conditions are altered, such as standing on a declining hill, PD patients have difficulties estimating the magnitude of balance adjustments required for the appropriate postural adjustments. Postural adaptation and learning can occur following the trial, however PD patients commonly over-respond to the required counterbalancing adjustments (Macpherson & Horak, 2013), threatening their state of equilibrium, and consequently increasing their fall risks. The age-related loss of plantar mechanoreceptors, accompanied by PD induced changes in sensory nerve conduction, highlights the need for a greater understanding of the mechanisms available to increase plantar somatosensory feedback. This thesis focuses on the muscle activity of the tibialis anterior, peroneus longus, and medial gastrocnemius due to the two above mentioned rationales: the knowledge of decreased amplitudes of these specific muscles during diminished cutaneous feedback (Eils et al., 2004), and the decreased plantar foot sole sensitivity in PD individuals. To manipulate the plantar foot-sole interface, two intervention strategies were proposed: non-textured orthotics and textured orthotics. An increase in muscle activity, specifically during initial contact and toe-off, is suggestive of improvements to walking confidence in the single stance phase of gait. If these significant increases in muscle activity are noted during the appropriate times of

single stance (initial contact and push-off phases respectively), this increased amplitude could be attributed to the increase in sensory facilitation.

Interventions Strategies

Foot Orthoses

Minimal research has focused on using orthotics, over-the-counter or custom devices, to increase balance through increased somatosensory response. It is important to note that the terminology surrounding foot orthoses can be confusing throughout the literature. A recent systematic review by Aboutorabi et al. (2016) is a perfect example, whereby the summarized foot orthotic research includes all variations of foot-ground manipulations. Of the 22 articles reviewed, only 1 article examined a true custom orthotic (Gross, Mercer, & Lin, 2012). Footwear characteristics, manipulations, insole design changes, over-the-counter orthotics, and custom devices, are routinely grouped together under the keyword "foot orthoses".

Foot orthoses can be a valuable clinical tool in treatment options aimed at improving balance. Foot orthoses function by improving lower limb alignment and correcting abnormal motion during the gait cycle (Michaud, 1997). Furthermore, foot orthoses increase the surface contact of the plantar sole of the foot to the orthotic top cover. This increased surface contact, consequently increased mechanoreceptor activation, has been linked to postural sway changes improving dynamic balance task scores for individuals suffering from chronic ankle instability (Sesma, Mattacola, Uhl, Nitz, & McKeon, 2008). The use of custom foot orthoses on static and dynamic balance was evaluated in children with flexible flat feet. There was a significant improvement in balance with long term (3 months) wear of the custom orthotics. Balance was defined as decreased center of gravity (COG) velocity, during static stance, with one eye closed (Lee, Lim, & Yoo, 2015). More recently, Shin et al. (2016) compared three different contact heights between orthotic and the plantar sole of the foot. Closer foot contact, between the plantar foot sole and the top of the

orthotic, resulted in larger improvements in static balance. These improvements were characterized by a decrease in ML COP, total AP distance, and ML velocity (Shin, Ryu, & Yi, 2016). Additional research is necessary to further understand the relationship between orthotics and postural sway, and more specifically, during dynamic movement.

Textured Insoles

One method of increasing the cutaneous receptors' sensory response is with the addition of texture between the plantar sole of the foot and walking surface. This interface manipulation has been shown to alter static double-limb balance (Hatton, Dixon, Rome, & Martin, 2011), improve postural control in the elderly (Palluel, Olivier, & Nougier, 2009), and have injury specific implications for rehabilitation professionals (Mckeon, Stein, Ingersoll, & Hertel, 2012). Perry et al. (2008) investigated the effects of a balance-enhancing insole, demonstrating how changes in insole design can influence balance control in older adults. This facilitative insole has also proven effective in increasing single-limb support time and normalizing muscle activation patterns of the tibialis anterior muscle in Parkinson's patients (Jenkins et al., 2009). The facilitative insole helped PD patients approach a normal heel-to-toe walking pattern, suggesting that increased plantar cutaneous sensation can alter gait parameters and muscle activation patterns. The use of textured insoles had been further explored in special populations, including multiple sclerosis (Kalron, Pasitselsky, Greenberg-Abrahami, & Achiron, 2015; Kelleher, Spence, Solomonidis, & Apatsidis, 2010), and Charcot-Marie-Tooth disease (Wegener, Wegener, Smith, Schott, & Burns, 2016). In respect to Parkinson's disease, Qiu et al. (2013) reported an improvement in static postural stability when wearing a textured insole (Qiu et al., 2013). Further PD-specific research is needed to gain a better understanding of the relationship between enhanced cutaneous sensation and PD walking kinematics.

Summary of The Literature and Research Implications

To summarize, individuals with Parkinson's disease have altered gait and turning performance characteristics compared to non-pathological populations. Postural instabilities and balance impairments

are among the largest contributing factors increasing fall risks. The somatosensory system plays a large role in balance control, and manipulations at the plantar sole of the foot has proven effective in facilitating sensory response.

The aim of this study is to combine the physiological benefits of increasing sensory augmentation and orthotics in Parkinson's patients. In this study, we aim to increase plantar foot sole mechanoreceptor activity with the addition of orthotics and texture under the plantar sole of the foot, as a potential treatment option for the gait deficits in individuals with Parkinson's disease. To date, no research has combined orthotics and added texture, towards the improvement of balance parameters, in either a non-pathological or pathological population. From a research perspective, this study will advance PD literature and gain a better understanding of the relationship between plantar sensory information and orthotics within this special population. Clinically, this research study has large-scale implications for rehabilitation professionals. Results may provide a cost-effective treatment option for PD patients, by improving gait, balance, and decreasing fear of falling, and consequently improving PD patient's quality of life.

Research Questions

The purpose of this research is to answer the following research questions. In individuals with Parkinson's disease, when completing a 180° turn to static stance:

1) Will the use of foot orthotics increase stability (defined as an increase in the distance between the COM and the lateral border of the BOS in the braking step) compared to footwear without foot orthotics? Does stability further increase with long-term wear? Does stability increase with the addition of texture to the orthotics?
2) Will the use of foot orthotics, with and without texture, alter walking and turn performance in the steps preceding and initiating a 180° turn?
3) Do the use of foot orthotics, with and without texture, alter the total activation magnitude of key lower limb muscles during single stance?

Purpose and Hypotheses

The purpose of this study was to evaluate turning behavior in PD participants between three different conditions: footwear only (F), non-textured orthotics (FO), and textured orthotics (FOT), and further subdivide these results between acute and long-term turning behavior. The variables of interest were divided into three classifications: gait stability, walking and turn performance, and muscle activation patterns.

It was hypothesized that gait stability would gradually increase between each condition, with greater increases noted with prolonged orthotic wear and the addition of texture. Increased stability was characterized by an increased distance between the COM and the lateral border of the BOS. It was hypothesized that walking and turn performance would improve with prolonged orthotic wear and the addition of texture. Improvements in turning performance are characterized by increased step length, width and velocity, and a decrease in step count. It was further hypothesized that the total magnitude of lower limb muscles activity during static stance (tibialis anterior, peroneus longus, and medial gastrocnemius) would change between the experimental conditions. More specifically, the largest changes in total muscle magnitude were expected in the textured orthotic conditions (both acute and long-term).

CHAPTER 2: METHODOLOGY

Participant Recruitment, Pre-Screening, and Attrition

All study procedures were reviewed and approved by the Wilfrid Laurier Research Ethics board (REB#5082). A convenience sample of 14 participants was originally recruited for the study. Male and female candidates, aged 55-75, with a diagnosis of idiopathic Parkinson's disease were eligible for participation. Recruitment occurred throughout Southwestern Ontario's PD support groups (Kitchener, Cambridge, Brantford, Woodstock, Stratford, Goderich, and London), the Parkinson's Society of Southwestern Ontario, and advertisements within the general population. Recruitment posters were placed on bulletin boards and common advertising locations of local communities and churches (See Appendix B). The study was further advertised electronically when churches noted email as their preferred method of communication.

All interested candidates completed a 'Pre-Screening Questionnaire'. This questionnaire was administered over the telephone to all study candidates. The questionnaire was designed to ensure all prospective participants met the study's general inclusion criteria (See Appendix C). All other criteria were exclusionary. The pre-screening questionnaire immediately excluded any candidate with a history of peripheral neuropathy, vestibular concerns, cognitive impairment, or other conflicting medical conditions. Individuals who had undergone deep brain stimulation, previously (within the past two years)/or currently wearing orthotics, or had an awareness of decreased sensation on the plantar surface of their feet, were also excluded. Candidates suffering from severe arthritic conditions or large amounts of pain in the low back, pelvic region, legs, or feet were not immediately excluded from the study; however, they were evaluated based on severity of the condition, and their ability to participate in the testing sessions. Participants were required to walk 10 meters unassisted. Walking sticks, canes, and/or other assistive devices were accepted, on condition that participants could ambulate short distances without such devices. The pre-screening questionnaire determined exclusion based on frequency of use and confidence to walk without these devices. Assistive devices were not permitted for use during the testing trials; however, they

were encouraged for assistance between testing sessions, and to ambulate to and from the biomechanics lab. One male candidate was excluded from the study as he was currently wearing orthotics.

Following successful completion of the questionnaire, the seven participants were scheduled for an initial screening assessment at Wilfrid Laurier's neuromechanics lab. Participants were provided verbal and/or emailed instructions, details on assessment expectations, and directions to the Bricker Academic Building. Participants were compensated for all parking fees when visiting the campus (screening appointment and each testing session). The screening appointment initiated with three exclusionary evaluations: 1) a footwear evaluation 2) the Montreal Cognitive Assessment (MoCA), and 3) Semmes Weinstein monofilament testing. As footwear plays a vital role in orthotic treatment success, participant's footwear was the first exclusionary evaluation. There was an expectation that all participants wore appropriate footwear throughout the duration of the study (Further details provided under the 'screening appointment' section). One participant was asked to purchase new footwear, whereas all other candidates had an appropriate footwear option. Details pertaining to the footwear evaluation, MoCA assessment, and monofilament testing are described under the 'screening appointment' section. Two male candidates were excluded during these evaluations. Eleven participants remained in the study. All participants were asked to sign the informed consent, as approved by the Wilfrid Laurier's research ethics board. This consent briefly outlined the purpose of the study, participant expectations, study procedures, risks and benefits, and confidentiality. See Appendix D for the informed consent statement signed by all participants. Between the screening appointment and initial testing session, two female participants withdrew from the study. One participant withdrew due to travel concerns throughout the winter weather, and one participant was no longer interested in study participation. Two participants withdrew from the study between baseline and week 5 testing. See Figure 3 for a flowchart outlining participant attrition. Consequently, seven participants completed all three testing sessions. Demographic information for these participants is presented in Table 1.

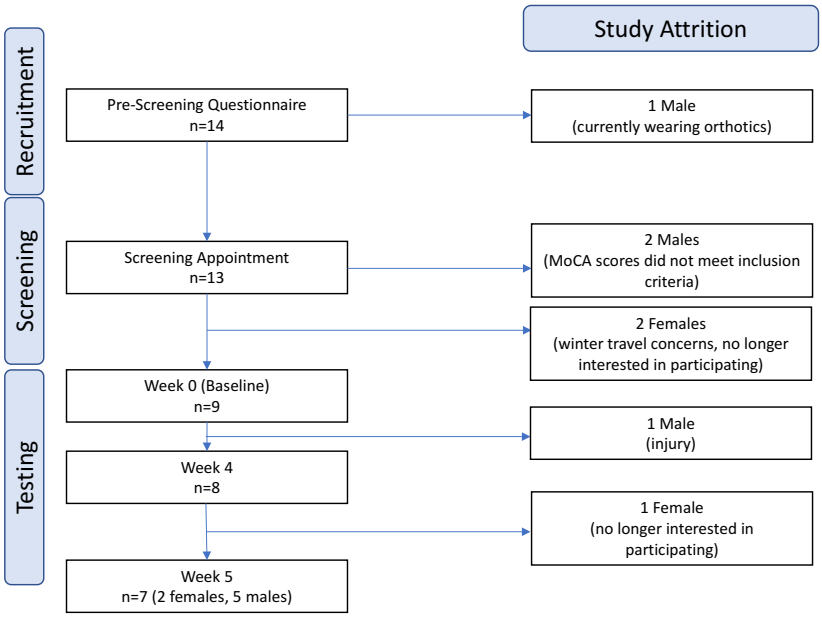

Figure 3: Summary of participant attrition throughout the study.

Table 1. Participant demographics and baseline scores

Participant	Gender	Age	Weight (kg)	Height (cm)	PD Dx (yrs)	MoCA	HY	UPDRS-III	S&E (%)
1	F	72	82.10	161.2	10	29	3	7	80
4	M	76	92.53	177.8	6	26	3	10	80
7	M	59	70.31	175.26	12	29	2	6	100
8	M	77	88.45	175.26	14	28	2	5	90
9	F	62	63.50	157.48	1	27	2	6	70
11	M	82	72.57	177.8	18	26	3	15	60
12	M	70	92.99	175.26	1	26	2	6	90
Mean	**--**	**71.54**	**80.35**	**171.44**	**8.86**	**27.29**	**2.43**	**7.86**	**81.43**
SD	**--**	**8.25**	**11.71**	**8.41**	**6.49**	**1.38**	**0.53**	**3.53**	**13.45**

**Note: PD Dx = years since Parkinson's disease diagnosis; HY = Hoehn and Yahr; S&E = Schwab and England Activities of Daily Living scale scores*

Screening Appointment

The screening appointment initiated with an evaluation of participant's footwear using the 'Footwear Assessment Form'. A comfortable walking shoe (athletic or casual dress) was required for study participation. As footwear was not standardized across all participants, footwear option restrictions were very specific during the length of study participation. Secondly, participants were required to wear the

same footwear, indoors and outdoors, throughout the entire five weeks. Participant's footwear required components of adjustability, torsion strength, a strong heel counter, a wide base of support, and a heel drop between 8-12mm. Participant's footwear was evaluated for a proper fit in length and width. Footwear with excessive wear patterns, inside or outside of the shoe, including the soling and/or upper forefoot were considered unacceptable. All footwear was loosely evaluated based on the Menz and Sherrington's (2000) 'Footwear Evaluation Form' (included in the Pedorthic assessment form, see appendix G); however, components of footwear comfort and practicality to participants were also considered. If the participant's current footwear met all requirements, it was considered acceptable for the study. There are strengths and drawbacks to standardizing participant's footwear. Allowing each participant to wear their own footwear removed the need of an adjustment period to any new footwear prior to the orthotic interventions. On the contrary, the between-participant variability of footwear is an important consideration in evaluating study results.

The MoCA assessment (Appendix E) was used as a screening tool to evaluate participants' cognitive impairment. The screening domains included attention, concentration, executive functions, memory, abstraction, calculation, orientation, and visuospatial abilities (Julayanont, Phillips, Chertkow, & Nasreddine, 2012). The test took approximately 10 minutes to complete, and was scored out of 30. A score of 26, which indicated an absence of cognitive impairment was required for study participation.

The UPDRS is a Parkinson's disease clinical rating scale evaluating motor and non-motor experiences of daily living. The scale is divided into four parts, including: 1) mentation, behavior, and mood, 2) activities of daily living, 3) motor examination, and 4) complications. Both the 'Hoehn and Yahr Staging' (HY), and the 'Schwab and England Activities of Daily Living' scales often accompany the UPDRS (Goetz, 2012). In this study, the UPDRS was used to quantify disease severity, specifically related to participants' motor impairments. Subsection III is directly related to motor difficulties; therefore, for the purposes of this thesis, and to remain consistent with previous motor related PD research, this was the only section of the UPDRS completed during the screening assessment, along with the HY and the 'Schwab and England

Activities of Daily Living'. These sections took approximately 5 to 15 minutes to complete. See Appendix F for a copy of these three assessment tools.

Plantar sole sensation was evaluated according to the Semmes Weinstein (North Coast Medical, Inc., Morgan Hill, CA) monofilament examination. Testing procedures were explained to all participants prior to commencing. Participants were asked to remove their socks and sit comfortably in a chair. With their eyes closed, participants were asked to respond 'yes' if they felt the monofilament touch the plantar sole of their foot. Each monofilament was pressed at a 90degree angle to four locations on the bottom of the foot: the hallux, 1st and 5th metatarsals, and the calcaneus. Each location was tested at random. Testing started with the 1.65 monofilament. If this monofilament was felt on all sites bilaterally, the testing was complete. When participants did not respond 'yes' to feeling this monofilament, testing continued with a larger monofilament. The 5.07 monofilament, exerting a 10g force on the plantar surface of the foot, was the plantar sole sensation threshold required to participate in the study. Two participants did not meet this sensation threshold (the same two participants who did not meet the MoCA exclusionary criteria), and were excluded from the study.

Following the questionnaires and monofilament testing, a basic pedorthic assessment included static and dynamic observations, and range of motion testing. See Appendix G for a copy of the pedorthic assessment, FPI, and footwear evaluation forms. Participants were asked to stand for approximately 2-5 minutes and perform basic movement tasks. Areas of observation included the hip/pelvis area, knee, tibia (lower leg alignment), and subtalar joint alignment. The Foot Posture Index (FPI) was used to evaluate static foot posture. The FPI is a 6-item clinical tool used to categorize static foot posture. It requires observation and palpation of the rearfoot and forefoot during static stance. FPI normative values range between 0 to +5, with an average of approximately +4 (slightly pronated) in healthy older adults (Redmond, Crane, & Menz, 2008). Physical testing included torso rotation, a double heel raise, and a double limb squat. These tests ensured the function of the tibialis posterior muscle, ensured no osseous block of the ankle joint, and provided confirmation of inversion/eversion movement of the subtalar joint. If

required, balance assistance was provided for all physical tests. In the presence of anxiety, discomfort, or pain, participants had the option to terminate any performance of exercises. None of the participants experienced discomfort. Participants were asked to walk for approximately 2 minutes. Visual observations of each participant's gait and balance were noted, specifically related to initial contact, midstance, toe-off, and swing phases bilaterally. The gait cycle was video recorded for all participants, and used as future reference when required. Lastly, participants were asked to sit in a chair for range of motion testing. Passive and active range of motion testing (ROM) was performed non-weight-bearing. The ROM assessment was difficult and highly inaccurate in this study's population, specifically when participants experienced tremors at the end ranges of joint motion. These measurements were complete in approximately 5-10 minutes.

It is important to note that there was a large amount of information collected during this pedorthic assessment, not all of which was utilized during the remainder of the thesis. For the completion of this thesis document, I have elected to note all details surrounding participant involvement; however, pedorthic related details, specifically the FPI results, were collected for future analysis.

Following these ROM assessments, study protocol and testing day expectations were explained. The rationale behind participant postcards were explained, noting the importance of communicating pertinent details surrounding medicine changes and the occurrence of falls during study participation. The total duration of participant involvement, from the completion of the initial screening appointment to the last testing day, was approximately 6-weeks. Screening appointments were approximately 1 hour and 30 minutes. Testing sessions occurred at baseline (week 0), 4-weeks post-baseline, and 5-weeks post-baseline. Baseline and week 4 testing sessions were between 1-2 hours, and the 5-week testing session was approximately 1 hour in length. All participant questions and/or concerns were answered, and most shared their personal stories surrounding their Parkinson's disease diagnosis, and discussed current ambulation difficulties during their activities of daily living.

Testing Sessions

Testing was complete 1 - 2 hours following the participant's ingestion of medication or during their self-reported "on" time during the day. Participants were instructed to arrive at each testing session immediately prior to their 'on' medicine times, and to take their medication at approximately the same time prior to each testing session. For example, if testing was scheduled at 11am, the participant would take their dose of medication around 10:15am. The participant's self-determined 'on' time may not occur until 11:30am, however this provided an important window for instrumentation set-up, synching the start of testing with the participant's 'on' time. All three testing sessions, for each participant, were scheduled at the same time of the day. At baseline testing (week 0), monofilament testing was repeated to ensure the sensation threshold for study inclusion was still met by all participants (see Table 2 for week 4 results). Orthotic break-in instructions were provided when dispensing the orthotics and socks were provided to all participants. Throughout the 5-week testing period, participants were encouraged to wear their socks daily. One participant (participant #12) provided valid medical reason to refrain from wearing the socks (he required daily compression therapy); however, all other participants wore the dispensed socks.

Table 2. Week 4 - Monofilament Results

	Plantar Surface Location					
	1st MTP Head		**5th MTP Head**		**Calcaneus**	
Participant	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
1	4.08	3.84	3.84	3.22	4.87	3.22
4	4.17	4.31	4.56	4.56	3.84	4.56
7	4.17	4.17	4.17	4.31	4.17	4.31
8	4.56	4.08	4.74	4.31	4.31	4.31
9	2.83	3.61	3.84	3.61	3.84	2.83
11	4.74	4.56	4.31	4.31	4.17	4.56
12	4.31	4.56	4.17	4.17	4.17	4.93
Mean	4.123	4.161	4.233	4.070	4.196	4.103
SD	0.617	0.354	0.338	0.476	0.347	0.773

Equipment

To collect all research variables of interest (discussed later in this thesis document), three apparatuses were used for data collection: three force plates, the Optotrak motion capture system, and electromyography collection system (EMG). The three force plates (AMTI OR6-5-2000; Watertown, Massachusetts, United States of America) were embedded in the ground of the participant walkway (see figure 10), and were used to collect ground reaction forces (GRF) of each participant's braking and turning steps. The vertical GRF allowed for the extrapolation of timing of the single stance phase of the gait cycle. The cameras and IRED markers of the Optotrak motion capture system (Optotrak3020; Norther Digital Inc., Waterloo, Ontario) were used to collect 3D kinematic data. Twelve IRED markers were placed on the following anatomical landmarks: bilateral 3rd metatarsals, ankle, knee, hip, shoulder, forehead, and xyphoid process (see Figure 4). Optotrak data was used to calculate the transverse plane center of mass (COM) location and the location of the lateral border of the base of support (BOS) required for COM-BOS relationship analysis.

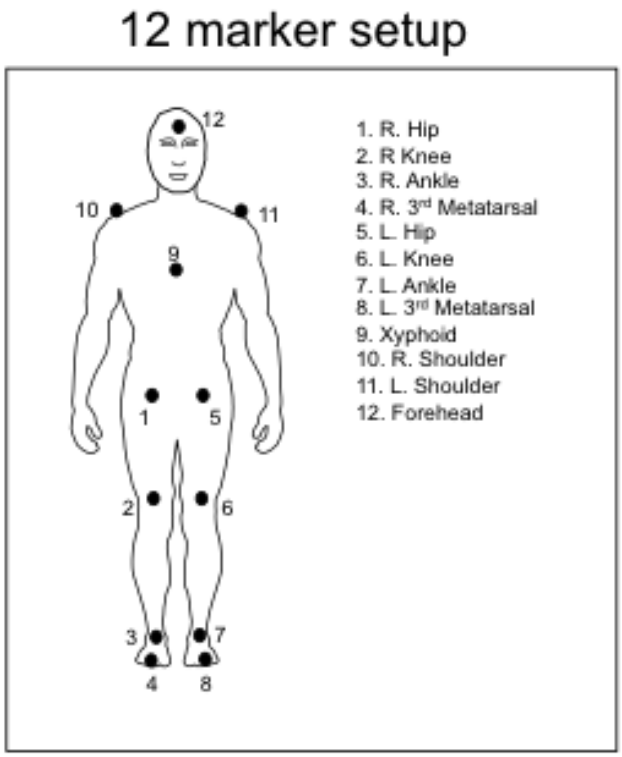

Figure 4: The location of 12 IRED markers placed on participant's anatomical locations, used during data collection to collect 3D kinematic data.

Electromyography (AMT-8 Octopus, Bortec, Calgary, AB) was recorded from the tibialis anterior, peroneus longus, and gastrocnemius muscles bilaterally. See Figure 5 for electrode placement. Electrodes on the peroneus longus muscles were located by initially palpating the fibular head, and placed side by side, along the muscle fibers, with three fingers below the fibular head (directed towards the lateral aspect of the fibula). To ensure adequate placement of the electrodes, the participant was asked to plantarflex and evert the foot. Initially locating the tibial tuberosity, and placing four fingers below this bony prominence, and one finger laterally, determined the location of the tibialis anterior. Participants were asked to dorsiflex the foot to ensure adequate placement on the muscle belly. The medial head of the gastrocnemius was located with one hand inferior to the popliteal crease, on the medial aspect of the calf muscle belly. To test proper placement, the participant was asked to plantarflex the foot with an extended knee. A reference electrode

was placed on the right tibial tuberosity. This protocol remained consistent for each participant and each testing session throughout the length of the study. All data was collected at a frequency of 1000Hz.

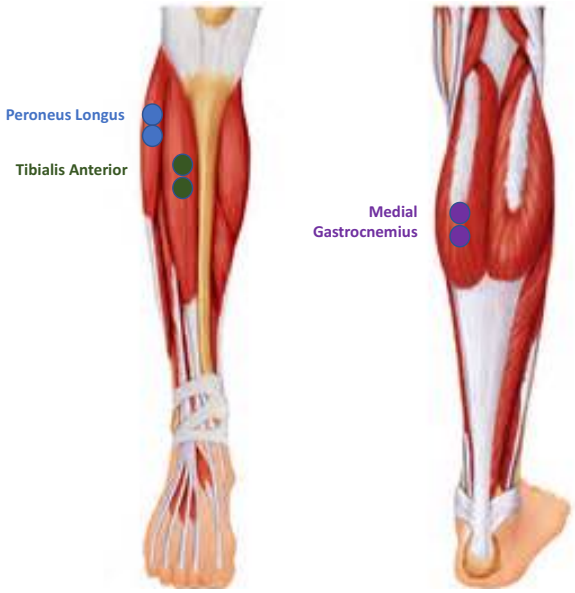

Figure 5: The bi-polar electrode placement on three lower limb muscles; tibialis anterior, medial gastrocnemius, and peroneus longus (Adapted from Pearson Education Inc., 2009).

All testing sessions were recorded using a video camera. These videos were used to ensure accurate foot placement on the force plates and provided the opportunity to review testing sessions as required. These videos were reviewed on two occasions: to review step count and participant's turning strategies.

Socks, FO and FOT

All participants were provided identical socks (ATW3202-014/M/TO2/P10/S04, Athletic Works, Wal-Mart Canada Corp.) to wear during the length of the experiment. As previously mentioned, only one participant was unable to wear them due to medical reasons. These socks were a thin material with minimal seams, and provided to participants based on their self-determined footwear size. Socks were made of 76% polyester, 22% olefine, and 2% rubber.

The Sole 'thin sport' orthotic (D609561, Sole Thin Sport Footbeds, Edge Marketing Corp; Calgary, AB, Canada) was used for both FO and FOT conditions. Sole orthotics are a heat-moldable, over-the-counter orthotic. These are not custom-made orthotics, and consequently, they are not individually fabricated for each participant. A sizing ring was used to best match the orthotic size to the arch length of participant's feet. Each orthotic was heated prior to participant wear, which provided the best contoured fit between plantar foot sole and the orthotic.

The textured orthotics were prepared prior to participant's week 4 testing session. Grooved plates (Gilad Shoham, Medonyx, Inc, Toronto, ON) were custom made to manufacture the desired top cover design (which was grooved into the plates) and thickness (Figure 6). Silicone rubber (Smooth-Sil 950 Series) was prepared based on the manufacturer's instructions (Smooth-ON, Inc.), and immediately poured into the grooved plates to cure for 24hrs. A thin layer (1.0mm) of black synthetic suede was placed over the wet silicone while it dried. Following the curing process, the silicone top cover was heat molded and glued to the 'Thin Sport' Sole orthotic. The 'Thin Sport' orthotic alone weighed 53.2g, whereas the 'Thin Sport' orthotic with added textured weighed 184.6g. See Figures 7 & 8 for both orthotics used in the study.

Figure 6: The custom made grooved plates used during the manufacturing process of the textured top cover design.

Figure 7: The Sole 'thin sport' (D609561, Sole Thin Sport Footbeds) over the counter orthotic, used as the "footwear+non-textured" orthotic condition throughout the study

Figure 8: The Sole 'thin sport' (D609561, Sole Thin Sport Footbeds) over the counter orthotic, with added texture, used as the "footwear+textured" orthotic condition throughout the study

There were many considerations throughout the development process of the textured orthotics. First and foremost, the goal of retaining the benefits of orthotics, and simply add the addition of texture. The most important aspect was to maintain contact between the entire length of the plantar sole of the foot and the textured material. Consequently, this required a flexible material to mold around the orthotic device (acting as a top cover to the orthotic), especially around the contours of the heel and medial longitudinal arch. Secondly, the material required a sufficient durometer (material hardness) to retain its

shape during weight-bearing. If the material compressed with prolonged wear, this would both confound study results and minimize sensory effects. During the initial attempts to glue the textured material to the Sole orthotic, the dry silicone was not adhering to the top cover of the orthotic. This was corrected by adding synthetic suede between both layers. The suede was applied to the silicone while still wet, dried during the silicone curing process, then adhered to the Sole orthotic. The final consideration was related to the textured design. Based on previous textured insole literature, insoles with cupped heels and harder materials provide the largest benefits to static and dynamic balance (Iglesias, Vallejo, & Peña, 2012; Qu, 2015). Horizontal ridges were selected to oppose the direction of participant's walking. This opposition, coupled with the allocated space between each ridge, enhanced the continuous stimulation of cutaneous mechanoreceptors, while minimizing the likelihood of habituation.

The manufacturing company's (Sole) fitting instructions were followed for each participant. At the time of orthotic dispensing, a heat gun was used on the orthotics for 2mins, at 200 degrees Fahrenheit. The orthotics were placed in participant's footwear and they were asked to walk around the biomechanics lab for two minutes prior to continuing testing. This molding process occurred at baseline testing for the FO condition, and at week 4 for the FOT condition.

Protocol

This experiment was a within-subject study design, whereby all participants were exposed to every experimental condition, and each testing session. From study inclusion to the final testing day, the experiment took approximately 6 weeks per participant to complete.

Each testing session (0, 4 and 5 weeks) consisted of four assessments, each administered per condition: 1) Static balance, double limb stance, with eyes closed 2) Timed Up and Go (TUG), 3) Functional Gait Assessment (FGA), and 4) Walking + 180° turn. Three conditions were tested throughout the study: 1) footwear only (F); 2) footwear + non-textured orthotic (FO); and, 3) footwear + textured orthotic (FOT). It

is important to note that all three conditions were not tested at each session. Conditions F and FO were tested at baseline, conditions FO and FOT at week 4, and only FOT at week 5. At baseline testing (week 0), monofilament testing was repeated to ensure the sensation threshold for study inclusion was still met by all participants. Immediately following the baseline testing session, participants were required to wear the FO for 4 weeks until the next testing session. Participants were required to wear the FOT for 1 week, between weeks 4 and 5 testing. See Figure 9. At baseline and over the next 4 weeks, participants were instructed to wear the FO's during 95% of their weight-bearing activities (including indoor and outdoor activities). The same instructions were provided for the FOT between the 4-week and 5-week testing sessions.

All participants were asked to complete weekly postcards to track changes in medicinal doses, their perceived level of comfort while wearing the orthotics, duration of wear time, and report of any falls. These postcards were mainly used to continue communication with participants during the off-testing weeks, and to ensure no major changes took place in their everyday activities. Participants were instructed to wear the orthotics 'as much as possible' throughout the length of the study. They were informed that the orthotics should 'not cause pain', however participants may feel minor aches and discomfort while acclimatizing to the devices. If the orthotics could not be tolerated by the participant, they were advised to communicate with the biomechanics lab. All participants tolerated the orthotics during the testing period. Three participants noted discomfort with the textured orthotics, however this was not communicated until their week 5 testing session. This discomfort has no effect on the time of wear in the textured orthotics. A follow up call was scheduled in circumstances where a participant experienced a fall between experimental sessions. One subject reported a fall; however, occurred during the hours of night, and was unrelated to study participation.

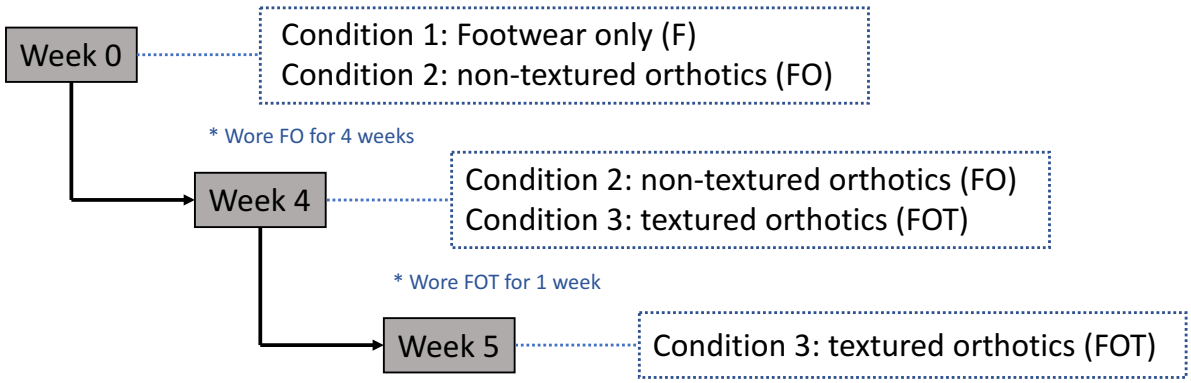

Figure 9: A flow chart graphically displaying the experimental conditions at each testing session.

Testing Sessions

All participant questions were answered prior to starting the experimental setup. The EMG electrodes and IRED markers were placed on participants as previously discussed. Maximum voluntary contractions (MVCs) were performed for each muscle of interest in the study, at each testing session. Testing began with static double limb stance with eyes closed. Participants were asked to stand as still as possible with their eyes closed for 1 minute. At baseline testing, tracing paper was used to identify the exact foot position on the force plates. This same tracing paper was used to ensure accuracy of foot position during each participant's static stance testing. The TUG and FGA were administered conforming to the instructional protocols for these two assessment tools. Prior to the completion of the "Timed Up and Go" (TUG) test, participants were asked to start the test sitting back comfortably in a chair, with both arms resting on their lap. On the command "go", participants stood from the chair, walked a clearly marked 3m distance on the floor, turned around, and returned to their chair, with their back resting against the chair. The timer started when the participant initiated movement from the chair, and stopped when they had returned to their original position. A practice trial was offered to all participants. The FGA required participants to perform various walking tasks, including turns, stepping over objects, walking backwards, and walking with a narrowed base of support (Appendix H). Note that the static stance, TUG, and FGA assessments are not analyzed for this thesis. They are described here as they were part of each participant's testing experience, however they are only being analyzed in future statistical analysis.

Walking Trials + 180° Turn

For each experimental condition, participants completed ten walking trials + 180° turn. A demonstration was provided to each participant prior to starting. Participants walked towards the force plates at a self-selected walking speed. When they arrived, they turned 180° on the force plate, and stopped with one foot on each plate. They remained in static stance until the 10seconds of data collection was complete (Figure 10). For the first trial, participants turned in their direction of choice. This choice of direction was determined to be their 'dominant', or 'preferred' turn direction, which remained consistent throughout the rest of the testing conditions and sessions. Following the first trial, participants were told which direction to turn prior to initiating the trial. In three of ten trials, participants were asked to turn in their 'non-dominant' direction. These walking trials + 180° turn were completed twice on week 0 (F and FO conditions), twice on week 4 (FO and FOT conditions), and once on week 5 (FOT condition only). A sample data collection sheet can be found in Appendix I.

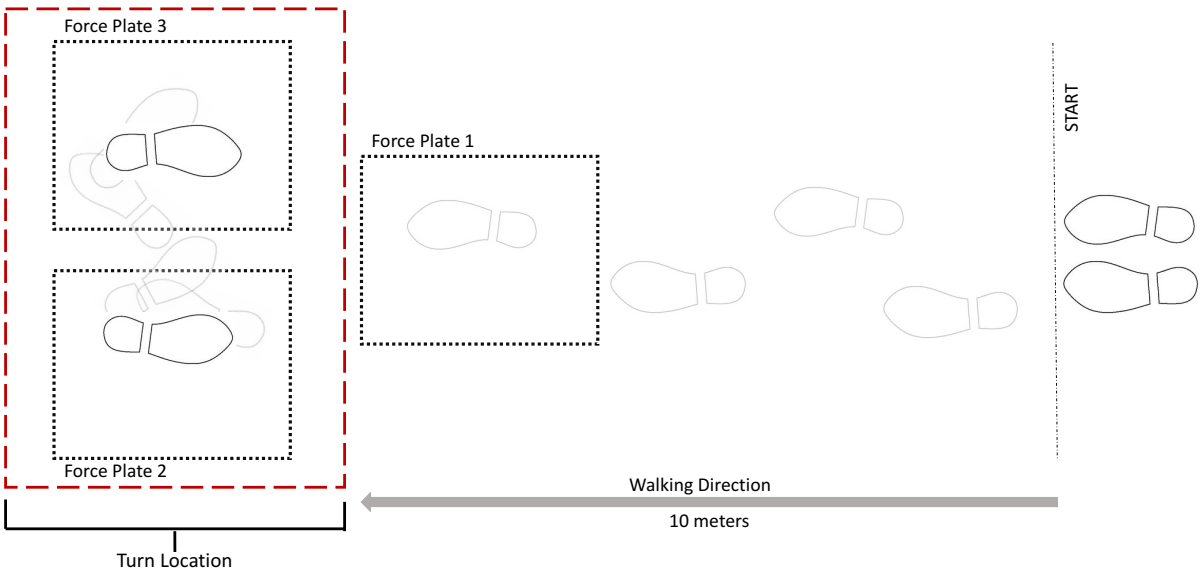

Figure 10: A graphical representation of the force plates and turn location when participants completed the walking trials + 180 degree turns.

Variables of Interest

All variables of interest were divided into three main categories: dynamic stability, turning performance, and average muscle activity. Outcome variables were isolated into two different analysis windows. The COM/BOS, average velocity, and average muscle activity, were isolated to the single stance phase of the braking step (refer to Figure 2). This braking foot was defined as the last step prior to the initiation of turning movement (torso or forefoot deviation towards the direction of the turn). Step length and step width were isolated to the step immediately following this braking step. The start of single stance was defined as the moment the contralateral limb was non-weight bearing, initiating the swing phase of gait, and cessation was defined as the moment the contralateral limb returned to ground contact. Consequently, the analysis window was the specific time in gait when only one foot was weight bearing. The variables of interest in determining dynamic stability were the maximum, minimum, and range of the COM/BOS relationship. Kinematic data was used to calculate the locations of the transverse plane COM and the lateral border of BOS. Based on each participant's anthropometric measures and foot width, the BOS was determined from the ankle and 3rd metatarsal IRED markers. This distance was translated to the lateral border of the BOS. The final values for COM/BOS maximum, minimum, and range were calculated from a custom visual basic program. Turning performance variables included step length, step width, average walking velocity, step count, and turning strategy. The average muscle activity during single stance was measured for the tibialis anterior, peroneus longus, and medial gastrocnemius muscles, bilaterally. The EMG signals were processed with an antialiasing low pass filter, using a cut off frequency of 40Hz. Muscle activity was synchronized with force plate data to ensure accuracy of the onset and offset timing of single stance. The EMG signal was normalized to the peak muscle activity, allowing comparisons between EMG data collected between participants, and across different testing sessions. EMG data was further corrected for which limb, the ipsilateral or contralateral limb, was used during the braking step. Results are expressed as a percentage of the average muscle activity that occurred during single stance of the braking step.

Data Processing

Three software programs were used in data processing. 'Optofix', a custom visual basic software program, was used to clean the data. A cubic spline interpolation was selected to join data gaps where marker values provided missing data. The "fixed" files were processes through a 'COM-12' custom program, which approximates the COM values from the optotrak markers. Lastly, the final visual basic software was customized for this experiment. Final processing synched ankle marker velocities and force plate GRF's, allowing for the extrapolation of the single stance analysis windows.

Statistical Analysis

Initially, a total of fifty-two one-way repeated measures analysis of variance (ANOVA) statistical tests were performed. These fifty-two ANOVA's were broken down into sixteen statistical tests per dependent variable; maximum ML COM/BOS, minimum ML COM/BOS, ML range COM/BOS, step count, step width, step length, average velocity, and EMG of 3 lower limb muscles, bilaterally. Subsequent analysis included twelve ANOVA's, discussed further in the discussion section of this document. SAS university edition, version 9.2, was used for all statistical analysis. The following four conditions were analyzed: acute and long-term non-textured orthotic wear, and acute and long-term textured orthotic wear. The acute non-textured orthotic results compared the variables of interest between week 0 F and FO conditions, whereas the acute textured orthotic results compared the variables between week 4 FO and FOT. The long-term non-textured orthotic results compared week 0 FO to week 4 FO, and the long-term textured orthotic results compared week 4 FOT to week 5 FOT. Consequently, these long-term results differ between comparisons: the non-textured orthotic results compare 4 weeks of FO wear, whereas the textured orthotic results compared 1 week of FOT wear. An alpha of 0.05 was set a priori. All data was inspected for outliers, and a rank-transformation was performed when the data did not meet the assumption of normality. Potential outliers were identified at two standard deviations from the means. No outliers were removed from the data set. Upon inspection of all potential outliers, these values were determined to be

representative of the variability between participants, rather than indicating an error within the data set. Consequently, this variability was considered important to retain in study results. When the differences between group means were statistically significant, a Tukey's post hoc procedure confirmed direction and significance.

All data analysis utilized a statistical model incorporating both inter-subject variability and between trial variability, for each factor. The reported error terms for the degrees of freedom (df) expressed in this document range from 83 to 126. These high values reflect a df error term that included each subject (7 participants in this study), each factor (footwear or week), and 10 walking trials per factor, providing a maximum df error term of 140. This ANOVA design was adopted to acknowledge the importance of considering both participant and walking trial variability, an important consideration in neurological populations such as PD.

CHAPTER 3: RESULTS

Postcards

As previously stated, the weekly postcards were used to continue communication with participants during the off-testing weeks, and to ensure no major changes took place in their everyday activities. All participants wrote on the postcards, or discussed during the testing sessions, the difference in thickness between the FO and FOT conditions. One participant experienced slight changes to their Levadopa medication, more specifically, this medication increased between weeks 1-2, and 4-5, by ½ a pill/dose. The FO's and FOT's were worn by all participants between 4-10 hours/day. All participants were comfortable in the FO condition; however, three participants reported discomfort while wearing the FOT. None of these participants decreased their wear time in the FOT; however, one participant reported a severe progression of discomfort through to the final week of testing. One participant experienced a fall during the study. The fall occurred during the evening hours when the participant misjudged the location of the bed. The participant was not wearing the orthotics at the time of fall and suffered no injuries from the incident. Additional participant feedback includes increased feelings of arch support during both orthotic conditions, and positive family member comments on improved walking patterns.

Four one-way repeated measures ANOVA were performed for each variable (totaling fifty-two one-way repeated measures ANOVA). Appendix J includes summary tables of all statistical results. Chapter 3 of this document details the statistical results for each variable of interest in the experimental study. Statistical significance is denoted by a star (*) on the data figures.

COM/BOS ANALYSIS

Maximum ML COM/BOS

The three variables of interest in the analysis of COM/BOS were maximum ML distance, minimum ML distance, and ML range. With the exception of the long-term non-textured orthotic condition, (Figure

11), all comparisons were non-significant. In the non-textured orthotic condition, there was a statistically significant increase in maximum ML COM/BOS distance at week 4, F(1,89)=7.46, p=.0076, ETA-square=.33 (0.1298m±0.0538) as compared to week 0 (0.1069m±0.0494). The acute wear of both non-textured orthotics (week 0-F [0.1170m±0.0478] as compared to week 0-FO [0.1069m±SD=0.0494]; week 4-FO [0.1298m±0.0538] as compared to week 4-FOT [0.1239m±0.0510]) and textured orthotics appear to slightly decrease maximum ML COM/BOS, however both non-significant. Long-term wear of the textured orthotics resulted in a slight, non-significant increase in maximum ML COM/BOS (week 4-FOT [0.1239m±0.0510] as compared to week 5-FOT [0.1317m±0.0556].

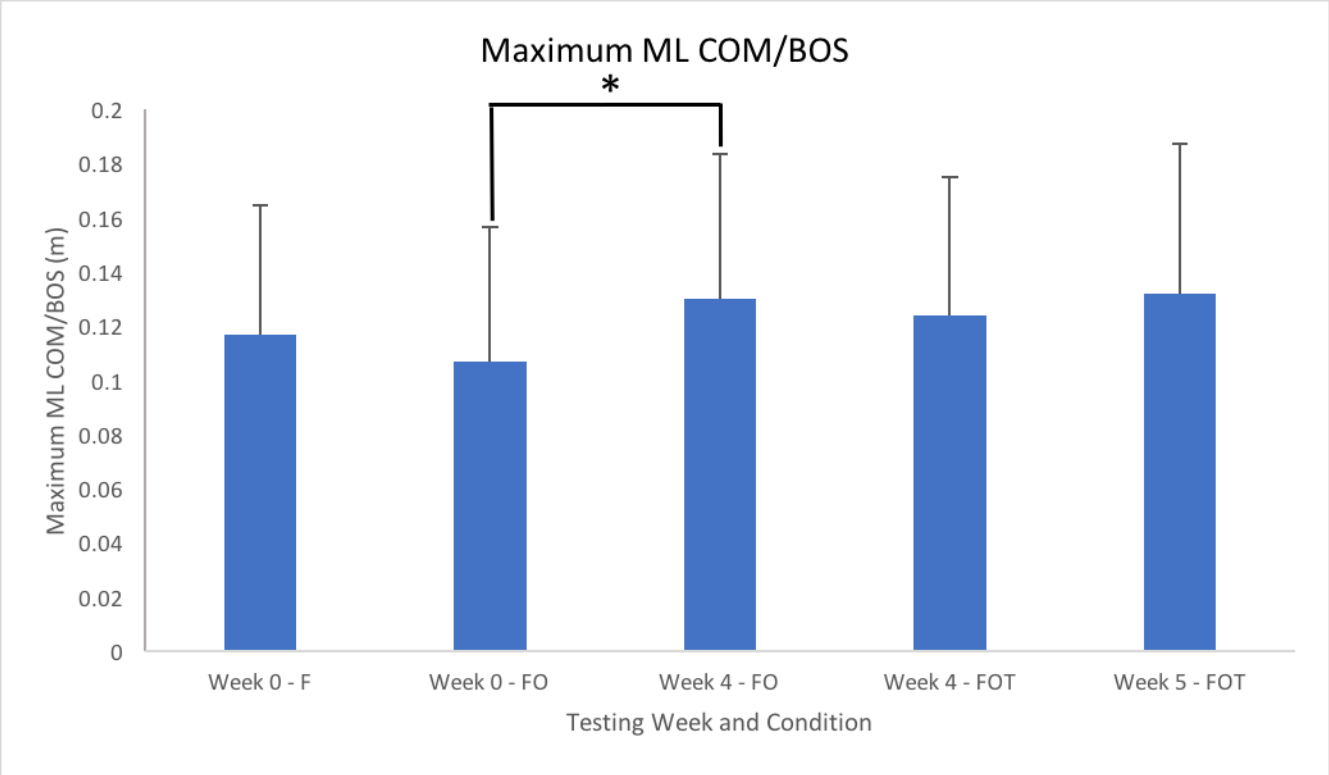

Figure 11: The maximum ML COM/BOS relationship across testing sessions (week 0, 4, and 5), and conditions (footwear only (F), non-textured orthotic (FO), and textured orthotic (FOT)) during the stance phase, of 1 step post-braking step.

Minimum ML COM/BOS

All minimum ML COM/BOS results were non-significant. Statistical results for minimum ML COM/BOS revealed small decreases in both acute orthotic conditions, (week 0-F [0.0823m±0.0426] compared to week 0-FO [0.0720m±0.0409], and (week 4-FO [0.0857m±0.0492] as compared to week 4-FOT [0.0844m±0.0485]), and small increases in both long-term orthotic conditions (week 0-FO [0.0720m±0.0409] as compared to week 4-FO [0.0857m±0.0492], and (week 4-FOT [0.0844m±0.0485] as compared to week 5-FOT [0.0874m±0.0471]).

ML Range COM/BOS

All statistic results for ML range revealed a slight increase between experimental conditions, apart from the acute textured orthotics. There was a slight decrease in ML range between week 4-FO (0.0441m±0.0259) compared to week 4-FOT (0.0395m±0.0296). All ML range COM/BOS results were non-significant.

Turning Performance Analysis

Turning performance was evaluated using turning strategy, step count, step length, step width, and average walking velocity analysis. All participants (100%) performed step turns for every trial, at each testing session, and under each experimental condition. There were a total of 416 braking steps on the right leg, and only 15 braking steps on the left leg.

Step Count

There were statistical significant decreases in step count between week 0-F (5.52steps±1.08) and week 0-FO (5.23steps±0.87) conditions, $F(1,108)=4.86$, $p=.0296$, ETA-square=.54, and between week 4-FO (5.23steps±1.31), and week 4–FOT (4.67steps±0.76) conditions, $F(1, 126)=13.21$, $p=.0004$, ETA-square=.55 (Figure 12). Small, non-significant, step count increases were observed in both long-term orthotic

conditions, (week 0-FO [5.23steps±0.87] compared to week 4-FO [5.24steps±1.31]) and (week 4-FOT [4.67steps±0.76] compared to week 5-FOT [4.73steps±0.78]).

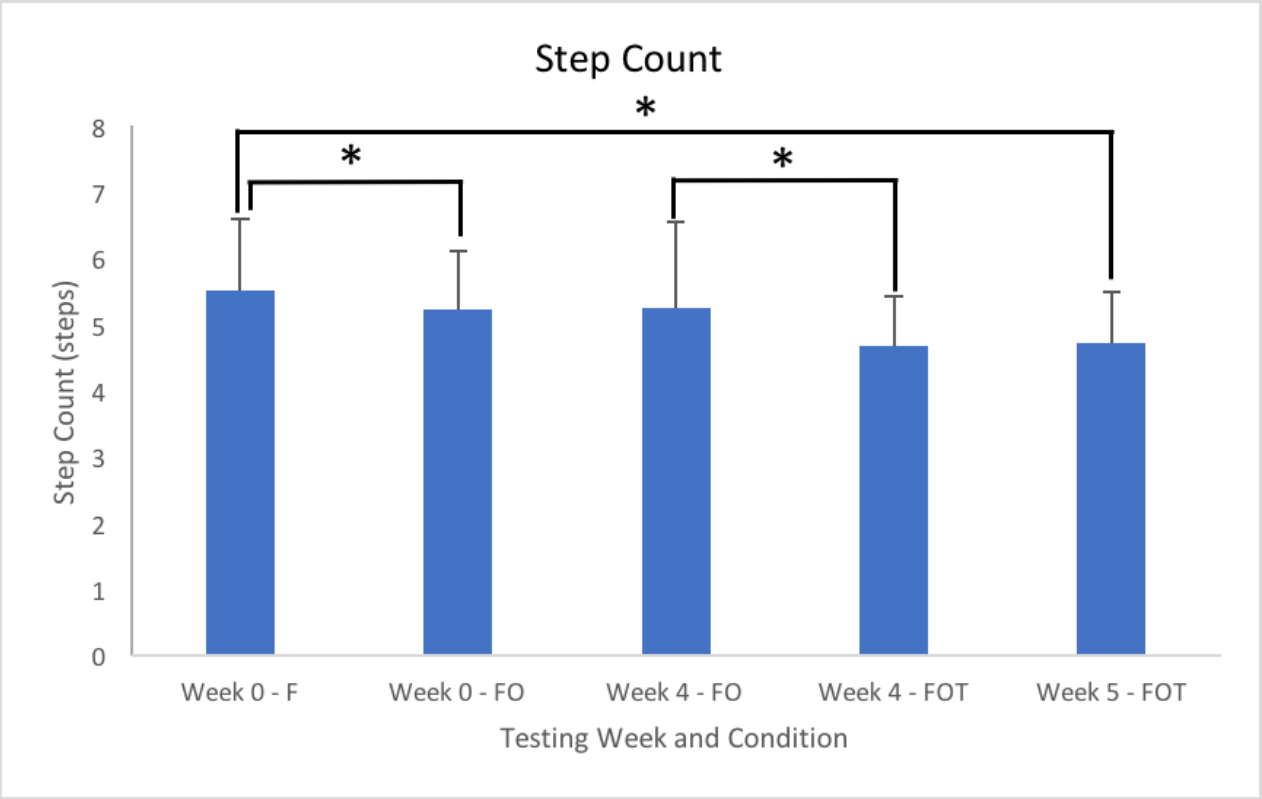

Figure 12: The average step count across testing sessions (week 0, 4, and 5), and conditions (footwear only (F), non-textured orthotic (FO), and textured orthotic (FOT)) during the stance phase, of 1 step post-braking step.

Step Length

All step length results were non-significant. There was a decrease in step length in the acute FO condition (week 0-F [0.7662m±0.4850] as compared to week 0-FO [0.7100m±0.3888]) and long-term FOT condition (week 4-FOT [0.8080m±0.3185] as compared to week 5-FOT [0.7773m±0.2693]); however an increase in step length between the long-term FO condition (week 0-FO [0.7100m±0.3888] as compared to week 4-FO [0.7952m±0.3094]), and acute FOT condition (week 4-FO [0.7952m±0.3094] as compared to week 4-FOT [0.8080m±0.3185]).

Step Width

All step width results were non-significant. Step width decreased between all comparisons, except for a slight increase between week 4-FO (0.1594m±0.0640) and week 4-FOT (0.1597m±0.0641).

Average Walking Velocity

Average walking velocity significantly decreased between week 0-F (0.9443m/s±0.1682) and week 0-FO (0.8143m/s±0.2723), $F(1,111)=16.91$, $p<.0001$, ETA square=.48, however it significantly increased between week 0-FO (0.8143m/s±0.2723), and week 4-FO (0.9180m/s±0.2196), $F(1,116)=12.20$, $p=.0007$, ETA square=.66 (Figure 13). Non-significant increases were observed between both FOT conditions (week 4-FO [0.9180m/s±0.2196] compared to week 4-FOT [0.9512m/s±0.2074]) and (week 4-FOT [0.9512m/s±0.2074] compared to week 5-FOT [0.9524m/s±0.1858]).

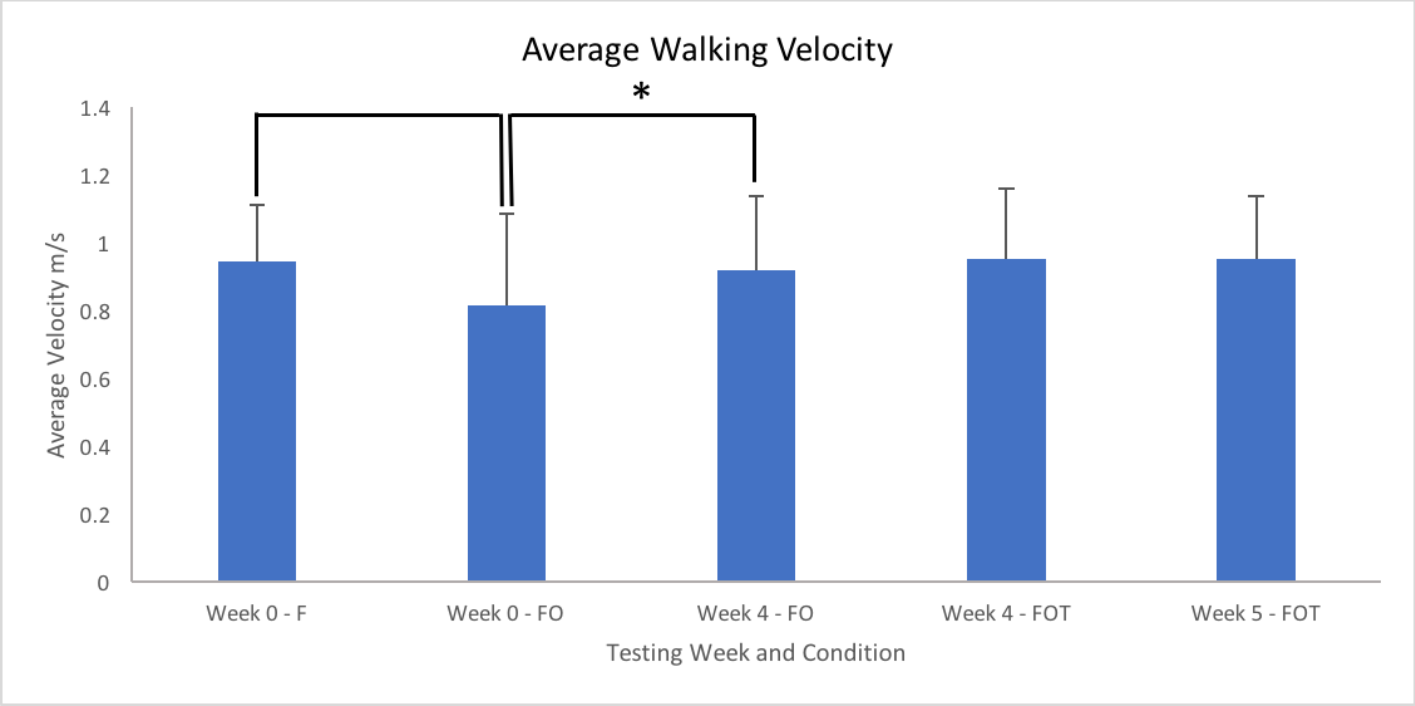

Figure 13: Average velocity during the first stance phase of the stepping strategy.

EMG Analysis

Statistical analysis was performed on the measurement of the average activation magnitude of six lower leg muscles; the ipsilateral and contralateral tibialis anterior, medial gastrocnemius, and peroneus longus. Results of the average EMG activity during the single stance phase of the gait cycle were expressed as a percentage of the peak EMG activation that occurred during the entire trial of interest (normalized). As most braking steps were performed on the right foot, the right limb musculature was mostly activated during weight-bearing single stance. There was large participant variability across all testing sessions and experimental conditions. See figure 14 for a sample of force plate data and EMG data.

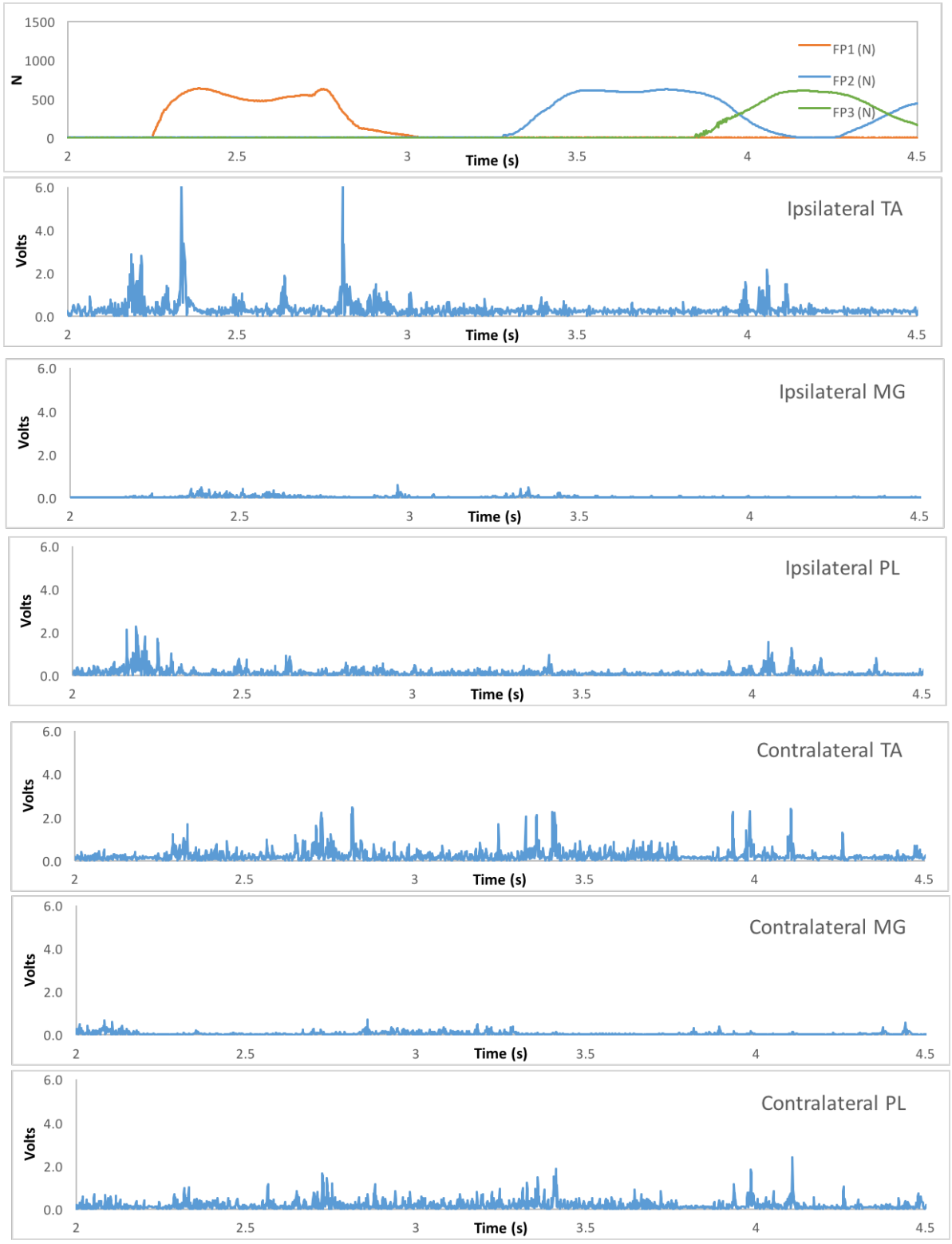

Figure 14: The timing of force plate contact synched with EMG results (TA = tibialis anterior; MG = medial gastrocnemius; PL = peroneus longus). The ipsilateral and contralateral muscle activity is demonstrating during single stance contact on force plate 1 and force plate 2.

Ipsilateral Tibialis Anterior

Average ipsilateral tibialis anterior muscle activity significantly increased between week 0-FO (4.75%±2.48) and week 4-FO (6.59%±3.40), $F(1,125)=17.42$, $p<.0001$, ETA-square=.42 (Figure 14). All other comparisons were non-significant. Average muscular activity for the ipsilateral tibialis anterior decreased in both acute orthotic conditions, FO (week 0-F [6.04%±5.6] as compared to week 0-FO [4.75%±2.48]) and FOT (week 4-FO [6.59%±3.40] as compared to week 4-FOT [6.04%±3.54]). These results were insignificant, along with the slight increase in muscular activity observed with long-term textured orthotic wear (week 4-FOT [6.04%±3.54] compared to week 5-FOT [6.84%±4.04]).

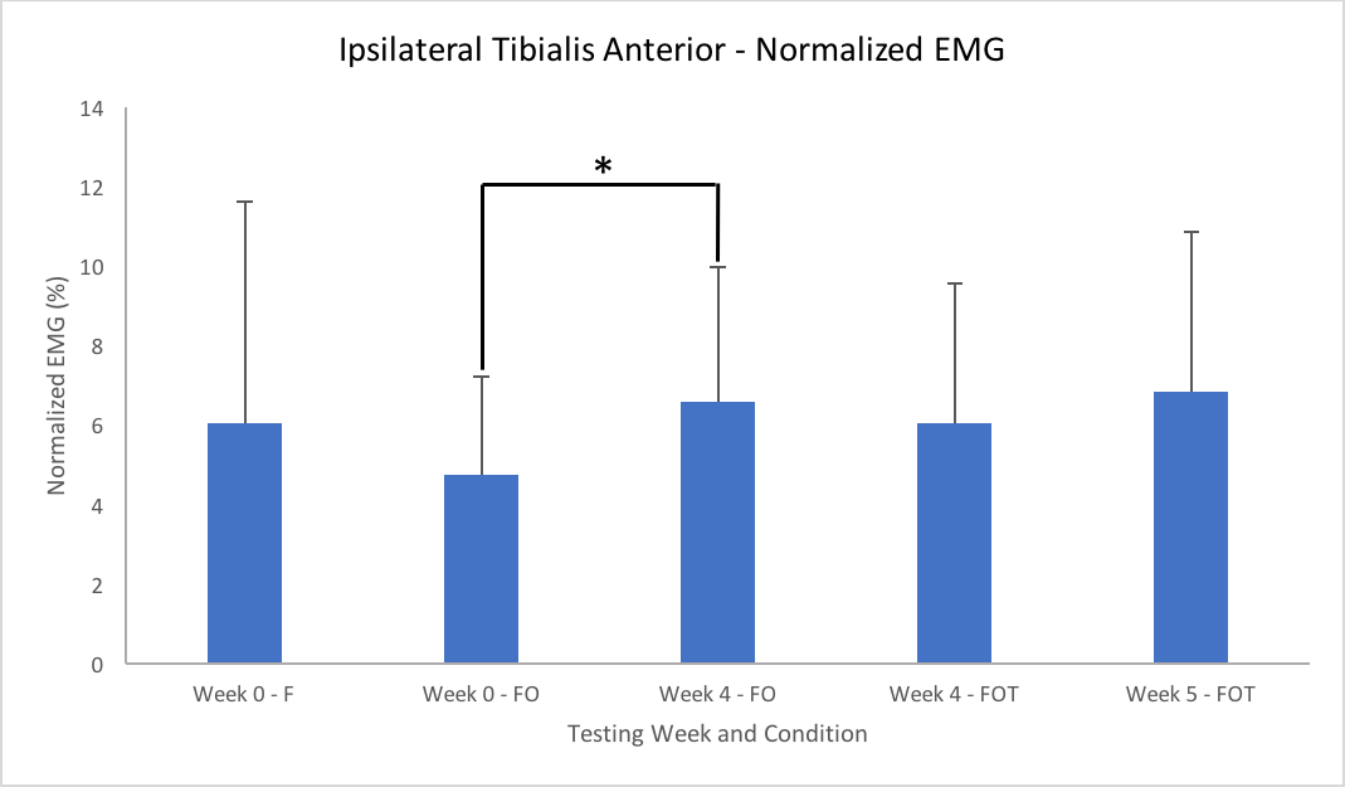

Figure 15: The averaged ipsilateral tibialis anterior muscle activity during the first stance phase of the stepping strategy.

Ipsilateral Medial Gastrocnemius

Statistical significance was observed in all ipsilateral medial gastrocnemius analyses, apart from acute FOT, (week 4-FO [4.39%±2.04] as compared to week 4-FOT [4.69%±2.04]). There was a statistical significant increase in average muscle activity of the ipsilateral medial gastrocnemius between week 0-F (4.91%±2.24) and week 0-FO (5.96%±3.48) F(1,124)=5.75, p=.0180, ETA-square=.39, and between week 4-FOT (4.69%±2.04) and week 5-FOT (5.97%±2.72), F(1,126)=11.67, p=.0009, ETA-square=.18. There was a significant decrease in average muscle activity of the ipsilateral medial gastrocnemius between week 0-FO (5.96%±3.48) and week 4-FO (4.39%±2.04), F(1,125)=14.52, p=.0002, ETA-square=.41 (Figure 15).

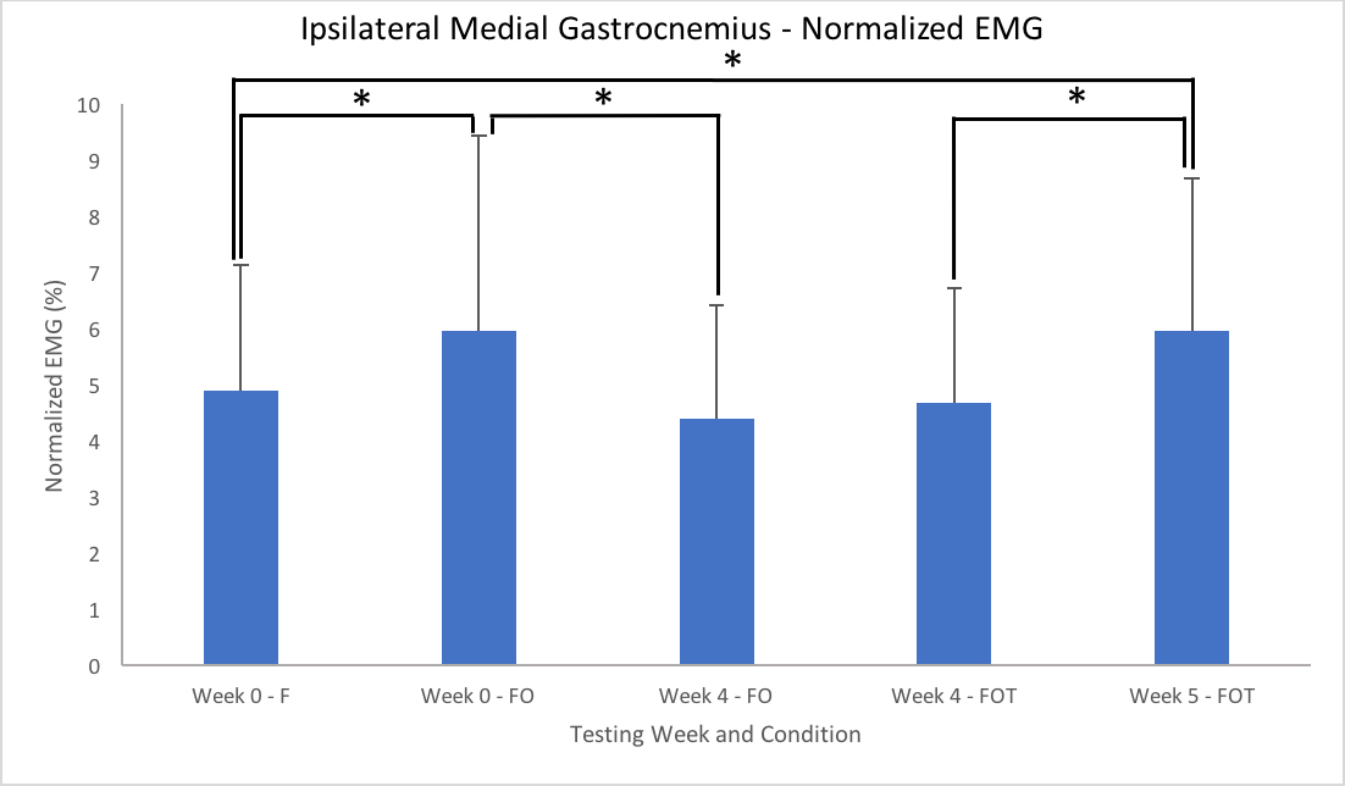

Figure 15: The averaged ipsilateral medial gastrocnemius muscle activity during the first stance phase of the stepping strategy.

Ipsilateral Peroneus Longus

Statistical significance in average muscle activity of the ipsilateral peroneus longus was observed in the same three comparisons as the ipsilateral medial gastrocnemius. There was a statistically significant decrease in average muscle activity of the ipsilateral peroneus longus muscle between week 0-F (8.57%±4.92) and week 0-FO (7.13%±3.02), F(1,124)=4.13, p=.0442, ETA-square=.20, and between week 4-FOT (8.94%±3.29) and week 5-FOT (7.23%±2.50), F(1,126)=14.37, p=.0001, ETA=square=.25. There was a statistically significant increase in average muscle activity of the ipsilateral peroneus longus muscle between week 0-F0 (7.13%±3.02) and week 4-FO (8.51%±3.07), F(1,125)=10.33, p=.0017, ETA-square=.26 (Figure 16). An insignificant increase in average muscle activity of the ipsilateral peroneus longus was observed between week 4-FO (8.51%±3.07) and week 4-FOT (8.94%±3.29).

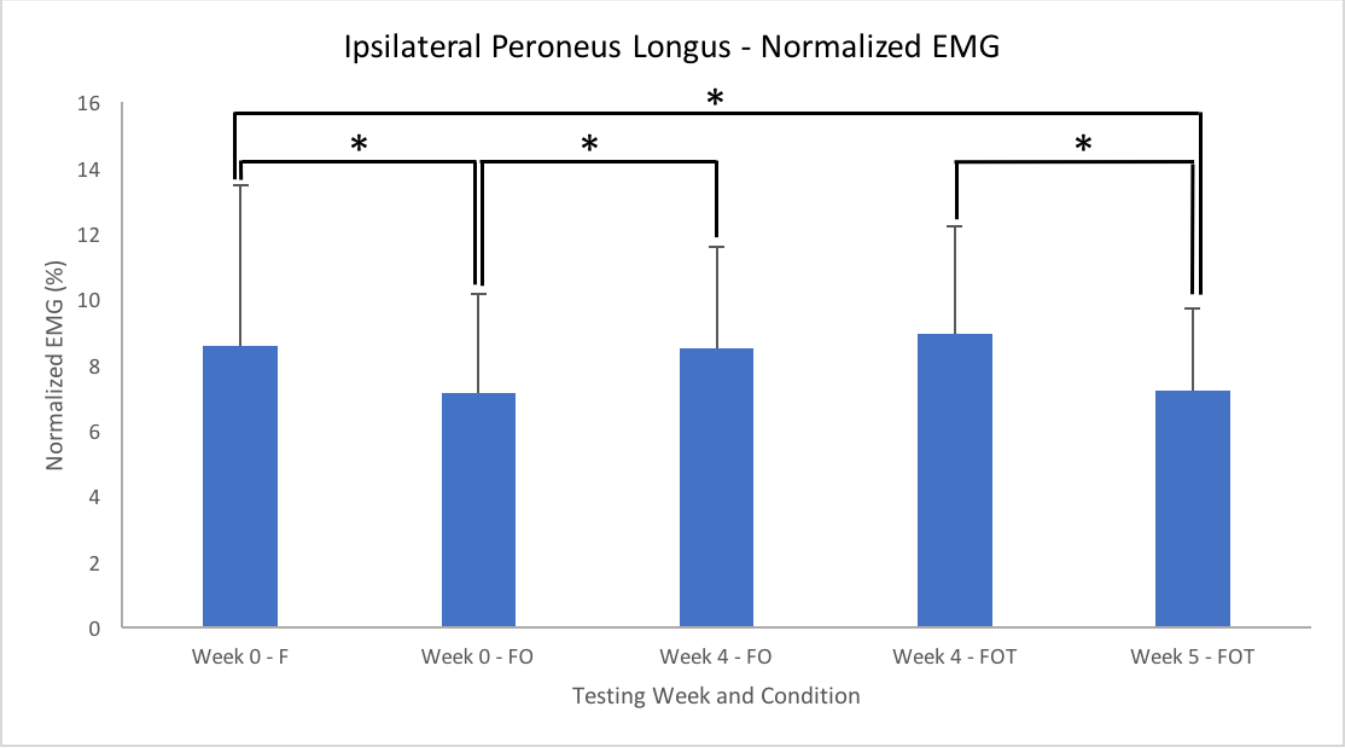

Figure 16: The averaged ipsilateral peroneus longus muscle activity during the first stance phase of the stepping strategy.

Contralateral Tibialis Anterior

Statistically significant increases in average muscle activity of the contralateral tibialis anterior muscle were observed in both FO comparisons, and non-significant decreases in both FOT comparisons. There was a statistically significant increase in average muscle activity of the contralateral tibialis anterior muscle between week 0-F (5.60%±5.30) and week 0-FO (6.44%±4.81), F(1,125)=6.03, p=.0154, ETA-square=.60, and between week 0-FO (6.44%±4.81) and week 4-FO (6.99%±3.14), F(1,126)=5.74, p=.0181, ETA-square=.52 (Figure 17). Non-significant decreases in average muscle activity of the contralateral tibialis anterior muscle was observed between week 4-FO (6.99%±3.14) and week 4-FOT (6.69%±4.02), and between 4-FOT (6.69%±4.02) and week 5-FOT (5.60%±5.30).

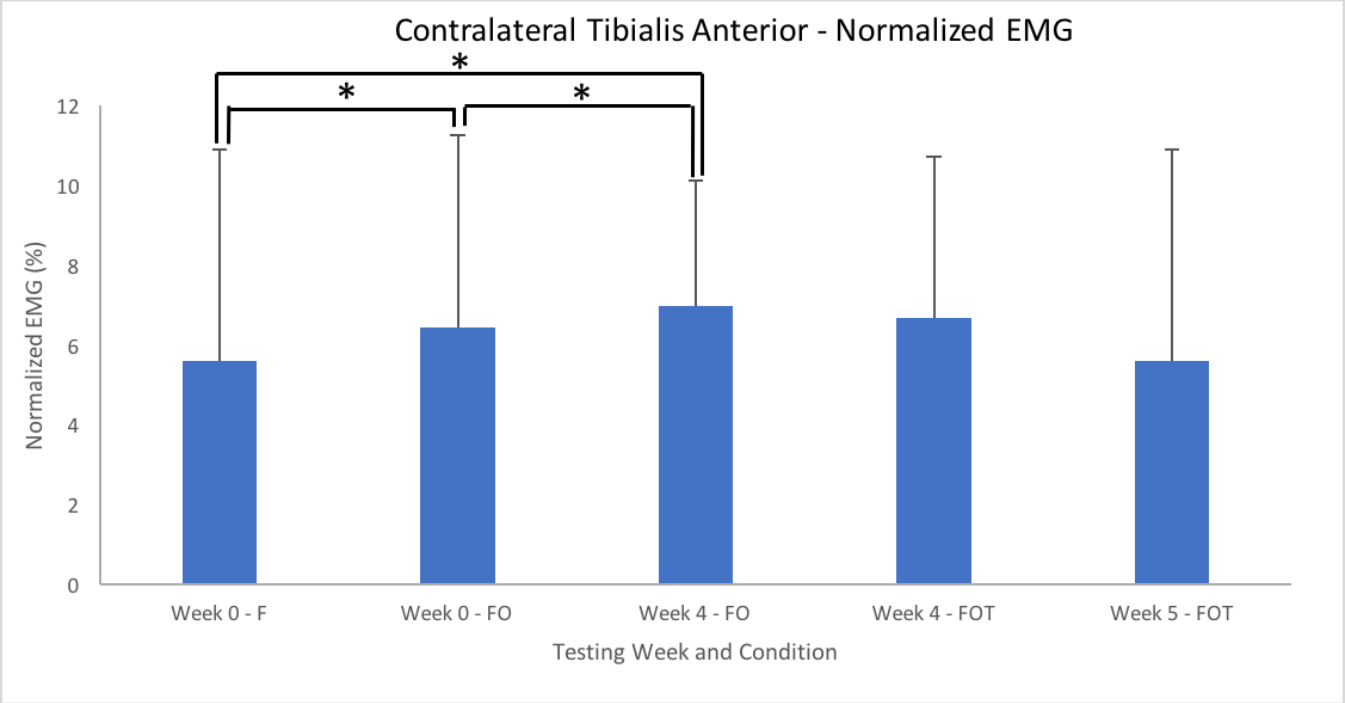

Figure 17: The averaged contralateral tibialis anterior muscle activity during the first stance phase of the stepping strategy.

Contralateral Medial Gastrocnemius

All contralateral medial gastrocnemius results were non-significant. Average muscle activity of the contralateral medial gastrocnemius muscle slightly increased in acute FO (week 0-F [5.21%±3.51] as compared to week 0-FO [5.39%±3.34]) and acute FOT (week 4-FO [5.04%±2.36] as compared to week 4-FOT [5.26%±2.55]) conditions, and slightly decreased in long-term FO (week 0-FO [5.39%±3.34] as compared to week 4-FO [5.04%±2.36]) and FOT (week 4-FOT [5.26%±2.55] as compared to week 5-FOT [4.63%±3.11]) conditions.

Contralateral Peroneus Longus

Similar non-significant results were observed in the average muscle activity of the contralateral peroneus muscle. Small, non-significant, muscle decreases were observed in both acute FO (week 0-F [7.53%±3.90] as compared to week 0-FO [7.33%±3.47]) and FOT conditions (week 4-FO [7.50%±2.93] as compared to week 4-FOT [7.35%±3.14]), and small, non-significant, muscle increases in both long-term FO (week 0-FO [7.33%±3.47] as compared to week 4-FO [7.50%±2.93]) and FOT conditions (week 4-FOT [7.35%±3.14] as compared to week 5-FOT [8.04%±3.97]).

CHAPTER 4: DISCUSSION

The purpose of this study was to evaluate turning behavior in PD participants between three different conditions: footwear only (F), non-textured orthotics (FO), and textured orthotics (FOT), and further subdivide these results between acute and long-term turning behavior. When individuals are required to change direction, the planning of direction change is initiated and programmed in the steps preceding the turn (Patla, Prentice, Robinson, & Neufeld, 1991). Consequently, the analysis of braking steps prior to turning movement are important analysis windows in understanding turning behavior. From a clinician's perspective, this experimental study provides two different sets of information. Acute FO and FOT results provide a greater understanding of the neuromuscular changes and adaptation process that a bodily system experiences when initially wearing a foot orthotic. However, these acute results were observed after only minutes of wearing the orthotics, and rarely will foot orthotics be used as such a short-term intervention strategy. Thus, these acute changes are important for clinicians to appreciate the orthotic adaptation process; however, the long-term FO and FOT results provide greater insight into using orthotics as a potential intervention strategy in Parkinson's disease. Consequently, this discussion is divided into the acute and long-term foot orthotic conditions.

Acute Non-Textured Foot Orthotics–Comparison Between Week 0-F and Week 0-FO

The experimental design of this study is important to note when considering the acute non-textured orthotic condition. Study inclusion insisted that participants had never worn orthotics previously, suggesting that all participants were naïve to orthotics until these first few minutes in the biomechanics lab. The COM/BOS analysis revealed slight decreases in maximum and minimum ML movement, and an increased ML range. Although non-significant, these results suggest a slight increase in instability when first wearing the orthotics. Without statistical significance, it is important to acknowledge these result as speculative. However, in considering the relationship between all COM/BOS variables, this interaction

provides compelling clinical knowledge. Turning performance behavior is consistent with these findings; when initially wearing the foot orthotics, participants' walking velocity significantly decreased. It appears that a more hesitant walking behavior occurred when an adaptation to the orthotics was required. PD subjects compensated for the decrease in stability, noted by the decrease in stability margin, by altering gait velocity to complete the turn task.

Interestingly, significant decreases in step count suggests that participants took fewer steps to complete the turns. Previous turning performance literature highlights the importance of self-perceived confidence in the ability of individuals with Parkinson's disease to complete turns. PD participants with self-reported turning difficulties require more steps to successfully perform a turn (Stack et al., 2006). Consequently, the current study results suggest that the balance disturbances (non-significant COM/BOS results) were not large enough to effect participant's self-perceived confidence to complete the task, however compensatory behaviors occurred to safely perform the turning movement.

All EMG was analyzed during the single stance phase of the braking step; i.e., the final forward facing step prior to initiating the turn. As most braking steps were performed on the ipsilateral foot, the ipsilateral limb musculature was activated in single stance weight-bearing, whereas the contralateral limb was in the swing phase of the gait cycle. A small non-significant decrease in ipsilateral tibialis anterior activity was noted; however more importantly, ipsilateral medial gastrocnemius activity significantly increased, whereas ipsilateral peroneus longus activity significantly decreased. These results suggest a greater magnitude of lower leg posterior compartment muscle activation, accompanied by a decrease in lateral compartment activation. When considering the role of the medial gastrocnemius in single stance, we can hypothesize this increased activity occurred at toe-off. This is simply a hypothesis, and cannot be inferred as a definitive conclusion until closer analysis of the muscular activity within each individual stance phase period is examined. This is important to note, as lower limb muscles have a phase dependency within single stance, and their primary role changes throughout the gait cycle. The decrease in peroneus longus activity may be a result of the orthotic causing a subtalar joint position change to the foot. The foot

orthotic raised the medial longitudinal arch, increased subtalar joint supination, and consequently decreased the peroneus longus demands to resist the supinatory forces generated by the posterior compartment musculature (Michaud, 1997). Furthermore, the orthotics have a mechanical role in changing the orientation of foot structures. As these 1% changes in muscular activity are expressed as an average across participant's stance phase, these small numerical percentages may significantly alter limb movement.

A significant increase in contralateral tibialis anterior muscle activation was observed in the swing phase of the gait cycle. Anterior compartment muscle activity in the swing phase of gait is quite typical, and tibialis anterior activity in PD individuals is generally overactive (Dietz, 1997). A potential explanation for this drastic increase in muscle activity, is the orthotic providing the sensation of greater muscle firing required to make the same amount of ground clearance as without the orthotic. Non-significant changes were observed in the contralateral medial gastrocnemius and peroneus longus muscles in the swing phase of gait.

Acute Textured Foot Orthotics–Comparison Between Week 4-FO and Week 4-FOT

The acute textured orthotics results compare 4 weeks of orthotic wear, to initially placing the textured orthotics under participant's feet. The dynamic balance analysis showed small, non-significant decreases across all COM/BOS variables, ML maximum, minimum, and ML range. These results are consistent with the COM/BOS changes during the acute non-textured condition, whereby the balance system felt a slight threat to dynamic stability. These non-significant results can be interpreted similarly to the acute non-textured condition, whereby the interaction of all three COM/BOS variables provide clinical insight into the balance system changes when initially exposed to texture. Positive outcomes were observed in turning performance, with a significant reduction in step count and an increase in walking velocity. This ambulatory performance suggests an increased confidence in the steps preceding turns, an important consideration in decreasing fear of falling in PD individuals (Lindholm et al., 2014).

Furthermore, we can speculate this acute increase in somatosensory feedback is a result of the added texture to the orthotic device. Specific to the turning performance variables (step count and average velocity), the increase in somatosensory feedback played a positive role in the postural system's ability to facilitate balance control.

Electromyography results are similar between acute non-texture and textured orthotic conditions. Slight changes between average muscle activity are observed; however, these could be equally attributed to the differences between participants then to the addition of texture to the orthotics. The addition of texture to the orthotics, and consequent increase in somatosensory feedback, appeared to have no effect on motor neuronal output. Minimal changes in step length and width were observed in both acute orthotic conditions.

Long-Term Non-Textured Foot Orthotics – Comparison Between Week 0-FO And Week 4-FO

All participants wore the non-textured foot orthotic for four weeks. In the analysis of COM/BOS, long-term FO wear resulted in a significant increase in maximum ML, and small non-significant increases in minimum ML and COM/BOS ML range. In returning to the adopted definition of stability, a body is considered balanced when the COM falls within the BOS. More specifically, a body is considered more stable when the distance between the COM and the lateral base of support increases, consequently increasing the stability margin (Perry et al., 2008). Study results indicate larger maximum ML COM/BOS values in the long-term FO condition, suggesting that participants experienced increased stability with prolonged orthotic wear. It is important to note, that these results are being compared to the acute FO condition, which experienced a slight decrease in maximum ML data. Improvements in COM/BOS are also observed when compared to the Week 0-F condition. Turning performance results reflect a similar interpretation. Step count between acute and long-term orthotic wear are very similar; however significantly less steps were used to complete turns compared to the footwear only condition. Consistent with acute findings, no changes were noted in step length and width.

The observed changes in walking velocity are quite interesting. Long-term orthotic wear (week 4-FO) revealed significant increases in walking velocity compared to the acute orthotic condition (week 0-FO). However, the average velocity in the week 4-FO condition is still slower than the week 0-F condition. These results suggest that participant's walking speed was faster with long-term orthotic wear compared to short-term wear; however, speed had yet to return to their normal walking velocity in the footwear-only condition. Participants were still adopting a more cautious walking pattern 4 weeks after wearing the orthotics.

EMG analysis in the long-term orthotic condition revealed significant increases in ipsilateral tibialis anterior and ipsilateral peroneus longus average muscle activation, accompanied by significant decreases in ipsilateral medial gastrocnemius activity. During typical static stance perturbations, the gastrocnemius has a strong compensatory reaction, followed by increased tibialis anterior activation. In Parkinson's disease individuals, this secondary tibialis anterior activation is stronger than in healthy age-matched controls (Dietz, Zijlstra, Assaiante, Trippet, & Berger, 1993). Decreased medial gastrocnemius activity is a positive suggestion that muscular response is not compensatory in nature; however, without isolating results to the specific phases of static stance, this interpretation is speculative in nature. If this interpretation is accurate, the increased tibialis anterior activity can be attributed to the increased sensory response between the plantar foot sole and orthotic device. A possible explanation for this muscle activity behavior, is the increased demand of tibialis anterior in decelerating the forefoot to the ground. As previously explained, the foot orthotic places the subtalar joint in a more supinated position, and the peroneus longus may partially resist this supinatory action. In comparing week 0-FO to week 4-FO, significant increases in peroneus longus activity are noted. However, when comparing these mean values to week 0-F, peroneus longus activity has simply returned to baseline values (footwear only condition), suggesting adaptation throughout the 4-weeks of orthotic wear.

Long-Term Textured Foot Orthotics – Comparison Between Week 4-FOT and Week 5-FOT

All dynamic balance variables, including maximum, minimum, and ML range, progressively improved throughout each orthotic condition in the study (See COM/BOS results in tables 3, 4, and 5). Significant difference between acute FOT and long-term FOT conditions were not observed, however I would argue that clinically important changes are observed between both long-term FO/FOT and footwear-only conditions. Consistent with previous research, this continued improvement suggests that postural control progressively improved with long-term orthotic wear, and with the addition of texture (Jenkins et al., 2009). I would encourage the consideration of a participant's foot width in evaluating the COM/BOS results. Two-centimeter changes are being observed between COM/BOS variables. It remains at the discretion of clinicians to determine if these differences are clinically significant, and if there is practical application in patient treatment. A continued decrease in step count was progressively observed throughout the study; however minimal changes were noted between acute and long-term FOT conditions. The 1 week of FOT wear had minimal effect on step count; however there remained approximately 1 step less in turn completion compared to the footwear only condition. A small progressive decrease in step width is observed, along with minimal, non-significant changes to step length. In this final testing week, participant's average walking velocity resulted in small increases in speed compared to acute FOT, and returned to similar values as the footwear-only condition. Overall, PD individuals demonstrated mean increases in the COM/BOS variables, along with decreases in step count and a return to normal average walking velocity. These long-term FOT results suggests that adding texture under the plantar foot sole had a role in increasing somatosensory activity, and further facilitating motor response. This is an interesting consideration for future textured top cover research.

In EMG analysis, the average muscle activity of the ipsilateral tibialis anterior consistently increased. Greater muscle activity is suggestive of a greater need to decelerate ankle dorsiflexion, implying that long-term use of orthotics may help PD individual's reach a more typical heel-to-toe walking pattern. Secondly, the average muscle activity of the contralateral tibialis anterior, during the swing phase of gait,

has returned its activity to baseline (week 0-FO). The medial gastrocnemius activity remained activated. Once again, it is hypothesized that this increased activity occurred at toe-off. This behavior is consistent with the observed increase in walking velocity; however, a closer breakdown of timing in the stance phase is required to make definitive conclusions. A consideration of muscular co-contraction and the activity of agonist vs. antagonist muscle activity merits closer analysis.

The textured orthotics weight and volume within participant's footwear are important considerations when evaluating these long-term FOT results. The difference in weight between the Sole orthotic with and without texture was 131.4g. Without the comparison of different weighted orthotics, we cannot attribute EMG results solely to long-term FOT exposure. Larger changes in EMG activity are expected during the swing phase of gait (as the limb is required to lift greater weight off the ground), however muscular fatigue could equally occur with prolonged FOT wear. Secondly, the textured orthotics filled greater volume within participant's footwear compared to the FO condition. Experimental studies and footwear reviews have evaluated various footwear features in hopes to optimize balance in older adults. The literature suggests that harder midsole materials and low heel collars improves dynamic stability (Branthwaite, Chockalingam, Greenhalgh, et al., 2013; Hijmans, Geertzen, Dijkstra, & Postema, 2007; Perry, Radtke, & Goodwin, 2007). The FOT condition had a harder durometer than the footwear only condition (F), however greater material compliance than the FO condition. Maximizing forefoot volume within a shoe's toe box decreases the likelihood of unwanted forefoot pressure (Branthwaite, Chockalingam, & Greenhalgh, 2013). When comparing previous literature to the thickness and weight of the textured orthotics, further research into the textured top cover selection is required to maximize balance improvements.

Additional Observations

The step turn strategy was adopted consistently across all experimental conditions. Minimal conclusions can be made regarding stepping strategy, as this appeared to be the preferred turning behavior

prior to both orthotic interventions. As the step turn is considered more stable than the spin turn, it is not surprising that Parkinson's individuals self-select this turning behavior. Interestingly, the step turn was adopted regardless of braking foot side and/or turn direction. With the majority of participants using their ipsilateral limb as the braking foot, these results suggest an adaptation in walking behavior occurred in the ambulation preceding the braking step. When turning in their non-dominant direction, stride length or walking velocity adapted to ensure their ipsilateral limb was the final forward facing step prior to initiating the turning movement. It is unclear if this behavior was a conscious compensatory change or a neuromuscular adaptation to the preferred braking limb.

Final Remarks

When initially placing foot orthotics (non-textured or textured) under PD participant's feet, it appeared the body felt a small threat to its balance system. Dynamic stability experienced a slight disturbance; however, posed no detrimental threats to turning performance behavior. Rather than interpreting these results negatively, I would encourage an evaluation of the neurological system's response to balance equilibrium. A potential explanation for this disturbance is the nervous system signaling the need for a balance adaptation, as a method of returning the body to its more comfortable state of equilibrium. Changes in muscle activity are required to regulate the relationship between the COM and BOS (Maki & McIlroy, 1996). These results suggest that the acute wear of orthotics, with and without texture, triggers a neuromuscular compensatory reaction, whereby the body is required to adjust its state of equilibrium. Muscular adaptation appears complete during the long-term FO condition, and adding texture to the orthotics appeared to increase the sensory information available to the motor system, facilitating the central nervous system's ability to adapt to postural changes. See Figure 22.

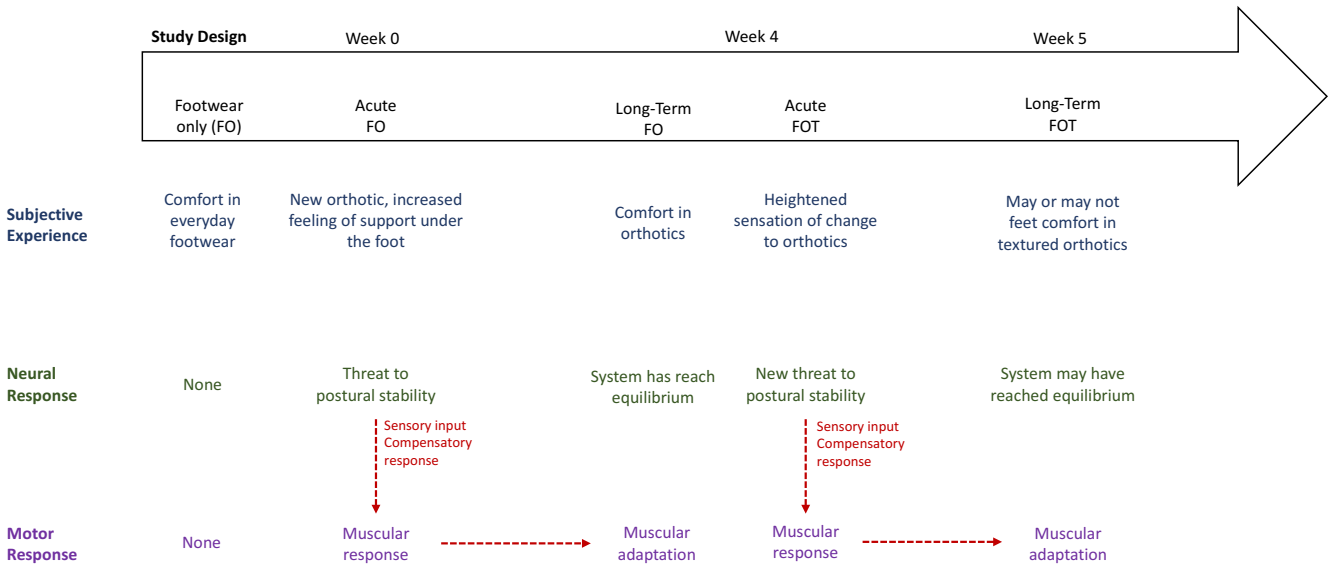

Figure 18: A graphical interpretation of the neuromuscular changes across orthotic conditions.

Consequently, there appeared to be no negative effects from both acute orthotic considerations; an important finding for rehabilitations professionals. The small balance fluctuations in the acute stages of orthotic wear can be communicated to patients when initially dispensing orthotics. Prolonged orthotic wear appeared to regulate these fluctuations. To further understand these results, a final statistical analysis was run between baseline, week 0-F and long-term textured orthotics, week 5-FOT (see Appendix K for complete result table). The FOT condition appeared to significantly increase the COM/BOS ML range and significantly decrease step count. This is suggestive of greater COM/BOS between-condition variability, and improved walking confidence when completing the turns. Statistical significance is observed across all ipsilateral musculature. Increased activity is observed in the tibialis anterior and medial gastrocnemius muscles, with a decreased activity in the peroneus longus. The addition of texture to the orthotics appeared to increase sensory input, consequently increasing motor output availability.

CHAPTER 5: CONCLUSIONS

The balance impairments of individuals with Parkinson's disease are a large contributing factor to increased fall risks. The somatosensory system's role in balance control, and manipulations at the plantar sole of the foot, has proven effective in facilitating sensory response. These study results suggest that orthotics and added texture may increase sensory augmentation, and provide a potential treatment option for PD. This is the first study to combine orthotics and added texture towards the improvement of balance parameters, in either non-pathological or pathological populations.

The use of non-textured foot orthotics appeared to impair stability short-term; however, improve long-term stability. Similar patterns were observed with the addition of texture, with greater stability improvements in the textured condition. Regardless of non-significant findings among some balance variables, these results increase our clinical understanding of the underlying adaptation process to acute and long-term orthotic wear. Improvements in turning performance were noted by a decreased step count and increased walking velocity. Progressive improvements were observed across conditions, suggesting larger improvements are associated with prolonged orthotic (non-textured and textured) wear. Both orthotic conditions altered the average magnitude of key lower limb muscles during single stance. Isolating muscular activity to distinct phases within single stance, will further clarify specific muscular behavior during ambulation.

Clinically, the addition of texture to orthotics may be a way to facilitate the sensory system to increase motor output in PD individuals, while retaining similar balance and performance benefits as non-textured orthotics. It is important to note that this interpretation cannot be generalized to all orthotic scenarios; however, can be applied to PD turning behavior. Secondly, the differentiation between statistical significance versus clinical significance should be highlighted. Statistical significance is not observed across all COM/BOS variables, however a 2cm difference within this vulnerable population is an improvement in the right direction. For rehabilitation professionals, these results provide initial evidence of using orthotics, with and without a textured top cover, as a cost-effective treatment option for PD patients. Non-textured

and textured orthotics appear to have improved gait parameters and dynamic balance, which can hopefully translate into decreased fear of falling and improve PD individual's quality of life.

Limitations

This research study leaves a few questions unanswered. Does an individual require an initial accommodation period to non-textured orthotics, prior to adding a textured top cover? This study demonstrated an important accommodation period, whereby the body required time to adapt to the changes under the plantar sole of the foot. The textured orthotics were dispensed following this non-textured orthotic accommodation period. If textured orthotics were dispensed without prior foot orthotic experience, would this accommodation period increase? I would exercise caution in the immediate dispensing of textured orthotics in these conditions, as it remains unclear if the threat to balance disturbances would be large enough to increase fall risks.

The results of this study are limited to idiopathic Parkinson's patients. Further research is required for individuals diagnosed with early onset PD and to generalize these results to healthy older adults. EMG muscle activity is only being recorded for three muscles: the tibialis anterior, peroneus longus, and gastrocnemius. Previous research has revealed a decrease in muscular activity to these muscles under diminished cutaneous sensation (Eils et al., 2004), and consequently, were intentionally selected in this study. Further research could evaluate the effects of orthotics, with and without a textured top cover, on other lower limb muscles.

The role of footwear merits discussion, as participants wore their own walking shoes in the study. Variations in participant's footwear are unavoidable and important to highlight as a study limitation. Footwear has shown to play a role in increasing somatosensory response in older adults, by improving lateral stability, thus decreasing fall risks within this demographic (Hatton, Rome, Dixon, Martin, & McKeon, 2013). Secondly, participants were asked to wear footwear during 95% of their weight-bearing activities. In other words, footwear was worn in and out of the house, not a typical behavior for all study participants. If the supportive footwear increased self-perceptions of support and walking self-efficacy, these factors

alone could have decreased fear of falling. Consequently, within this study, it is difficult to isolate the influence of orthotics alone, and footwear must be taken into consideration when interpreting results.

Future Research

This research study opens the door to additional research questions. As mentioned throughout this thesis, the EMG activity within individual phases of single stance is an important next step in understanding muscular behavior. The turning tasks were a planned behavior, whereby participants balance system had the ability to pre-program and adapt to the upcoming turning task. Future research can consider the effects of neurological control on preplanned tasks versus those that pose a larger threat to the disturbance of the balance system. Variables of interest were isolated to the braking foot, the final forward facing step prior to initiating the turn. Additional research is required during different analysis windows, more specifically, the stance phases of each step completing the turn.

Additional research is required in orthotics and textured top covers. The optimal combination of orthotic + textured top cover remains undetermined. It is unclear if larger benefits would be observed between custom orthotics and over-the-counter devices. Furthermore, different top cover materials, textured designs, and weight of materials, all merit further exploration. Lastly, the benefits of textured orthotic are worth exploring in other neurological disorders and healthy populations.

REFERENCES

Anderson, K. E. (2015). Neurobehavioral Disorders Associated with Basal Ganglia Lesions. In *Parkinson's Disease & Movement Disorders* (sixth, pp. 14–16). Philadelphia, PA: Wolters Kluwer.

Ashburn, A., Stack, E., Ballinger, C., Fazakarley, L., & Fitton, C. (2008). The circumstances of falls among people with Parkinson's disease and the use of Falls Diaries to facilitate reporting. *Disability and Rehabilitation*, *30*(16), 1205–1212.

Bloem, B. R., Hausdorff, J. M., Visser, J. E., & Giladi, N. (2004). Falls and freezing of Gait in Parkinson's disease: A review of two interconnected, episodic phenomena. *Movement Disorders*, *19*(8), 871–884. https://doi.org/10.1002/mds.20115

Branthwaite, H., Chockalingam, N., & Greenhalgh, A. (2013). The effect of shoe toe box shape and volume on forefoot interdigital and plantar pressures in healthy females. *Journal of Foot and Ankle Research*, *6*(1), 1. https://doi.org/10.1186/1757-1146-6-28

Branthwaite, H., Chockalingam, N., Greenhalgh, A., Perry, S. D., Radtke, A., Goodwin, C. R., … Lord, S. R. (2013). Effects of Shoe Characteristics on Dynamic Stability When Walking on Even and Uneven Surfaces in Young and Older People. *Gait and Posture*, *89*(1), 94–98. https://doi.org/10.1186/1757-1146-6-28

Carpenter, M. G., & Bloem, B. R. (2011). Postural control in Parkinson patients: A proprioceptive problem? *Experimental Neurology*, *227*(1), 26–30. https://doi.org/10.1016/j.expneurol.2010.11.007

Conradsson, D., Paquette, C., & Lo, J. (2017). Pre- and unplanned walking turns in Parkinson's disease - effects of dopaminergic medication, *341*, 18–26. https://doi.org/10.1016/j.neuroscience.2016.11.016

Crenna, P., Carpinella, I., Rabuffetti, M., Calabrese, E., Mazzoleni, P., Nemni, R., & Ferrarin, M. (2007). The association between impaired turning and normal straight walking in Parkinson's disease. *Gait and Posture*, *26*(2), 172–178. https://doi.org/10.1016/j.gaitpost.2007.04.010

Curtze, C., Nutt, J. G., Carlson-Kuhta, P., Mancini, M., & Horak, F. B. (2015). Levodopa Is a Double-Edged Sword for Balance and Gait in People With Parkinson's Disease. *Movement Disorders*, *30*(10), 1361–1370. https://doi.org/10.1002/mds.26269

Dietz, V. (1997). Neurophysiology of gait disorders: Present and future applications. *Electroencephalography and Clinical Neurophysiology*, *103*(3), 333–355. https://doi.org/10.1016/S0013-4694(97)00047-7

Dietz, V., Zijlstra, W., Assaiante, C., Trippet, M., & Berger, W. (1993). Balance control in Parkinson's disease. *Gait & Posture*, *1*(2), 77–84. https://doi.org/10.1016/0966-6362(93)90018-V

Disorders, N. I. of N. (2015). *Parkinson's disease: challenges, progress, and promise*. Retrieved from http://www.ninds.nih.gov/disorders/parkinsons_disease/parkinsons_research.htm

E.P., G., & Johnson, K. O. (2013). The Somatosensory System: Receptors and Central Pathways. In *Principles of Neural Science* (Fifth, pp. 475–497). United States of America: McGraw Hill Education.

Eils, E., Behrens, S., Mers, O., Thorwesten, L., Völker, K., & Rosenbaum, D. (2004). Reduced plantar sensation causes a cautious walking pattern. *Gait and Posture*, *20*(1), 54–60. https://doi.org/10.1016/S0966-6362(03)00095-X

Eils, E., Nolte, S., Tewes, M., Thorwesten, L., Völker, K., & Rosenbaum, D. (2002). Modified pressure distribution patterns in walking following reduction of plantar sensation. *Journal of Biomechanics*, *35*(10), 1307–1313. https://doi.org/10.1016/S0021-9290(02)00168-9

Fahn, S., & Elton, R. (1987). Unified Parkinson ' S Disease Rating Scale. *Recent Developments in Parkinson's Disease*, *2*, 153–163, 293–304. https://doi.org/10.1016/S1779-0123(06)74622-8

Gardner, E. P., & Johnson, K. O. (2013a). Sensory Coding. In *Principles of Neural Science* (Fifth, pp. 449–474). United States of America: McGraw Hill Education.

Gardner, E. P., & Johnson, K. O. (2013b). Touch. In *Principles of Neural Science* (Fifth, pp. 498–529). United States of America: McGraw Hill Education.

Goetz, C. (2012). Unified Parkinson's Disease Rating Scale (UPDRS) and Movement Disorder Society Revision of the UPDRS (MDS-UPDRS). In *Rating Scales in Parkinson's Disease* (pp. 62–83). New York, New York: Oxford University Press.

Gross, M. T., Mercer, V. S., & Lin, F.-C. (2012). Effects of Foot Orthoses on Balance in Older Adults. *Journal of Orthopaedic & Sports Physical Therapy*, *42*(7), 649–657. https://doi.org/10.2519/jospt.2012.3944

Hamill, J., Knutzen, K. M., & Derrick, T. R. (2015a). Glossary. In *Biomechanical Basis of Human Movement* (Fourth, pp. 459–472). Philadelphia, PA: Wolters Kluwer.

Hamill, J., Knutzen, K. M., & Derrick, T. R. (2015b). Linear Kinematics. In *Biomechanical Basis of Human Movement* (Fourth). Philadelphia, PA: Wolters Kluwer.

Hase, K., & Stein, R. B. (1999). Turning strategies during human walking. *Journal of Neurophysiology*, *81*(6), 2914–2922.

Hatton, A. L., Dixon, J., Rome, K., & Martin, D. (2011). Standing on textured surfaces: effects on standing balance in healthy older adults. *Age and Ageing*, *40*, 363–368. https://doi.org/10.1111/j.

Hatton, A. L., Rome, K., Dixon, J., Martin, D. J., & McKeon, P. O. (2013). Footwear interventions: a review of their sensorimotor and mechanical effects on balance performance and gait in older

adults. *Journal of the American Podiatric Medical Association*, *103*(6), 516–33. https://doi.org/10.1055/s-0035-1567069

Hausdorff, J. M., Schaafsma, J. D., Balash, Y., Bartels, A. L., Gurevich, T., & Giladi, N. (2003). Impaired regulation of stride variability in Parkinson's disease subjects with freezing of gait. *Experimental Brain Research*, *149*(2), 187–194. https://doi.org/10.1007/s00221-002-1354-8

Herman, T., Giladi, N., & Hausdorff, J. M. (2011). Properties of the "Timed Up and Go" test: More than meets the eye. *Gerontology*, *57*(3), 203–210. https://doi.org/10.1159/000314963

Herman, T., Weiss, A., Brozgol, M., Giladi, N., & Hausdorff, J. M. (2014). Gait and balance in Parkinson's disease subtypes: objective measures and classification considerations. *Journal of Neurology*, *261*(12), 2401–2410. https://doi.org/10.1007/s00415-014-7513-6

Hijmans, J. M., Geertzen, J. H. B., Dijkstra, P. U., & Postema, K. (2007). A systematic review of the effects of shoes and other ankle or foot appliances on balance in older people and people with peripheral nervous system disorders. *Gait and Posture*, *25*(2), 316–323. https://doi.org/10.1016/j.gaitpost.2006.03.010

Hirtz, D., Thurman, D. J., Mohamed, M., Chaudhuri, A. R., & Zalutsky, R. (2007). How common are the " common " neurologic disorders ? *Neurology*, *68*(5), 326–337.

Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism : onset , progression , and mortality, *17*(5), 427–442. https://doi.org/10.1212/WNL.17.5.427

Hong, M., Perlmutter, J. S., & Earhart, G. M. (2009). A kinematic and electromyographic analysis of turning in people with Parkinson disease. *Neurorehabilitation and Neural Repair*, *23*(2), 166–76. https://doi.org/10.1177/1545968308320639

Iglesias, M. E., Vallejo, R., & Peña, D. (2012). Impact of Soft and Hard Insole Density on Postural Stability in Older Adults. *Geriatric Nursing*, *33*(4), 264–271.

https://doi.org/10.1016/j.gerinurse.2012.01.007

Jenkins, M. E., Almeida, Q. J., Spaulding, S. J., van Oostveen, R. B., Holmes, J. D., Johnson, A. M., & Perry, S. D. (2009). Plantar cutaneous sensory stimulation improves single-limb support time, and EMG activation patterns among individuals with Parkinson's disease. *Parkinsonism and Related Disorders*, *15*(9), 697–702. https://doi.org/10.1016/j.parkreldis.2009.04.004

Julayanont, P., Phillips, N., Chertkow, H., & Nasreddine, Z. (2012). Montreal Cognitive Assessment (MoCA): concept and clinical review. *Cognitive Screening Instruments: A Practical Approach*, (10), 111–151. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4471-2452-8_6

Kalron, A., Pasitselsky, D., Greenberg-Abrahami, M., & Achiron, A. (2015). Do textured insoles affect postural control and spatiotemporal parameters of gait and plantar sensation in people with multiple sclerosis? *PM and R*, *7*(1), 17–25. https://doi.org/10.1016/j.pmrj.2014.08.942

Kelleher, K. J., Spence, W. D., Solomonidis, S., & Apatsidis, D. (2010). The effect of textured insoles on gait patterns of people with multiple sclerosis. *Gait and Posture*, *32*(1), 67–71. https://doi.org/10.1016/j.gaitpost.2010.03.008

Latt, M. D., Lord, S. R., Morris, J. G. L., & Fung, V. S. C. (2009). Clinical and physiological assessments for elucidating falls risk in Parkinson's disease. *Movement Disorders*, *24*(9), 1280–1289. https://doi.org/10.1002/mds.22561

Lee, H., Lim, K., & Yoo, J. (2015). Effect of Custom-Molded Foot Orthoses on Foot Pain and Balance in Children With Symptomatic Flexible Flat Feet, *39*(6), 905–913.

Lindholm, B., Hagell, P., Hansson, O., & Nilsson, M. H. (2014). Factors associated with fear of falling in people with Parkinson's disease. *BMC Neurology*, *14*(1), 19. https://doi.org/10.1186/1471-2377-14-19

Macpherson, J. M., & Horak, F. B. (2013). Posture. In *Principles of Neural Science* (Fifth, pp. 935–959). United States of America: McGraw Hill Education.

Maki, B. E., & McIlroy, W. E. (1996). Postural Control in The Older Adult. *Gait and Balance Disorders*, *12*(4), 635–658.

Marieb, E. N., Mallatt, J., & Wilhelm, P. B. (2005). Muscles of the Body. In *Human Anatomy* (Fourth, pp. 255–318). San Francisco, CA: Pearson Benjamin Cummings.

Matinolli, M., Korpelainen, J. T., Korpelainen, R., Sotaniemi, K. A., Virranniemi, M., & Myllylä, V. V. (2007). Postural sway and falls in Parkinson's disease: A regression approach. *Movement Disorders*, *22*(13), 1927–1935. https://doi.org/10.1002/mds.21633

Mckeon, P. O., Stein, A. J., Ingersoll, C. D., & Hertel, J. (2012). Altered Plantar-Receptor Stimulation Impairs Postural Control in Those With Chronic Ankle Instability. *Journal of Sport Rehabilitation*, *21*, 1–6.

Michaud, Thomas, C. (1997). *Foot Orthoses and Other Forms of Conservative Foot Care*. Newton Massachusetts.

Morris, M. E., Huxham, F., McGinley, J., Dodd, K., & Iansek, R. (2001). The biomechanics and motor control of gait in Parkinson disease. *Clinical Biomechanics*, *16*(6), 459–470. https://doi.org/10.1016/S0268-0033(01)00035-3

Morris, M., Iansek, R., Matyas, T., & Summers, J. (1998). Abnormalities in the stride length-cadence relation in parkinsonian gait. *Movement Disorders*, *13*(1), 61–69. https://doi.org/10.1002/mds.870130115

Nanhoe-Mahabier, W., Snijders, A. H., Delval, A., Weerdesteyn, V., Duysens, J., Overeem, S., & Bloem, B. R. (2011). Walking patterns in Parkinson's disease with and without freezing of gait. *Neuroscience*, *182*, 217–224. https://doi.org/10.1016/j.neuroscience.2011.02.061

Nieuwboer, A., & De Weerdt, W. (1998). Plantar Force Distribution in Parkinsonian Gait: A comparison between patients and age-matched control subjects. *Physiotherapy*, *84*(8), 402–403.

Nilsson, M. H., Hariz, G. M., Iwarsson, S., & Hagell, P. (2012). Walking ability is a major contributor to fear of falling in people with Parkinson's disease: Implications for rehabilitation. *Parkinson's Disease*, *2012*. https://doi.org/10.1155/2012/713236

Nolano, M., Provitera, V., Estraneo, A., Selim, M. M., Caporaso, G., Stancanelli, A., … Santoro, L. (2008). Sensory deficit in Parkinson's disease: Evidence of a cutaneous denervation. *Brain*, *131*(7), 1903–1911. https://doi.org/10.1093/brain/awn102

Palluel, E., Olivier, I., & Nougier, V. (2009). The lasting effects of spike insoles on postural control in the elderly. *Behavioral Neuroscience*, *123*(5), 1141–7. https://doi.org/10.1037/a0017115

Patla, A. E., Prentice, S. D., Robinson, C., & Neufeld, J. (1991). Visual control of locomotion: Strategies for changing direction and for going over obstacles. *Journal of Experimental Psychology: Human Perception and Performance*, *17*(3), 603–634. https://doi.org/10.1037/0096-1523.17.3.603

Perry, S. D., McIlroy, W. E., & Maki, B. E. (2000). The role of plantar cutaneous mechanoreceptors in the control of compensatory stepping reactions evoked by unpredictable, multi-directional perturbation. *Brain Research*, *877*(2), 401–406. https://doi.org/10.1016/S0006-8993(00)02712-8

Perry, S. D., Radtke, A., & Goodwin, C. R. (2007). Influence of footwear midsole material hardness on dynamic balance control during unexpected gait termination. *Gait and Posture*, *25*(1), 94–98. https://doi.org/10.1016/j.gaitpost.2006.01.005

Perry, S. D., Radtke, A., McIlroy, W. E., Fernie, G. R., & Maki, B. E. (2008). Efficacy and Effectiveness

of a Balance, *63*(6), 595–602.

Plotnik, M., Giladi, N., Balash, Y., Peretz, C., & Hausdorff, J. M. (2005). Is freezing of gait in Parkinson's disease related to asymmetric motor function? *Annals of Neurology*, *57*(5), 656–663. https://doi.org/10.1002/ana.20452

Prätorius, B., Kimmeskamp, S., & Milani, T. L. (2003). The sensitivity of the sole of the foot in patients with Morbus Parkinson. *Neuroscience Letters*, *346*(3), 173–176. https://doi.org/10.1016/S0304-3940(03)00582-2

Przedborski, S. (2015). Etiology and Pathogenesis of Parkinson's Disease. In *Parkinson's Disease & Movement Disorders* (Sixth, pp. 51–64). Philadelphia, PA: Wolters Kluwer.

Qiu, F., Cole, M. H., Davids, K. W., Hennig, E. M., Silburn, P. A., Netscher, H., & Kerr, G. K. (2013). Effects of textured insoles on balance in people with Parkinson's disease. *PLoS ONE*, *8*(12), 6–13. https://doi.org/10.1371/journal.pone.0083309

Qu, X. (2015). Impacts of different types of insoles on postural stability in older adults. *Applied Ergonomics*, *46*(PA), 38–43. https://doi.org/10.1016/j.apergo.2014.06.005

Redmond, A. C., Crane, Y. Z., & Menz, H. B. (2008). Normative values for the Foot Posture Index. *Journal of Foot and Ankle Research*, *1*(1), 6. https://doi.org/10.1186/1757-1146-1-6

Robertson, D., Caldwell, G., Hamill, J., Kamen, G., & Whittlesey, S. (2014). Glossary. In *Research Methods in Biomechanics* (second, pp. 389–393). Champaign, IL: Human Kinetics.

Sesma, A. R., Mattacola, C. G., Uhl, T. L., Nitz, A. J., & McKeon, P. O. (2008). Effect of Foot Orthotics on Single- and Double-Limb Dynamic Balance Tasks in Patients With Chronic Ankle Instability. *Foot & Ankle Specialist*, *1*(6), 330–337. https://doi.org/10.1177/1938640008327516

Shin, J. Y., Ryu, Y. U., & Yi, C. W. (2016). Effects of insoles contact on static balance. *Journal of Physical Therapy Science*, *28*(4), 1241–1244. https://doi.org/10.1589/jpts.28.1241

Stack, E. L., Ashburn, A. M., & Jupp, K. E. (2006). Strategies used by people with Parkinson's disease who report difficulty turning. *Parkinsonism & Related Disorders*, *12*(2), 87–92. https://doi.org/10.1016/j.parkreldis.2005.08.008

Stylianou, A. P., McVey, M. a, Lyons, K. E., Pahwa, R., & Luchies, C. W. (2011). Postural sway in patients with mild to moderate Parkinson's disease. *The International Journal of Neuroscience*, *121*(November), 614–21. https://doi.org/10.3109/00207454.2011.602807

Visser, J. E., Voermans, N. C., Nijhuis, L. B. O., van der Eijk, M., Nijk, R., Munneke, M., & Bloem, B. R. (2007). Quantification of trunk rotations during turning and walking in Parkinson's disease. *Clinical Neurophysiology*, *118*(7), 1602–1606. https://doi.org/10.1016/j.clinph.2007.03.010

Wegener, C., Wegener, K., Smith, R., Schott, K.-H., & Burns, J. (2016). Biomechanical effects of sensorimotor orthoses in adults with Charcot–Marie–Tooth disease. *Prosthetics and Orthotics International*, *40*(4), 436–446. https://doi.org/10.1177/0309364615579318

Wong, S. L., Gilmour, H., & Ramage-Morin, P. L. (2014). Parkinson's disease: Prevalence, diagnosis and impact. *Statistics Canada Health Report*, *25*(11), 10–14. https://doi.org/82-003-X201401114112 [pii]

APPENDICES

Appendix A: The Somatosensory System

Somatosensory receptors, located throughout the body, provide the afferent feedback to the central nervous system required for the performance of human movement. More specifically, sensory receptors transform stimuli into electrical energy, and transmit this sensory information to the supraspinal structures and cerebral cortex. There are four types of receptors responsible for somatic sensation response: 1) cutaneous and subcutaneous mechanoreceptors; 2) thermoreceptors; 3) nociceptors, and 4) muscle and skeletal mechanoreceptors. Each receptor type transforms energy to the central nervous system via one sensory modality. Each modality has a specific pathway dedicated to their receiving stimulus. In balance control, proprioceptors and mechanoreceptors are most important, responding to muscle length and force changes, joint angle changes, and skin deformation (Gardner & Johnson, 2013a). The mechanoreceptors in the feet, and the proprioceptors located in our muscles and joints have important roles in the response to postural changes.

Proprioceptors

When there is a threat to the body's state of equilibrium, in static and dynamic movement, muscle spindles and golgi tendon organs (GTO's) sense the threat to the body's state of equilibrium, and activate to assist in the control of balance and awareness of body segments relative to their position in space. Muscle spindle afferents detect both the speed and amplitude of voluntary muscle contractions, along with passive limb movement from external stimuli, whereas GTO's respond to muscle contraction force (E.P. & Johnson, 2013). These specialized receptors play a large role in the neural mechanisms responsible for controlling center of mass motion. When the body experiences an unpredicted disturbance to its state of equilibrium, automatic postural adjustments and muscle activation produce direction-specific forces to maintain balance control. In response to the change in muscle and joint properties, length, speed, and force, spindles

and GTO's signal the recruitment of antagonistic muscles and suppress the stretch reflex of others (Macpherson & Horak, 2013).

Mechanoreceptors

There are four types of mechanoreceptors located in the plantar sole of the foot, each responding to stimulus based on their morphology, innervation pattern, and depth in cutaneous tissue. These mechanoreceptors are further subdivided according to their firing rate (slow-adapting and fast-adapting innervating axons) and the size of their receptive fields (type 1 and type 2). A receptive field is defined as the location on the skin surface in which an external stimulus can activate a sensory neuronal response (Gardner & Johnson, 2013b).

Merkel cells/SA1. Merkel cells are small epithelial cells, clustered, and surrounding sweat ducts in superficial glabrous skin. They respond to deformation and pressure on the skin. They are sensitive in detecting edges, corners, points and curve stimulus, providing sensory information on object shape, size, and texture (Gardner & Johnson, 2013b). They are slow-adapting receptors, where firing rate is highest at initial stimulus detection. With the application of continuous pressure, slow-adapting mechanoreceptors will provide continuous neurological response, however, when the stimulus is removed, the firing terminates. The action potential firing is proportional to the application of stimulus pressure (Gardner & Johnson, 2013a). As a type 1 receptor, Merkel cells have small and localized receptive fields, with many highly sensitive areas (Gardner & Johnson, 2013b).

Meissner corpuscle/RA1. Meissner corpuscles are fluid filled globular receptors, enclosing lamellar cells, and located within the papillary ridges of superficial skin. These receptors are highly sensitive to lateral motion stimulus, and have similar receptive fields are SA1 mechanoreceptors (Gardner & Johnson, 2013b). Meissner corpuscles are fast-adapting receptors, where action potential response is only present at the onset and termination of the stimulus. Consequently, RA1 neurons inform the somatosensory system when a stimulus touches the skin and once the stimulus is removed. There is no firing during continual pressure (Gardner & Johnson, 2013a).

Ruffini endings/SA2. Ruffini endings are located deep in the dermal tissue of the skin. These receptors are elongated in shape and surround collagen fibrils. Type 2 receptors are larger than type 1, have broader receptive fields, and only one area of high sensitivity. This mechanoreceptor activation is greatest when a stimulus is placed directly over these area of high sensitivity (Gardner & Johnson, 2013a). Ruffini endings respond to skin stretch, and as a slow-adapting receptor, will provide continual action potential response to continual pressure.

Pacinian corpuscle/RA2. The Pacinian corpuscle is the most sensitive receptor in the somatosensory system, responding to vibratory stimulation. They are located in subcutaneous tissue and are formed of layered connective tissue separated by fluid-filled space (Gardner & Johnson, 2013b). They are rapid-adapting type 2 receptors.

Appendix B: Recruitment Poster

VOLUNTEERS NEEDED

PARKINSON'S DISEASE STUDY

The purpose of this study is to increase clinical knowledge of the relationship between increased plantarsensory information and orthotics in a Parkinsonian gait. Research findings can increase clinical treatment options goaled at improving balance, functional mobility and decreasing fall risks in the Parkinson's community.

This study requires the participation of **i**ndividuals **(55-75 yrs of age)** diagnosed with idiopathic **Parkinson's disease**. Each volunteer will be asked to participate in a pedorthic clinical assessment and perform various walking and balance tasks in the biomechanics lab. The total time commitment is approximately **8 hours, spread over 4 different assessment/testing days.** The study will take 5 weeks to complete.

During the testing sessions, participants will have orthotics placed in their footwear, and sensors placed on their clothing and skin. Participants will be compensated **with paid parking, and two pairs of orthotics** for their participation.

For further information or to volunteer, please e-mail: **Parkinson's Study** at biomch@wlu.ca
Or leave a message at **884-0710 ext 2370.**
This project has been reviewed and approved by the University Research Ethics Board (**REB#5082**), and registered as a clinical trial (Clinicaltrial.gov Identifier No: NCT02809391).

Parkinson's Study (biomch@wlu.ca)
Or leave a message at 884-0710 x2370

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Or leave a message at 884-0710 x2370

Appendix C: Pre-Screening Questionnaire

SCREENING QUESTIONNAIRE

Participant # _____

Date: (MM/DD/YYYY): _____ , _____ , _____

Name: _____

Address: _____

_____

City, Province: _____, _____ Postal Code _____

Tel #: (_____)-_____ Best time to call: _____

Email address: _____

Preferred method of communication: _____

This information will be kept separate from the remainder of this document

SCREENING QUESTIONNAIRE

Participant # _____

Date: (MM/DD/YYYY): _____ , _____ , _____

VOLUNTEER EXCLUSION CRITERIA

Age: _____ yrs. **Height**: _____ cm **Weight**: _____ kg **Shoe Size**: _____

Gender: M ☐ F ☐

Do you use an assistive device for mobility purposes? select

How dependent are you upon your assistive device?
I always use it ☐ I use it sometimes ☐ I hardly use it ☐

Can you walk 10m without your assistive device? select

Do you have a health care provider helping you with walking? select

Do you have any conditions that limit the use of your arms or legs? select

	little or none	moderate	a great deal
If yes, how much does the condition interfere with your activities?	☐	☐	☐

Please describe: _____

Have you, within the last two years, or currently wear orthotics? select

Do you have or have you ever had:		Please check all that applies
a)	paralysis	☐
b)	epilepsy	☐
c)	cerebral palsy	☐
d)	multiple sclerosis	☐
e)	stroke	☐
f)	any other neurological disorder _____	

g)	diabetes	☐
h)	peripheral neuropathy	☐
i)	spina bifida	☐
j)	problems with your vision, not corrected by glasses	☐
k)	cataract surgery	☐
l)	deep brain stimulation	☐
m)	an inner ear disorder	☐
n)	hearing problems	☐
o)	constant ringing in your ears	☐
p)	ear surgery	☐

Have you ever had any serious problems with your memory? select

Do you have or ever had recurrent ear infections? select

Do you have or have you ever had :

			How much does the condition interfere with your activities?		
		Y/N	little or none	moderate	a great deal
a)	problems with your heart or lungs	select	☐	☐	☐
b)	high blood pressure	select	☐	☐	☐
c)	cancer	select	☐	☐	☐
d)	arthritis	select	☐	☐	☐
e)	rheumatism	select	☐	☐	☐
f)	back problems	select	☐	☐	☐
g)	a joint disorder	select	☐	☐	☐
h)	a muscle disorder	select	☐	☐	☐
i)	a bone disorder	select	☐	☐	☐

Have you ever severely injured or had surgery on your :

a)	head	select	☐	☐	☐
b)	neck	select	☐	☐	☐
c)	back	select	☐	☐	☐

d)	pelvis	select	☐	☐	☐
e)	ankle, knee, or hip joints?	select	☐	☐	☐

Have you ever broken any bones? select ☐ ☐ ☐

Which ones? : _____

		How much does the condition interfere with your activities?		
	Y/N	little or none	moderate	a great deal
Have you experienced a fall* within the last 6 months?	select	☐	☐	☐

*A fall is defined as: "an event which results in a person coming to rest inadvertently on the ground or floor or other lower level"

If yes, how many times? Please describe how you fell: _____

			How much does the condition interfere with your activities?		
		Y/N	little or none	moderate	a great deal
Have you had any recent (specify)					
a)	illnesses	select	☐	☐	☐
b)	injuries	select	☐	☐	☐
c)	operations	select	☐	☐	☐
d)	gait retraining	select	☐	☐	☐

Do you have difficulties performing any daily activities? select ☐ ☐ ☐

Which activities?: _____

Are you currently taking any medications (prescription or over-the-counter), or other drugs?

Medication	Ailment	Frequency of use
_____	_____	_____
_____	_____	_____

Appendix D. Informed Consent

INFORMED CONSENT STATEMENT

WILFRID LAURIER UNIVERSITY
INFORMED CONSENT STATEMENT
Orthotics and Parkinson's Disease: The Acute and Long-term Effects of Increased Somatosensory Feedback
Principle Investigator: Kelly Robb
Supervisor: Dr. Stephen Perry, Associate Professor and Faculty Researcher

We welcome your participation in the following research study. The purpose of this study is to increase clinical knowledge of the relationship between increased plantarsensory information and orthotics in a Parkinsonian gait. Research findings can increase clinical treatment options goaled at improving balance, functional mobility and decreasing fall risks in the Parkinson's community.

INFORMATION

You will be asked to participate in an initial screening appointment. During this appointment, your footwear will be evaluated, and you may complete two questionnaires: the 'Unified Parkinson's Disease Rating Scale (UPDRS), and the Montreal Cognitive Assessment Tool (MoCA). These questionnaires evaluate your experiences of daily living and cognitive impairment. UPDRS results do not effect study participation, and will only be administered if required. A score of 26 on the MoCA questionnaire is required for study participation. A pedorthic assessment will follow. Observations will be made while you stand and walk. You will be asked to participate in basic physical testing, and measurements will be taken, as your feet are moved through a series of range of motion exercises. A thin monofilament will be pressed to different areas on the bottom of your foot. This will measure you level of sensation, and should not cause any pain. During this assessment, you can choose to stop anytime, if you feel uncomfortable, or experience any discomfort or pain. Following completion, you will be scheduled for 3 testing sessions: one booked immediately, the 2nd in 4-weeks, and the 3rd in 5-weeks time.

Each testing session will be approximately 2 hours in length. In the first session, two pairs of orthotics will be customized to your feet. They will be heated, placed in your shoes, and you will be asked to walk around the laboratory. Four different assessments will be performed during each testing session. You will be asked to perform a combination of sitting, standing, and walking tasks, with and without the orthotics provided. Markers will be placed on your clothing and skin. Between each testing session, you will be provided with instructions to wear one pair of orthotics until our next session together. A self-reported diary will be encouraged, documenting concerns, level of comfort, daily orthotic wear and report of any falls.

Approximately 20-25 male and female participants diagnosed with idiopathic Parkinson's disease will be recruited for this experiment.

RISKS

Physical risks of study participation include loss of balance and tripping. The cable required for EMG recordings can pose a tripping hazard. You will be asked to reach past your comfortable base of support, step over obstacles, stand and sit from a chair, and turn in different directions. All these activities can increase the likelihood of you loosing balance and experiencing a fall. There is also a potential of skin irritation from the tape placed on your skin, which adheres the sensors and EMG electrodes to you. At the

screening appointment, minor muscular discomfort is possible during the range of motion and physical testing. There is a risk of you experiencing boredom, frustration and anxiety during the questionnaire completion. A loss of confidence is possible, during or following, the completion of the MoCA questionnaire. As domains of concentration, memory and visuospatial abilities are evaluated, you may experience disappointment in your personal performance. Emotional fatigue and anxiety can occur during the testing trials.

The physical risks of loosing balance and experiencing a fall will be minimized with the help of your research assistants. Assistants will walk beside you during the testing trials, and as required, respond to any loss of balance or tripping. Any required cables on the ground will be visibly marked and highlighted to you. Excess cables/wires will be carried. If you have ever experienced skin irritation from tape, an alternate method of electrode adhesion will be used. If unknown, and skin irritation does occur, the skin will be immediately cleaned. During the screening appointment, you will be demonstrated proper form for all physical tests. Manual range of motion testing will be evaluated in slow, gradual movements of the foot/ankle.

Verbal encouragement will be provided to you during and following the MoCA questionnaire, and we ask that you openly communicate any questions or concerns during any questionnaire. To limit boredom, all the testing preparations will be complete prior to your arrival in the biomechanics lab. Ongoing communication will take place between the you and your caregiver. Rest periods will be planned between each testing session, and available to you upon request. To decrease testing anxiety, each testing trial will be verbally explained to you, demonstrated if required, and all questions will be answered prior to beginning.

BENEFITS

This proposed study provides increased knowledge of the relationship between increased plantarsensory information and orthotics in a Parkinsonian gait. Observing gait parameters and muscle activation changes, in orthotics with and without a textured top cover, provides an increased understanding of conservative treatment options available to the Parkinson's population. Research findings can increase clinical treatment options goaled at improving balance, functional mobility and fall risks in the Parkinson's community. Results can be further applied to individual experiencing sensory deficits and older adults experiencing frequent falls.

CONFIDENTIALITY

During the recruitment process, directly identifying information will be collected. Your name and phone number are required for scheduling the screening appointment and testing sessions. Once study eligibility is confirmed, your identifying information will be replaced by a code, which will replace your true identity for the remainder of the study. Your true identity will only be known by your caregiver, Kelly Robb and Dr. Stephen Perry. In the event of study publication, findings will be summarized as group effects, rather than individual participant results. All participants shall remain anonymous in all publications, presentations, posters…etc.

Your personal information linked to your participant code will be stored in a locked cabinet. In a separate cabinet, all coded data and result collection will be stored. In the event that research assistants are involved in the experimental protocol, data collection, or analysis, they will not have access to your true identity. Electronic data and video recordings will be stored on a password protected computer. All data will be stored in the Biomechanics Lab (SR 119) in the Laurier Science Research Centre. This biomechanics lab has

controlled access, required a number code to gain access. All data will be retained for five years following all necessary analysis, reports, and publication.

IMAGES

Images may be taken of your feet and lower legs during your pedorthic assessment and testing sessions. These images allow for supplementary information during the analysis process. No directly identifying information will be linked to these images.

VIDEOTAPING

In an effort to minimize data collection errors, certain assessments require specific foot placement on the force plates under your feet. You may be videotaped below the shoulders, allowing the availability of video review if required. These videos may also be used for presentations and educational conferences following the completion of the study. All videos will be coded, removing all personal information, and ensuring the removal of all distinguishable features. Videos will be stored in a locked cabinet in the Biomechanics Lab (SR 119) in the Laurier Science Research Centre.

COMPENSATION

Financial reimbursement will be provided for all parking fees while attending the biomechanics lab. You may keep all socks and both pairs of custom orthotics provided to you during the study.

CONTACT

Shall you have any questions or concerns, throughout the recruitment process, screening or testing sessions, please do not hesitate to contact the main researcher, Kelly Robb, at robb8660@mylaurier.ca, or (519) 884-1970, extension 3298. This project has been reviewed and approved by the University Research Ethics Board (REB#5082), and registered as a clinical trial (Clinicaltrial.gov Identifier No: NCT02809391). If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Wilfrid Laurier's University Research Ethics Board, REB contact: Robert Basso, PhD Chair Research Ethics Board rbasso@wlu.ca 519.884.0710 Extension 4994.

PARTICIPATION

Participation in this study is voluntary, and you may decline participation, without penalty, anytime prior to the start of the study. Shall you choose to participate, you may choose to withdraw from the study at any time, without penalty and without loss of benefits to which you are otherwise entitled. In instances of withdrawal, every attempt will be made to remove your data from the study. All confidential information will be destroyed. You have the right to omit any sections of questionnaires, procedures, and testing sessions you choose.

FEEDBACK AND PUBLICATION

The outcome of this study may result in potential publications, presentations, and reports. Presentations of research outcomes may be made at scientific symposiums, meetings, and poster presentations.

☐ Please indicate by checking the box if you would like to be contacted in the future with results of this study.

CONSENT

I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Participant's signature_____ Date _____

Investigator's signature_____ Date _____

CAREGIVER'S

I am comfortable with having my caregiver present during the screening appointment and testing sessions.

Participant's signature_____ Date _____

Caregiver's signature _____ Date _____

Investigator's signature_____ Date _____

CONSENT TO VIDEOTAPE

I have read and understand the details surrounding the potential of images being taken and being videotaped. I consent to having any images or video footage used in presentations and scientific conferences.

Participant's signature_____ Date _____

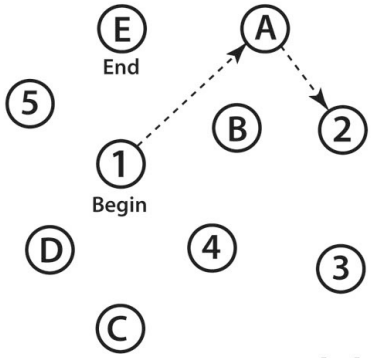
Investigator's signature_____ Date _____

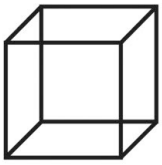
Appendix E. MoCA

MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE





Copy cube

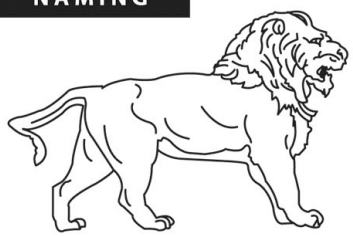
[ ] [ ]

Draw CLOCK (Ten past eleven)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

POINTS ___/5

NAMING



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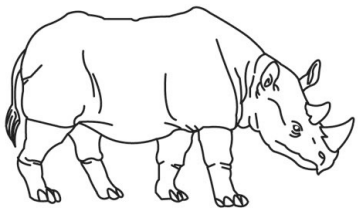
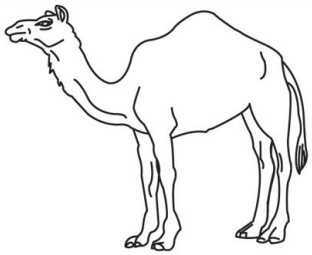


[ ]



[ ]

___/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).
Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2
___/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B
___/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**
___/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ]
___/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words)
___/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler
___/2

DELAYED RECALL

	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

___/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City
___/6

© Z.Nasreddine MD **www.mocatest.org** Normal ≥ 26 / 30

TOTAL ___/30
Add 1 point if ≤ 12 yr edu

Administered by: _____

Appendix F. Unified Parkinson's Disease Rating Scale (UPDRS)

I. MENTATION, BEHAVIOR AND MOOD

1. Intellectual Impairment

0 = None.
1 = Mild. Consistent forgetfulness with partial recollection of events and no other difficulties.
2 = Moderate memory loss, with disorientation and moderate difficulty handling complex problems. Mild but definite impairment of function at home with need of occasional prompting.
3 = Severe memory loss with disorientation for time and often to place. Severe impairment in handling problems.
4 = Severe memory loss with orientation preserved to person only. Unable to make judgments or solve problems. Requires much help with personal care. Cannot be left alone at all.

2. Thought Disorder (Due to dementia or drug intoxication)

0 = None.
1 = Vivid dreaming.
2 = "Benign" hallucinations with insight retained.
3 = Occasional to frequent hallucinations or delusions; without insight; could interfere with daily activities.
4 = Persistent hallucinations, delusions, or florrid psychosis. Not able to care for self.

3. Depression

1 = Periods of sadness or guilt greater than normal, never sustained for days or weeks.
2 = Sustained depression (1 week or more).
3 = Sustained depression with vegetative symptoms (insomnia, anorexia, weight loss, loss of interest).
4 = Sustained depression with vegetative symptoms and suicidal thoughts or intent.

4. Motivation/Initiative

0 = Normal.
1 = Less assertive than usual; more passive.
2 = Loss of initiative or disinterest in elective (nonroutine) activities.
3 = Loss of initiative or disinterest in day to day (routine) activities.
4 = Withdrawn, complete loss of motivation.

II. ACTIVITIES OF DAILY LIVING (for both "on" and "off")

5. Speech

0 = Normal.
1 = Mildly affected. No difficulty being understood.
2 = Moderately affected. Sometimes asked to repeat statements.
3 = Severely affected. Frequently asked to repeat statements.
4 = Unintelligible most of the time.

6. Salivation

0 = Normal.
1 = Slight but definite excess of saliva in mouth; may have nighttime drooling.
2 = Moderately excessive saliva; may have minimal drooling.
3 = Marked excess of saliva with some drooling.
4 = Marked drooling, requires constant tissue or handkerchief.

7. Swallowing

0 = Normal.
1 = Rare choking.
2 = Occasional choking.
3 = Requires soft food.
4 = Requires NG tube or gastrotomy feeding.

8. Handwriting
0 = Normal.
1 = Slightly slow or small.
2 = Moderately slow or small; all words are legible.
3 = Severely affected; not all words are legible.
4 = The majority of words are not legible.

9. Cutting food and handling utensils
0 = Normal.
1 = Somewhat slow and clumsy, but no help needed.
2 = Can cut most foods, although clumsy and slow; some help needed.
3 = Food must be cut by someone, but can still feed slowly.
4 = Needs to be fed.

10. Dressing
0 = Normal.
1 = Somewhat slow, but no help needed.
2 = Occasional assistance with buttoning, getting arms in sleeves.
3 = Considerable help required, but can do some things alone.
4 = Helpless.

11. Hygiene
0 = Normal.
1 = Somewhat slow, but no help needed.
2 = Needs help to shower or bathe; or very slow in hygienic care.
3 = Requires assistance for washing, brushing teeth, combing hair, going to bathroom.
4 = Foley catheter or other mechanical aids.

12. Turning in bed and adjusting bed clothes
0 = Normal.
1 = Somewhat slow and clumsy, but no help needed.
2 = Can turn alone or adjust sheets, but with great difficulty.
3 = Can initiate, but not turn or adjust sheets alone.
4 = Helpless.

13. Falling (unrelated to freezing)
0 = None.
1 = Rare falling.
2 = Occasionally falls, less than once per day.
3 = Falls an average of once daily.
4 = Falls more than once daily.

14. Freezing when walking
0 = None.
1 = Rare freezing when walking; may have starthesitation.
2 = Occasional freezing when walking.
3 = Frequent freezing. Occasionally falls from freezing.
4 = Frequent falls from freezing.

15. Walking
0 = Normal.
1 = Mild difficulty. May not swing arms or may tend to drag leg.
2 = Moderate difficulty, but requires little or no assistance.
3 = Severe disturbance of walking, requiring assistance.
4 = Cannot walk at all, even with assistance.

16. Tremor (Symptomatic complaint of tremor in any part of body.)
0 = Absent.
1 = Slight and infrequently present.
2 = Moderate; bothersome to patient.
3 = Severe; interferes with many activities.
4 = Marked; interferes with most activities.

17. Sensory complaints related to parkinsonism
0 = None.
1 = Occasionally has numbness, tingling, or mild aching.
2 = Frequently has numbness, tingling, or aching; not distressing.
3 = Frequent painful sensations.
4 = Excruciating pain.

III. MOTOR EXAMINATION
18. Speech
0 = Normal.
1 = Slight loss of expression, diction and/or volume.
2 = Monotone, slurred but understandable; moderately impaired.
3 = Marked impairment, difficult to understand.
4 = Unintelligible.

19. Facial Expression
0 = Normal.
1 = Minimal hypomimia, could be normal "Poker Face".
2 = Slight but definitely abnormal diminution of facial expression
3 = Moderate hypomimia; lips parted some of the time.
4 = Masked or fixed facies with severe or complete loss of facial expression; lips parted 1/4 inch or more.

20. Tremor at rest (head, upper and lower extremities)
0 = Absent.
1 = Slight and infrequently present.
2 = Mild in amplitude and persistent. Or moderate in amplitude, but only intermittently present.
3 = Moderate in amplitude and present most of the time.
4 = Marked in amplitude and present most of the time.

21. Action or Postural Tremor of hands
0 = Absent.
1 = Slight; present with action.
2 = Moderate in amplitude, present with action.
3 = Moderate in amplitude with posture holding as well as action.
4 = Marked in amplitude; interferes with feeding.

22. Rigidity (Judged on passive movement of major joints with patient relaxed in sitting position. Cogwheeling to be ignored.)
0 = Absent.
1 = Slight or detectable only when activated by mirror or other movements.
2 = Mild to moderate.
3 = Marked, but full range of motion easily achieved.
4 = Severe, range of motion achieved with difficulty.

23. Finger Taps (Patient taps thumb with index finger in rapid succession.)
0 = Normal.
1 = Mild slowing and/or reduction in amplitude.

2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

24. Hand Movements (Patient opens and closes hands in rapid succesion.)
0 = Normal.
1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

25. Rapid Alternating Movements of Hands (Pronation-supination movements of hands, vertically and horizontally, with as large an amplitude as possible, both hands simultaneously.)
0 = Normal.
1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

26. Leg Agility (Patient taps heel on the ground in rapid succession picking up entire leg. Amplitude should be at least 3 inches.)
0 = Normal.
1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

27. Arising from Chair (Patient attempts to rise from a straightbacked chair, with arms folded across chest.)
0 = Normal.
1 = Slow; or may need more than one attempt.
2 = Pushes self up from arms of seat.
3 = Tends to fall back and may have to try more than one time, but can get up without help.
4 = Unable to arise without help.

28. Posture
0 = Normal erect.
1 = Not quite erect, slightly stooped posture; could be normal for older person.
2 = Moderately stooped posture, definitely abnormal; can be slightly leaning to one side. 3 = Severely stooped posture with kyphosis; can be moderately leaning to one side.
4 = Marked flexion with extreme abnormality of posture.

29. Gait
0 = Normal.
1 = Walks slowly, may shuffle with short steps, but no festination (hastening steps) or propulsion.
2 = Walks with difficulty, but requires little or no assistance; may have some festination, short steps, or propulsion.
3 = Severe disturbance of gait, requiring assistance.
4 = Cannot walk at all, even with assistance.

30. Postural Stability (Response to sudden, strong posterior displacement produced by pull on shoulders while patient erect with eyes open and feet slightly apart. Patient is prepared.)
0 = Normal.
1 = Retropulsion, but recovers unaided.
2 = Absence of postural response; would fall if not caught by examiner.
3 = Very unstable, tends to lose balance spontaneously.
4 = Unable to stand without assistance.

31. Body Bradykinesia and Hypokinesia (Combining slowness, hesitancy, decreased armswing, small amplitude, and poverty of movement in general.)
0 = None.
1 = Minimal slowness, giving movement a deliberate character; could be normal for some persons. Possibly reduced amplitude.
2 = Mild degree of slowness and poverty of movement which is definitely abnormal. Alternatively, some reduced amplitude.
3 = Moderate slowness, poverty or small amplitude of movement.
4 = Marked slowness, poverty or small amplitude of movement.

IV. COMPLICATIONS OF THERAPY (In the past week)
A. DYSKINESIAS
32. Duration: What proportion of the waking day are dyskinesias present? (Historical information.)
0 = None
1 = 1-25% of day.
2 = 26-50% of day.
3 = 51-75% of day.
4 = 76-100% of day.

33. Disability: How disabling are the dyskinesias? (Historical information; may be modified by office examination.)
0 = Not disabling.
1 = Mildly disabling.
2 = Moderately disabling.
3 = Severely disabling.
4 = Completely disabled.

34. Painful Dyskinesias: How painful are the dyskinesias?
0 = No painful dyskinesias.
1 = Slight.
2 = Moderate.
3 = Severe.
4 = Marked.

35. Presence of Early Morning Dystonia (Historical information.)
0 = No
1 = Yes

B. CLINICAL FLUCTUATIONS
36. Are "off" periods predictable?
0 = No
1 = Yes

37. Are "off" periods unpredictable?
0 = No
1 = Yes

38. Do "off" periods come on suddenly, within a few seconds?
0 = No
1 = Yes

39. What proportion of the waking day is the patient "off" on average?

0 = None
1 = 1-25% of day.
2 = 26-50% of day. 3 = 51-75% of day. 4 = 76-100% of day.

C. OTHER COMPLICATIONS

40. Does the patient have anorexia, nausea, or vomiting?
0 = No
1 = Yes

41. Any sleep disturbances, such as insomnia or hypersomnolence?
0 = No
1 = Yes

42. Does the patient have symptomatic orthostasis?
(Record the patient's blood pressure, height and weight on the scoring form)
0 = No
1 = Yes

V. MODIFIED HOEHN AND YAHR STAGING

STAGE 0 = No signs of disease.
STAGE 1 = Unilateral disease.
STAGE 1.5 = Unilateral plus axial involvement.
STAGE 2 = Bilateral disease, without impairment of balance.
STAGE 2.5 = Mild bilateral disease, with recovery on pull test.
STAGE 3 = Mild to moderate bilateral disease; some postural instability; physically independent.
STAGE 4 = Severe disability; still able to walk or stand unassisted.
STAGE 5 = Wheelchair bound or bedridden unless aided.

VI. SCHWAB AND ENGLAND ACTIVITIES OF DAILY LIVING SCALE

100% = Completely independent. Able to do all chores without slowness, difficulty or impairment. Essentially normal. Unaware of any difficulty.
90% = Completely independent. Able to do all chores with some degree of slowness, difficulty and impairment. Might take twice as long. Beginning to be aware of difficulty.
80% = Completely independent in most chores. Takes twice as long. Conscious of difficulty and slowness.
70% = Not completely independent. More difficulty with some chores. Three to four times as long in some. Must spend a large part of the day with chores.
60% = Some dependency. Can do most chores, but exceedingly slowly and with much effort. Errors; some impossible.
50% = More dependent. Help with half, slower, etc. Difficulty with everything.
40% = Very dependent. Can assist with all chores, but few alone.
30% = With effort, now and then does a few chores alone or begins alone. Much help needed.
20% = Nothing alone. Can be a slight help with some chores. Severe invalid.
10% = Totally dependent, helpless. Complete invalid.
0% = Vegetative functions such as swallowing, bladder and bowel functions are not functioning. Bedridden.

Appendix G. Pedorthic Assessment Form

DATE: _____

PARTICIPANT NUMBER: _____

RELEVANT MEDICAL HISTORY: _____
_____
_____
_____
_____
_____
_____

ADL'S: _____ **OCCUPATION:** _____

OTHER MEDICAL CONDITIONS: _____
Diabetes RA Obesity

PRESENT FOOTWEAR: _____

WEAR PATTERN: RIGHT Upper: _____ Tread: _____
LEFT Upper: _____ Tread: _____

STATIC WEIGHT-BEARING ASSESSMENT

KNEE ALIGNMENT: Neutral
Rotation Internal / External L / R

Varum L / R Valgum L / R
severe
Recurvatum L / R

TIBIAL ALIGNMENT:
Straight L / R

Varum **L**: mild / mod / severe **R**: mild / mod /

FOOT APPEARANCE:
Normal L / R Cavus L / R Planus L / R
R
L: mild / mod / severe **R**: mild / mod / severe

FOREFOOT POSITION:
Neutral L / R Pronated L / R Supinated L /

L: mild / mod / severe **R**: mild / mod / severe

MIDFOOT POSITION:
Neutral L / R Pronated L / R Supinated L / R
L: mild / mod / severe **R**: mild / mod / severe

REARFOOT POSTION:
Neutral L / R Varus L / R Valgus L / R
L: mild / mod / severe **R**: mild / mod / severe

PELVIC ALIGNMENT: _____
LLD: yes / no **Discrepancy:** _____

MUSCLE TESTS AND COMMENTS: _____
Squat: _____ Heel Raise: _____
CKC STJ ROM: _____ Single Stance: _____

FOOT POSTURE INDEX

	FACTOR	PLANE	SCORE	
			Left -2 to +2	Right -2 to +2
RF	Talar head palpation	Transverse		
	Curves above and below the lateral malleolus	Frontal/Transverse		
	Inversion/Eversion of the calcaneus	Frontal		
FF	Prominence in the region of the TNJ	Transverse		
	Congruence of the medial longitudinal arch	Sagittal		
	Abd/adduction forefoot on rearfoot	Transverse		
	TOTAL			

GAIT ASSESSMENT

INITIAL CONTACT: Rearfoot **L:** Lateral / Central / Medial **R:** Lateral / Central / Medial
Midfoot L / R
Forefoot L / R

MIDSTANCE: Pronation Early onset L / R Excessive Magnitude L / R Excessive Varus L / R
Supination **L:** Mild / Mod / Severe **R:** Mild / Mod / Severe

TOE OFF: normal failure to resupinate / early heel lift / weak propulsion / abductory twist L / R

SWING PHASE: normal limited ankle dorsiflexion L / R Drop Foot L / R

Trendelenburg Shuffling Gait Assistive devices: _____

ADDITIONAL NOTES:
_____
_____
_____
_____
_____

NONWEIGHT-BEARING ASSESSMENT

FOOT STRUCTURE:
Normal L / R Planus L / R Cavus L / R
L: Mild / Mod / Severe **R:** Mild / Mod / Severe

FOREFOOT STRUCTURE:
Straight L / R
Hammer L / R 2 3 4 5 Fixed / Flexible
Claw L / R 2 3 4 5 Fixed / Flexible
Mallet L / R 2 3 4 5 Fixed / Flexible
Morton's Foot / Toe L / R
Dropped metatarsal arch L / R
Hypermobile
Prominent MT head(s) 2 3 4 5 L / R
Hypermobile

FOREFOOT ALIGNMENT:
Neutral L / R
Varus L / R Mild / Mod / Severe
Valgus L / R Fixed / Flexible

FIRST RAY:
Neutral L / R Short L / R
Plantarflexed L / R Fixed / Flexible
Dorsiflexed L / R Fixed / Flexible
ROM: Normal L / R
Hypermobile L / R
Plantarflexion L / R Limited /
Dorsiflexion L / R Limited /

FIRST MTP JOINT:
Hallux Valgus L / R Mild / Mod / Severe
Bunion L / R Mild / Mod / Severe
Dorsal osteophytes L / R
ROM: Normal L / R
Limitus / FHL L / R
Severe
Rigidus L / R
Hypermobile L / R
Severe

SUBTALAR JOINT:
Neutral L / R
Varus L / R Valgus L / R
ROM: Normal L / R
Hypermobile: inversion / eversion
L: Mild / Mod / Severe **R:** Mild / Mod /

Limited: inversion / eversion
L: Mild / Mod / Severe **R:** Mild / Mod /

ANKLE ROM:

Dorsiflexion:	Normal L / R	Plantarflexion:	Normal L / R
	Excessive L / R		Excessive L / R
	Soft tissue equinus L / R		Limited L / R
	Osseous equinus L / R		

ADDITIONAL NOTES:

_____
_____
_____
_____
_____

THE FOOTWEAR ASSESSMENT FORM

General shoe style/covering

❍ barefoot	❍ socks only	❍ stockings only	❍ backless slipper
❍ mule	❍ high heel	❍ courtshoe	❍ boot
❍ slipper	❍ sandal	❍ moccasin	❍ athletic shoe
❍ walking shoe	❍ Oxford shoe	❍ ugg boot	❍ thong
❍ surgical/bespoke footwear			

Heel height

❍ 0–2.5 cm	❍ 2.6–5.0 cm	❍ >5.0 cm

Fixation

❍ none	❍ laces	❍ straps/buckles	❍ Velcro	❍ zips

Heel counter stiffness

❍ minimal	❍ <45°	❍ <45°

Longitudinal sole rigidity

❍ minimal	❍ <45°	❍ <45°

Sole flexion point

❍ at level of MTPJs	❍ before MTPJs

Tread pattern

❍ textured	❍ smooth (i.e. no pattern)	❍ partly worn	❍ fully worn

Sole hardness

❍ soft	❍ firm	❍ hard

Appendix H. Functional Gait Assessment

Requirements: A marked 6-m (20-ft) walkway that is marked with a 30.48-cm (12-in) width.

1. GAIT LEVEL SURFACE

Instructions: *Walk at your normal speed from here to the next mark (6 m [20 ft]).*
Grading: Mark the highest category that applies.
(3) Normal—Walks 6 m (20 ft) in less than 5.5 seconds, no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside of the 30.48-cm (12-in) walkway width.
(2) Mild impairment—Walks 6 m (20 ft) in less than 7 seconds but greater than 5.5 seconds, uses assistive device, slower speed, mild gait deviations, or deviates 15.24–25.4 cm (6–10 in) outside of the 30.48-cm (12-in) walkway width.
(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnor- mal gait pattern, evidence for imbalance, or deviates 25.4– 38.1 cm (10–15 in) outside of the 30.48-cm (12-in) walkway width. Requires more than 7 seconds to ambulate 6 m (20 ft).
(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside of the 30.48-cm (12-in) walkway width or reaches and touches the wall.

2. CHANGE IN GAIT SPEED

Instructions: *Begin walking at your normal pace (for 1.5 m [5 ft]). When I tell you "go," walk as fast as you can (for 1.5 m [5 ft]). When I tell you "slow," walk as slowly as you can (for 1.5 m [5 ft]).*
Grading: Mark the highest category that applies.
(3) Normal—Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast, and slow speeds. Devi- ates no more than 15.24 cm (6 in) outside of the 30.48-cm (12-in) walkway width.
(2) Mild impairment—Is able to change speed but demonstrates mild gait deviations, deviates 15.24 –25.4 cm (6 –10 in) outside of the 30.48-cm (12-in) walkway width, or no gait deviations but unable to achieve a significant change in velocity, or uses an assistive device.
(1) Moderate impairment—Makes only minor adjustments to walk- ing speed, or accomplishes a change in speed with significant gait deviations, deviates 25.4–38.1 cm (10–15 in) outside the 30.48-cm (12-in) walkway width, or changes speed but loses balance but is able to recover and continue walking.
(0) Severe impairment—Cannot change speeds, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width, or loses balance and has to reach for wall or be caught.

3. GAIT WITH HORIZONTAL HEAD TURNS

Instructions: *Walk from here to the next mark 6 m (20 ft) away. Begin walking at your normal pace. Keep walking straight; after 3 steps, turn your head to the right and keep walking straight while looking to the right. After 3 more steps, turn your head to the left and keep walking straight while looking left. Continue alternating looking right and left every 3 steps until you have completed 2 repetitions in each direction.* Grading: Mark the highest category that applies.
(3) Normal—Performs head turns smoothly with no change in gait. Deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.
(2) Mild impairment—Performs head turns smoothly with slight change in gait velocity (eg, minor disruption to smooth gait path), deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width, or uses an assistive device.
(1) Moderate impairment—Performs head turns with moderate change in gait velocity, slows down, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width but recov- ers, can continue to walk.
(0) Severe impairment—Performs task with severe disruption of gait (eg, staggers 38.1 cm [15 in] outside 30.48-cm (12-in) walkway width, loses balance, stops, or reaches for wall).

4. GAIT WITH VERTICAL HEAD TURNS

Instructions: *Walk from here to the next mark (6 m [20 ft]). Begin walking at your normal pace. Keep walking straight; after 3 steps, tip your head up and keep walking straight while looking up. After 3 more steps, tip your head down, keep walking straight while looking down. Continue alternating looking up and down every 3 steps until you have completed 2 repetitions in each direction.*
Grading: Mark the highest category that applies.
(3) Normal—Performs head turns with no change in gait. Deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.
(2) Mild impairment—Performs task with slight change in gait velocity (eg, minor disruption to smooth gait path), deviates 15.24 –25.4 cm (6 –10 in) outside 30.48-cm (12-in) walkway width or uses assistive device.
(1) Moderate impairment—Performs task with moderate change in gait velocity, slows down, deviates 25.4 –38.1 cm (10 –15 in) outside 30.48-cm (12-in) walkway width but recovers, can continue to walk.
(0) Severe impairment—Performs task with severe disruption of gait (eg, staggers 38.1 cm [15 in] outside 30.48-cm (12-in) walkway width, loses balance, stops, reaches for wall).

5. GAIT AND PIVOT TURN
Instructions: *Begin with walking at your normal pace. When I tell you, "turn and stop," turn as quickly as you can to face the opposite direction and stop.*
Grading: Mark the highest category that applies.
(3) Normal–Pivot turns safely within 3 seconds and stops quickly with no loss of balance.
(2) Mild impairment–Pivot turns safely in 3 seconds and stops with no loss of balance, or pivot turns safely within 3 seconds and stops with mild imbalance, requires small steps to catch balance.
(1) Moderate impairment–Turns slowly, requires verbal cueing, or requires several small steps to catch balance following turn and stop.
(0) Severe impairment–Cannot turn safely, requires assistance to turn and stop.

6. STEP OVER OBSTACLE
Instructions: *Begin walking at your normal speed. When you come to the shoe box, step over it, not around it, and keep walking.*
Grading: Mark the highest category that applies.
(3) Normal–Is able to step over 2 stacked shoe boxes taped together (22.86 cm [9 in] total height) without changing gait speed; no evidence of imbalance.
(2) Mild impairment–Is able to step over one shoe box (11.43 cm [4.5 in] total height) without changing gait speed; no evidence of imbalance.
(1) Moderate impairment–Is able to step over one shoe box (11.43 cm [4.5 in] total height) but must slow down and adjust steps to clear box safely. May require verbal cueing.
(0) Severe impairment–Cannot perform without assistance.
(Continued)

7. GAIT WITH NARROW BASE OF SUPPORT
Instructions: *Walk on the floor with arms folded across the chest, feet aligned heel to toe in tandem for a distance of 3.6 m [12 ft]. The number of steps taken in a straight line are counted for a maximum of 10 steps.* Grading: Mark the highest category that applies.
(3) Normal–Is able to ambulate for 10 steps heel to toe with no staggering.
(2) Mild impairment–Ambulates 7–9 steps.
(1) Moderate impairment–Ambulates 4 –7 steps.
(0) Severe impairment–Ambulates less than 4 steps heel to toe or
cannot perform without assistance.

8. GAIT WITH EYES CLOSED
Instructions: *Walk at your normal speed from here to the next mark (6 m [20 ft]) with your eyes closed.*
Grading: Mark the highest category that applies.
(3) Normal–Walks 6 m (20 ft), no assistive devices, good speed, no evidence of imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width. Ambulates 6 m (20 ft) in less than 7 seconds.
(2) Mild impairment–Walks 6 m (20 ft), uses assistive device, slower speed, mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width. Ambulates 6 m (20 ft) in less than 9 seconds but greater than 7 seconds.
(1) Moderate impairment–Walks 6 m (20 ft), slow speed, abnor- mal gait pattern, evidence for imbalance, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width. Requires more than 9 seconds to ambulate 6 m (20 ft).
(0) Severe impairment–Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width or will not attempt task.

9. AMBULATING BACKWARDS
Instructions: *Walk backwards until I tell you to stop.* Grading: Mark the highest category that applies.
(3) Normal–Walks 6 m (20 ft), no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.
(2) Mild impairment–Walks 6 m (20 ft), uses assistive device, slower speed, mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width.
(1) Moderate impairment–Walks 6 m (20 ft), slow speed, abnor- mal gait pattern, evidence for imbalance, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width.
(0) Severe impairment–Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width or will not attempt task.

10. STEPS

Instructions: *Walk up these stairs as you would at home (ie, using the rail if necessary). At the top turn around and walk down.*

Grading: Mark the highest category that applies.

(3) Normal–Alternating feet, no rail.

(2) Mild impairment–Alternating feet, must use rail.

(1) Moderate impairment–Two feet to a stair; must use rail. (0) Severe impairment–Cannot do safely.

TOTAL SCORE: _____ MAXIMUM SCORE 30

Appendix I. Data Collection Sheet

DATA COLLECTION PACKAGE

PARTICIPANT NO: _____

DATE: _____

Testing Protocol Order:
1. Monofilament Testing
2. EMG normalization
3. MVCs

Condition 1:
4. Static balance
5. TUG
6. FGA
7. Walking

Condition 2:
8. Static balance
9. TUG
10. FGA
11. Walking

To add Condition 3 at 5-week testing day

DATA COLLECTION SHEET

Participant No: _____ Date: _____ Time: _____

Shoes worn on testing day: _____

Sensory Testing (Monofilaments)

Plantar Surface Location	Smallest Filament Detected	Notes
1st MTP head		
5th MTP head		
Calcaneus		

EMG Normalization

Muscle	EMG GAIN	
	RIGHT	LEFT
Tibialis Anterior		
Med. Gastroch		
Peroneus Longus		

*per. Longus – "point toe down and outward"

☐ Trace feet of participant on force plate paper

(Condition 1 = footwear only) (Condition 2 = orthotic only) (Condition 3 = orthotic+texture)
(OT # = Optotrak Trial Number)

Condition: _____

MVC's Data Collection: 5 seconds

Trials	OT #	Muscle	Comments
MVC_1		R - Tib. Ant.	
MVC_2		L – Tib. Ant.	
MVC_3		R – Med. Gastroc	
MVC_4		L – Med. Gastroc	
MVC_5		R – Per. Longus	
MVC_6		L – Per. Longus	

Static Balance – Double limb support, eyes closed- 2 minutes (120 seconds)

Trials	OT #	Comments
STAT.BAL_7		

TUG Data Collection: 20 seconds

Trials	OT #	Completion Time	Comments
TUG_8			
TUG_9			

FGA Data Collection: 10 seconds

Trials	OT #	FGA #	Score	Comments
FGA_10		1		
FGA_11		2 "go"		
FGA_12		2 "slow"		
FGA_13		3		
FGA_14		4		
FGA_15		5		
FGA_16		6		
FGA_17		7		
FGA_18		8		
FGA_19		9		
FGA_20		10		
FGA total score:				

Walking Trial Dominant turn direction = 0
Non-dominant turn direction = 1

Data Collection: 20 seconds

Trials	OT #	Turn Direction	Comments
Walking_21		0	
Walking_22		0	
Walking_23		1	
Walking_24		0	
Walking_25		0	
Walking_26		0	
Walking_27		1	
Walking_28		0	
Walking_29		0	
Walking_30		1	

(Condition 1 = footwear only) (Condition 2 = orthotic only) (Condition 3 = orthotic+texture)
(OT # = Optotrak Trial Number)

Condition: _____

Static Balance – Double limb support, eyes closed- 2 minutes (120 seconds)

Trials	OT #	Comments
STAT.BAL_31		

TUG Data Collection: 20 seconds

Trials	OT #	Completion Time	Comments
TUG_32			
TUG_33			

FGA Data Collection: 10 seconds

Trials	OT #	FGA #	Score	Comments
FGA_34		1		
FGA_35		2 "go"		
FGA_36		2 "slow"		
FGA_37		3		
FGA_38		4		
FGA_39		5		
FGA_40		6		
FGA_41		7		
FGA_42		8		
FGA_43		9		
FGA_44		10		
FGA total score:				

Walking Trial Dominant turn direction = 0
Non-dominant turn direction = 1

Data Collection: 20 seconds

Trials	OT #	Turn Direction	Comments
Walking_45		0	
Walking_46		0	
Walking_47		1	
Walking_48		0	
Walking_49		0	
Walking_50		0	
Walking_51		1	
Walking_52		0	
Walking_53		0	
Walking_54		1	

Appendix J. Result Tables (*Note:* F: Footwear only; FO: Non-textured orthotics; FOT: Textured orthotics; GLMW1F: general linear model within 1 factor ANOVA)

Table 3: Maximum ML COM/BOS results across orthotic conditions

Maximum ML - COM/BOS Analysis		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	0.1170 (0.0478)	**Type I SS:** F(1, 88)=0.21, p=.6514 **ETA-Square:** 0.35 **Tukey's HSD Post hoc test:** non-significant
Week 0 – FO	0.1069 (0.0494)	
Week 0 – FO	0.1069 (0.0494)	**Type I SS:** F(1,89)=7.46, p=.0076 **ETA-Square:** 0.33 **Tukey's HSD Post hoc test:** significant
Week 4 – FO	0.1298 (0.0538)	
Week 4 – FO	0.1298 (0.0538)	**Type I SS:** F(1,98)=0.66, p=.4182 **ETA-Square:** 0.34 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	0.1239 (0.0510)	
Week 4 – FOT	0.1239 (0.0510)	**Type I SS:** F(1,107)=0.84, p=.3615 **ETA-Square:** 0.37 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	0.1317 (0.0556)	

Table 4: Minimum ML COM/BOS results across orthotic conditions

Minimum ML - COM/BOS Analysis		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	0.0823 (0.0426)	**Type I SS:** F(1,83)=0.77, p=.3833 **ETA-Square:** 0.35 **Tukey's HSD Post hoc test:** non-significant
Week 0 – FO	0.0720 (0.0409)	
Week 0 – FO	0.0720 (0.0409)	**Type I SS:** F(1, 87)=2.53, p=.1151 **ETA-Square:** 0.28 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FO	0.0857 (0.0492)	
Week 4 – FO	0.0857 (0.0492)	**Type I SS:** F(1, 98)=0.13, p=.7182 **ETA-Square:** 0.25 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	0.0844 (0.0485)	
Week 4 – FOT	0.0844 (0.0485)	**Type I SS:** F(1, 107)=0.19, p=.6651 **ETA-Square:** 0.25 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	0.0874 (0.0471)	

Table 5: ML Range COM/BOS results across orthotic conditions

Range ML - COM/BOS Analysis		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	0.0343 (0.0214)	**Type I SS:** F(1,83)=0.96, p=0.3293 **ETA-Square:** 0.14 **Tukey's HSD Post hoc test:** non-significant
Week 0 – FO	0.0376 (0.0242)	
Week 0 – FO	0.0376 (0.0242)	**Type I SS:** F(1,87)=4.67, p=0.335 **ETA-Square:** 0.14 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FO	0.0441 (0.0259)	
Week 4 – FO	0.0441 (0.0259)	**Type I SS:** F(1,98)=0.65, p=.4222 **ETA-Square:** 0.34 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	0.0395 (0.0296)	
Week 4 – FOT	0.0395 (0.0296)	**Type I SS:** F(1,107)=0.82, p=.3672 **ETA-Square:** 0.37 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	0.0443 (0.0296)	

Table 6: Step count results across orthotic conditions

Step Count – Performance Analysis		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	5.5167 (1.0813)	**Type I SS:** F(1,108)=4.86, p=.0296 **ETA-Square:** 0.54 **Tukey's HSD Post hoc test:** significant
Week 0 – FO	5.2333 (0.8707)	
Week 0 – FO	5.2333 (0.8707)	**Type I SS:** F(1,117)=0.32, p=.5730 **ETA-Square:** 0.51 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FO	5.2429 (1.3125)	
Week 4 – FO	5.2429 (1.3125)	**Type I SS:** F(1, 126)=13.21, p=.0004 **ETA-Square:** 0.55 **Tukey's HSD Post hoc test:** significant
Week 4 – FOT	4.6714 (0.7561)	
Week 4 – FOT	4.6714 (0.7561)	**Type I SS:** F(1,126)=0.33, p=.5647 **ETA-Square:** 0.47 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	4.7286 (0.7787)	

Table 7: Step length results across orthotic conditions

Step Length: Performance Analysis		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	0.7662 (0.4850)	**Type I SS:** F(1,96)=1.20, p=.2768 **ETA-Square:** 0.55 **Tukey's HSD Post hoc test:** non-significant
Week 0 – FO	0.7100 (0.3888)	
Week 0 – FO	0.7100 (0.3888)	**Type I SS:** F(1,107)=1.07, p=.3022 **ETA-Square:** 0.40 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FO	0.7952 (0.3094)	
Week 4 – FO	0.7952 (0.3094)	**Type I SS:** F(1,114)=0.26, p=.6095 **ETA-Square:** 0.30 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	0.8080 (0.3185)	
Week 4 – FOT	0.8080 (0.3185)	**Type I SS:** F(1,118)=0.17, p=.6816 **ETA-Square:** 0.35 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	0.7773 (0.2693)	

Table 8: Step width across orthotic condition

Step Width: Performance Analysis		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	0.1637 (0.0719)	**Type I SS:** F(1,95)=0.16, p=.6890 **ETA-Square:** 0.14 **Tukey's HSD Post hoc test:** non-significant
Week 0 – FO	0.1612 (0.0725)	
Week 0 – FO	0.1612 (0.0725)	**Type I SS:** F(1,107)=0.01, p=.9399 **ETA-Square:** 0.18 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FO	0.1594 (0.1594)	
Week 4 – FO	0.1594 (0.0640)	**Type I SS:** F(1,114)=0.03, p=.8551 **ETA-Square:** 0.17 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	0.1597 (0.0641)	
Week 4 – FOT	0.1597 (0.0641)	**Type I SS:** F(1,118)=0.68, p=.4119 **ETA-Square:** 0.25 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	0.1518 (0.0582)	

Table 9: Average velocity results across orthotic conditions

Average Velocity: Performance Analysis		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	0.9443 (0.1682)	**Type I SS:** F(1,111)=16.91, p<.0001 **ETA-Square:** 0.48 **Tukey's HSD Post hoc test:** significant
Week 0 – FO	0.8143 (0.2723)	
Week 0 – FO	0.8143 (0.2723)	**Type I SS:** F(1,116)=12.20, p=.0007 **ETA-Square:** 0.66 **Tukey's HSD Post hoc test:** significant
Week 4 – FO	0.9180 (0.2196)	
Week 4 – FO	0.9180 (0.2196)	**Type I SS:** F(1,119)=1.51, p=.2209 **ETA-Square:** 0.68 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	0.9512 (0.2074)	
Week 4 – FOT	0.9512 (0.2074)	**Type I SS:** F(1,124)=1.28, p=.2606 **ETA-Square:** 0.59 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	0.9524 (0.1858)	

Table 10: Ipsilateral tibialis anterior – Normalized EMG results across orthotic conditions

Ipsilateral Tibialis Anterior - Normalized EMG		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	6.04 (5.60)	**Type I SS:** F(1,124)=0.56, p=.4560 **ETA-Square:** 0.20 **Tukey's HSD Post hoc test:** non-significant
Week 0 – FO	4.75 (2.48)	
Week 0 – FO	4.75 (2.48)	**Type I SS:** F(1,125)=17.42, p<.0001 **ETA-Square:** 0.42 **Tukey's HSD Post hoc test:** significant
Week 4 – FO	6.59 (3.40)	
Week 4 – FO	6.59 (3.40)	**Type I SS:** F(1,126)=1.89, p=.1716 **ETA-Square:** 0.35 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	6.04 (3.54)	
Week 4 – FOT	6.04 (3.54)	**Type I SS:** F(1,126)=2.00, p=.1593 **ETA-Square:** 0.30 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	6.84 (4.04)	

Table 11: Ipsilateral medial gastrocnemius - Normalized EMG results across orthotic conditions

Ipsilateral Medial Gastrocnemius - Normalized EMG		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	4.91 (2.24)	**Type I SS:** F(1,124)=5.75, p=.0180 **ETA-Square:** 0.39 **Tukey's HSD Post hoc test:** significant
Week 0 – FO	5.96 (3.48)	
Week 0 – FO	5.96 (3.48)	**Type I SS:** F(1,125)=14.52, p=.0002 **ETA-Square:** 0.41 **Tukey's HSD Post hoc test:** significant
Week 4 – FO	4.39 (2.04)	
Week 4 – FO	4.39 (2.04)	**Type I SS:** F(1,126)=0.88, p=.3494 **ETA-Square:** 0.18 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	4.69 (2.04)	
Week 4 – FOT	4.69 (2.04)	**Type I SS:** F(1,126)=11.67, p=.0009 **ETA-Square:** 0.18 **Tukey's HSD Post hoc test:** significant
Week 5 - FOT	5.97 (2.72)	

Table 12: Ipsilateral peroneus longus - Normalized EMG results across orthotic conditions

Ipsilateral Peroneus Longus - Normalized EMG		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	8.57 (4.92)	**Type I SS:** F(1,124)=4.13, p=.0442 **ETA-Square:** 0.20 **Tukey's HSD Post hoc test:** significant
Week 0 – FO	7.13 (3.02)	
Week 0 – FO	7.13 (3.02)	**Type I SS:** F(1,125)=10.33, p=.0017 **ETA-Square:** 0.26 **Tukey's HSD Post hoc test:** significant
Week 4 – FO	8.51 (3.07)	
Week 4 – FO	8.51 (3.07)	**Type I SS:** F(1,126)=0.82, p=.3679 **ETA-Square:** 0.27 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	8.94 (3.29)	
Week 4 – FOT	8.94 (3.29)	**Type I SS:** F(1,126)=14.37, p=.0001 **ETA-Square:** 0.25 **Tukey's HSD Post hoc test:** significant
Week 5 - FOT	7.23 (2.50)	

Table 13: Contralateral tibialis anterior - Normalized EMG results across orthotic conditions

Contralateral Tibialis Anterior - Normalized EMG		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	5.60 (5.30)	**Type I SS:** F(1,125)=6.03, p=.0154 **ETA-Square:** 0.60 **Tukey's HSD Post hoc test:** significant
Week 0 – FO	6.44 (4.81)	
Week 0 – FO	6.44 (4.81)	**Type I SS:** F(1,126)=5.74, p=.0181 **ETA-Square:** 0.52 **Tukey's HSD Post hoc test:** significant
Week 4 – FO	6.99 (3.14)	
Week 4 – FO	6.99 (3.14)	**Type I SS:** F(1,126)=0.46, p=.4998 **ETA-Square:** 0.50 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	6.69 (4.02)	
Week 4 – FOT	6.69 (4.02)	**Type I SS:** F(1,126)=0.47, p=.4920 **ETA-Square:** 0.49 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	5.60 (5.30)	

Table 14: Contralateral medial gastrocnemius - Normalized EMG results across orthotic conditions

Contralateral Medial Gastrocnemius - Normalized EMG		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	5.21 (3.51)	**Type I SS:** F(1,125)=0.19, p=.6665 **ETA-Square:** 0.40 **Tukey's HSD Post hoc test:** non-significant
Week 0 – FO	5.39 (3.34)	
Week 0 – FO	5.39 (3.34)	**Type I SS:** F(1,126)=0.73, p=.3945 **ETA-Square:** 0.35 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FO	5.04 (2.36)	
Week 4 – FO	5.04 (2.36)	**Type I SS:** F(1,126)=0.35, p=.5556 **ETA-Square:** 0.22 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	5.26 (2.55)	
Week 4 – FOT	5.26 (2.55)	**Type I SS:** F(1,126)=2.20, p=.1410 **ETA-Square:** 0.28 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	4.63 (3.11)	

Table 15: Contralateral peroneus longus - Normalized EMG results across orthotic conditions

Contralateral Peroneus Longus - Normalized EMG		
Comparison	**Mean (SD)**	**GLMW1F ANOVA Results**
Week 0 - F	7.53 (3.90)	**Type I SS:** F(1,125)=0.00, p=.9570 **ETA-Square:** 0.40 **Tukey's HSD Post hoc test:** non-significant
Week 0 – FO	7.33 (3.47)	
Week 0 – FO	7.33 (3.47)	**Type I SS:** F(1,126)=0.14, p=.7087 **ETA-Square:** 0.33 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FO	7.50 (2.93)	
Week 4 – FO	7.50 (2.93)	**Type I SS:** F(1,126)=0.19, p=.6610 **ETA-Square:** 0.25 **Tukey's HSD Post hoc test:** non-significant
Week 4 – FOT	7.35 (3.14)	
Week 4 – FOT	7.35 (3.14)	**Type I SS:** F(1,126)=0.47, p=.4921 **ETA-Square:** 0.34 **Tukey's HSD Post hoc test:** non-significant
Week 5 - FOT	8.04 (3.97)	

Appendix K: Results between Week 0-F and Week 5-FOT

Table 16: Results between Week 0-F and Week 5-FOT

COM/BOS ML Maximum:	**Type I SS:** F(1,104)=4.18, p=0.0434 **ETA-Square:** 0.41 **Tukey's HSD Post hoc test:** non-significant
COM/BOS ML Minimum:	**Type I SS:** F(1,101)=0.28, p=0.5979 **ETA-Square:** 0.35 **Tukey's HSD Post hoc test:** non-significant
COM/BOS ML Range:	**Type I SS:** F(1,101)=7.71, p=0.0066 **ETA-Square:** 0.36 **Tukey's HSD Post hoc test:** significant
Step Count:	**Type I SS:** F(1,117)=44.10, p<.0001 **ETA-Square:** 0.67 **Tukey's HSD Post hoc test:** significant
Step Length:	**Type I SS:** F(1,97)=0.81, p=0.3714 **ETA-Square:** 0.47 **Tukey's HSD Post hoc test:** non-significant
Step Width:	**Type I SS:** F(1,96)=0.04, p=0.8363 **ETA-Square:** 0.47 **Tukey's HSD Post hoc test:** non-significant
Average Velocity:	**Type I SS:** F(1,116)=0.57, p=0.4533 **ETA-Square:** 0.66 **Tukey's HSD Post hoc test:** non-significant
Ipsilateral Tibialis Anterior:	**Type I SS:** F(1,125)=5.86, p=0.0169 **ETA-Square:** 0.25 **Tukey's HSD Post hoc test:** significant
Ipsilateral Medial Gastrocnemius:	**Type I SS:** F(1,125)=7.34, p=0.0077 **ETA-Square:** 0.25 **Tukey's HSD Post hoc test:** significant
Ipsilateral Peroneus Longus:	**Type I SS:** F(1,125)=4.64, p=0.0331 **ETA-Square:** 0.22 **Tukey's HSD Post hoc test:** significant
Contralateral Tibialis Anterior:	**Type I SS:** F(1,125)=2.01, p=0.1588 **ETA-Square:** 0.40 **Tukey's HSD Post hoc test:** non-significant
Contralateral Medial Gastrocnemius:	**Type I SS:** F(1,125)=7.34, p=0.0077 **ETA-Square:** 0.25 **Tukey's HSD Post hoc test:** significant
Contralateral Peroneus Longus:	**Type I SS:** F(1,125)=0.71, p=0.4023 **ETA-Square:** 0.35 **Tukey's HSD Post hoc test:** non-significant