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The Influence of Visual Cueing on Freezing of Gait Among Individuals with Parkinson's Disease

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

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THE INFLUENCE OF VISUAL CUEING ON FREEZING OF GAIT
AMONG INDIVIDUALS WITH PARKINSON'S DISEASE

(Thesis Format: Integrated Article)

by

L. Keltie Brigham

Graduate Program in Health and Rehabilitation Sciences

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

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Abstract

Freezing of gait (FOG) is a distressing symptom of Parkinson's disease with a significant impact on fall risk and quality of life. Although medication improves some of the symptoms of slowness and rigidity, it is only minimally effective in treating FOG. Therefore, a better understanding of alternative treatment strategies is needed to manage this symptom. To investigate the effectiveness of visual cueing in the management of FOG, and to determine if visual cueing is dependent upon the spatial location of cue presentation. Six individuals with Parkinson's disease who experience FOG were asked to complete the Timed Up and Go test three times in each of the following conditions: (i) no visual cue, (ii) cue presented at the users feet, (iii) cue presented at a distance equivalent to step length, and (iv) cue presented at a distance equivalent to stride length. Step length, velocity, and the elapsed time taken to complete a 180 degree turn was assessed using a 10-ft Zeno electronic walkway. In addition, time taken to complete the Timed Up and Go test was recorded, and walker positioning assessed via Kinovea motion analysis software. The results of this study identified that irrespective of the spatial location of cue presentation, visual cueing led to an improvement in four out of the five outcome measures (timed up and go, turn time, walker positioning and step length). Findings from this study may help lead to the development of best practice guidelines for implementing this novel treatment strategy.

Key Words: Parkinson's disease, Freezing of Gait, Visual Cue, Gait, Walker study

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List of Abbreviations

PD: Parkinson's Disease

FOG: Freezing of Gait

FOF: Fear of Falling

HRQL: Health Related Quality of Life

UPDRS: Unified Parkinson's Disease Rating Scale

TUG: Timed Up & Go test

PKMAS: ProtoKinetics Movement Analysis Software

FOG-Q: Freezing of Gait Questionnaire

QoL: Quality of Life

Chapter 1: Introduction

Parkinson's Disease

First described in 1817 by James Parkinson (Parkinson, 2002) and later formally labeled by Jean-Martin Charcot (Jankovic, 2008), Parkinson's disease (PD) is one of the most common movement disorders in the world (Samii, Nutt, & Ransom, 2004), affecting over 100,000 Canadians (Parkinson Society Canada, 2011). The average age of onset is estimated to be early to mid 60's (Inzelberg, Schectman, & Paleacu, 2002), with a higher prevalence in males than females (Bower, Maraganore, McDonnell, & Rocca, 1999). The frequency of PD increases with age, making the number of PD diagnoses more prevalent within the current ageing population (Lees, Hardy, & Revesz, 2009; de Rijk et al., 1995).

Clinically, PD is a progressive neurodegenerative disorder distinguished by bradykinesia (reduced speed of voluntary movement), resting tremor, postural instability and rigidity (Benatru, Vaugoyeau, & Azulay, 2008). Although motor symptoms dominate the clinical presentation, non-motor symptoms including but not limited to depression, anxiety, and sleep disturbance, are also believed to affect the majority of individuals at some point during the course of the disease (Aarsland et al., 2009). Parkinsonian symptoms result from a degeneration of dopamine producing neurons within the substantia nigra pars compacta of the basal ganglia (Damier, Hirsch, Agid, & Graybiel, 1999). Following cell loss, the reduced dopamine levels lead to diminished function of the basal ganglia (Bloem, Hausdorff, Visser, & Giladi, 2004), a collection of nuclei that are responsible for regulating motor control as well as the initiation and termination of voluntary movements (ten Donkelaar, 2011).

Along with degeneration within the basal ganglia, there is evidence of widespread damage throughout the central nervous system including the autonomic nervous system, spinal cord, olfactory region, limbic cortex, locus coeruleus (norepinephrine neurons), and nucleus basalis of Meynert (cholinergic neurons) (Sethi, 2008). Although the role of neurotransmitter depletion including acetylcholine, serotonin and noradrenaline is not yet fully understood, Macphee & Stewart (2012) propose that the decrease in neurotransmitters could be partially responsible for the expression of non-motor symptoms.

While the etiology of PD remains largely unknown, evidence suggests that a combination of factors including both genetic and environmental are involved (Samii et al., 2004; Lees et al., 2009; Nuytemans, Theuns, Cruts, & Van Broeckhoven, 2010; Singleton, Farrer, & Bonifati, 2013). A recent review of the literature reported mutations in α -synuclein (SNCA), and Leucine-rich repeat kinase 2 (LRRK2) cause autosomal dominant forms of PD, whereas mutations in parkin (PARK2), PTEN-induced putative kinase 1 (PINK1), and DJ-1 (PARK7) lead to autosomal recessive forms of PD (Singleton et al., 2013). Interestingly, Nuytemans et al. (2010) identified that only 15 to 20% of individuals with PD have a clear family history of PD, thus suggesting that the etiology of PD is a combination of multiple genetic and environmental factors (Nuytemans et al., 2010).

From an environmental perspective, evidence suggests that certain types of toxins elicit degeneration of dopaminergic neurons. For example, Brooks, Chadwick, Gelbard, Cory-Slechta, & Federoff (1999), found a strong correlation between the incidences of PD and continued exposure to paraquat - one of the most widely used herbicides in the world. In their investigation, Brooks et al. (1999), systematically administered the

herbicide to mice and documented a decrease in the dopaminergic neurons of the substantia nigra, as well as a demonstration of PD like symptoms including rigidity and tremor (Brooks et al., 1999). Similarly, a review by Bové, Prou, Perier, & Przedborski (2005), examined four neurotoxins (6-hydroxydopamine (6-OHDA), 1-methyl-4-phenyl-1,2,3,6- tetrahydropyridine (MPTP), rotenone, and paraquat) and concluded that each substance was capable of producing selective damage to the dopamine producing neurons. Epidemiological studies have also implicated agents such as well water (Koller et al., 1990), metals including manganese and iron (Zayed et al., 1990), and prolonged pesticide exposure (Priyadarshi, Khuder, Schaub, & Priyadarshi, 2001).

There is currently no diagnostic test to confirm PD, thus diagnosis is established based on clinical observations (Jankovic, 2008). Specifically, in order to be diagnosed with PD an individual must present with bradykinesia and at least one of the other cardinal features - resting tremor, postural instability, or rigidity (Tolosa, Wenning & Poewe, 2006). Bradykinesia, the hallmark indicator is verified through demonstration of slowness during gait, speech or expression of emotion, and/or the progressively decreased speed with which individuals complete finger or foot tapping tests (Lees et al., 2009). The most common assessments to classify stage and progression of the disease is the use of the Modified Hoehn and Yahr scale, (Jankovic, 2008) and the Unified Parkinson's Disease Rating Scale (UPDRS) respectively (Goetz et al., 2003).

Clinical Features of Parkinson's Disease

In addition to the primary motor features of PD previously addressed (tremor, rigidity, bradykinesia, and postural instability), individuals with PD may experience several secondary motor complications. These secondary features include: stooped posture, dystonia, festination, freezing of gait, impaired fine motor dexterity, hypophonia,

difficulty swallowing, sexual dysfunction, micrographia, and hypomimia (Jankovic, 2008; Lees et al., 2009; Yarnall, Archibald, & Burn, 2012). These symptoms vary in severity and do not present universally among all individuals (Jankovic, 2008).

While the cardinal motor features of PD dominate the clinical presentation, many individuals with PD also experience several non-motoric concerns. These may include fatigue, anxiety, sleep disturbance, constipation, bladder and gastrointestinal disturbance, and sensory complaints such as pain, numbness, tingling, and burning in the limbs (Jankovic, 2008, Fahn, 2003). Behavioural and mental symptoms are also common among individuals with PD and may include changes in mood such as depression, decreased motivation and apathy, slowness in thinking, and dementia (Jankovic, 2008; Fahn, 2003). In fact, recent research has identified that individuals with PD report that non-motoric concerns are just as troubling, if not more so than some of the motor symptoms faced by this clinical population. For example, in 2010, Politis et al., asked 265 individuals with PD to rank order their most troublesome symptoms. Individuals early in the disease course (diagnosed within the previous 6 years) identified that slowness, tremor, stiffness, pain and loss of smell/taste were most troublesome, whereas individuals with more advanced PD (living with PD for ≥ 6 years) reported that fluctuating response to medications, mood changes, drooling, sleep problems, and tremor were most bothersome (Politis et al., 2010). These findings are further supported by research that identified that Health Related Quality of Life (HRQOL), which is from the patient's perspective, decreases with disease progression and is impacted by more than just the movement interruptions associated with PD (Karlsen, Tandberg, Arslan, & Larsen, 2000). For example, Forsaa, Larsen, Wentzel-Larsen, Herlofson, & Alves, (2008) followed 227 individuals with PD over 8 years to assess levels of HRQL in relation to

disease progression. Although decline in physical function was reported to be the single most important factor contributing to decreased HRQL, collectively cognitive non-motor aspects such as loss of friends, isolation, depression, loss of independence and other emotional consequences, surpassed the impact of motor function on levels of HRQL (Forsaa et al., 2008). Similarly in a community based cross sectional study, Schrag, Jahanshahi, & Quinn, (2000) concluded that individuals with PD differed most from an age matched population in areas relating to limitations in social and physical function, as well as in perceptions about health status, both of which were found to be associated with a significantly impacted HRQL (Schrag et al., 2000).

Postural instability and freezing of gait (FOG) are two phenomena that have been reported to impact negatively on an individual's independence and ability to actively engage in meaningful occupations (Giladi, Kao, & Fahn, 1997, Lindholm, Hagell, Hansson, & Nilsson, 2014). Specifically, these gait impairments are most troubling as they lead to an increased risk of falls and/or increased anxiety associated with fear of falling (Lindholm et al., 2014). Wood, Bilclough, Bowron, & Walker (2002) conducted a prospective study with 109 individuals with idiopathic PD and identified that following a year of observation, falls were documented to have occurred in 68% of participants and over 50% of these individuals fell on more than one occasion. This is not surprising as when compared to other medical conditions, PD has been found to be the leading cause of falls in the elderly (Teno, Kiel, & Mor, 1990). Specifically, the risk of falls and near falls in PD compared to the general population has been reported to be two and threefold respectively (Teno, et al., 1990; Wood et al., 2002). As a result of the gait and balance impairments, including a stooped forward posture, falls within this population occur most frequently in the anterior or lateral directions (Bloem et al., 2004). Unfortunately, forty to

sixty-five percent of falls in PD have been reported to lead to injury, and over seventy-five percent of these injuries require healthcare services (Gray & Hildebrand, 2000; Wielinski, Erickson-Davis, Wichmann, Walde-Douglas, & Parashos, 2005). The increased risk of falls associated with PD is particularly important not only because of the propensity for injury, but also because of the fear and anxiety related to decreased functional mobility that ultimately contributes to a loss of independence, increased risk of depression, and a reduced quality of life (QoL) (Moore, Peretz, & Giladi, 2007; Bloem et al., 2004; Benatru et al., 2008; Lindholm et al., 2014).

Fear of falling (FOF), recognized as the anxiety related to the fear of future falls, impacts QoL such that it is the major factor contributing to self-imposed activity restriction (Rahman, Griffin, Quinn, & Jahanshahi, 2011; Murphy, Williams, & Gill, 2002). The phenomenon originates as a feeling/thought, but as an individual's confidence in their physical ability decreases, FOF limits daily activities and becomes a real/tangible problem (Perez-Jara, Walker, Heslop, & Robinson, 2010). Typically, individuals with a heightened FOF either tend to rely more heavily upon others to accomplish basic tasks or else they avoid situations all together thus leading to social isolation and depression. As a result, caregivers may experience a larger burden resulting from increased demands being placed upon them, or a greater need for home based care, consequently posing an economic burden on society (Perez-Jara et al., 2010). Rahman et al., (2011) evaluated 130 individuals with PD to identify factors associated with FOF. Gait disturbances such as FOG, as well as advanced disease progression were reported to lead to greater levels of FOF. In their study FOF was quantified via three questionnaires (Falls Efficacy Scale, Consequences of Falling, and Survey of Activities and Fear of Falling in the Elderly), and accounted for 65% of the variation in QoL scores, thus indicating that FOF is a significant

factor that warrants consideration when dealing with individuals with PD (Rahman et al., 2011).

Management of Symptoms

While there currently remains no cure for PD, advances in the pharmaceutical industry have resulted in treatment being focused on symptom management and geared towards maintaining independence and QoL (Lees et al., 2009). Specifically, Levodopa was developed in the late 1960's and was the first pharmaceutical proven to be effective in the treatment of PD (Cotzias, Papavasiliou, & Gellene, 1969). Surprisingly, since its development, Levodopa remains the single most efficacious medication (Schapira, Emre, Jenner & Poewe, 2009; Zappia, Colosimo, & Poewe, 2010). Although Levodopa replacement therapy leads to clear improvements in motor symptoms such as bradykinesia and rigidity (Lees et al., 2009), after approximately 5 years of beginning treatment, 50% of individuals taking Levodopa develop motor complications including wearing off and dyskinesia's (involuntary uncontrolled movements) (Kumar, Van Gerpen, Bower, & Ahlskog, 2005; Mazzella, et al., 2005; Rascol et al., 2000). To help delay the onset of these motor complications and to help ensure that the drug remains effective as the disease progresses into the more advanced stages, pharmacological management often begins with the administration of dopamine agonists (Hubble, 2002). While dopamine agonists have the advantage over Levodopa in that they do not cause dyskinesia's, they are however believed to be between 10%-20% less effective (Parkinson Study Group, 2000; Lees, Katzenschlager, Head, & Ben-Shlomo, 2001; Rascol et al., 2000), and are associated with additional side effects including dizziness, hallucinations, and nausea (Tuite & Ebbitt, 2001).

While medication has been found to improve some of the symptoms of PD such as bradykinesia, rigidity, and tremor, it has been found to be only partially effective in managing FOG (Bowes et al., 1990; Levy-Tzedek, Krebs, Arle, Shils, & Poizner, 2011). For example, Sethi (2008) examined the literature on the effectiveness of Levodopa in managing FOG and identified in general that positive effects of Levodopa treatment were reported in studies that included participants early in the disease process, whereas FOG was more apt to be unresponsive to Levodopa treatment among individuals in more advanced stages of the disease. The results of this review suggested that the observed benefits might have been attributed to improvements in rigidity and bradykinesia as opposed to a direct effect on FOG (Sethi, 2008).

Freezing of Gait

Freezing of gait (FOG), also known as a motor block, is a type of gait disturbance commonly associated with the later stages of PD (Giladi et al., 2001). Described by individuals as feeling like their feet are glued to the floor (Browner & Giladi, 2010), FOG is defined as a temporary hesitation or inability to initiate normal gait (Rahman, Griffin, Quinn, & Jahanshahi, 2008, Contreras & Grandas, 2012). Triggers that commonly induce freezing episodes include initiating movement, turning, approaching obstacles or doorways, as well as emotional factors such as stressful situations or fatigue (Contreras & Grandas, 2012; Lamberti et al, 1997; Rahman et al., 2008). Performing more than one task at a time (i.e., dual or multi tasking), or ambulating in situations that place increased attentional demands on the individual (i.e., walking in a crowded mall), have also been reported to elicit FOG (Rahman et al., 2008). Interestingly freezing episodes may also occur spontaneously in absence of FOG-provoking stimuli (Schaafsma et al., 2003). One possibility that may account for spontaneous FOG is offered by Nieuwboer et al., (2001)

who suggests that FOG while walking may stem from failure to generate normal amplitude in step length. This possibility is supported by Chee, Murphy, Danoudis, Georgiou-Karistianis, & Iansek (2009) who reported an increased frequency of FOG with reduced stride length and a gradual step-to-step reduction, called a sequence effect.

While the pathophysiology of FOG remains unknown, it is well established that the frequency of freezing episodes increases with disease duration with up to 80% of individuals experiencing episodes during the more advanced stages of the disease (Macht et al., 2007). Similarly, although much remains unknown about FOG, it is clear that the consequences of this motor symptom are severe. For example, not only does FOG affect the independence of individuals living with PD because of its propensity to cause falls (Bloem et al., 2004), but this phenomena leads to a significantly reduced QoL (Giladi et al., 2001). Moore et al. (2007) examined how the severity of FOG impacted QoL within individuals with PD, through the use of self-reports and questionnaires. They concluded that the unpredictable nature of FOG was one of the main factors in reducing QoL. FOG is a source of embarrassment and frustration when an individual seemingly loses control over basic functions, such as walking, and these emotional costs were most significantly related to decreased QoL. The importance of treating this highly visible and sometimes embarrassing symptom, as well as understanding its causes are critical for improving patient QoL (Michalowska, Fiszler, Krygowska-Wajs, & Owczarek, 2005; Moore et al., 2007).

Management of Freezing of Gait

While pharmacological management has proven to be an effective strategy in mitigating some symptoms of PD, it has minimal effects on improving postural stability (Bloem, 1992) and in fact has in some cases been found to exacerbate FOG symptoms (Bloem et al., 2004; Lamberti et al., 1997). For example, Contreras & Grandas (2012) conducted a cross sectional study to determine the risk factors involved in FOG. One hundred and sixty individuals (both males and females) of, varying ages and disease duration were compared to assess differences between those with and without FOG. Results indicated that on average subjects who experienced FOG were taking a significantly higher dose of Levodopa (474.6 vs. 650.1mg/day). Moreover of the 44% of individuals who experienced FOG, 35% experienced freezing episodes during the “on” phase of their medication cycle. As a result of the limited effectiveness of medications to manage FOG and postural instability, many individuals with PD require the use of assistive devices such as a walker to help maintain their mobility in the later stages of the disease. Although the utilization of walker’s are beneficial in that they provide a stable base of support and a sense of security for users, they also significantly reduce walking speed (Cubo, Moore, Leurgans & Goetz, 2003). Cubo et al. (2003) examined the gait patterns of individuals with PD with and without the use of standard and wheeled walkers under conditions known to elicit FOG. Findings indicated that gait speed decreased for each trial involving either type of walker, and that the number and length of freezing episodes increased in trials involving the standard walker (Cubo et al., 2003).

A second factor that bares consideration when dealing with the use of walkers is that of their impact on posture. Research conducted by Liu (2009) assessed the usage of

rolling walkers by 158 older adults identified that as many as 50% of participants adopted a forward leaning posture while ambulating with the walker. This common problem among walker users is known to increase the potential for falls (Liu, 2009), thus coupled with the characteristic stooped posture associated with PD, the risk for falls would likely be even greater in this population. Thus, while walkers provide support to help minimize falls during episodes of freezing, they also have an effect on spatiotemporal parameters of gait that may consequently exacerbate the very phenomena they were designed to assist with. One strategy that has been found to help normalize gait among individuals with PD is to use external cues.

External Cues

External cueing is one strategy that has emerged as a promising non-pharmacological option to help normalize gait patterns and manage FOG (Bloem et al., 2004). External cues can be presented in the form of tactile, auditory, and visual information that can trigger movements or provide rhythmic or spatial support to improve the quality of movements (Rochester et al., 2005). Cueing is believed to work by evoking increased sensory stimulation thus directly focusing attention on the gait task, therefore shifting the locus of control from the automatic control of the basal ganglia to other conscious pathways.

Tactile Cueing

While impairment of the motor system (basal ganglia and motor cortex) is traditionally considered to be the major cause of conventional parkinsonian gait (Bartels, & Leenders, 2009), increasing evidence suggests that sensory abnormalities may also be responsible (Labyt, et al., 2013). Specifically, it has been proposed that impaired central

sensorimotor integration at the striatum and defective peripheral sensory proprioceptive feedback may contribute to abnormal movement in PD (Abbruzzese & Berardelli, 2003; Lewis, & Byblow, 2002). This is a particularly interesting finding given that among individuals without neurological disease, decreased peripheral sensation achieved by anesthesia of the foot sole has been demonstrated to impair static and dynamic balance control (McKeon & Hertel, 2007; Meyer, Oddsson, & De Luca, 2004). Conversely, sensory stimulation of the plantar cutaneous surface in elderly subjects has been shown to improve balance and gait (Maurer, Mergner, Bolha, & Hlavacka, 2001). Similar improvements have also been reported among individuals with PD. For example, Novak & Novak (2006) assessed the effects of enhanced proprioceptive feedback using step synchronized vibratory insoles among 8 individuals with mild-moderate PD (Novak, & Novak, 2006). Results demonstrated that when the vibratory insoles were worn, improvements were noted in stride length, velocity, cadence, and stride variability. Improvements to gait have also been demonstrated using a shoe insole with a raised ridge near the perimeter of the sole (Jenkins et al., 2009). Results demonstrated that among 40 individuals with mild PD, single limb support time and velocity both increased with use of the facilitatory insole. Furthermore, use of the insole resulted in an improvement in the timing of tibialis anterior muscle activation during the heel strike phase of gait, leading to improvement in the gait pattern (Jenkins et al., 2009). While results are encouraging, proprioceptive insoles of this nature have yet to become commercially available. In addition, some consideration must be given to the use of this form of cueing over a longitudinal time period as this may elicit potential risks associated with skin breakdown, especially among individuals with reduced circulation.

Researchers have also investigated the use of both auditory and visual cueing as means of improving gait among individuals with PD (Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004). Glickstein & Stein (1991) suggest that these types of external cues make use of a patient's cerebellar pathway which is unaffected by PD. For example, in cases where visual cues are adopted, movements are directed by vision as opposed to the basal ganglia, which is usually involved in motor control, effectively bypassing the disease affected region of the brain (Glickstein, & Stein, 1991).

Auditory Cueing

To date, several different types of auditory cueing have been investigated and include strategies such as listening to the beat of a metronome, or listening to the rhythm of music. For example, Willems et al., (2006) examined the influence of auditory cueing among 20 individuals with PD. Auditory cues in the form of a metronome beat were administered as participants walked along an 8 m long walkway. Results indicated that while all participants benefited from receiving rhythmic auditory cues in relation to step frequency (steps/minute) and speed, cueing had minimal impact on step length. Spildooren et al., (2012) also investigated the effects of using a metronome to improve gait among 30 individuals with PD classified as either non-freezers (n=14) or freezers (n=16). Unlike previous research wherein auditory tones are provided to cue each step, Spildooren et al., (2012) examined the utility of cueing each stride - an approach that was termed unilateral cueing. Similar to the findings of Willems et al., (2006), Spildooren et al., (2012) identified that rhythmic auditory cueing serves as a useful strategy for managing FOG. Specifically, results demonstrated that cueing significantly decreased episodes of FOG, as freezing occurred in 53.8% of trials during baseline compared with only 3.8% during cued trials.

Rhythmic auditory stimulation delivered in the form of a music stimulus has also been reported to lead to significant improvements in spatiotemporal parameters of gait. For example, Thaut et al., (1996) investigated the effects of a 3 week home based gait training program focused on improving mobility via auditory music cueing among 15 individuals with demonstrated gait impairment secondary to PD. In their investigation, the auditory cues consisted of audiotapes with metronome-pulse patterns embedded into the on/off beat structure of rhythmically accentuated instrumental music. Results established the effectiveness of this intervention as the musical cues were found to significantly improve participants gait velocity by 25%, stride length by 12%, and step cadence by 10%. Furthermore, timing of muscle activation patterns for the tibialis anterior and vastus lateralis were found to improve on trials involving the rhythmic stimuli (Thaut et al., 1996).

While the effectiveness of using rhythmic auditory cues to improve gait among individuals with PD is promising, application of auditory cues may pose a practical problem in day-to-day situations. For example, to deliver an external auditory cue outside of a controlled setting requires the use of headphones. This has the potential to interfere with an individual's ability to interact with their environment and could become a hazard when navigating crowded public areas. For example, Brown, Bruin, Doan, Suchowersky, and Hu (2009) identified that listening to music while walking may be detrimental to ones safety as this places the individual in a dual-task situation wherein they may have their attention divided. As a result of this divided attention, individuals may have less cognitive resources available (Grimbergen, Dijk, Munneke, & Bloem, 2006) thus diminishing their capacity to navigate their environment safely. In addition, listening to repetitive tones such as those produced by a metronome may become quite monotonous, and may lead to

diminished efficacy of the intervention over time as a result of habituation.

Visual Cueing

To date, studies have evaluated the effect of visual cues on gait among individuals with PD in both laboratory and home settings, and have provided evidence of short-term treatment fidelity. In fact, research suggests that visual cueing is the most effective form of cueing modality. For example, Rahman et al., (2008) surveyed 130 individuals with PD regarding the cues and strategies that help them overcome episodes of FOG. The results revealed that 31.5% of the sample reported that visual cues improved their mobility, whereas tactile and auditory cueing were effective to a lesser extent with 27.7% and 19.2% of the sample reporting these cues to be effective, respectively. The most common visual cues that have been investigated include transverse lines marked on the floor, and the use of various forms of laser lights. For example, Morris, Ianssek, Matyas, and Summers (1996), examined the effects of using visual floor markers on the walking pattern of 54 individuals with PD. Their results demonstrated that the ability to generate a normal stepping pattern is not lost in PD as evidenced by the ability of participants to elicit normal stride length when using the visual cues. Similar findings were also reported by Jiang and Norman (2006) who observed that visual cues were effective at improving gait among 14 individuals with PD. The visual cues used were high contrast transverse lines on the floor and were found to result in increases to both pace and stride length. More recently, Lee et al. (2012) used both visual and auditory cues as a means to discern their effects as a possible treatment for FOG in 15 individuals with PD troubled by FOG. The visual stimuli presented were evenly spaced transverse white lines placed along a walkway corresponding to set distances of a normalized step length for each subject, and the auditory cue was a rhythmic tone created by a metronome. Results

indicated that both visual and auditory cues significantly increased velocity and stride length, and reduced both cadence and number of freezing episodes as compared to baseline. While both visual and auditory cues were able to positively affect parameters of gait, when the two forms of cueing were compared, visual cueing was found to lead to improvements that were significantly greater than those obtained with the auditory cue (Lee et al., 2012).

Although significant improvements are realized when using visual cues such as transverse lines on the floor, there is a considerable limitation with adopting this approach in a community setting. For example, while it may be possible to design the home environment to support a visual cueing approach using transverse lines on the floor, this would not be possible to do for all venues visited outside of the home. As a means to overcome this limitation, In Step Mobility Products Inc, launched an, innovative walker called the U-Step. The U-step walking stabilizer is a specialized walker prescribed to many individuals with gait and balance problems. In particular, individuals with PD benefit from the U shaped frame that provides support in many directions and increases stability. While similar in design to other wheeled walkers, the U-Step is unique in that it contains a built in cueing device that emits a laser beam of light on the ground (In Step Mobility, 2009). This transverse line of light progresses with the walker and acts as a dynamic stimulus that can be stepped over, thus promoting effective ambulation much the same way in which the static transverse stripes function.

Donovan et al. (2011) assessed the efficacy of the U-Step walker and visual cue for overcoming FOG within a sample of 26 individuals with PD. Participants were first provided the opportunity to become familiar with the walker without the visual cue turned on over a 1-2 month baseline period, following which they were instructed to use the

walker for an additional month with the laser light turned on during ambulation. Results indicated that the visual cue lead to improvements in gait as demonstrated by a mean improvement of 6.6% on the freezing of gait questionnaire. Specifically, secondary analyses of the individual items that comprised the freezing of gait questionnaire indicated the laser cue resulted in a significant reduction in both the number of freezing episodes experienced and the duration of start hesitations as compared to values at baseline.

Kegelmeyer, Parthasarathy, Kostyk, White, and Kloos (2013) also investigated the utility of the U-Step walker to improve gait among 27 individuals with PD. In their investigation, spatiotemporal parameters of gait were examined as participants walked in both a straight path and around obstacles. Similar to the findings of Donovan et al. (2011), the U-Step walker was found to lead to improvements in gait patterns including increased velocity, and a decrease in the incidence of freezing episodes. It is important to note, however, that the U-Step walker was also found to produce significant variability in gait, a factor known to be associated with falls (Shaafsma et al., 2003). The authors suggest that the increased variability may be the result of several design factors including added walker weight, a reverse braking system, and the requirement for participants to look down at the ground to see the laser. In addition, results indicated that the laser light on the U-Step walker did not improve gait measures or safety when participants walked around obstacles. This finding is not surprising, given the research conducted by Patla (1998), and Marigold & Patla (2007, 2008) on the importance of fixating visual gaze ahead of oneself to assist with obstacle avoidance and planning subsequent foot placement.

Given the aforementioned literature on the importance of directing visual gaze ahead of oneself, a limitation of the U-Step walker is that the visual laser cue is directed

towards the ground between the rear wheels. As a result, when individuals use the visual cue they must focus their attention downwards, preventing them from looking ahead. In addition to disrupting visual gaze, this action encourages individuals to adopt a forward flexed posture. This is important, especially for individuals with PD who already manifest a stooped posture and compromised postural reflexes that place them at an increased fall risk (Latt, Lord, Morris, & Fung, 2009; Liu, 2009). A second limitation associated with the U-Step is that it has a prominent heavy frame that is not aesthetically pleasing and cannot be customized to suit the user's preferences (e.g., restricted colours available). The limited options the U-Step provides along with frame design can lead to embarrassment and feelings of being socially unacceptable that in turn may result in diminished adherence or device abandonment (Parette, & Scherer, 2004).

In lieu of the aforementioned limitations, a company named ProtoKinetics developed a portable laser cue named the Mobilaser. This device is innovative in design as the laser cue is emitted from an extension that swivels thus serving as an adjustable visual cue (MAP/CIR Inc., 2011). As a result of this articulating portable design, the device is able to be attached to any assistive mobility device of the user's choice and the articulating head can be adjusted as to properly align the visual cue while the device is mounted in various positions specific to the frame design of each walker. In a recent cross over study, Van Gerpen, Rucker, Matthews, & Saucier (2012) examined the Mobilaser while attached to a wheeled walker to determine its effects on the occurrence of FOG and time taken for 6 individuals with Parkinsonism to complete a predetermined course. As opposed to the fixed traditional laser, which projects a line of light near the users feet, Van Gerpen et al. (2012) utilized the adjustability of the Mobilaser to project the laser line approximately where each person's next step would fall. Although this placement is

similar to the traditional cue location (e.g., within the walker frame near the rear wheels) it allows for customization to accommodate varying user heights. The study was conducted in a realistic environment and the testing protocol required subjects to walk a course that involved exiting a doorway, turning right, walking down a hallway, turning around, and returning to the doorway. Analyses revealed that the Mobilaser produced a significant reduction in the number of freezing episodes and resulted in faster times walking the course compared to when the wheeled walker was used without the visual cue.

As briefly mentioned previously, one limitation to the aforementioned visual cueing approach is that both the U-Step walker and Mobilaser™ require users to direct their attention downward to the ground immediately in front of their feet. This is important because research has identified that when vision is limited to less than 2 step lengths ahead of someone as they walk, their walking speed decreases and they experience more frequent collisions with obstacles (Matthis & Fajen, 2013). Specifically, vision is critical for control of safe movement as it provides information regarding step-to-step progress as well as incorporating environmental conditions into route planning (Patla, 1997, 1998). Moreover, vision allows for avoidance strategies to be implemented and for accurate step placement that helps maintain balance during locomotion (Patla, 1997; Marigold & Patla, 2007). For example, Marigold and Patla (2007) investigated walking across varied types of terrain while recording gaze fixation and identified that individuals spent 56% of the time with their visual gaze fixated roughly two steps ahead. This strategy of fixating visual gaze ahead of oneself serves to allow a large amount of peripheral vision to remain available within the lower visual field. This is important as the information obtained from the lower visual field is used to control gait, and is particularly

important for obstacle avoidance and planning subsequent foot placement (Patla, 1998). A follow up study conducted by Marigold and Patla (2008), examined the impact of obstructing the lower visual field on spatiotemporal parameters of gait and identified that gait speed and step length became significantly reduced in trials wherein the lower visual field was obstructed compared to those when vision was unobstructed.

Provided that both the U-Step walker and Mobilaser™ require users to direct their visual gaze downward towards the ground immediately in front of their feet, individuals who adopt these devices are likely less able to pay attention to the environment ahead of them. As a result, it is possible that these individuals are at an inherent risk of colliding with an object that may subsequently precipitate a trip or a fall (Matthis & Fajen, 2013). Taken together with research indicating that both using a walker (Cubo et al., 2003) and directing visual gaze less than 2 step lengths ahead (Matthis & Fajen, 2013) results in diminished spatial temporal parameters of gait, and with research illustrating that FOG may be exacerbated by decreased spatial temporal parameters of gait (Cubo et al., 2003); a logical next step in this line of inquiry would be to determine whether the efficacy of visual cueing is dependent upon the spatial location of cue presentation. Specifically, stemming from the research conducted by Patla, (1998) and Marigold & Patla, (2007), research is needed to determine whether visual cueing remains an effective strategy to improve gait among individuals with PD when the visual cue is directed ahead of the user instead of in the traditional spatial location at their feet.

As a first step in this process, initial feasibility testing is required. Therefore, the purpose of this investigation was to conduct a feasibility study to test study protocol and elucidate pragmatic indicators that will need to be considered in the design of a future full-scale study intended to investigate the effect of spatial location on visual cue

effectiveness. Specifically, the objectives of this feasibility study were twofold: **i) to test** the study protocol and outcome metrics (i.e., effectiveness of recruitment strategy, visibility of visual cues, levels of protocol compliance), and, **ii) to determine whether** there are preliminary indications that the intervention involving a more forward placed visual cue will be successful and thus worth pursuing (i.e., examine trends).

Chapter 2: Methods

Recruitment Strategy and Sample

A purposive sample of 6 participants with idiopathic Parkinson's disease (PD), with a history of freezing of gait (FOG) and falls, were recruited for this study.

Recruitment of participants and confirmation of PD diagnosis based on established diagnostic criteria (Hughes, Daniel, Kilford, & Lees, 1992), were completed by a neurologist specializing in movement disorders from a clinical practice in London, Ontario.

In order to be eligible to participate, individuals were required to: i) be at least 50 years of age, ii) have a clinical diagnosis of PD with a history of FOG and falls, iii) be capable of walking 20 feet with or without the use of an assistive device, and iv) have functional vision that allowed them to see the visual cue (laser beam of light projected on the ground). Individuals were excluded from participating if they reported experiencing major back or lower limb pathology that may influence gait, or if they were unable to perceive the visual cue.

Testing Protocol

Testing for each participant was completed in a single session held within the Interdisciplinary Movement Disorder Laboratory, located in Elborn College at The University of Western Ontario. At the beginning of the testing session each participant received a copy of the letter of information to review (Appendix A), had all aspects of the study verbally explained to them, and were provided with an opportunity to ask any questions. Once all questions were answered to their satisfaction, participants were asked to provide informed written consent (Appendix B). The research protocol, recruitment

method, and mechanism for obtaining informed consent were approved by the Health Sciences Research Ethics Board, at The University of Western Ontario (Appendix C).

Upon providing informed consent, participants received a brief clinical examination by the study neurologist to determine disease severity. Specifically participants were assessed on the motor subscale (subsection III) of the Unified Parkinson's Disease Rating Scale (UPDRS-III; Appendix D) and on the modified Hoehn & Yahr staging scale (H&Y; Appendix E). Subsection III of the UPDRS was used to describe a participant's motor function by assigning a value of 0 to 4, within several domains related to: bradykinesia, postural stability, gait, rigidity, tremor and speech. Within the UPDRS, a score of 0 indicates normal function, whereas a score of 4 indicates severe presence of the symptom (Movement Disorder Society, 2003). Subsection III is scored out of 56, with a higher overall score being indicative of greater disease severity. The UPDRS is a widely used evaluation tool shown to have high inter-rater reliability (The total sum of all UPDRS motor scores, ICC = 0.82) (Richards, Marder, Cote, & Mayeux, 1994).

The modified Hoehn & Yahr Staging scale is a tool that was developed to describe how the symptoms of PD progress. The scale is comprised of an 8 stage rating system that ranges from 0 through 5 where a score of 0 represents the absence of disease signs, whereas a score of 5 represents significant progression wherein the individual is wheelchair or bedridden unless aided (Goetz et al., 2004). The modified Hoehn & Yahr scale is an expanded version of the original six level scale developed by Hoehn and Yahr in 1967 (Hoehn & Yahr, 1998).

Each participant was also asked to fill out a Freezing of Gait Questionnaire (FOG-Q). The FOG-Q is a self-report survey consisting of six questions that subjectively

assesses the severity and frequency of FOG (Giladi et al., 2000). For each question, the respondent is asked to assign a value of 0 to 4 regarding different aspects of FOG or gait disturbance. The cumulative total of these values range from 0-24, with a higher overall score corresponding to more severe the FOG. This questionnaire has been shown to have excellent intrarater reliability (ICC = 0.84) (Nieuwboer et al., 2007), and excellent test-retest reliability ($r = 0.84$) (Giladi et al., 2009) in people with PD. Participants' demographics are presented in Table 1.

Table 1. Participant Demographics

Participant	Sex	Age	Duration of Illness (years)	Medication	UPDRS III	Hoehn & Yahr	FOG
1	M	86	13	Levodopa 1200mg	41	4	16
2	M	62	5	Comtan 800mg	37	2.5	11
3	M	77	10	Levodopa 700mg	31	3	16
4	M	77	18	Entacapone 400mg	47	4	22
5	F	83	10	Levodopa 2400mg	33	3	18
6	M	84	6	Entacapone 400mg	51	4	20
				Levodopa 800mg			
				Ropinirole 4mg			

To ensure participant safety, each participant was placed in a balance support harness system (SoloStep™) consisting of a support vest attached to an overhead rail (Figure 1). To ensure a proper fit and to help participants become accustomed to the harness system, participants were asked to walk to the end of the room, turn, and walk back (approximately 20 feet). Next, participants completed a series of 12 videotaped walking trials using a wheeled walker instrumented with a laser cueing device (i.e., Mobilaser) (Figure 2). Specifically, participants were asked to complete 3 walking trials

under each of the following four conditions: (i) no visual cue (Baseline), (ii) visual cue projected between the centre of the rear wheels of the walker (traditional cue placement), (iii) visual cue projected at a distance equivalent to mean sex specific step length (Male = 62cm, Female = 60cm) in front of the centre of the rear wheels (step length), and (iv) visual cue projected at a distance equivalent to mean sex specific stride length (Male = 123cm, Female = 119cm) in front of the centre of the rear wheels (stride length) (Ko, Tolea, Hausdorff, & Ferrucci, 2011). Each walking trial followed the protocol of the Timed Up & Go test (TUG) as follows. Participants started in a seated position in a standard arm chair (seat height = 45 cm), and when instructed to begin, stood up, walked 3 meters at a comfortable pace, turned around, walked back to the chair and sat down. The time it took participants to complete the trial was recorded using an Adanac 3000[®] Digital Economy Stopwatch.

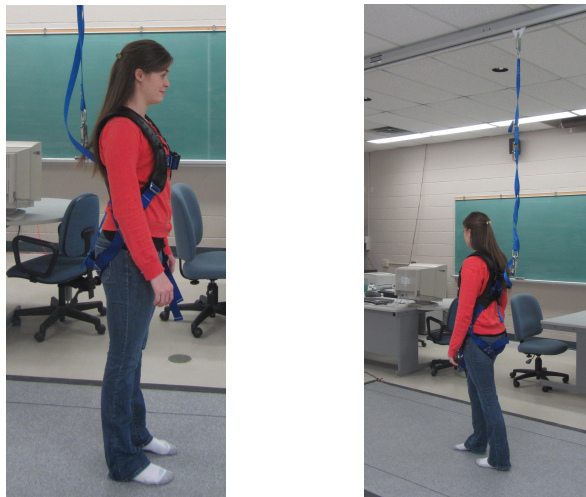


Figure 1. Images of the Solo-Step[™] Support System

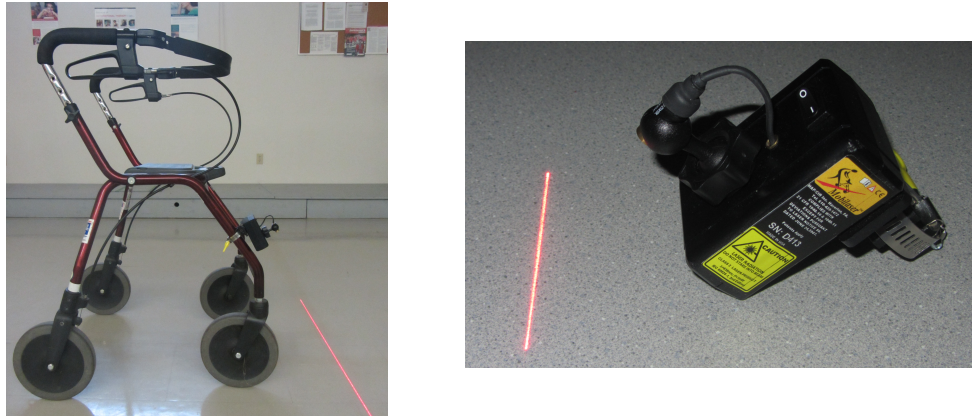


Figure 2. Mobilaser - Visual Cueing Device

Immediately prior to the beginning of each trial, the participant's received one of three sets of instructions. For trials with no visual cue (baseline), participants received the verbal instruction "When I say go, I would like you to stand up, walk at a comfortable pace to the end of the mat, turn around, walk back, and sit down". For trials where the visual cue was located between the walker rear wheels (traditional cue placement), participants received the verbal instructions "When I say go, I would like you to stand up, walk at a comfortable pace to the end of the mat, turn around, walk back, and sit down. As you walk, I would like you to focus on *stepping over the laser cue*". For trials where the visual cue was located ahead of the walker rear wheels (i.e., either step length, or stride length conditions), participants received the verbal instructions "When I say go, I would like you to stand up, walk at a comfortable pace to the end of the mat, turn around, walk back, and sit down. As you walk I would like you to focus on *stepping towards the laser cue*". To ensure participants understood the instructions, a single practice trial was completed for each condition at the beginning of each block of walking trials. To avoid practice effects, the order of presentation of the walking conditions was randomized for each participant.

All testing was completed while participants were on their self-determined peak, or “on” phase, of their medication cycle. To help ensure all participants were within their “on” phase, testing was conducted approximately two hours after participants had taken their usual dosage as per the recommendations of Gauntlett-Gilbert and Brown (1998).

Outcome Measures

Spatial Temporal Parameters of Gait

Spatiotemporal parameters of gait for each walking trial were acquired using a 4 foot wide x 10 foot long Zeno Electronic Walkway© Model Z4x10 and ProtoKinetics Movement Analysis Software (PKMAS) (Zenometrics LLC, Peekskill, NY, USA) (Figure 3). Using sensor array technology, the Zeno walkway© samples gait at 120Hz and has a spatial resolution accuracy of 1.27cm and temporal resolution accuracy of 1 sample (ProtoKinetics Movement Analysis Software, 2012). The Zeno walkway© (formerly GaitRite) has been found to be a reliable measurement of gait parameters in this population (Chien et al., 2006). The dependent variables included: velocity, step length, and the time taken to complete the 180° turn at the end of the walkway. To minimize the potential for outlying data to influence the results, trials were averaged within each condition such that a single value was obtained for each outcome measure.



Figure 3. Zeno Electronic Walkway©

Timed Up and Go (TUG)

Functional mobility was assessed as participants completed each walking trial via the Timed-Up-And-Go (TUG) testing protocol under each condition. This test has been shown to have good test-retest reliability ($r = 0.80$) (Huang, Hsieh, Wu, Tai, & Lu, 2011), and high inter-rater reliability ($ICC \geq 0.87$) (Morris, Morris, & Ianssek, 2001) in people with PD.

Walker Positioning

To determine if the position of the walker in relation to the participant changed as a result of the spatial location of the visual cue presentation, all walking trials were videotaped using a Canon PowerShot SX 220 HS camera and analyzed using Kinovea (version 0.8.15) software. Two reflective markers (A & B) were placed in parallel on the walker frame and one reflective marker (C) placed on the balance harness positioned over the lateral aspect of the participants' iliac crest. Using Kinovea, a vertical line was drawn between markers A and B and a horizontal line drawn at a right angle from the vertical line to marker C. The horizontal distance between the vertical line (walker) and marker C (participant) was used to determine the relative position of the walker in relation to the participant, an example of this configuration is shown in Figure 4.

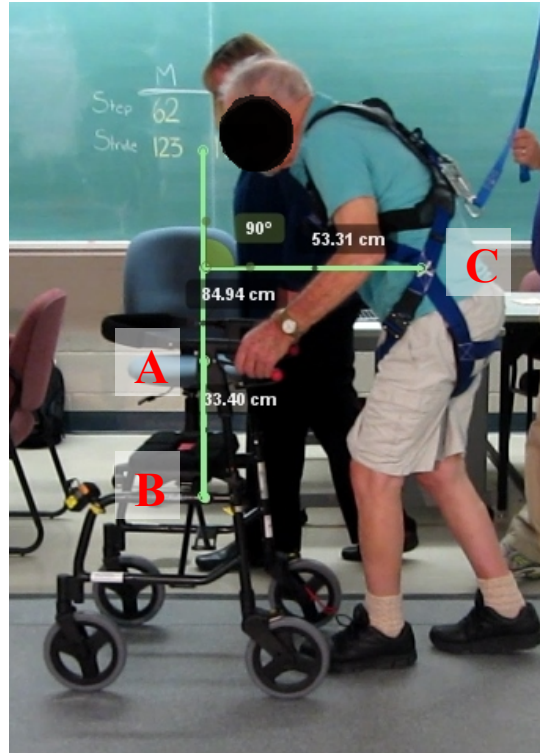


Figure 4. Reflective Marker Set-up (A, B, & C)

Chapter 3: Results

Objective 1 – Study Feasibility

Recruitment Strategy

Participants were recruited from a single neurological practice over a two month timeframe. In total, 7 individuals agreed to participate; however one of these individuals did not meet the inclusion criteria and was therefore excluded. The six participants recruited were highly varied across numerous demographic characteristics. For example, the participants' ages ranged from 62 to 86, disease duration ranged from 5 to 18 years, and the Hoehn and Yahr scale results varied from 2.5 to 4. Specifically, the Hoehn and Yahr results indicated that some participants were experiencing symptoms ranging from mild bilateral disease to severe disability (Hoehn & Yahr, 1998). The level of FOG disturbance also varied greatly among participants. This was evident from the FOG-Q scores, which ranged from 11 to 22.

Level of Protocol Compliance

With altering the spatial location of the visual cue, it was unknown as to whether the intensity of the visual stimulus would be strong enough for participants to clearly see the cue when projected ahead of the walker. All participants indicated that they were able to clearly observe the visual cue even when it was directed to the furthest position away from the walker, - equivalent to the average stride length of an older adult (119-123cm).

With respect to trial completion, the majority of participants (4/6) were able to complete all aspects of testing procedures. Two participants (P4, P6) were unable to complete the testing protocol in its entirety. Both of these individuals experienced fatigue near the end of some of the trials and required adjustments to be made to the position of

the chair to complete the final turn of the walking trials. This was most evident with participant 4 who experienced severe fatigue as a result of extended periods of freezing, and was unable to complete all twelve trials.

An impact of anxiety was also exhibited by P4, who repeatedly voiced concern regarding their performance during the walking trials. Following the initial completion of a single baseline trial, the participant was recognizably fatigued as a result of the duration of the trial and the occurrence of severe freezing (Figure 6d). A decision was made to have the participant subsequently complete only a single trial of each visual cue condition. After completing 4 trials, P4 took a 5 minute rest break and then expressed a desire to attempt the cue conditions again. The individual completed 3 more trials (1 of each visual cue condition) revealing a dramatic change in their performance. For example, across each of the visual cue conditions P4 was approximately 60 seconds slower at initially completing the TUG test, compared to the second attempt with the same cue condition.

Each testing session lasted 30-45 minutes within the lab, which included obtaining informed consent, and trial demonstrations provided by the researchers. Due to the relatively short length of the testing session, participants did not report experiencing any issues with wearing off their medication over the course of the session.

Lastly, all participants were able to independently complete the FOG-Q. This is important in terms of a future home based longitudinal follow-up study, as the FOG-Q can be used as a measure of change that can be collected without the researcher's presence.

Objective 2 - Preliminary Findings

To determine whether the intervention showed promise as an effective management strategy, spatial temporal parameters of gait were evaluated on the Zeno

Electronic Walkway. Participants were assessed at baseline in the absence of a visual cue, and with the visual cue positioned in each of the following spatial locations: i) between the centre of the rear wheels of the walker (traditional cue placement), (ii) at a distance equivalent to one step length in front of the centre of the rear wheels (step length), and (iii) at a distance equivalent to one stride length in front of the centre of the rear wheels (stride length). For each of the dependent variables acquired (step length, velocity, turn time, timed up and go score, and walker positioning) comparisons were made between values obtained at baseline (no visual cue) to those reported during each presentation of the visual cue (baseline vs. traditional cue; baseline vs. step length; and baseline vs. stride length). Specifically, using the statistical software package SPSS, three paired t-tests were conducted for each of the dependent variables with alpha set at .05. As a result of multiple comparisons being performed, it was anticipated that the potential for a Type I error to occur would be increased, however this was a feasibility study and therefore the decision was made not to apply bonferroni corrections. The results for each of the t-tests associated with the respective outcome measures are presented below.

Spatial Temporal Parameters of Gait

Means and standard deviations, along with individual participant data for step length, velocity, and turn time are presented in Table 2. For step length there were no significant differences between baseline (M= 30.67cm, SD= 13.98) and each of the visual cue locations: traditional cue placement (M= 38.50cm, SD= 14.27); $t(5) = -2.159$, $p = 0.08$, step length cue placement (M= 35.33cm, SD= 17.85); $t(5) = -1.075$, $p = 0.33$, or stride length cue placement (M= 34.17cm, SD= 18.02); $t(5) = -1.069$, $p = 0.33$. Similar findings were also identified for velocity as there were no significant differences detected between baseline (M= 51.17cm/s, SD= 28.91) and each of the visual cue locations: traditional cue

placement (M=48.50cm/s, SD=8.63); $t(5)=0.392$, $p = 0.71$, step length cue placement (M=51.33cm/s, SD= 32.02); $t(5)= -0.027$, $p = 0.98$, or stride length cue placement (M=51.67cm/s, SD= 31.98); $t(5)= -0.088$, $p = 0.93$. Similar to the findings reported for step length and velocity, no significant differences were identified between the length of time it took participants to turn in the absence of a visual cue (M= 20.17s, SD= 25.96) compared to when they used a visual cue irrespective of cue location: traditional cue placement (M= 7.83s, SD= 3.71); $t(5)= 1.312$, $p = 0.24$, step length cue placement (M= 12.67s, SD= 14.35); $t(5)= 0.802$, $p = 0.45$, or stride length cue placement (M= 15.17s, SD= 16.53); $t(5)= 0.722$, $p = 0.50$.

Although results for each of the variables were statistically non-significant, results suggest the presentation of visual cues did have an impact on spatiotemporal parameters of gait for some participants (Table 2 and Figures 5a - 5c and Figures 6a - 6f). For example, with the Mobilaser turned on, 5 out of 6 participants' demonstrated increases to step length, and 3 out of 6 participants demonstrated increases to velocity and decreases to turn time. While on the individual level the utilization of the visual cue lead some participant's to experience substantial improvement (i.e., step length for participant 3 increased from 41cm at baseline to 66cm with the cue projected at step length) whereas other individuals only experienced marginal gains (i.e., step length for participant 5 increased from 37cm, at baseline, to 41cm with the cue projected at stride length). It is important to note that despite there being an overall trend for the visual cue to evoke improvements to gait, there was no consistent pattern delineating which of the visual cueing spatial locations was most effective. For example, for step length, one participant performed best at baseline (P1), three participants performed best when the laser line was projected at the traditional location near the back wheels of the walker (P2, P4, and P6),

one participant experienced greatest benefits from the cue at step length (P3), and one participant performed best under the stride length condition (P5). Similar findings were also noted for velocity and turn time. For velocity, 3 participants performed best at baseline (P1, P2, and P6), 1 performed best with the cue placed in the traditional location (P4), 1 at step length (P3), and 1 at stride length (P5). For turn time, 2 participants performed best at baseline (P1, P5), 2 with the cue placed in the traditional location (P4 and P6), 1 performed equally as well across all conditions (P2), and 1 performed equally as well at step length and stride length (P3). Gait patterns for each trial completed on the Zeno Electronic Walkway© are presented for each participant in Figures 6a – 6f. These images represent the influence of the visual cue and provide the means to visualize freezing of gait.

Table 2.

Spatiotemporal Parameters of Gait - Mean Step Length (cm) & Mean Velocity (cm/sec) across trials for each condition of the visual cue. Turn Time (sec) Average time taken to turn 180° across trials for each condition of the visual cue

	Participant	Baseline	Traditional	Step Length Cue	Stride Length Cue
<i>Step Length (cm)</i>	1	40	35	37	37
	2	37	44	36	38
	3	41	61	66	60
	4	5	17	11	7
	5	37	38	34	41
	6	24	36	28	22
		Mean	30.67	38.50	35.33
	SD	13.98	14.27	17.85	18.02
<i>Velocity (cm/sec)</i>	1	62	46	49	51
	2	79	65	65	68
	3	81	98	107	104
	4	6	24	16	16
	5	46	27	42	48
	6	33	31	29	23
		Mean	51.17	48.50	51.33
	SD	28.91	8.63	32.02	31.98
<i>Turn Time (sec)</i>	1	4	6	6	5
	2	4	4	4	4
	3	4	4	3	3
	4	67	12	13	28
	5	7	9	9	8
	6	35	12	41	43
		Mean	20.17	7.83	12.67
	SD	25.96	3.71	14.35	16.53

Note: Results were collected using the Zeno Walkway ProtoKinetics Movement Analysis Software. Time was recorded from the first active sensor of the first turning step to the last active sensor of the last step involved in the turn

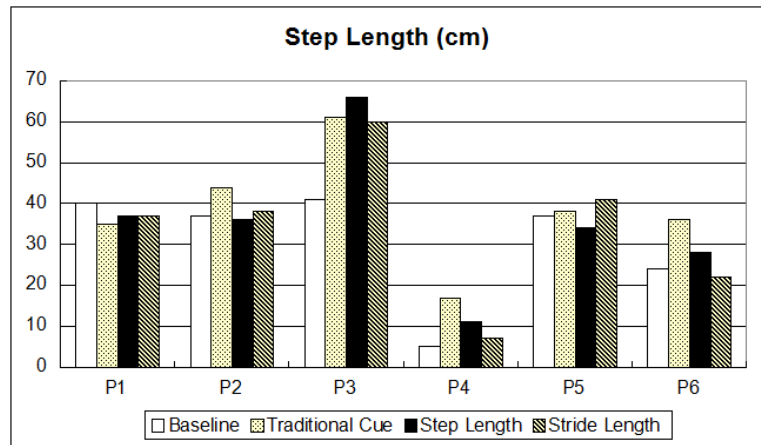


Figure 5a.

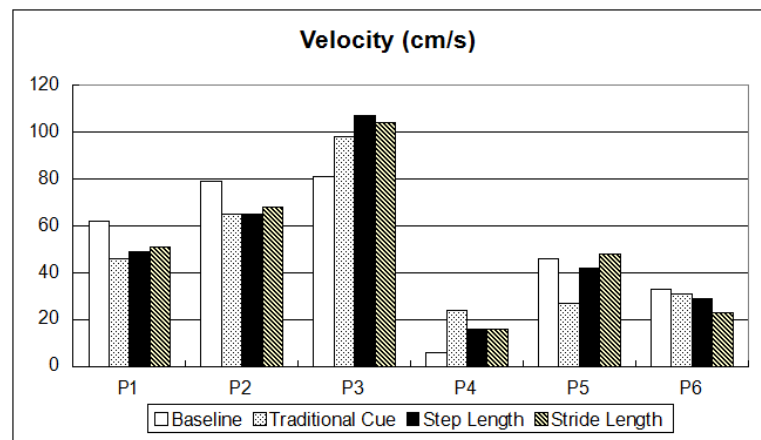


Figure 5b.

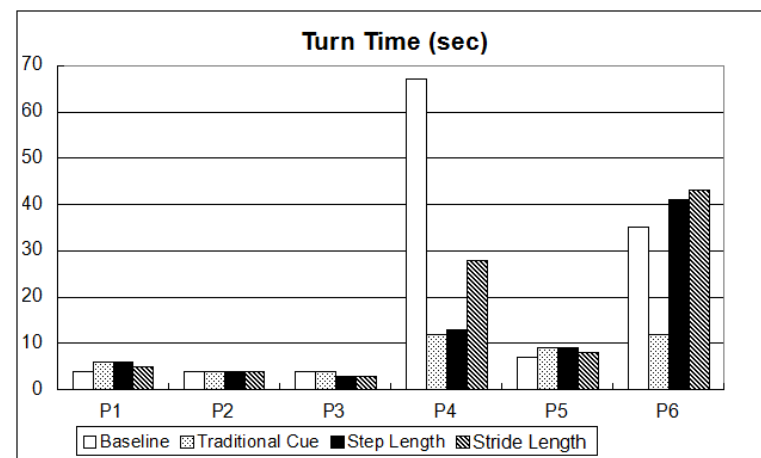


Figure 5c.

Figure 5. Spatiotemporal parameters of gait displayed as a function of condition and participant: (a) Step Length; (b) Velocity; and (c) Turn Time

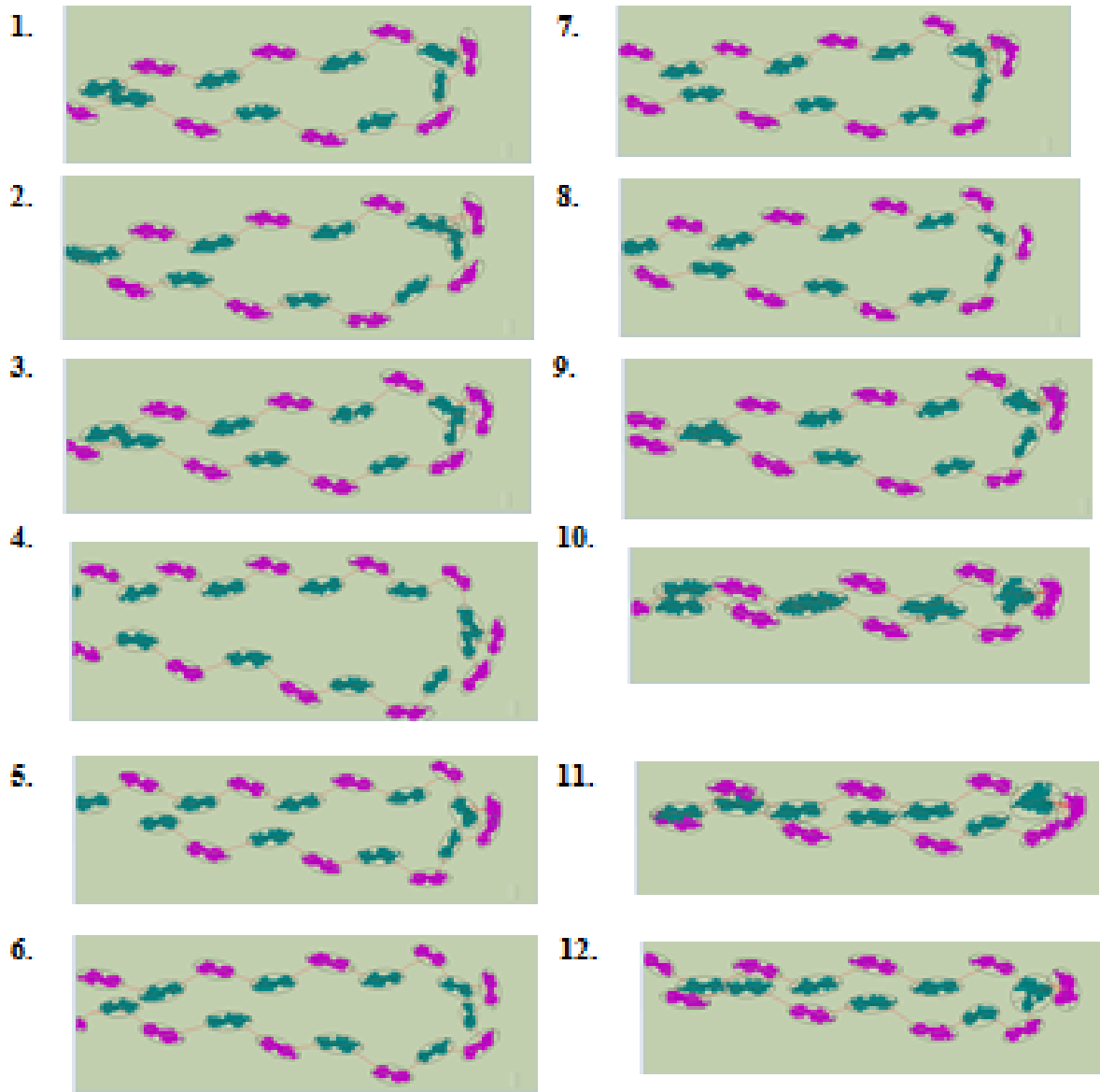


Figure 6a. Participant 1

- | | |
|--|---|
| <ol style="list-style-type: none"> 1. Baseline - No Cue Trial 1 2. Baseline - No Cue Trial 2 3. Baseline - No Cue Trial 3 4. Traditional Cue Placement Trial 1 5. Traditional Cue Placement Trial 2 6. Traditional Cue Placement Trial 3 | <ol style="list-style-type: none"> 7. Step Length Cue Placement Trial 1 8. Step Length Cue Placement Trial 2 9. Step Length Cue Placement Trial 3 10. Stride Length Cue Placement Trial 1 11. Stride Length Cue Placement Trial 2 12. Stride Length Cue Placement Trial 3 |
|--|---|

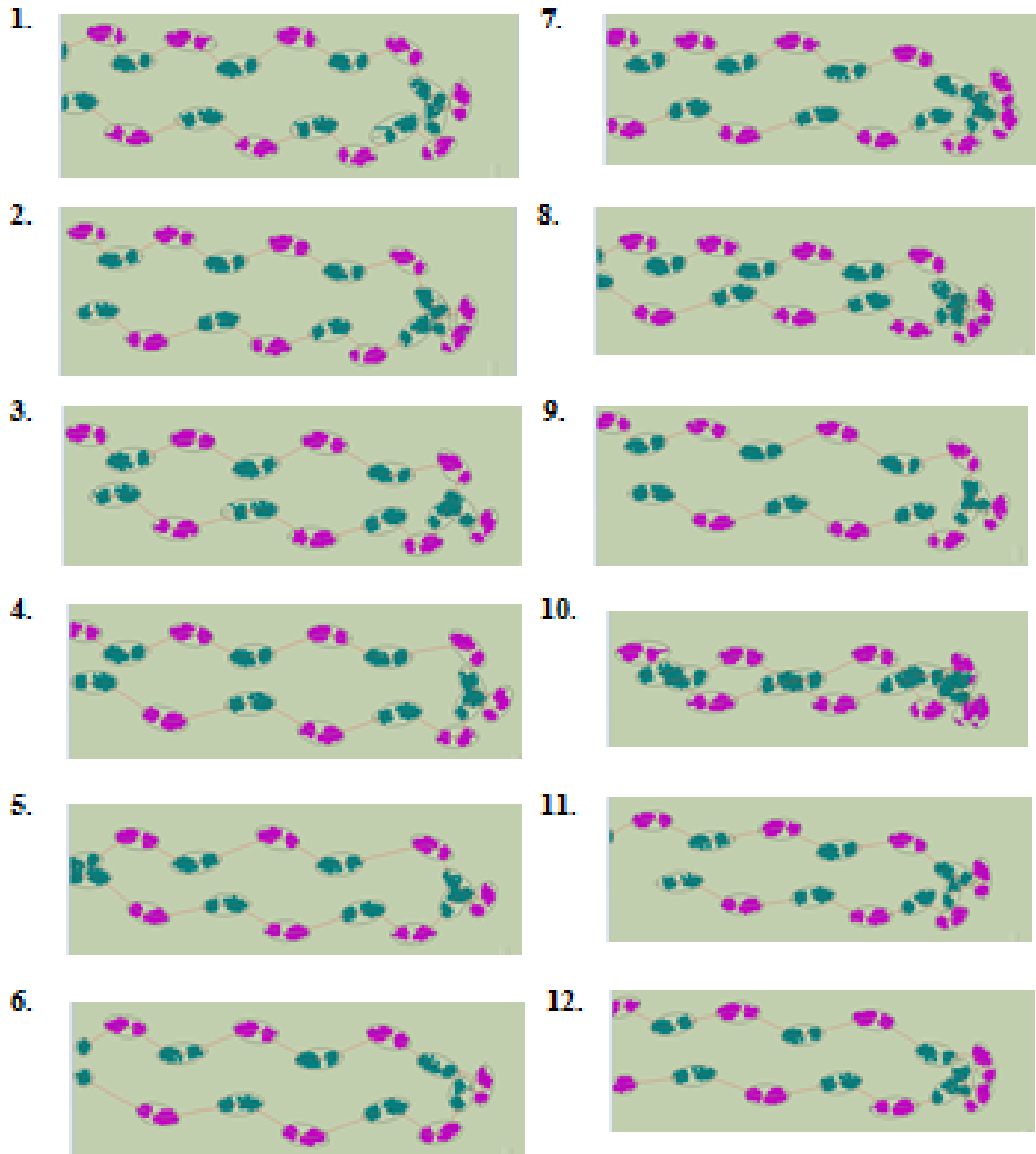


Figure 6b. Participant 2

1. Baseline - No Cue Trial 1
2. Baseline - No Cue Trial 2
3. Baseline - No Cue Trial 3
4. Traditional Cue Placement Trial 1
5. Traditional Cue Placement Trial 2
6. Traditional Cue Placement Trial 3

7. Step Length Cue Placement Trial 1
8. Step Length Cue Placement Trial 2
9. Step Length Cue Placement Trial 3
10. Stride Length Cue Placement Trial 1
11. Stride Length Cue Placement Trial 2
12. Stride Length Cue Placement Trial 3

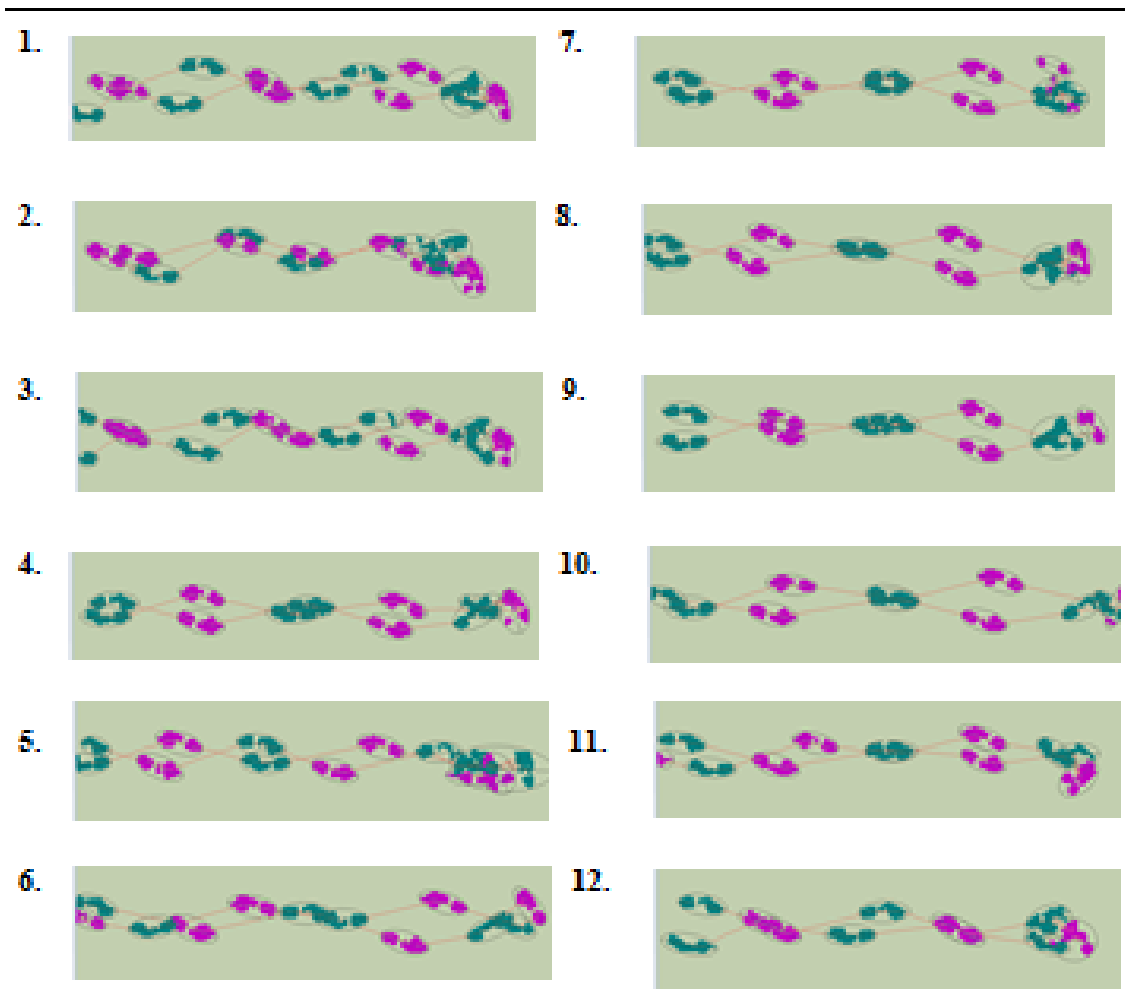


Figure 6c. Participant 3

- | | |
|--------------------------------------|---|
| 1. Baseline - No Cue Trial 1 | 7. Step Length Cue Placement Trial 1 |
| 2. Baseline - No Cue Trial 2 | 8. Step Length Cue Placement Trial 2 |
| 3. Baseline - No Cue Trial 3 | 9. Step Length Cue Placement Trial 3 |
| 4. Traditional Cue Placement Trial 1 | 10. Stride Length Cue Placement Trial 1 |
| 5. Traditional Cue Placement Trial 2 | 11. Stride Length Cue Placement Trial 2 |
| 6. Traditional Cue Placement Trial 3 | 12. Stride Length Cue Placement Trial 3 |

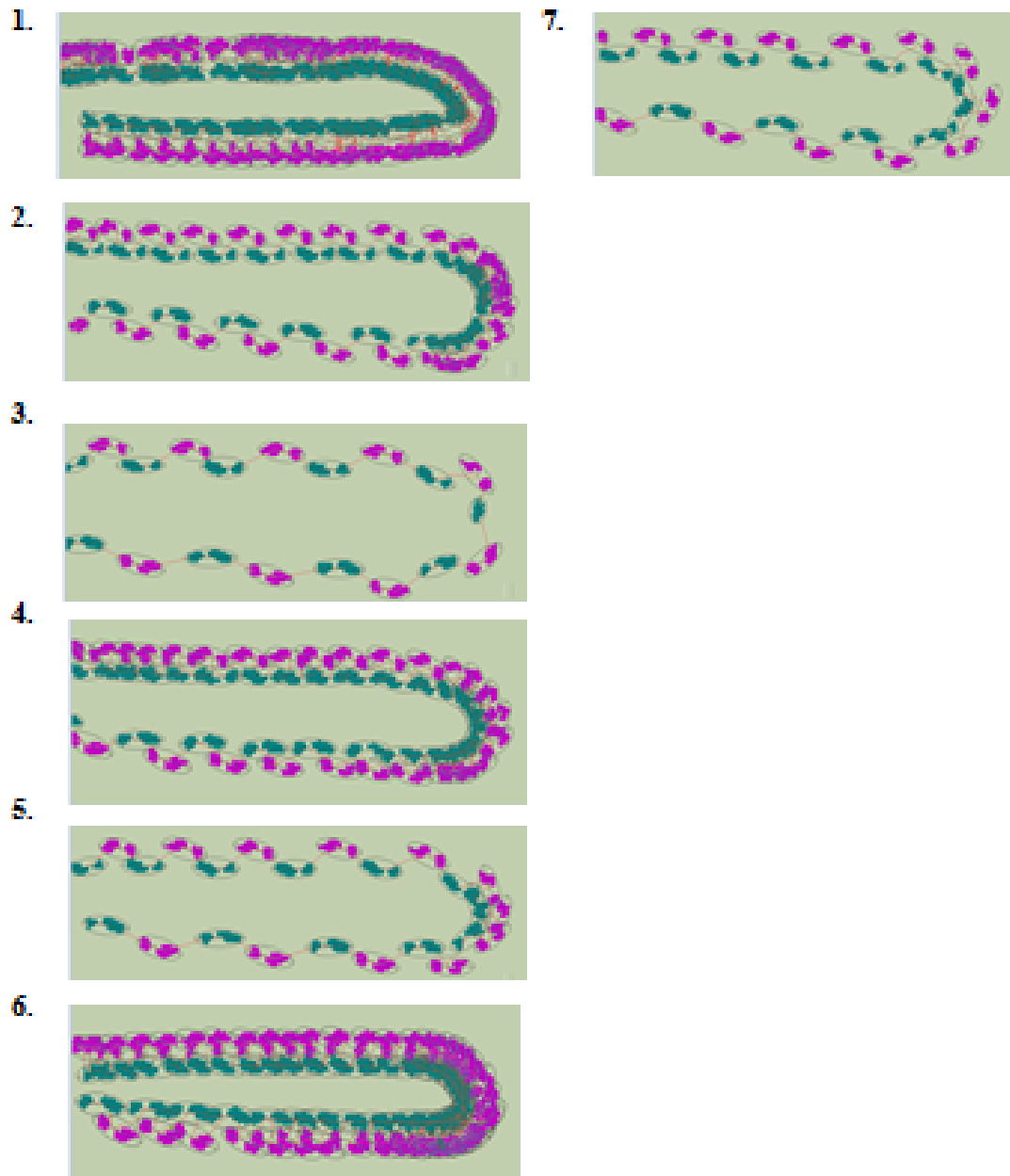


Figure 6d. Participant 4

1. Baseline - No Cue Trial 1
2. Traditional Cue Placement Trial 1
3. Traditional Cue Placement Trial 2
4. Step Length Cue Placement Trial 1
5. Step Length Cue Placement Trial 2
6. Stride Length Cue Placement Trial 1

7. Stride Length Cue Placement Trial 2

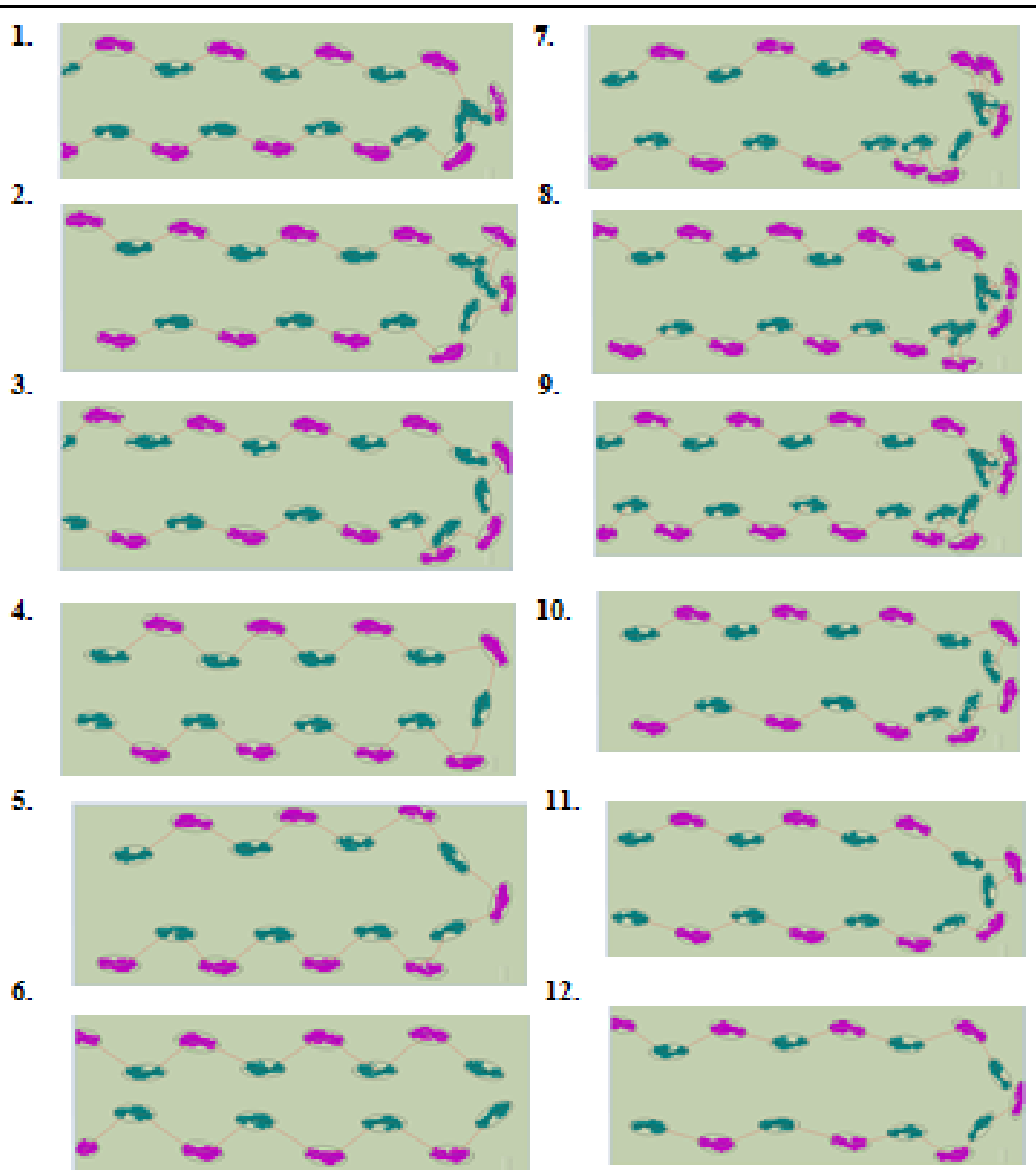


Figure 6e. Participant 5

- | | |
|--------------------------------------|---|
| 1. Baseline - No Cue Trial 1 | 7. Step Length Cue Placement Trial 1 |
| 2. Baseline - No Cue Trial 2 | 8. Step Length Cue Placement Trial 2 |
| 3. Baseline - No Cue Trial 3 | 9. Step Length Cue Placement Trial 3 |
| 4. Traditional Cue Placement Trial 1 | 10. Stride Length Cue Placement Trial 1 |
| 5. Traditional Cue Placement Trial 2 | 11. Stride Length Cue Placement Trial 2 |
| 6. Traditional Cue Placement Trial 3 | 12. Stride Length Cue Placement Trial 3 |

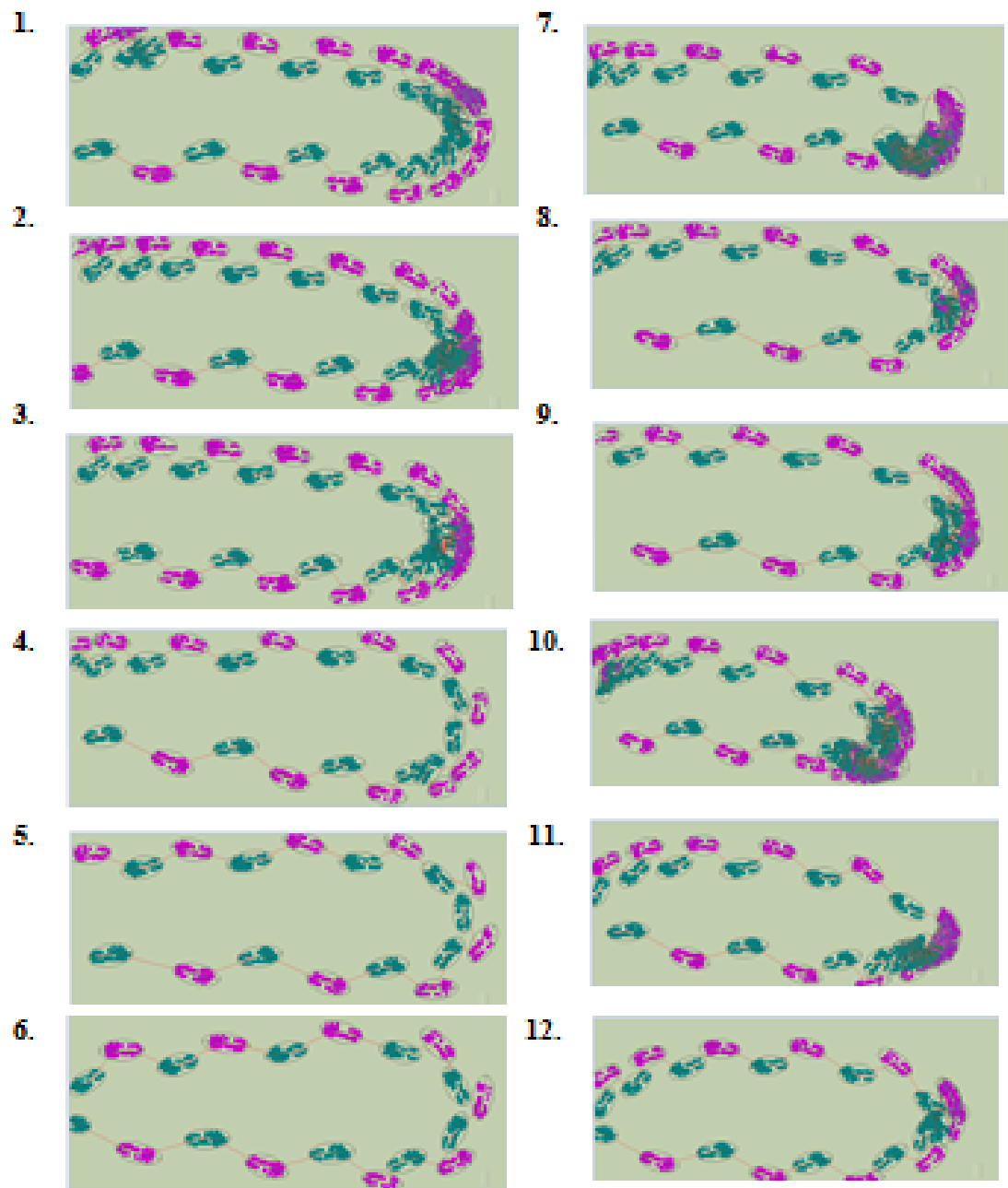


Figure 6f. Participant 6

- | | |
|--------------------------------------|---|
| 1. Baseline - No Cue Trial 1 | 7. Step Length Cue Placement Trial 1 |
| 2. Baseline - No Cue Trial 2 | 8. Step Length Cue Placement Trial 2 |
| 3. Baseline - No Cue Trial 3 | 9. Step Length Cue Placement Trial 3 |
| 4. Traditional Cue Placement Trial 1 | 10. Stride Length Cue Placement Trial 1 |
| 5. Traditional Cue Placement Trial 2 | 11. Stride Length Cue Placement Trial 2 |
| 6. Traditional Cue Placement Trial 3 | 12. Stride Length Cue Placement Trial 3 |

TUG Test

The means and standard deviations, along with individual participant data for TUG test times are presented in Table 3. Similar to the findings reported for the spatiotemporal parameters of gait, there were no significant differences between the time it took participants to complete the TUG test at baseline (M= 67.83s, SD= 77.58) compared to when visual cues were presented in the following spatial locations: traditional cue placement (M= 40.17s, SD= 21.01); $t(5)= 1.127$, $p = 0.31$, step length cue placement (M= 48.00s, SD= 33.18); $t(5)= 0.827$, $p = 0.44$, or stride length cue placement (M= 49.33s, SD= 36.95); $t(5)= 0.966$, $p = 0.37$. Again, although results were statistically non-significant, a participant substantially improved their test scores while using a visual cue. The most prominent example of this occurrence is illustrated by participant 4 who without the use of the visual cue took over 3.5 minutes to complete a single trial, whereas with the visual cue their gait improved such that their best trial was completed in just over 1 minute (Table 3 and Figure 7).

Table 3.

TUG Test (seconds) - Average time to complete each trial for each condition of the visual cue

	Participant	Baseline	Traditional	Step Length Cue	Stride Length Cue
<i>Time (sec)</i>	1	33	37	36	37
	2	18	20	20	19
	3	18	15	15	15
	4	219	72	80	105
	5	38	47	40	35
	6	81	50	97	85
	Mean	67.83	40.17	48.00	49.33
	SD	77.58	21.01	33.18	36.95

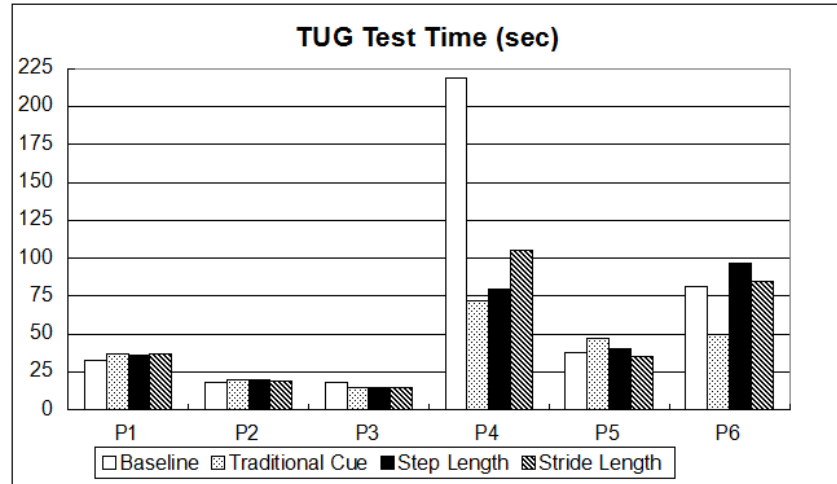


Figure 7. Time taken to complete each walking trial following the Timed-Up & Go protocol

Walker Positioning

To determine whether the use of the visual cueing strategies altered the way participants positioned their walkers in relation to their body, comparisons in distance between the anterior superior iliac spine (ASIS) of the participants and their walker frame were made between baseline and each level of the visual cue. The means and standard deviations, along with individual participant data for the distance between walker and the ASIS of each participant are presented in Table 4.

In contrast to the aforementioned non-significant results reported for spatiotemporal parameters of gait and the TUG test, significant differences in walker positioning were identified between baseline ($M= 53.83$, $SD= 11.41$) and each of the cueing positions: traditional cue position ($M= 42.17$, $SD= 8.28$); $t(5)= 3.38$, $p = 0.02$, step length cue position ($M= 39.67$, $SD= 9.89$); $t(5)= 5.395$, $p = 0.003$, and stride length cue position ($M= 44.00$, $SD= 9.88$); $t(5)= 4.941$, $p = 0.004$. These results suggest that regardless of the spatial location of the visual cue, participants positioned themselves closer to their walker during trials wherein the Mobilaser was turned on, and positioned

themselves further away from their walker when they ambulated in the absence of a visual cue (Figure 8).

Table 4.

Walker Positioning - Average distance between participants left hip and the walker (cm) across trials for each condition of the visual cue

	Participant	Baseline	Traditional	Step Length Cue	Stride Length Cue
<i>Distance (cm)</i>	1	57	50	42	45
	2	57	36	43	45
	3	42	43	40	42
	4	40	29	24	29
	5	56	45	35	43
	6	71	50	54	60
	Mean	53.83	42.17	39.67	44.00
	SD	11.41	8.28	9.89	9.88

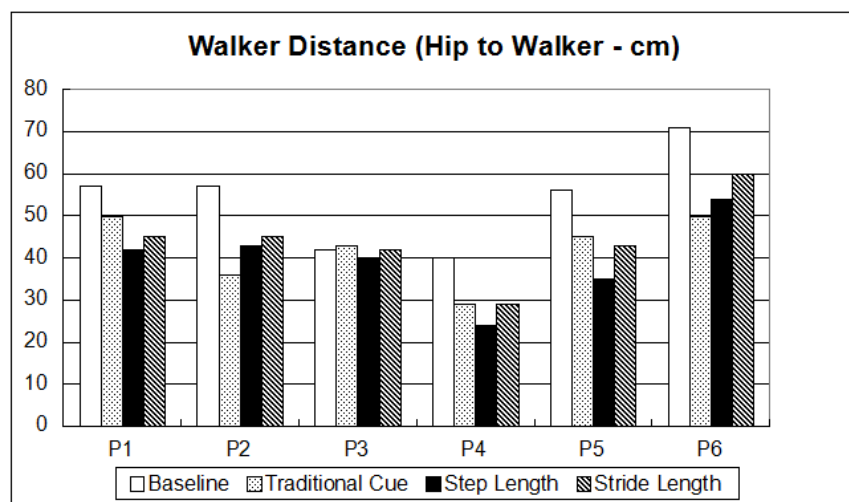


Figure 8. Distance between hip and walker (cm) across each condition of the visual cue.

Lastly, observations were recorded assessing the individual's ability to ambulate within the frame of the walker (Table 5). To safely and correctly use a wheeled walker, the user's feet should at minimum land within the back wheels of the walker. This prevents the walker from getting too far in front of the individual. We observed that

during baseline trials 4 participants (P2, P4, P5, & P6) were walking behind the walker frame. However across each visual cue condition (traditional cue, step length cue, and stride length cue) all of the participant's footsteps were at least meeting the back wheels of the walker, indicating a maintenance or improvement in the safety of walker use.

Table 5.

Walker Use - Observation regarding the participants ability to walk within the frame of the walker (yes/no) across trials for each condition of the visual cue

	Participant	Baseline	Traditional	Step Length Cue	Stride Length Cue
Safe Position	1	Yes	Yes	Yes	Yes
	2	No	Yes	Yes	Yes
	3	Yes	Yes	Yes	Yes
	4	No	Yes	Yes	Yes
	5	No	Yes	Yes	Yes
	6	No	Yes	Yes	Yes

Individual Variability

Results suggest that participants demonstrated individual variability in cue effectiveness across each of the dependent variables (Table 6).

Table 6 – Most effective Cue for each dependent variable

Participant	Step Length	Velocity	Turn Time	TUG	Walker Positioning
1	Base	Base	Base	Base	Step
2	Trad	Base	Equiv	Base	Trad
3	Step	Step	Step/Stride	Trad/Step/Stride	Step
4	Trad	Trad	Trad	Trad	Step
5	Stride	Stride	Base	Stride	Step
6	Trad	Base	Trad	Trad	Trad

Note: Base = Baseline cue, Trad = Traditional cue location, Step = Cue projected at a distance equivalent to average step length, Stride = Cue projected at a distance equivalent to average stride length

Chapter 4: Discussion

The purpose of this investigation was to conduct a feasibility study to test the protocol and clarify the components necessary to consider in the design of a future full-scale study aimed at investigating the spatial location of visual cue placement as a strategy for managing FOG among individuals with PD.

Feasibility

The purpose of conducting a feasibility study is to identify any modifications that need to be observed when conducting a future full scale study with respect to a novel technique or technology. This study provided an opportunity to determine if the components of our design were viable for use in a larger scale study (Leon, Davis, & Kraemer, 2011). The present research was not intended to validate the efficacy of visual cues but to determine if there is evidence to support that the location at which the cue was presented was important to the cuing modalities overall impact. This study was also intended to identify if the forward placed cues had any influence on walker positioning, which is necessary for safe ambulation. This study was an essential precursor in examining the location of cue presentation and investigating the testing protocol and methods.

Recruitment Strategy

The method of participant recruitment was evaluated to determine whether it would be feasible to recruit for a larger scale study from a single neurological practice that drew from a base of approximately 400 patients. Results suggested that this single site strategy would likely be insufficient to be able to populate a future large scale study. Over a two month timeframe only 6 participants met the inclusion criteria and were

enrolled in the study. Although the sample was small, the individuals who were recruited demonstrated significant variability in regards to participant demographics and clinical characteristics thus increasing the likelihood that if enough participants could be recruited from this single site the results could be generalizable to the larger population. Given that results indicated that recruitment was more difficult than originally predicted, future studies should either expand inclusion criteria to include non-freezers, or expand recruitment efforts to include multiple neurological practices, or utilize community based national organizations such as the Parkinson Society Canada. However, it is important to note that if the inclusion criteria were to be expanded to include individuals with PD and generalized gait disturbance (i.e., not necessarily FOG) the focus of the research question would also need to be adjusted accordingly.

Protocol Compliance

In the early stages of this study, concerns regarding the Mobilaser™ and the visibility of forward placed cues were necessary to address. Originally, it was unknown if participants would be able to see the line of light projected at a distance equivalent to both step and stride lengths. Visual obstructions caused by the walker (frame and or seat/basket) and a result of the laser light reducing in intensity the further it was projected away were factors contributing to the uncertainty of forward placed cues. The feedback received from participants concerning the device indicated satisfaction and highlighted the overall strengths of using this device. The clarity of the visual cue was observable at all projected distances under the environmental conditions. The laboratory setting consisted of slightly dimmed overhead incandescent lights along with a spotlight to help illuminate the reflective markers used in assessing walker positioning. Additional strengths of the Mobilaser included the overall ease of use. The device was operated by a

single on/off switch that would require minimal training for an individual to use independently outside of a laboratory setting. The Mobilaser also attached easily and securely to each participants walker frame.

Study Protocol

The informed consent and execution of the study was completed in an efficient manner requiring a minimal time commitment of 30 - 45 minutes, with no return visits. To control for practice effects, the original study protocol called for each condition (including baseline) to be presented in a random order to every participant. By chance, due to this randomization the first participant was assigned to complete the baseline condition last. Interestingly, in contrast to the study hypothesis, this participant was observed to perform best under the baseline condition. Given these findings, it was suggested that the participant's performance may have been affected by a carry over effect that resulted from the order in which the visual cues were presented. For example, by completing baseline testing after having just completed trials that involved the visual cues, it could not be determined whether the individual was completing a true baseline trial (free of visual cues) or whether they were still benefiting from prior practice with the visual cues. As a result, the experimental protocol was adapted such that baseline was always completed first by subsequent participants, prior to the presentation of the randomized cued conditions.

Despite each testing session only lasting 30-45 minutes, and the fact that participants were allowed to take breaks as needed, fatigue was believed to impact performance of some of the participants. For example, P4 required a break after only 4 trials, and was only able to complete three additional trials. Thus, in total, P4 was only able to complete seven out of the twelve trials prior to fatigue, precluding his/her ability

to safely complete the remaining 5 trials. Similarly, two participants (P4, P6) required assistance in completing the final turn necessary to return to the sitting position. The assistance provided entailed a research assistant shifting the chair on an angle, thus facilitating the participants to sit down without completing the full turn. These results suggest that the study protocol in its current form may be too demanding for this population.

The participants were originally required to perform 12 walking trials (3 trials per condition). Based on a previous study conducted (Chee et al., 2009) with regards to cueing and PD, this was determined to be a reasonable demand to ask of participants. However, based on the performance of two participants who demonstrated fatigue, the original testing protocol may be too challenging for individuals with severe FOG to complete. One likely explanation that may account for why some participants were unable to complete all testing could be related to the manner in which each trial began. For instance, the demands of sitting and standing during the TUG increased the demand of each trial. For future investigations of this nature modifications could be made to the study protocol to help minimize fatigue. One possibility would be to reduce the number of walking trials, another option would be to remove the sitting and standing component of the Timed-Up & Go test. This alteration would be appropriate in minimizing any extraneous exertion caused by rising from a chair numerous times. Similarly, raising or lowering into a seated position is not a known trigger of FOG (Contreras & Grandas, 2012; Lamberti et al, 1997; Rahman et al., 2008) and therefore suggests that the Timed-Up & Go test may not be the most appropriate measure to use when studying this phenomenon.

Safety concerns while working with a population that has known gait disturbances and increased risk of falling were addressed by using a Solo Step safety system. While the device was found to be comfortable to wear, easy to employ, and appropriately followed a track that ran the length of the walking trial, the harness height was not retractable. This proved to be a challenge in that a research assistant was required to manually adjust the harness system each time participants stood up and sat down. If not completed, and a participant fell, they would have been prevented from hitting the ground, but placed in a very awkward position that could have still resulted in injury. Therefore, to ensure safety a research assistant was required to walk beside the participant acting as a spotter ready to remove the slack in the harness strap, if the participant were to fall. Unfortunately, it is possible that having an individual walk beside the participants may have served as a distraction away from the visual cue. In the future this concern could be avoided by incorporating a self-retracting fall prevention harness, a device used in construction and regulated by the Canadian Standards Association (Infrastructure Health & Safety Association, 2013). Alternatively, as previously suggested, if the sit and stand portion of the trials were removed this would eliminate the need for a retractable device and the SOLO Step safety device could be used for further study.

It is believed that anxiety/stress played a greater role in the study than originally predicted. Stressful environments are a known trigger of FOG (Contreras & Grandas, 2012; Lamberti et al, 1997; Rahman et al., 2008), and this could have been better controlled within the current protocol. To minimize the amount of stress/anxiety experienced by participants, each individual was provided with an opportunity to walk around the lab and acclimatize to the testing setup. Despite this opportunity, one participant (P4) reported that they felt some anxiety during the first half of the testing

session as they were unsure of their perceived performance during the trials (i.e., they were concerned they were not meeting the expectations of the research team). Following a short break, wherein the individual was provided with positive reinforcement, the individual indicated that they were more relaxed and wanted to continue. The effect on performance that resulted was evidenced by a substantial improvement within their quality of gait, as demonstrated in Figure 6d.

Due to current knowledge relating to the role of anxiety and stress on FOG, incorporation of a longitudinal study design may be warranted. For example, a study by Rahman et al. (2011) that evaluated fear of falling (FOF), a form of anxiety relating to the fear of potentially falling, determined that individuals experiencing gait disturbances (including FOG) also experienced increased levels of FOF. In terms of the current study, the participants recruited may be experiencing anxiety due to their familiarity with freezing. This could have been exacerbated by a new environment and the knowledge that their gait was being evaluated. Despite the reassurance that each participant received, their experience with gait disturbances may have indicated a predisposition to anxiety. Further exploration would need to be conducted to determine effective ways to reduce the anxiety and stress perceived by the participants. For instance, individuals could become accustomed to the testing environment and using visual cueing (ie. multiple testing sessions or the ability to practice prior to the researchers presence), in hopes of decreasing their anxiety. However, by integrating a longer practice period or expanding the number of testing sessions to put the participants at ease, this may exacerbate concerns related to fatigue and an increase in testing time.

Finally, the technologies used to capture and analyze the data within this study were being employed for the first time in this research lab. As a result, an important

component of this study was determining the utility of this equipment within this context. The practicality of using the Zeno Electronic Walkway needs to be addressed in further detail due to shortcomings that were experienced with analyzing the data. The manufacturer specified the carpets ability to quantify the turning aspects of walking as well as its capacity to analyze freezing episodes. However, the ProtoKinetics Movement Analysis Software, which is used in conjunction with Zeno Walkway, had difficulty isolating the overlapping footsteps during turning and extreme freezing. For example, P3 completed the walking trials in an “out and back” manner. The participant retraced their steps making it difficult to separate the footsteps, particularly during the turning portion of the trial. Following assistance from a company representative, the problem could not be resolved. As a result, the footstep pattern could only be quantified during the straight-line walking segments of each trial. Consequently, the analysis of turning relied solely on the time it took to turn which may not be the most sensitive measure to express a change in the participants turning capabilities. For example, by only analyzing the time taken to turn, the carpet was unable to analyze information regarding the number of steps taken to turn or the relative arc of the turn. These variables may be particularly important to consider given that observable changes in gait patters were noted for 2 out of the six participants. Specifically, P1 demonstrated a much narrower turn during stride length visual cue use (Figure 6a), and, P5 required fewer steps to turn using the traditional cue (Figure 6e). In light of these unexpected limitations, the Zeno walkway may not be the most appropriate device to use to examine these outcome measures. Instead, future research in this area may require the use of a 3D motion capture system.

Kinovea movement analysis software has been determined to be a feasible method in which to analyze the videotaped trials. The program is free to download, user friendly,

and relatively simple to become familiar with. One limitation identified was the program's inability to continuously track the distance between two markers (B and C) in real time. To overcome this limitation for the current study, a distance measurement during the straight walking portion of each trial at a predetermined location was taken. The location ensured participants were directly in line with the video camera. Clinically, Kinovea could be a useful tool due to its readily available nature but may not be the most appropriate with regards to real time gait analysis.

Improvement in Walker Positioning

Previous research that evaluated the use of rolling walkers by older adults indicated that 50% of participants assumed a forward leaning posture during walker use (Liu, 2009). As a result of the posture adopted, the user's feet did not maintain a safe position between the rear wheels of the walker, thus increasing the risk of a fall (Liu, 2009). Therefore while walkers are designed to provide support to help with balance and minimize falls risk, if not used properly they may have a negative impact on the user's posture that in turn may exacerbate the symptom they were originally prescribed to assist with. Consistent with these previous literature findings the current study demonstrated that during the baseline condition, 4 of 6 participants adopted a forward leaning posture and did not walk within the walker frame. However, with the application of visual cueing, in each prearranged location, all participants changed their positioning in relation to the walker. With visual cueing each participant significantly decreased the distance between themselves and the walker and safely walked within the walker frame, thus decreasing the potential for falls. It is unclear why participants adopted a safer position in relation to the walker when using the visual cues. One possibility could be that by focusing attention on the visual cues participants were more aware of their body positioning with regards to the

walker. To examine this possibility, future studies could incorporate a qualitative component that asks participants to comment on their experience of using the cues in relation to walker positioning.

Rationale for Non-Significant Findings

The purpose of this study was to determine the feasibility of the methods and study components. Therefore, not finding statistical significance within the spatiotemporal parameters of gait and the Timed-Up & Go test results was expected due to the small sample from which the data were collected. Despite non significant findings, participants did demonstrate a range of performance improvements across the outcome measures thus suggesting this line of inquiry is appropriate for further study. The pattern of improvement varied among individuals thus speaking to the diversity of our sample characteristics and the variable nature of PD (Jankovic, 2008).

The results of this study indicated that the traditional cue was the most effective cue in terms of increasing step length (4 of 6 participants). This was consistent with previous cueing studies conducted by Morris et al., (1996) and Jiang & Norman (2006). However, with regards to walker positioning, results suggest that visual cues presented 60-62cm (step length) in front of the walker, were most effective in decreasing the distance between the participant and their walker. Through improving walker positioning, the forward leaning posture of participants, that is commonly adopted when a walker is too far in front of the individual, is effectively decreased. This study demonstrates the possibility of a trade-off between the effectiveness of a visual cue in the traditional position compared with in the step length position. The step length position, while less

effective (in terms of improving step length) appears safer, regarding walker positioning and environmental awareness.

Visual cueing and the spatial location of its presentation may be highly individualized in terms of managing gait disturbance. Consistent with the study by Rahman et al., (2008) where 31.5% of their sample improved mobility with use of the visual cues and a lesser percent expressed similar benefits through tactile and auditory cues. The positioning of visual cues may also be preferential to individuals. Findings from the current study indicate that presenting a visual cue in a specified single spatial location is not optimal for everyone. Further research is needed to determine the individualized characteristics that may predict where the optimal visual cue location is for each specific user.

Study Limitations

The results of the study are promising and indicate the need for further research; however, some limitations warrant attention in the interpretation of findings as well as necessary modifications for future design.

This was designed as a feasibility study and therefore the small highly variable sample size (N=6) was limited in statistical power. Similarly, the nature of PD is variable across the rate of progression and the symptoms experienced from person to person. It is therefore difficult to quantify improvement and establish a standard baseline across individuals (Jankovic et al., 1990).

The study was limited in terms of there being no known clinically meaningful difference regarding the outcome measures of interest within a PD population. Studies have been done regarding meaningful change in older adults but little has been done with PD. In order to address the results of this study, results were compared to those of healthy

older adults without neurologic impairment. For example, according to Ko et al. (2011), the average normal stride length of male and female older adults is 123 and 119cm, respectively (Ko et al., 2011). To assess if the use of visual cueing helped to normalize step length, the changes in this variable were compared to the values established with individuals without PD. Moreover, due to the lack of information regarding what is considered a minimally important change, a limitation is apparent.

For instance, in a study conducted by Perera, Mody, Woodman, & Studenski (2006), they investigated a meaningful and substantial change within the physical performance of older adults. Their initial estimate regarding a substantial meaningful change in gait speed was 10cm/s in older adults, and they deemed 5cm/s as a small meaningful change (Perera et al., 2006). In a subsequent study by Verghese, Holtzer, Lipton, & Wang (2009), 10-unit changes in performance was applied to a variety of gait markers including cadence, stride length, swing, double support, stride length variability, and swing time variability. They reported that changes equivalent to 10-unit changes were considered meaningful based on Perera et al., (2006) to make their observations clinically intuitive despite only having information regarding gait speed.

Working with a population that is considerably non-normal in terms of gait performance we cannot appropriately apply this method without determining the relevancy of clinically and minimally important differences. For example, the average gait speed in the study by Verghese et al., (2009) was 92.8 ± 24.1 cm/s. They determined that slow gait speed was operationally defined as that of less than 70cm/s (Verghese et al., 2009). The results of the present study observed mean velocity at baseline to be 51.17 cm/s and visual cue use mean gait speed ranged from 48.50 cm/s to 51.67 cm/s. With drastic differences across the sample populations' performance comparisons cannot

justifiably be made to the same measures. Further research is needed to determine a clinically or minimally significant difference for this population as well as determining an effect size estimate for sample size calculation. The current feasibility research is not able to provide a meaningful effect size estimate due to the imprecise and non-generalizable nature of data collected from small samples (Leon et al., 2011).

Limitations were found in terms of the dimensions (4ft by 10ft) of the Zeno Electronic Walkway used during the trials. The width of the mat posed a problem in terms of the requiring a tight turning radius be performed by participants which is difficult while operating a rolling walker. The constraints this placed on participants may have played a role in the speed at which they tried to complete the turn.

Simultaneously the length of the mat also was a limitation of the study. To insure the turning portion of the TUG test remained on the mat participants began the test 1 metre behind the mat. Due to the dimensions of the Zeno Walkway, the participants were initiating gait off the mat thus data were not captured on FOG that occurred during this portion of the trial. According to the Zeno Walkway output only 2 out of 6 participants visibly froze. The majority of the participants actually demonstrated FOG upon the initiation of gait and this was not captured by the Zeno Walkway or through video. Videotaping was primarily used to capture the straight walking portions of the trial in order to analyze walker positioning and posture. To accomplish this, the camera was placed on a tripod to maintain a stable image but in doing so it prevented the recording of the entire trial. As a result, the ability to capture data when participants were off the mat at the start and end of each trial was limited.

Limitations encountered during analysis had to do with the inability of the Kinovea software to continuously track distance between participant and walker in real

time. Although a standardized position within each trial was used to capture this data it would be more appropriate to determine the mean distance over the duration of the trial. As mentioned earlier the inability of the Zeno Electronic Walkway to accurately capture turning and freezing during walking trials was a weakness of the study. Further research must be done to determine a more precise measurement of these elements.

Future Directions

An original portion of the study included the use of Electromyography (EMG) to assist with the understanding of FOG. EMG quantifies the electrical activity produced by skeletal muscles providing a means to observe the effect of FOG and PD at the level of the muscle (Konrad, 2006). EMG was to be incorporated within this study to record any effect that the visual cue may have had on the gait of participants, such as the timing of muscle activation and strength of muscle contraction. Nieuwboer et al., (2004) compared the EMG profiles of the lower limbs in 11 individuals with PD. This was done to analyze the temporal aspects of gait prior to freezing compared with a voluntary stop as well as a normal stride. The study observed significantly abnormal timing within the EMG recordings from the tibialis anterior (TA) and gastrocnemius (GS) muscles prior to freezing. Results indicated that the TA was prematurely activated 72.6% of the time prior to freezing and the GS muscle activity was also initiated and inhibited earlier in the gait cycle prior to freezing. The study concluded that the overall reduced EMG activity resulting from a shortened muscle activation period contributed to slower movements, a decrease in step length, and ultimately interrupted movement (Nieuwboer et al., 2004). For the purpose of this study, EMG was to reveal the effects of visual cues specifically with respect to distal and proximal lower limb muscle activity patterns preceding the

freeze-provoking aspects of walking trials. However, upon beginning of the initial testing session with the first participant technical problems occurred with the EMG device and it was removed from future trials. With the EMG system not functioning, the ability to capture participant trunk angle via an inclinometer was also lost. It is recommended that EMG and Inclinometer be used in further studies to broaden the current knowledge of FOG.

The results of this study lead to the conclusion that several modifications to the study protocol could be made to better capture the influence of visual cueing. For instance a case based ABA design would be an appropriate means to visualize any carryover effects. It is suspected that some results may have been washed out due the effects of one experimental condition affecting another. Incorporating an ABA design would allow for the comparison of baseline values pre and post visual cueing conditions thus providing for the identification of carryover effects. Alternatively, as described earlier, the integration of a longitudinal study design would be appropriate to assist with individuals becoming accustomed to the testing environment and the use of visual cueing. This would effectively deal with any anxiety or stress causing aspects of a new environment or management strategy.

Given that current findings indicate that individuals respond differently to visual cues and their spatial locations, it is recommended that future research focus on developing a screening tool to enable clinicians to predict which cue placement would be most appropriate for specific individuals. Lastly, the inclusion of participant journals to capture the participants perspective of using visual cues in various locations would summarize aspects of the study that are not identified by quantitative results alone.

Chapter 5: Conclusion

Parkinson's disease (PD) is a progressive neurodegenerative movement disorder (Samii et al., 2004) with an increasing prevalence among the current aging population (Lees et al., 2009; de Rijk et al., 1995). The disease is characterized by bradykinesia, resting tremors, postural instability, and rigidity (Benatru et al., 2008); however, the non-motor symptoms are just as troubling in terms of the impact on quality of life (Karlsen et al., 2000). Accompanying the primary features of PD, freezing of gait (FOG), festination and a stooped forward leaning posture (Jankovic, 2008; Lees et al., 2009; Yarnall et al., 2012) contribute largely to the increased risk of falling and loss of independence within this population (Bloem et al., 2004; Giladi et al., 1997).

Treatment of PD focuses on symptom management (Lees et al., 2009) and primarily relies on dopamine replacement therapy, known as Levodopa (Cotzias et al., 1969). While drug therapy is effective in the management of many motor symptoms, Levodopa is limited in its ability to ameliorate FOG and postural instability (Bowes et al., 1990; Levy-Tzedek et al., 2011). The uses of external cueing, including tactile, auditory, and visual cue modalities, have shown potential as a non-pharmacological option to improve quality of movements (Rochester et al., 2005). Research suggests that visual cueing is most effective at reducing the occurrence of freezing (Rahman et al., 2008).

The MobilaserTM is a promising dynamic visual cue that emits a red line of light on the ground for the user to step over (In Step Mobility, 2009). The device provides a solution to the previously effective, yet impractical, static transverse lines marked on the floor. However, to step over the prompt created by the MobilaserTM, the user must direct their attention towards their feet. This is known to decrease gait speed, decrease step

length, increase the risk of obstacle collisions due to lack of environmental awareness (Matthis & Fajen, 2013; Marigold & Patla, 2008) and interfere with peripheral vision which is important in gait control (Patla, 1998).

The current research suggests that forward placed cues may be a feasible alternative therapy. Significant improvements in walker positioning occurred in participants regardless of the spatial location of the visual cue. Despite not finding statistically significant improvements in the spatial temporal parameters of gait, the performance changes in some participants indicated the capacity for further development. Positive participant feedback, along with the strengths and user friendly nature of the Mobilaser™ device, provided additional rationale to further the investigation of forward placed cues.

In conclusion, although forward placed visual cueing indicates potential as a novel management strategy of FOG and gait disturbance, future research is required on a larger scale before it can be put into practice.

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Appendix A: LETTER OF INFORMATION

The influence of external cueing on balance, freezing of gait and falls among individuals with Parkinson's disease

Phase 2

INVESTIGATORS:

[REDACTED]

[REDACTED]

You are invited to participate in a research study in which we will examine the influence of using a visual cueing device that projects a beam of light on the floor (mobilaser) on freezing of gait (FOG), and falls among individuals with Parkinson's disease (PD).

The purpose of this letter is to provide you with information required for you to make an informed decision regarding participation in this research.

Background

Freezing of gait, is a troublesome motor symptom of Parkinson's disease with a significant impact on fall risk and quality of life. Studies suggest that approximately 30% of individuals with PD experience FOG within 5 years and nearly 60% report FOG after 10 years. Although medication improves some of the symptoms of slowness and rigidity, it is only minimally effective in treating FOG or reducing fall risk. Therefore, a better understanding of alternative treatment strategies is needed to manage these symptoms.

Inclusion and Exclusion Criteria

We plan to test a total of 30 participants. In order to be eligible for participation, you must be at least 50 years of age, have a clinical diagnosis of PD with a history of freezing of gait and falls, are capable of walking 20 feet with or without the use of an assistive device, able to stand independently for 5 minutes at a time, have functional vision that allows you to see the visual cue (laser beam of light projected on the ground), and are able to complete a daily freezing of gait/falls journal.

You will not be eligible to participate if you report experiencing major back or lower limb pathology that may influence standing balance or gait, if you are unable to complete a daily freezing of gait/fall journal, or if you cannot see the visual cue.

Description of Research

If you agree to participate in this research study you will be asked to participate in two gait laboratory testing sessions wherein your walking patterns will be assessed. You will also be asked to take the visual cueing device home with you and use it on a regular basis for 12 consecutive weeks. A description of the activities that you will be asked to participate in during both the laboratory sessions and during the 12 week home based trial period is provided below.

Both of the laboratory based testing sessions will be identical and will take place in the Interdisciplinary Movement Disorders Laboratory, Room 1545 Elborn College, at the University of Western Ontario. To measure your walking pattern, you will be asked to perform nine walks at your normal pace down a GAITRite instrumented carpet, a device with approximately 16,000 sensors built into its surface. These sensors feed information to an attached computer, and this information is utilized to provide us with information concerning your walking (e.g., the length of each step you take, the speed at which you walk, etc.). The nine walks will be divided such that you complete three walks under each of the following conditions: i) no visual cue, ii) visual cue projected directly in front of your feet, and iii) visual cue projected 1 – 2 meters in front of your feet. The testing order of cue presentation will be randomly assigned. To help you become familiar with the cue location, you will be asked to walk around the lab at a self-selected pace, for three complete circuits prior to the start of testing within each condition.

You will also be asked to complete the Timed Up and Go test nine times as follows: three times with no visual cue, three times with the visual cue projected directly in front of your feet, and three times with the visual cue projected 1 – 2 meters in front of your feet. For this test you will be asked to stand up from a chair, walk three meters, turn around, walk back to the chair and sit down while walking at a comfortable pace

While you are completing the previously outlined tests of gait, we will be recording muscle activity patterns from four muscles in your legs using wireless surface electromyography. To record this activity four sets of surface electrodes will be placed on each of your legs, two sets on the front, and two sets on the back. This test will provide us with information about what muscles are activated in your legs.

The final task that you will be asked to complete during each of the laboratory sessions will be to fill out a short freezing of gait questionnaire.

Twelve Week Intervention

At the end of the first laboratory based testing session you will be randomly assigned to one of the following three groups: i) visual cue projected directly in front of feet (test group 1), ii) visual cue projected 1 – 2 meters in front of feet (test group 2), or iii) no visual cue (control group). If you are assigned to either test group you will be provided with a visual cueing device (mobilaser) for your personal use over the course of the 12

week study. During the 12 week period you will be asked to use the visual cueing device on a regular basis throughout the course of each day. If you are assigned to the control group you will be asked to complete your daily activities as usual (i.e., without using an external cueing device). During the 12 week time period, all study participants (regardless of which group you are assigned to) will be asked to keep a daily journal with information pertaining to hours of use, and number of FOG episodes or falls that occur. To help remind you to complete the daily journals you will receive a weekly telephone call by a member of the research team throughout the duration intervention.

Following the 12 week intervention period, you will be asked to return to the laboratory for the second laboratory based session to repeat the same gait testing completed earlier in the study. Upon study completion, participants who were assigned to the control group will be given the opportunity to take a Mobilaser unit home with them to use for a trial period.

The tasks involved in each testing session will take approximately 60 minutes to complete, and should involve no risks or discomforts beyond those normally experienced by you in performing normal everyday walking tasks.

Potential Benefits

Although you may not experience any direct benefits from participating in this research, we anticipate that you will experience an improvement in your walking, and a reduction in the frequency in which you experience freezing episodes, thus your participation may increase your ability to participate within the community. In addition, we anticipate that the results obtained through this study will provide us with valuable information concerning the benefits of implementing visual cueing strategies as a clinical rehabilitation tool.

Potential Risks or Discomforts

There is a small risk in this study that you may experience a temporary loss of balance while performing the tasks used to assess your gait. To minimize the risk of injury you will complete study tasks while wearing a balance support harness. There is also a small risk that you may experience discomfort when the electrodes used to measure your muscle activity are removed. It is believed such discomfort will not be greater than that which is experienced when removing a band-aid.

Voluntary Participation and Protection of Information

Your participation in this research project is voluntary. You may refuse to participate, refuse to answer any questions, and you may withdraw your participation at any time with no effect on the future healthcare that you receive or future participation in activities sponsored by the University. If you withdraw your participation in the study before the conclusion of data collection, your data will be destroyed. In order to assure complete confidentiality, no identifying information will be attached to the data collected in this study. The only record of your name that will be retained will be on the attached consent

form, and this information will be stored in a locked file cabinet, within a locked room, that is (in turn) inside the Interdisciplinary Movement Disorders Laboratory (which remains locked at all times). This information will not be linked, in any way, with the study information. This also means that your data may not be withdrawn from the study after the testing session is concluded, and the information is entered into the computer. If the results of this study are published, your name will not be used, and no information that discloses your identity will be released or published without your explicit consent to the disclosure. Electronic data collected during the course of this study will be kept indefinitely.

You will not receive remuneration for participation in this study.

Further Questions

If you have any questions about this research project, please contact the principal investigators, [REDACTED]

[REDACTED]. If you have any questions about your rights as a research participant, or the conduct of this study, you may contact the Office of Research Ethics, [REDACTED]

[REDACTED]. You are not waiving any legal rights by signing the attached consent form. This letter is yours to keep.

Appendix B: CONSENT TO PARTICIPATE IN RESEARCH FORM

**The influence of external cueing on balance, freezing of gait and falls among
individuals with Parkinson's disease**

Phase 2

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

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

Participant (Printed Name): _____

Participant (Signature): _____

Person Obtaining Informed Consent (Printed Name): _____

Person Obtaining Informed Consent (Signature): _____

Date: _____

Appendix C: RESEARCH ETHICS BOARD APPROVAL FORM



Research Ethics

Use of Human Participants - Ethics Approval Notice

Principal Investigator: Dr. Jeffrey Holmes
File Number: 103725
Review Level: Delegated
Approved Local Adult Participants: 90
Approved Local Minor Participants: 0
Protocol Title: The influence of external cueing on balance, freezing of gait and falls among individuals with Parkinson's disease
Department & Institution: Health Sciences/Occupational Therapy, Western University
Sponsor:
Ethics Approval Date: May 29, 2013 **Expiry Date:** June 30, 2015
Documents Reviewed & Approved & Documents Received for Information:

Document Name	Comments	Version Date
Other	Freezing of Gait Questionnaire	2013/04/09
Other	Activity Specific Balance Confidence Scale	2013/04/09
Advertisement	Parkinson Update Recruitment Advertisement	2013/04/09
Advertisement	Phase 1 Recruitment Poster	2013/04/09
Advertisement	Phase 2 Recruitment Poster	2013/04/09
Advertisement	Phase 3 Recruitment Poster	2013/04/09
Western University Protocol		2013/04/10
Revised Letter of Information & Consent	LOI and Consent Phase 1	2013/05/14
Revised Letter of Information & Consent	LOI and Consent Phase 2	2013/05/14
Revised Letter of Information & Consent	LOI and Consent Phase 3	2013/05/14

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

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

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

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

[Redacted Signature]

Ethics Officer to Contact for Further Information

[Redacted Contact Information]

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

Appendix D: Unified Parkinson Disease Rating Scale
Subsection III
Unified Parkinson's disease Rating Scale III. Motor Examination
(Fahn & Elton, 1987)

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 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.

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 straight backed 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.

Appendix E: Modified Hoehn and Yahr Scale

(Hoehn &Yahr, 1998)

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.

Appendix F: Freezing of Gait Questionnaire (FOGQ)

1. During your worst state—Do you walk:

- 0 Normally
- 1 Almost normally—somewhat slow
- 2 Slow but fully independent
- 3 Need assistance or walking aid
- 4 Unable to walk

2. Are your gait difficulties affecting your daily activities and independence?

- 0 Not at all
- 1 Mildly
- 2 Moderately
- 3 Severely
- 4 Unable to walk

3. Do you feel that your feet get glued to the floor while walking, making a turn or when trying to initiate walking (freezing)?

- 0 Never
- 1 Very rarely—about once a month
- 2 Rarely—about once a week
- 3 Often—about once a day
- 4 Always—whenever walking

4. How long is your longest freezing episode?

- 0 Never happened
- 1 1–2 s
- 2 3–10 s
- 3 11–30 s
- 4 Unable to walk for more than 30 s

5. How long is your typical start hesitation episode (freezing when initiating the first step)?

- 0 None
- 1 Takes longer than 1 s to start walking
- 2 Takes longer than 3 s to start walking
- 3 Takes longer than 10 s to start walking
- 4 Takes longer than 30 s to start walking

6. How long is your typical turning hesitation: (freezing when turning)

- 0 None
- 1 Resume turning in 1–2 s
- 2 Resume turning in 3–10 s
- 3 Resume turning in 11–30 s
- 4 Unable to resume turning for more than 30 s

CURRICULUM VITAE

Name: L. Keltie Brigham

Post-secondary Education and Degrees: University of Western Ontario
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2008-2012 Honors Specialization B.A. Kin

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Related Work Experience: Graduate Teaching Assistantship
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Graduate Teaching Assistantship
Occupational Therapy: Enabling Occupation through Assistive
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Scholarships & Awards: Western Scholarship of Excellence 2008

Dean's Honor List 2010

Dean's Honor List 2011

Western Graduate Research Scholarship 2012

Canadian Interuniversity Sport Academic All-Canadian 2013

Western Graduate Research Scholarship 2013