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The effects of cueing on walking stability in people with Parkinson's disease

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The effects of cueing on walking stability in people with Parkinson’s disease

by

Andrew Jennings Carrel

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in partial fulfillment of the requirements for the degree of

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This thesis is dedicated to my parents, my brother, my girlfriend, and my sister who profoundly impacted every aspect of my life for her 13 short years and continues to impact it currently.
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ABSTRACT

Research indicates that visual and verbal cues change gait spatiotemporal parameters in people with Parkinson’s disease (PD) (Morris, Iansek, Matyas, & Summers, 1994a, 1994b; Bagley, Kelly, Tunnicliffe, Turnbull, & Walker, 1991). But the degree to which these cues affect walking stability has not been investigated. Previous studies show that utilizing harmonic analysis based on acceleration patterns (a measure of walking stability) differentiates walking patterns between old and young adults (Menz, Lord, & Fitzpatrick, 2003). One purpose of this study is to examine the differences in harmonic ratios between people with PD and healthy older adults. A second purpose is to determine the effect of visual and verbal cues on the harmonic ratios of participants with PD when compared with their harmonic ratios during preferred walking. Eleven people with PD and 11 age- and gender-matched healthy older adults walked an 18 meter walkway under preferred walking conditions and visual and verbal conditions. The visual cues consisted of stripes on the walkway at distances equal to 40% of the participant’s height and 20% longer than preferred step length. The verbal cues consisted of the participants thinking “big step” (internal verbal), the experimenter saying “big step” to the participant (external verbal), and telling the participant to walk faster than preferred. A triaxial accelerometer measured acceleration of the trunk during the testing session to measure acceleration of the trunk in three orthogonal planes (anterior-posterior, vertical, and medial-lateral). The data showed significant group differences in preferred walking and across most experimental conditions indicating lower walking stability in people with PD. Of note, the spatiotemporal variables (velocity, step length, stride time, cadence) did not differentiate between groups. The one exception for harmonic ratios was the external verbal condition in which there were no group differences.
These data suggest that the external verbal cue given while walking was most effective for improving walking stability in people with PD. Finally, there was an association between stride time variability and lower harmonic ratios.
CHAPTER 1.

INTRODUCTION

Parkinson’s disease (PD) is caused by apoptosis of dopaminergic neurons in the substantia nigra. The loss of these neurons leads to the primary symptoms associated with PD, which include akinesia (difficulty initiating movement) and bradykinesia (slowness of movements). Akinesia and bradykinesia lead to difficulties with gait in persons with PD causing a reduction in movement amplitude, or hypokinesia. Hypokinesia in persons with PD leads to hesitant and shuffling steps. These hesitant, shuffling steps can lead to postural instability in persons with PD resulting in an increase in falls and injuries.

Treatment for PD is directed mainly at replacing the dopamine deficiency with dopamine agonists and levodopa therapy. However, with disease progression and prolonged use of these drugs, individuals with PD become less responsive to medications and develop fluctuations in their response to the treatments (Hamani & Lozano, 2003). More importantly, dopamine therapy does not significantly improve postural instability (Bloem, Beckley, van Dijk, Zwinderman, Remler, & Roos, 1996).

In order to increase postural stability and decrease the probability of falls among persons with PD, sensory cueing using visual and verbal cues has been used to facilitate locomotion in persons with PD. Examples of sensory cues used in the facilitation of locomotion include colored lines on the floor (Suteerawattananon et al., 2004), laser beams elicited from subject-mounted light devices (Lewis et al., 2000), and metronomes (Rochester et al., 2005). The use of sensory cues for persons with PD results in changes in spatiotemporal variables, such as increased velocity, step length, and decreased cadence.
Assessment of gait in persons with PD has focused mainly on measuring changes in these spatiotemporal parameters (Morris et al., 1996; Howe et al., 2003). An innovative method of gait analysis uses trunk accelerations as an indicator of the overall smoothness (harmonic ratios), or stability of the walking pattern (Smidt, Arora, & Johnston, 1971). Recent research shows that these measures offer unique information into the overall coordination of the walking pattern and appear to be more sensitive than typical spatiotemporal parameters (Menz, Lord, Fitzpatrick, 2003a, 2003b).

One purpose of this study is to examine the differences in walking stability during preferred walking between people with PD and healthy older adults. A second purpose is to determine the effect of visual and verbal cues on the harmonic ratios of participants with PD when compared with their harmonic ratios during preferred walking. It was hypothesized that people with PD would exhibit lower harmonic ratios than the control group during preferred walking. It was also hypothesized that the implementation of visual and verbal cues would differentially affect the gait of the PD group compared to the control group. More specifically, it was expected the external verbal condition would improve walking stability in the PD group and disrupt walking stability in the control group.

Eleven persons with PD and eleven age-and gender-matched neurologically healthy controls participated in the study. Participants completed walking conditions while walking at a preferred pace (performed at the beginning and end of the testing session), conditions in which the distance of stripes on a floor were placed at distances equal to 40% of the participant’s height (40H) and 20% longer than preferred step length (20L) (visual cues). There were also conditions in which they heard the experimenter say “big step” (external verbal, EV), thought “big step” (internal verbal, IV) and were also instructed in one condition
to walk faster than preferred pace (F) (verbal cues). Accelerometry was used to assess the walking pattern.

Results from the study showed consistent group differences in the harmonic ratios of the participants with the PD group exhibiting lower harmonic ratios than the control group across all conditions except for EV. There were no differences between groups during preferred walking in the spatiotemporal variables (velocity, step length, cadence, stride time, and stride time variability). However, there were significant differences in all the spatiotemporal variables except for stride time variability when comparing preferred walking at the beginning and preferred walking at the end.

The visual cues (20L and 40H) had little effect on the harmonic ratios of the participants compared to preferred walking. There were significant differences between the PD group and the control group for both visual cueing conditions with the PD group exhibiting lower harmonic ratios than the control group. In addition, there were significant differences in all spatiotemporal variables except for stride time variability for the 20L condition compared to preferred walking. The 40H condition showed no differences in the spatiotemporal variables compared to preferred walking.

The data from the verbal cueing conditions (EV, IV, F) showed significant group x condition interactions for the anterior-posterior and vertical planes. The EV condition differentially impacted the PD group and the control group by increasing the harmonic ratios of the PD group and decreasing the harmonic ratios of the control group. Again, there were significant differences for all spatiotemporal variables except for stride time variability compared to preferred walking. EV showed the greatest increase in step length and velocity,
followed by IV, then F. In addition, only the F condition significantly increased stride time and decreased cadence.

The data confirm the hypothesis that the PD group would exhibit lower harmonic ratios during preferred walking and partially confirm the hypothesis that the PD group and the control group would react differently to the implementation of visual and verbal cues.
CHAPTER 2.

REVIEW OF LITERATURE

Parkinson’s disease (PD) is a debilitating disease. It is estimated that approximately one million people in North America suffer from PD. Parkinson’s was first described in 1817 by James Parkinson and harshly affects voluntary movements of persons with PD. PD is caused by apoptosis of at least eighty percent of cells in the substantia nigra of the basal ganglia. In humans, the substantia nigra contains approximately 220,000 dopaminergic neurons in each hemisphere (Hamani & Lozano, 2003). These cells produce dopamine, a key neurotransmitter that when depleted, gives rise to the symptoms of PD. Symptoms of PD include rigidity, resting tremor, akinesia (lack of movement or slowness to initiate movement), and bradykinesia (slowness of movement). These symptoms result in postural instability and gait difficulties.

Postural instability can lead to a high incidence of falling in persons with PD. Falls not only pose substantial threats to the well being of persons with Parkinson’s, but also cause mounting health care costs for society (Bloem, Hausdorff, Visser, & Giladi, 2004). Statistics indicate that 38 out of 100 patients with Parkinson’s fall (13% more than once per week) with 13% experiencing fractures, 18% experiencing hospitalization, and 3% being confined to a wheelchair (Koller, Glatt, Vetere-Overfield, & Hassanein, 1989). Persons with PD fall mostly forward (45% of all falls) but approximately 20% of falls are directed laterally. The characteristic stooped posture during stance and gait increases the likelihood of forward falls because of the associated forward shift in the center of gravity (Bloem et al., 2004). Because
walking difficulties are associated with an increased risk of falls (Aita, 1982), there has been a considerable research effort investigating the control and treatment of walking in PD.

Parkinson’s disease proceeds through five stages. In Stage I persons with PD exhibit unilateral symptoms with little or no functional impairment. Stage II is characterized by bilateral body involvement with minimal functional difficulties. Stage III is characterized by increased postural instability leading to moderate functional impairments. In Stage IV persons with PD are frequently unable to perform basic activities of daily living without assistance, and in the end stage of the disease (Stage V) patients are typically wheelchair- or bed-bound and need long-term nursing care (Yahr & Brodsky, 2002). Thus, as persons advance through the stages of the disease, they become progressively unstable, demonstrating balance difficulties in both standing and walking.

Consistent with the overall poverty of movement seen as the disease progresses, gait in persons with PD is characterized by a general hypokinesia, or a reduction in movement amplitude. One component that contributes to hypokinesia is akinesia, or the inability to initiate movement. Akinesia, also referred to as freezing, can occur at the beginning of movements or during movements. Bradykinesia can also contribute to gait difficulties in persons with PD. When these symptoms occur during walking hypokinesia occurs, resulting in decreased stride length, increased cadence, and overall decreased walking speed.

Treatment for PD is directed mainly at replacing the dopamine deficiency with dopamine agonists and levadopa therapy. This is the most effective medical therapy to date. However, with disease progression and prolonged use of these drugs, individuals with PD become less responsive to medications and start developing fluctuations in their response to the treatments (Hamani & Lozano, 2003). Chronic use of these medications can cause
adverse effects, including drug-induced involuntary movements (i.e., dyskinesias). More importantly, research shows that dopamine therapy does not significantly improve postural instability (Bloem et al., 1996). Thus, clinical gait research has focused on increasing stride length and walking speed through the use of sensory cueing and attentional strategies (Morris, Iansek, Matyas, & Summers, 1996; Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004; Bagley, Kelly, Tunnicliffe, Turnbull, & Walker, 1991).

This review will focus on the use of different cueing strategies to improve gait in PD. Specifically, the following topics will be addressed in this review: 1) the circuitry involved in the control of gait; 2) the impact of PD on gait; 3) different sensory cues that help to improve movement initiation and gait; 4) the effect of long-term gait training for persons with PD; and 5) the use of harmonic gait analysis to quantify walking stability and how this technique may be particularly useful in studying gait in PD.

Current knowledge suggests that the basal ganglia, cerebellum, brain stem, and areas in the cerebral cortex are involved in the control of voluntary movements, including gait. Evidence indicates that the basal ganglia contribute to the execution of voluntary movements via a series of parallel basal ganglia-thalamocortical loops (Alexander, 1994). The basal ganglia also receive topographical inputs from many of the sensorimotor areas of the cortex. The areas include the primary and secondary somatosensory areas, the primary motor cortex the supplementary motor area (SMA) and the premotor areas (Alexander, 1994). The outflow of the basal ganglia reaches the brainstem where fundamental neuronal networks for controlling muscle tone and locomotor movements are located (Takakusaki, Habaguchi, Ohtinata-Sugimoto, Saitoh, & Sakamoto, 2003).
The anatomical control of locomotion is important to understand so researchers can investigate and develop alternative methods for intervention. Much locomotion research has been done in rats and cats. This research is very invasive and cannot be performed on humans, so the information obtained from research in cats and rats must be extrapolated to humans. It has been suggested by many studies that the mesencephalic locomotor region largely corresponds to the cuneiform nucleus and a region of the pedunculopontine tegmental nucleus, and that non-cholinergic neurons in these areas are involved in the generation of locomotion (Takakusaki et al., 2003). Garcia-Rill (1991) in decerebrate cats and Mori, Sakamoto, Ohta, Takakusaki, and Matsuyama (1989) in alert cats have shown that repetitive electrical stimulation of the mesencephalic locomotor region evokes locomotion. The mesencephalic locomotor region has been established as the functional region involved in the initiation of locomotion on the basis of its connections with limbic structures and the basal ganglia (Armstrong, 1986 as cited by Takakusaki et al., 2003).

Based on the following findings, Garcia-Rill (1991) suggested that an activation of cholinergic neurons in the pedunculopontine tegmental nucleus is required to initiate locomotion. First, locomotion was induced by electrical or chemical stimulation within the pedunculopontine tegmental nucleus pars compacta where cholinergic neurons were abundantly located. Second, mesencephalic locomotor region-induced locomotion was blocked by injections of atropine sulfate into the medioventral medulla where efferent fibers from the pedunculopontine tegmental nucleus terminate.

However, Takakusaki et al. (2003) produced results that were not consistent with Garcia-Rill’s (1991) observations. The investigators found the locomotor region to be mainly located within and around the cuneiform nucleus, but including the dorsal part of the
pedunculopontine tegmental nucleus. Electrical stimuli possibly activated either fibers from
the subthalamic nucleus and/or subthalamic locomotor region projecting to the
mesencephalic locomotor region or dendrites of cuneiform nucleus neurons. Next, the
researchers found cholinergic neurons were mostly distributed in the inhibitory region rather
than the locomotor region and the non-cholinergic neurons are the major components of the
mesencephalic locomotor region. These results were opposite to the findings of Garica-Rill

Takakusaki et al. (2003) also gave two reasons why the cholinergic pedunculopontine
tegmental nucleus neurons could play a role in controlling locomotion. First, an atropine
injection into the pontine reticular formation increased step cycles of mesencephalic
locomotor region-induced locomotion associated with an enhancement of muscle tone. Next,
injecting GABA antagonists into the pedunculopontine tegmental nucleus initiated and
terminated locomotor movements (depending on the level of muscle tone). Takakusaki et al.
(2003) emphasized that cholinergic pedunculopontine tegmental nucleus neurons can be
involved in both the initiation and termination of locomotion and the maintenance of the
locomotor movements through their capability of modulating postural muscle tone. Thus, the
connection between the basal ganglia and the mesencephalic locomotor region is important in
the study of gait and the aforementioned problems with gait in persons with PD.

The anatomical control of gait described previously develops some of the
mechanisms for gait control and helps researchers understand what is occurring in these areas
of the brain. However, in order to understand the reasons why persons with PD have
problems generating an appropriate stride length, one must also consider studies investigating
the pathogenesis of hypokinesia. Studies on persons with PD (Cunnington, Iansek, Bradshaw
& Phillips, 1995) have proposed that in hypokinesia, the communication between the basal ganglia and SMA is interrupted during movement performance. The SMA shows a continuous increase in neuronal activity in order to prepare for an upcoming movement. Once the external signal to move occurs, the neuronal activity in the SMA suddenly terminates (Mushiake, Inase & Tanji, 1990). The basal ganglia have been shown to elicit brief bursts of phasic activity at the end of submovements performed in a sequence. This suggests there is an internal cue from the basal ganglia that elicits this drop in SMA neuronal activity (Brotchie, Iansek, Horne, 1991a, 1991b). These studies appear to provide evidence that the basal ganglia interact with the SMA for learned movement sequences. Therefore, if the basal ganglia cue is absent or disturbed, as in PD, it is plausible that the premovement SMA activity is disturbed. This could lead to aberrant planning and execution of movements (Morris et.al., 1996). Thus, for well-learned sequences such as gait persons with PD could be presented cues in order to bypass this loop between the basal ganglia and the SMA.

Research shows that activities elicited by external stimuli utilize different pathways from those driven by internal decisions (Goldberg, 1985). These external stimuli (e.g. vision) can help to bypass the defective basal ganglia and possibly activate pathways associated with the cerebellum (Suteerawattanan on et.al., 2004). The cerebellum may play a larger role in persons with PD in order to compensate for the defective basal ganglia. In using animal models, it has been shown that cells highly sensitive to moving targets in the cerebral cortex provide the cerebellum with the major visual input through the pontine nuclei (Glickstein, May & Mercer, 1985). These results led Glickstein and Stein (1991) to hypothesize that information regarding visual motion may use a specific visuomotor pathway that passes through the cerebellum and therefore, bypasses the damaged basal ganglia. These data
suggest that sensory cueing using visual cues could be beneficial in normalizing movements in persons with PD.

As mentioned earlier, the movement patterns of persons with PD are characterized by bradykinesia and hypokinesia, especially gait. Sensory cueing that is introduced to individuals with PD can provide them with the appropriate stimuli to bypass the defective basal ganglia in order to normalize their movements. Previous evidence shows that external cueing can be used to normalize movements and increase movement velocity has been reported by Majsak, Kaminski, Gentile, and Flanagan (1998). The researchers showed that persons with PD were able to generate reaching velocities while intercepting a moving ball that exceeded their self-regulated maximal speed while reaching for a stationary ball. The speed of reaching while intercepting a moving ball also matched the speed of the healthy subjects. These data show that administering sensory cues to individuals with PD can help to normalize movements and gait patterns and also support the hypothesis that individuals with PD can bypass the damaged basal ganglia.

The earliest investigation of gait in persons with PD was performed in the 1960’s (Martin, 1967 as cited by Azulay et al., 1999). Martin reported the effectiveness of utilizing vision to facilitate locomotor activity. He showed that only certain visual stimuli were effective in improving gait, which were transverse lines, lines that were greater than or equal to one inch in width, greater than or equal to eighteen inches in length, and lines with contrasting color to the floor. Zigzag lines, lines parallel to the movement direction, very narrow lines, lines wider than six feet, or stripes without contrasting color had no influence on the gait of persons with PD. This research demonstrates the value of vision for persons with PD in the control and maintenance of locomotion.
Vision, as an external sensory cue, is important for improving the gait of individuals with PD. One type of visual cue given to persons with PD that coincides with Martin’s original study was the use of bright yellow transverse strips of tape placed at 40% of the subject’s height (Suteerawattananon et al., 2004). This inter-strip distance of 40% was chosen to encourage a normal step length. They found that the use of visual cues increased stride length by 18% compared with the uncued condition. The effectiveness of visual cues used as lines on the floor was further substantiated by Lewis, Byblow, and Walt (2000). They conducted a study where strips of white tape were placed along the walkway at intervals corresponding to a normal step length for the participant. Both studies found significant improvements in stride length for persons with PD when using colored strips secured to the floor when compared to uncued conditions.

In recent years, a device referred to as an automatic computerized walkway (or a gait mat) has been used frequently to analyze walking patterns of healthy and clinical groups. Bagley et al. (1991) used a series of these mats to create a grid for conducting the study that were collected and processed through a control box. All participants had strips of self-adhesive aluminum tape attached to the soles of their shoes which served to complete a current path to ground when the tape was in contact with the mat, through otherwise electrically isolated rods. The colored strips used on the gait mat were bright yellow triangular tubes. Once again, these cues improved the gait of individuals with Parkinson’s disease and every participant was able to step over the strips without losing their balance. The use of lines on the floor has prompted researchers to investigate other modes of delivering visual cues.
Visual cues can be presented in many ways. A recently tested device is called a visual
cue cane (Kompoliti, Goetz, Leurgans, Morrissey & Siegel, 2000). The visual cue canes were
presented in two forms. The first cue cane was a modified-inverted stick, which consisted of
a rod with a slat of wood attached to the bottom of the rod. The other cue cane tested was a
laser beam stick with a laser attached to the bottom of the rod. The participants used the
canes as visual cues to step over the slat of wood or to step over the laser beam to
compensate for the freezing individuals with Parkinson’s disease experience. Kompoliti et al.
found that the cue canes did not improve the number of freezing episodes or the time to
complete the trial. These results suggest that these cue canes were ineffective in stimulating
the alternate pathway within the brain in order to bypass the defective basal ganglia in
persons with PD.

Visual cueing studies using alternate forms of laser beams have also been tested. In
one study, a subject-mounted light device was used to project the visual cues onto the
walkway (Lewis et al., 2000). The subject-mounted light device condition involved the use of
a laser device that was attached to the participant’s chest. The device projected two laser
lines on to the floor at a width of the participant’s normal step length. The researchers
concluded that for those individuals with small to moderate reductions in stride length that
the subject-mounted light device was effective in increasing stride length to values that were
equal to (in some cases larger than) the participant’s height-predicted estimate. However, it
was less successful in those participants with severe reductions in baseline stride length,
suggesting there may be an optimal stage of PD to successfully implement the subject-
mounted light device.
Azulay et al. (1999) took a different approach in their study looking at visual cues in PD. They wanted to determine which types of visual cues (static or dynamic) were required for the control of locomotion in individuals with PD. Two different conditions were tested: normal lighting and stroboscopic illumination. The stroboscopic illumination was used in order to suppress dynamic visual cues completely. So, if transverse lines generate an improvement in walking performance under normal lighting, the removal of this improvement under the stroboscopic condition would determine whether or not it is linked to the perceived motion of the lines (i.e. optical flow). A significant effect of the stroboscopic light was only found in the Parkinson’s group. The people with Parkinson’s disease reduced their velocity and stride length when walking in the stroboscopic light. These results suggest that the Parkinson’s disease group was dependent on dynamic visual information to improve their gait.

Monitoring gait for a short time after the use of visual cues has also been performed. In one of the landmark studies on gait in individuals with PD, participants were trained for 20 minutes by repeated walks set at a controlled stride length using either visual floor markers or a mental picture of the appropriate stride length (Morris et al., 1996). Gait patterns were monitored every fifteen minutes for two hours while delivering progressively more complex secondary tasks after both visual and cognitive training. Throughout the testing period, there were intermittent periods where the participants were unaware they were being monitored. The results demonstrated that people with PD who trained with both visual cues and cognitive strategies could maintain normal gait. Thus, visual cue and cognitive training can lead to positive retention in persons with PD.
The use of visual cues in long-term gait training has also been shown to be effective, although based only on a few studies. In one study, a subject trained 3 times per week for two 4-week periods with the use of visual cues (Sidaway, Anderson, Danielson, Martin, & Smith, 2006). Retention tests were conducted for one month with the frequency of these retention tests being reduced over that time span. The researchers concluded that gait training with visual cues established a lasting improvement in gait speed and step length while increasing the stability of the underlying motor control system responsible for gait.

The previous studies have demonstrated that the use of visual cues can lead to a significant increase in the stride length of persons with PD. This improvement from visual cueing has been attributed to the use of optic flow in these individuals. Persons with PD appear to be reliant on optic flow to avoid increased hypokinesia. This is important for these individuals to maintain a self-sufficient lifestyle. However, increasing stride length is only one component of normalizing gait. Thus, along with increased stride length and decreased bradykinesia (i.e. walking faster), auditory cueing may help to increase other aspects of locomotion, such as cadence.

Auditory cueing is usually in the form of rhythmic auditory stimulation. In most studies involving, the common way of delivering an auditory cue is by using a metronome. However, the rates at which the auditory sounds are delivered vary greatly. The rates of auditory cues have been delivered at the participant’s preferred cadence (Rochester et al., 2005), 125% of preferred cadence (Suteerawattananon et al., 2004), and at 85%, 92.5%, 107.5%, and 115% of preferred cadence (Howe, Lovgreen, Cody, Ashton, & Oldham, 2003). The auditory cueing rates of 7.5%, 15%, and 25% faster than preferred all had significant effects on the gait of persons with PD. In the studies performed by Suteerawattananon et al.
and Howe et al., auditory cueing showed significant improvements in step cadence and velocity, improving the temporal parameters (timing) of gait. However, Rochester et al. (2005) showed no improvement with step cadence or velocity. This lack of improvement could be due to use of auditory rates that were not sufficient enough for the individuals with PD maximize their cadence. These studies also had no significant results that auditory cueing affects the spatial parameters (step length) of gait.

In the previous studies gait was assessed by spatiotemporal parameters, such as stride length, velocity, and cadence. A way of analyzing gait that is increasing in popularity is to examine the coordination of gait through the use of harmonics based on acceleration patterns. In using harmonics for analyzing data, the term harmonic ratio was devised as a numerical expression of the harmonic spectrum in an attempt to discriminate among variations in gait patterns for different individuals (Smidt, Arora, & Johnston, 1971). The harmonic ratio reflects the frequency of force changes experienced by the body during the walking cycle and provides an index for the smoothness of walking (Smidt, Deusinger, Arora, & Albright, 1977). For each spectrum a harmonic ratio is obtained, which is the sum of the coefficients for the even-numbered harmonics divided by the sum of the coefficients for the odd-numbered harmonics (Smidt et al., 1971). This calculation reveals what is called the index of smoothness. According to Smidt et al. (1971), the following classification system for harmonic ratios might be used to indicate the smoothness of walking: normal equals greater than 2.00; fair equals 1.50 to 2.00; poor equals 1.00 to 1.49; and very poor is less than 1.00. Thus, smoother walking is associated with a higher number of even harmonics and/or a decrease in the number of odd harmonics.
These harmonic ratios can decrease when people get older or when normal walking patterns are altered due to surface irregularity or injury. Older participants, when compared to younger participants, exhibit reduced velocity and step length, and increased timing variability. This represents the characteristically “cautious” gait pattern commonly observed in older people. This may be a compensatory strategy to ensure that the head and pelvis remain stable, thereby reducing the likelihood of falls when walking (Menz, Lord, Fitzpatrick, 2003a).

In a study performed by Yack and Berger (1993), elderly people who had reported stability problems showed a greater difficulty controlling their trunk resulting in lower indexes of smoothness. These changes in harmonic ratios indicate that the forces acting on the trunk (in the anterior-posterior and vertical directions) are more variable in individuals with unstable gait.

When walking on an unpredictable irregular surface, young people altered their gait pattern just slightly when compared to walking on a level surface. These data suggest that the main motor control pattern to stabilize the body was by increasing step length in an attempt to minimize the number of foot contacts over a given distance (Menz et al., 2003b). However, older people adopt the aforementioned cautious gait pattern on irregular surfaces in an attempt to minimize the displacement of the upper body. In contrast to the trunk, there were no significant differences in acceleration root mean square at the head when walking on the irregular surface compared to the level surface. The walking surface produced significant findings with respect to amplitude variability in the vertical direction (Menz et al., 2003b).

This review shows that gait in persons with PD is characterized by short, shuffling steps, decreased cadence, and decreased velocity. However, there are many different types of visual
and auditory cues and most of these cues appear to facilitate the gait of individuals with Parkinson’s disease. Research suggests that one of the most effective methods of delivering visual cues are transverse lines, an inch or more wide, approximately 18 inches, and the color of the lines contrasting with that of the floor.

The majority of studies on gait and PD measured solely spatiotemporal variables, such as stride length, velocity, and cadence. However, a recent method for analyzing gait is through the use of harmonic ratios. The research using harmonic ratios has been minimal. One purpose of this study is to examine the differences in harmonic ratios in preferred walking between people with PD and healthy older adults. Another purpose is to determine the effects of visual and verbal cues on the harmonic ratios in persons with PD. It was hypothesized that the visual and verbal cues would increase harmonic ratios (improve the stability) in people with PD compared to preferred walking but would not cause an increase in the control participants.

**Reference List**


CHAPTER 3.

EXPERIMENT

Introduction

Gait difficulties are among the primary motor problems in individuals with Parkinson’s disease (PD). The gait pattern in individuals with PD is characterized by shuffling steps, decreased stride length, increased cadence (steps/minute), and an overall decreased velocity (Lewis, Byblow, & Walt, 2000). As the severity of the symptoms progress, postural instability increases, thus leading to an increased risk of falls. Improving gait in individuals with PD through increased step length and increased velocity is a principle intervention in physical therapy settings.

Typical clinical practice in physical therapy settings is to instruct people with PD to walk faster and increase stride length. One way that physical therapists address gait disturbances in people with PD is through visual cues (Morris, 2006). Several studies show that individuals with PD improve their gait when given appropriate visual cues (Morris, Iansek, Matyas, & Summers, 1994a, 1994b; Morris, Iansek, Matyas, & Summers, 1996). More specifically, Martin (1967) showed improved gait using colored strips placed on a walkway. Subsequent studies also reported the effectiveness of colored strips on a walkway to improve gait (Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004; Lewis et al., 2000; Bagley, Kelly, Tunnicliffe, Turnbull, & Walker, 1991).

Another type of cueing shown to be effective for improving gait in individuals with PD is auditory cueing. Auditory cueing is frequently delivered in the form of rhythmic auditory stimulation, commonly through the use of a metronome. Auditory cueing results in
increases in cadence and velocity (Howe, Lovgreen, Cody, Ashton, & Oldham, 2003; McIntosh, Brown, Rice, & Thaut, 1997; Suteerawattananon et al., 2004). Some studies show auditory cueing increases stride length (Ito et al., 2000; Enzensberger & Fischer, 1996) while other studies show no increase in stride length (Rochester et al., 2005; Howe et al., 2003).

The above studies provide evidence that visual and verbal cues improve gait for individuals with PD. However, an important question remains: do improving gait spatiotemporal parameters improve walking stability in these individuals? In order to quantify the stability of a walking pattern, Smidt and colleagues (Smidt, Deusinger, Arora, & Albright, 1977) used trunk acceleration measures to determine a harmonic ratio, which reflects the frequency of force changes experienced by the body during the walking cycle and provides an index for the smoothness of walking. Yack and Berger (1993) showed older adults with stability problems exhibited a greater difficulty controlling their trunk resulting in a lower index of smoothness. More recent research shows that older adults also adopt a more conservative gait pattern to reduce the magnitude of acceleration patterns at the head and pelvis (Menz, Lord, & Fitzpatrick, 2003c). These changes in harmonic ratios indicate that the forces acting on the trunk (in the anterior-posterior and vertical directions) are more variable in individuals with unstable gait.

One purpose of this study was to examine the differences in walking stability during preferred walking between people with PD and healthy older adults. A second purpose was to determine the effect of visual and verbal cues on the harmonic ratios of participants with PD when compared with their harmonic ratios during preferred walking. A third purpose is to examine the correlations between spatiotemporal variables and harmonic ratios to determine the contribution of harmonic ratios to the understanding of gait in people with PD and older
adults. It was hypothesized that people with PD would exhibit lower harmonic ratios than the control group during preferred walking. It was also hypothesized that the implementation of visual and verbal cues would differentially affect the gait of the PD group compared to the control group. More specifically, it was expected the external verbal condition would improve walking stability in the PD group and disrupt walking stability in the control group. It was also hypothesized that harmonic ratios would not correlate with spatiotemporal variables, thus indicating that harmonic ratios provide a unique contribution to the understanding of gait.

Method

Participants

Thirteen people with PD and 13 neurologically healthy adults were recruited for this study. One person with PD could not complete data collection and data from another person were corrupted. The remaining 11 participants with PD (age=67.97 ± 7.65 years; height=174.8 ± 6.2 cm) were age- and gender-matched with 11 people from the control group (age=70.63 ± 9.15 years; height=171.5 ± 7.4 cm). The severity of the disease for the PD group ranged from mild (Hoehn and Yahr 1) to moderate (Hoehn and Yahr 3) (see Table 1). The exclusionary criteria for the study included: 1) the presence of any neuropathy other than PD; 2) persons unable to walk independently without an assistive device; 3) moderate to severe dyskinesias; 4) significant cardiovascular disease; 5) moderate to severe dementia or depression; and 6) the presence of significant musculoskeletal impairment. Testing was carried out while the participants were in an “on” state of medication and during the time when the participant’s self-reported medication was most effective. Recruitment and testing
were performed according to institutional review board procedures. Informed consent was obtained prior to participation in the study.

Table 2 provides comparison information between the groups. The PD group had a lower score on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) \([t(20)=2.360, p=.029]\), although all participants were within the normal range, thus no participant exhibited signs of dementia. The PD group exhibited greater depression than the control group based on the Geriatric Depression Scale (Ertan, Ertan, Kiziltan, & Uygucgil, 2005) \([t(20)=2.590, p=.017]\); however, all participants scored within the normal range except for one person with PD who exhibited mild depression. Both groups were equally active as measured by the Physical Activity Scale for the Elderly (Washburn, Smith, Jette, & Janney, 1993). No participant was at risk for falling based on the Berg Balance Scale (Berg, Wood-Dauphinee, Williams, & Gayton, 1989), but the PD group did exhibit poorer balance than the control group \([t(20)=2.320, p=.031]\). The PD group also had lower balance confidence as measured by the Activities-Specific Balance Confidence Scale (Powell & Myers, 1995) \([t(20)=2.220, p=.038]\). As expected, the PD group performed more slowly on the Purdue Pegboard task \([t(20)=3.772, p=.001]\) and the Reciprocal Tap task \([t(20)=4.279, p<.001]\).1

**Instrumentation**

Two triaxial accelerometers (Crossbow CXLO2LF3, range ±2g) were placed on the participants. One was mounted on a plastic base plate on a gait belt, which was secured and aligned with L2 (Smidt et al., 1971). The other accelerometer was mounted to an adjustable plastic headpiece that was secured around the head (see Figure 1). Prior to data collection,

---

1 The tests were administered and scored based on instructions provided with each test. The Purdue Pegboard and Reciprocal Tap tasks were performed with the most affected hand for those with PD, and the controls were matched for hand use, i.e., if the most affected hand was the nondominant hand then one control participant also used their nondominant hand. Participants completed three 12-second trials for Reciprocal Tap.
<table>
<thead>
<tr>
<th>ID</th>
<th>Age (yrs)</th>
<th>Disease Duration (yrs)</th>
<th>Hoehn &amp; Yahr (0-5)</th>
<th>Medication</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59.07</td>
<td>2</td>
<td>1</td>
<td>pramipexole</td>
</tr>
<tr>
<td>2</td>
<td>63.25</td>
<td>5</td>
<td>2</td>
<td>ropinirole carbidopa/levodopa/entacapone raloxifene</td>
</tr>
<tr>
<td>3</td>
<td>76.66</td>
<td>6.75</td>
<td>3</td>
<td>escitalopram carbidopa/levodopa/entacapone mirtazapine</td>
</tr>
<tr>
<td>4</td>
<td>65.63</td>
<td>4.75</td>
<td>1</td>
<td>pramipexole sertraline</td>
</tr>
<tr>
<td>5</td>
<td>67.32</td>
<td>1.5</td>
<td>1</td>
<td>amantadine</td>
</tr>
<tr>
<td>6</td>
<td>81.29</td>
<td>1.5</td>
<td>1</td>
<td>none</td>
</tr>
<tr>
<td>7</td>
<td>71.25</td>
<td>5</td>
<td>3</td>
<td>levodopa pramipexole</td>
</tr>
<tr>
<td>8</td>
<td>56.93</td>
<td>16</td>
<td>3</td>
<td>carbidopa/levodopa pramipexole amantadine entacapone selegiline amitriptyline</td>
</tr>
<tr>
<td>9</td>
<td>67.16</td>
<td>3</td>
<td>2</td>
<td>levodopa amantadine ropinirole escitalopram</td>
</tr>
<tr>
<td>10</td>
<td>63.00</td>
<td>6.5</td>
<td>2</td>
<td>levodopa amantadine</td>
</tr>
<tr>
<td>12</td>
<td>76.13</td>
<td>4-5</td>
<td>2</td>
<td>levodopa/carbidopa</td>
</tr>
</tbody>
</table>
each accelerometer was statically calibrated on a flat surface, so that the output corresponded to -1g for the vertical axis, and zero for the orthogonal axes. Accelerometer data were sampled at 200 Hz using a portable data logger (Crossbow AD2000 Ready DAQ) that was worn in a small backpack. The backpack was firmly fitted to the participant, taking care not to restrict normal arm swing.

**Task**

To determine the effect of different cues on harmonic ratios, all participants were asked to walk an 18-meter walkway in different conditions. One condition was at each

<table>
<thead>
<tr>
<th>Test</th>
<th>PD Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geriatric Depression Scale</td>
<td>*8.36 (5.24)</td>
<td>3.23 (3.72)</td>
</tr>
<tr>
<td>(0-9 normal; 10-19 mild; 20-30 severe)</td>
<td>0-17</td>
<td>0-14</td>
</tr>
<tr>
<td>Mini-Mental State Examination</td>
<td>*28.36 (1.86)</td>
<td>29.46 (0.88)</td>
</tr>
<tr>
<td>(30=perfect score)</td>
<td>24-30</td>
<td>27-30</td>
</tr>
<tr>
<td>Purdue Pegboard</td>
<td>**10 (1.89)</td>
<td>12.87 (1.76)</td>
</tr>
<tr>
<td>(# of pegs in 30 sec)</td>
<td>5-13</td>
<td>8-16</td>
</tr>
<tr>
<td>Reciprocal Tapping</td>
<td>**31.67 (6.67)</td>
<td>43.74 (6.92)</td>
</tr>
<tr>
<td>(# of taps in 12 sec)</td>
<td>20-44</td>
<td>26-56</td>
</tr>
<tr>
<td>Berg Balance Scale</td>
<td>*51.7 (4.61)</td>
<td>55.1 (1.75)</td>
</tr>
<tr>
<td>(56=perfect score)</td>
<td>43-56</td>
<td>50-56</td>
</tr>
<tr>
<td>Activities Balance Confidence Scale</td>
<td>*85.63 (10.47)</td>
<td>95.48 (9.56)</td>
</tr>
<tr>
<td>(subjective measure of physical abilities)</td>
<td>0-100</td>
<td>0-100</td>
</tr>
<tr>
<td>Physical Activity Scale for the Elderly</td>
<td>149.51 (71.46)</td>
<td>169.25 (80.16)</td>
</tr>
<tr>
<td>(measure of physical activity)</td>
<td>24.7-265.69</td>
<td>47.85-314.39</td>
</tr>
</tbody>
</table>
person’s preferred pace, which was walking at each person’s self-selected comfortable pace. This was performed at the beginning (PFB) and end of the testing session (PFE). There were three verbal cueing conditions: 1) internal verbal (IV) in which participants were instructed to think “big step” and focus on taking longer steps; 2) external verbal (EV) in which the experimenter instructed participants to take longer steps and verbally cued “big step” during the swing phase of every third step; and 3) was asking participants to walk faster than preferred, but not at maximal speed (F). There were also two visually cued conditions, one in which colored strips were spaced at a distance of 40% of the participant’s height (40H) and the other in which the strips were spaced at a distance 20% longer than the participant’s preferred step length (20L). The colored strips were bright blue measuring 4 inches wide by 22 inches long. Participants were asked to match their step size with the positions of the colored strips on the floor without aiming.
Procedures

All measurements were obtained during a single session. Participants performed three trials of each condition. Prior to walking, each participant’s height was measured to determine the distance of the strips for the 40H condition. Average preferred step length was determined by counting the number of steps taken for the entire walkway during preferred pace (calculated as 18m/number of steps). Calculation for the 20L distance was determined by multiplying 1.2 times average preferred step length. The first and last conditions for all participants were preferred walking; the second condition was F; and all other conditions were counterbalanced. Participants were given adequate rest between conditions to avoid fatigue. Tests administered to characterize the sample (tests listed in Table 2) were given before testing or during periods of rest.

Dependent Measures

Harmonic Ratios. The primary dependent measures were anterior-posterior (AP), vertical (V), and medial-lateral (ML) harmonic ratios, which are based on acceleration data. Typical AP and V acceleration patterns of the trunk during walking have repeatable biphasic signals that reflect the cyclical movement of the trunk during one stride (heel contact to heel contact of the same foot). Due to the biphasic characteristic of the AP and V acceleration patterns, frequency decomposition through Fourier analysis yields a dominance of the second harmonic and subsequent even harmonics. The even harmonics are the intrinsic harmonics (Zilstra & Hof, 1997) for the AP and V planes and indicate the in-phase components of the signal; the even harmonics are the expected harmonics in a biphasic pattern. The odd harmonics comprise the extrinsic or out-of-phase components; odd harmonics should be minimal in the V and AP planes in walking. A ratio can be calculated by dividing the even
harmonics (summed amplitudes of the first 10 even harmonics) by the odd harmonics (summed amplitudes of the first 10 odd harmonics). Thus, for both the AP and V planes, this ratio should be high if the even harmonics dominate the pattern and odd harmonics are small, which is expected in a healthy, stable gait pattern.

Conversely, the ML accelerations in walking are a monophasic pattern. Thus, what is expected is the dominance of the first harmonic and subsequent odd harmonics. In the ML plane, the odd harmonics are intrinsic and the even harmonics are extrinsic. Therefore, for the ML plane the harmonic ratio is calculated from a ratio of the odd harmonics divided by the even harmonics (Menz, Lord, & Fitzpatrick, 2003b).

Harmonic analysis was applied to all acceleration data using custom software developed in Visual Basic. A low-pass second-order Butterworth filter with a cutoff frequency of 21 Hz was applied to the raw acceleration data for stride segmentation. Stride segmentation was determined from a custom Visual Basic program by finding consecutive maximum deceleration values (heel strike to heel strike of the same foot) and classifying these as one stride. This stride segmentation was then applied to the original raw data for determining a harmonic ratio per stride. In addition to harmonic ratios, the following variables were calculated: (1) Step length (m), calculated during PFB (number of steps/18 m); (2) Velocity (m/s), calculated based on time to traverse the middle 10 meters of the walkway (to calculate velocity within these 10 meters, a push-button trigger was applied by the experimenter when the toe crossed these markers); (3) Stride time (seconds), derived from acceleration data by determining the number of samples from the data logger between consecutive heel strikes of the same foot; (4) Cadence (strides/min), derived by determining number of strides and dividing by the total time for each trial; and (5) Coefficient of variation
(CV), which is standard deviation/mean*100 and used to quantify the variability of the harmonic ratios and stride time.

**Data Reduction and Analysis**

Prior to calculation of means each trial was visually inspected to determine if the program correctly selected strides. In the few cases where strides were not properly identified, those strides were omitted from analyses. For all gait variables, the first trial was considered practice and analyses were performed on the data from trials 2 and 3. To avoid acceleration and deceleration effects, the first and last two strides were not included in the analyses. (The remaining number of strides analyzed ranged from 6-14 in preferred walking and 4-14 in the other conditions). The middle stride values for each parameter were averaged across trials 2 and 3. Although head acceleration data were collected in this study, these data were not included.

Effect Size (ES) was calculated for each analysis to determine the meaningfulness of the data. An ES ≥ 0.8 is large, 0.5 is moderate, and < 0.2 is small (Thomas, Nelson, & Silverman, 2005). Statistics were performed on the data using SPSS statistical software. Group x condition Analyses of Variance (ANOVA) with repeated measures on the second factor were used to test each dependent variable. Within-group Pearson r correlations were also performed for selected variables. Alpha level was set at .05 with Bonferroni pairwise comparisons as follow-up tests.

**Results**

The data are presented for each set of conditions (preferred, visual cues and verbal cues). Within each section spatiotemporal variables are presented followed by harmonic ratios. In addition, correlations between spatiotemporal variables and harmonic ratios are
presented. Only significant effects are discussed. When there is a significant interaction, main effects are not reported.

**Preferred Beginning/End**

*Spatiotemporal variables.* Velocity, step length, cadence and stride time during preferred walking were each analyzed using a group (2) by condition (PFB and PFE) ANOVA. No group main effects were found for the spatiotemporal variables. However, condition main effects were found for velocity \(F(1,20)=30.331, p<.001, ES=1.8\), step length \(F(1,20)=52.4, p<.001, ES=2.38\), cadence \(F(1,20)=5.440, p=.03, ES=.70\), and stride time \(F(1,20)=4.866, p=.039, ES=.69\). These results indicate that participants in both groups walked faster, exhibited a longer step length and an increased cadence at the end of testing compared to the beginning (see Table 3 for means and standard deviations). There were no significant differences for CV of stride time.

*Harmonic ratios.* A group (2) by condition (2) ANOVA for each of the three planes resulted in a group main effect for all three planes (AP: \(F(1,20)=5.853, p=.025, ES=.95\); V: \(F(1,20)=6.832, p=.017, ES=.79\); ML: \(F(1,20)=14.236, p=.001, ES=1.13\)). In addition, there was a trend for a condition main effect in the AP plane \(p=.06\) (see Figure 2). These data show that the PD group exhibited lower harmonic ratios for both preferred walking conditions compared to the control group.

**Visual Cues**

*Spatiotemporal variables.* A group (2) by condition (PFB, 20L, and 40H) ANOVA showed no significant group effects although there were condition main effects for velocity \(F(1.31,26.24)=8.962, p=.003, ES=1.51\), step length \(F(1.22,24.44)=49.8, p<.001, ES=6.2\), cadence \(F(2,40)=6.735, p=.003, ES=.94\), and stride time \(F(2,40)=5.864, p=.006, ES=.78\).
Table 3. Means and (standard deviations) in preferred walking.

<table>
<thead>
<tr>
<th></th>
<th>PFB PD</th>
<th>PFB CON</th>
<th>PFE PD</th>
<th>PFE CON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (m/s)</td>
<td>1.05 (.27)</td>
<td>1.26 (.30)</td>
<td>1.15 (.23)</td>
<td>1.34 (.32)</td>
</tr>
<tr>
<td>Step length (m)</td>
<td>.66 (.07)</td>
<td>.71 (.08)</td>
<td>.71 (.08)</td>
<td>.76 (.09)</td>
</tr>
<tr>
<td>Stride time (sec)</td>
<td>1.05 (.13)</td>
<td>1.09 (.07)</td>
<td>1.02 (.10)</td>
<td>1.08 (.07)</td>
</tr>
<tr>
<td>Cadence (strides/min)</td>
<td>57.69 (6.18)</td>
<td>55.52 (3.65)</td>
<td>59.10 (5.06)</td>
<td>55.98 (3.39)</td>
</tr>
<tr>
<td>Harmonic ratios (AP plane)</td>
<td>2.73 (.60)</td>
<td>3.75 (1.05)</td>
<td>3.01 (1.08)</td>
<td>4.01 (1.26)</td>
</tr>
<tr>
<td>Harmonic ratios (V plane)</td>
<td>2.69 (.49)</td>
<td>3.34 (.66)</td>
<td>2.83 (.78)</td>
<td>3.49 (.62)</td>
</tr>
<tr>
<td>Harmonic ratios (ML plane)</td>
<td>1.95 (.36)</td>
<td>2.53 (.43)</td>
<td>1.97 (.31)</td>
<td>2.52 (.45)</td>
</tr>
<tr>
<td>CV of stride time</td>
<td>3.08 (1.50)</td>
<td>2.71 (.99)</td>
<td>2.95 (1.54)</td>
<td>2.39 (.85)</td>
</tr>
</tbody>
</table>
There was a trend for a step length interaction (p=.06) due to decreased average step length in the control group (see Table 4 for means and standard deviations). As expected, the data showed that the 20L condition increased velocity, increased step length, decreased cadence, and increased stride time for all participants. Again, the CV for stride time showed no significant results.
Harmonic ratios. Harmonic ratios for the visual cues were analyzed using a group (2) by condition (3) ANOVA for the three planes. As in preferred walking, there was a group main effect for all three planes (AP: [F(1,20)=7.513, p=.013, ES=.83]; V: [F(1,20)=8.280, p=.009, ES=.87]; ML: [F(1,20)=16.819, p=.001, ES=1.24]). These data demonstrate that the PD group exhibited lower harmonic ratios throughout the visual cueing conditions. In addition, there was a trend for a condition main effect (p=.07) in the AP plane for the 20L condition. Overall, the lack of a condition main effect or interaction indicates that the visual cues did not affect harmonic ratios (see Figure 3).
Verbal Cues

Spatiotemporal variables. The spatiotemporal variables were analyzed using a group (2) by condition (PFB, EV, IV, F) ANOVA. The ANOVA showed no significant group effects. However, the significant findings were condition main effects for velocity \([F(3,60)=18.562, p<.001, ES=2.3]\), step length \([F(3,60)=106.730, p<.001, ES=4.4]\), cadence \([F(1.71,34.21)=17.82, p<.001, ES=1.8]\), and stride time \([F(2.06,41.18)=19.08, p<.001, ES=2.15]\). Pairwise comparisons indicated that the verbal cues increased velocity and step
length compared PFB. Specifically, EV showed the greatest increase in step length and velocity, followed by IV, then F. In addition, only the F condition significantly decreased stride time and increased cadence. The CV of stride time showed a trend for a group main effect (p=.08) with the PD group exhibiting higher variability (see Table 5 for means and standard deviations).

Harmonic ratios. Harmonic ratios for the verbal cues were analyzed using a group (2) by condition (4) ANOVA for the three planes. There was a significant interaction for the AP plane \([F(3,60)=3.564, p=.019]\). Within-group pairwise comparisons indicated that there were no differences for either group compared to PFB. However, the control group showed lower harmonic ratios in EV compared to the other verbal cues. Between-group comparisons indicated that the PD group exhibited lower harmonic ratios in all conditions except EV. There was also a significant interaction in the V plane \([F(3,60)=2.857, p=.044]\). Within-group pairwise comparisons indicated that there were no differences for either group compared to PFB. Again, between-group comparisons indicated that the PD group exhibited lower harmonic ratios in all conditions except EV. Data from the ML plane showed a group main effect \([F(1,20)=14.565, p=.001, ES=1.16]\). Overall, the data show that the PD group exhibited lower harmonic ratios than controls in the verbal conditions except for EV. In addition, the verbal conditions showed no effect on the harmonic ratios of participants compared to PFB (see Figure 4).

Follow-up ANOVA for Selected Variables

A follow-up group (2) by condition (EV, 20L) ANOVA was performed using one condition from each type of cue that showed the largest effect on the harmonic ratios of participants to determine which cue was more effective between EV and 20L.
Spatiotemporal variables. The follow-up ANOVA showed condition main effects for velocity \[F(1,20)=22.672, p<.001, ES=1.43\], step length \[F(1,20)=15.785, p=.001, ES=1.23\], cadence \[F(1,20)=12.572, p=.002, ES=1.07\], and stride time \[F(1,20)=9.441, p=.006, ES=.96\]. These data show that participants walked faster, took larger steps, increased cadence, and decreased stride time in the external verbal condition compared to the 20L

| Table 5. Means and (standard deviations) for the verbal cue conditions. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 | PFB            | EV             | IV             | F              |
|                 | PD  | CON | PD  | CON | PD  | CON | PD  | CON |
| Velocity        |     |     |     |     |     |     |     |     |
| (m/s)           | 1.05 (.27) | 1.26 (.30) | 1.30 (.37) | 1.51 (.34) | 1.29 (.40) | 1.46 (.37) | 1.25 (.36) | 1.54 (.46) |
| Step length     | .66 (.07)  | .71 (.08)  | .84 (.07)  | .88 (.11)  | .82 (.07)  | .86 (.09)  | .72 (.08)  | .79 (.11)  |
| (m)             |     |     |     |     |     |     |     |     |
| Stride time     | 1.05 (.13) | 1.09 (.07) | 1.03 (.09) | 1.09 (.06) | 1.02 (.10) | 1.09 (.09) | .95 (.09)  | .93 (.12)  |
| (sec)           |     |     |     |     |     |     |     |     |
| Cadence         | 57.7 (6.2) | 55.5 (3.7) | 58.8 (5.0) | 55.5 (3.2) | 59.3 (5.9) | 55.4 (4.3) | 63.8 (5.9) | 65.3 (8.8) |
| (strides/min)   |     |     |     |     |     |     |     |     |
| Harmonic ratios | 2.73 (.60) | 3.75 (1.1) | 3.10 (.89) | 3.46 (.98) | 3.08 (.77) | 4.03 (.96) | 2.70 (.88) | 3.91 (.84) |
| (AP plane)      |     |     |     |     |     |     |     |     |
| Harmonic ratios | 2.69 (.49) | 3.34 (.66) | 3.15 (.72) | 3.15 (.68) | 2.93 (.69) | 3.62 (.85) | 2.72 (.86) | 3.39 (.75) |
| (V plane)       |     |     |     |     |     |     |     |     |
| Harmonic ratios | 1.95 (.36) | 2.53 (.43) | 2.80 (.47) | 2.48 (.71) | 1.97 (.32) | 2.88 (.69) | 1.92 (.49) | 2.66 (.54) |
| (ML plane)      |     |     |     |     |     |     |     |     |
| CV of stride    | 3.08 (1.5) | 2.71 (.99) | 3.34 (1.7) | 3.23 (1.8) | 3.75 (3.5) | 1.97 (.85) | 3.45 (2.2) | 2.26 (1.1) |
| time            |     |     |     |     |     |     |     |     |
condition. The CV for stride time showed no significant results.

**Harmonic ratios.** Data from the AP plane showed no significant differences. The V plane showed a group x condition interaction \([F(2,40)=5.414, p=.031]\). Within-group pairwise comparisons indicated that there were no differences for either group. Between-group comparisons indicated that the PD group exhibited lower harmonic ratios in the 20L condition. The ML plane showed a group main effect \([F(1,20)=5.921, p=.024, ES=.73]\). These data indicate that EV had the greatest effect on the harmonic ratios of the participants.
Correlations between Spatiotemporal Variables and Harmonic Ratios for PFB, 20L, EV

For the PFB condition, correlations showed a significant correlation between the AP plane and CV for stride time \( (r=-.772, p=.005) \) for the PD group but no significant correlations for the control group. This negative correlation indicates that as stride variability decreased, harmonic ratios increased. In the 20L condition, there were no significant correlations for the PD group. For the control group all three planes were positively correlated with velocity \( (AP: r=.607, p=.048; V: r=.742, p=.009; ML: r=.730, p=.011) \) and negatively correlated with CV of stride time \( (AP: r=-.827, p=.002; V: r=-.610, p=.046; ML: r=-.832, p=.001) \). These correlations indicate that as stride variability decreased, harmonic ratios increased and as velocity increased, harmonic ratios increased. In the EV condition, there were again no significant correlations for the PD group. For the control group, all three planes were again negatively correlated with CV for stride time \( (AP: r=-.755, p=.007; V: r=-.776, p=.005; ML: r=-.679, p=.022) \). These correlations indicate that as stride variability decreased, harmonic ratios increased.

Discussion

One purpose of this study was to examine the differences in harmonic ratios for preferred walking between people with PD and healthy older adults. Harmonic analysis has been used in previous studies to differentiate walking stability between older adults and young adults (Menz, Lord, & Fitzpatrick, 2003c) and also healthy older adults and frail older adults (Menz, Lord, & Fitzpatrick, 2003a). Calculation of the harmonic ratios from acceleration patterns provides an indicator of stability (Menz, Lord, Fitzpatrick, 2003a). While the spatiotemporal variables did not differentiate the PD group from the control group in preferred walking, we found consistent group differences in the harmonic ratios, with the
PD group exhibiting lower harmonic ratios in all three planes. This indicates that the PD group was less stable than the control group, thus confirming the first hypothesis. While there were no spatiotemporal group differences in the first preferred walking condition, there were harmonic ratio differences. The data from this study are the first to show that harmonic analysis is a useful measure to differentiate walking stability between people with PD and healthy older adults. The data from this study also demonstrate that harmonic analysis is a more sensitive measure of the changes in gait for the two groups than the commonly used spatiotemporal variables. The use of harmonics adds a measurable, quantitative value to the assessment of PD gait.

The second purpose of the study was to examine the effect of visual and verbal cues on walking stability. These cues are often used by physical therapists in the clinical setting. As expected, these cues changed velocity, step length, cadence, and stride time. These data are similar to other studies (Morris et al., 1994a; Suteerawattananon et al., 2004) that found changes in the spatiotemporal variables when people were administered visual and verbal cues. Despite changes in spatiotemporal parameters, the cueing conditions had little effect on the harmonic ratios of the participants. This indicates that spatiotemporal variables can be manipulated without affecting walking stability.

The one condition where there was a differential impact in the AP and V planes on walking stability was external verbal, i.e., the experimenter telling participants every third step to take a ‘big step’. This is the only condition in which there were no group differences; the PD group exhibited increased harmonic ratios and the control group exhibited decreased harmonic ratios. An explanation for this effect for the PD group is that the external cue bypassed the defective basal ganglia and activated an alternate circuit for the control of
locomotion (Goldberg, 1985). The external verbal cue may have caused a decrease in the harmonic ratios in the control group due to interrupting their natural gait cycle. Healthy older adults may be distracted by hearing a verbal cue at set intervals causing them to change their walking pattern to correspond to the cue itself.

Another purpose was to determine the degree to which harmonic ratios provide a unique source of information regarding gait. The correlations between spatiotemporal variables and harmonic ratios indicated that there are significant associations between stride time variability and harmonic ratios. For the PD group, there was a negative correlation between the AP plane and stride time variability in preferred walking, i.e., the higher the stride time variability, the lower harmonic ratio. Although there were no significant correlations in preferred walking for the control group, there were negative correlations between stride time variability and all three planes in the 20L and external verbal conditions. One interpretation for these associations is that the cues interrupted the natural gait pattern for the control group. Previous studies show that older adults with a history of falling have greater stride time variability (Hausdorff, Edelberg, Mitchell, Goldberger, & Wei, 1997) and that stride time variability was increased in people with PD who had freezing of gait (Hausdorff et al., 2003). This study showed an apparent relationship between increased stride time variability and lower harmonic ratios for the control group.

The only other correlation found in the control group in the 20L condition was between velocity and the three orthogonal planes. This finding could indicate that walking faster results in increased stability. However, this correlation did not exist in the fast condition. Together these results indicate that increased velocity alone can not explain the
increased harmonic ratios, but may be due to a combination of increased step length and velocity in the 20L condition.

When examining the harmonic ratios in preferred walking in the beginning compared to preferred walking in the end, there was a trend for a condition effect in the AP plane. One explanation could be a practice effect, but this task was not novel (simply walking) and all participants completed a practice trial prior to any data collection. Therefore, we think the higher harmonic ratios at the end of practice are better explained by the participants completing multiple trials of the experimental conditions in which they were encouraged to step with longer steps. Previous research shows that long-term gait training improves retention of spatiotemporal variables during cued gait and these improvements are maintained following removal of the cues (Sidaway, Anderson, Danielson, Martin, & Smith, 2006; Morris et al., 1996). The conditions in this study could have functioned like a therapy session by manipulating spatiotemporal parameters aimed at increasing step length. A future study could focus on the effect on harmonic ratios of a long-term gait-training program using visual and verbal cues.

One limitation of this study was the small sample size. The small sample size may hinder the generalizability of the results. A second limitation was that the range of the severity of the disease for the PD group was large (Hoehn and Yahr scores 1-3). Because of this range, the descriptive power of the harmonic ratios is less clear. This severity of the disease may have an impact on the effectiveness of the cues for the PD group.

Since these measurements were obtained during a single session, a future study could present visual and verbal cues to two groups of people with PD, one group with mild
symptoms and one with moderate symptoms. This would help determine if the cues have a larger impact on mild or moderate people with PD or if the effect is equal.

One implication of this study is that harmonic ratios appear to be useful in assessment of gait in people with PD. Harmonic ratios differentiated the two groups whereas spatiotemporal variables did not differentiate the two groups. In addition, harmonic ratios allow researchers to examine gait in three planes of motion as opposed to just examining specific spatiotemporal parameters. Second, the EV condition appeared to be the most effective cue for increasing walking stability and improving spatiotemporal parameters in individuals with PD. Lastly, the cues used in this study did not appear to destabilize the PD group, i.e., the cues did not decrease the mean harmonic ratios of the PD group during any cued condition below the mean harmonic ratios of the preferred walking condition. These results add support to the use of verbal and visual cues in the therapeutic setting.

Reference List


CHAPTER 4.

CONCLUSION

One purpose of this study was to examine the differences in walking stability during preferred walking between people with PD and healthy older adults. A second purpose was to determine the effect of visual and verbal cues on the harmonic ratios of participants with PD when compared with their harmonic ratios during preferred walking. Previous experiments examining gait in individuals with PD using visual and verbal cues focused primarily on the changes in spatiotemporal variables, such as velocity, stride length, cadence, and stride time (Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004; Bagley, Kelly, Tunnicliffe, Turnbull, & Walker, 1991). This experiment expanded the assessment of gait in people with PD to include analyzing trunk acceleration patterns of participants while walking.

The data from the present study showed consistent differences in the harmonic ratios between the PD group and the control group except for the external verbal condition. This is an interesting finding because analyses of the spatiotemporal variables showed no group differences in any of the walking conditions. These results indicate that harmonic analysis is a more sensitive measure of walking stability than spatiotemporal parameters.

The analyses of the spatiotemporal parameters showed increases for all variables (except stride time variability) for preferred walking at the end of the testing session compared to preferred walking at the beginning of the testing session. There were also increases for all variables (except stride time variability) for the visual (20L) and verbal cueing conditions. These data are interesting because the participants improved their
performance on all the variables but these improvements were not large enough to increase the harmonic ratios of the PD group to a level of the control group. The lack of improvement in harmonic ratios shows that improvement in spatiotemporal measures does not mean that participants are becoming more stable.

The finding that improving spatiotemporal parameters does not destabilize people with PD or healthy older adults is important for clinicians that use these techniques in the therapy setting. An interesting finding from this study that could be useful for therapy settings is the significant correlation between stride time variability and all three planes of movement. For the visual cue condition that used 120% of preferred step length and for the external verbal cue condition, lower stride time variability resulted in increased harmonic ratios in the control group. This finding implies that an effective strategy could be to continue using visual and verbal cues in the therapy setting but to focus on maintaining a consistent stride time throughout the session in addition to the common focus of increasing step length.

Another interesting finding was that the external verbal condition had a differential impact on the PD group and the control group, i.e., this condition increased harmonic ratios in the PD group and decreased them in the control group. The external verbal condition could have increased harmonic ratios in the PD group by causing them to focus solely on locomotion, thus minimizing distractions from the surrounding environment. Another plausible explanation for the effect of the external verbal condition is that the cue bypasses the defective basal ganglia and activates an alternate circuit for the control of locomotion. The cue may cause a decrease in the harmonic ratios in the control group due to an alteration in an automatic movement that is not defective. Healthy older adults may be distracted by
hearing a verbal cue at set intervals causing them to change their walking pattern to correspond to the cue itself.

One shortcoming of this study was that all the data was collected in a single testing session. An interesting future study would be to design a long-term gait training program to determine the effect of visual and verbal cues on the harmonic ratios in people with PD. If participants were involved in a long-term training program in which they performed numerous sessions with visual and verbal cues, extrapolation from this data indicates that participants would improve their stability. This type of study would also be beneficial to the participants because they would improve their ability to ambulate in normal walking situations.
### APPENDIX A.

**ADDITIONAL CHARACTERISTICS FOR THE PD GROUP**

Additional characteristics of functional measures for participants with PD. A perfect score for the Berg Balance Scale is 56 and a perfect score for the Mini-Mental State Examination (MMSE) is 30. GDS-Geriatric Depression Scale.

<table>
<thead>
<tr>
<th>ID</th>
<th>Berg Balance Score (56)</th>
<th>MMSE Score (30)</th>
<th>GDS (Mild 10-19)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>56</td>
<td>30</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>56</td>
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</tr>
<tr>
<td>12</td>
<td>50</td>
<td>24</td>
<td>5</td>
</tr>
</tbody>
</table>
APPENDIX B.

INFORMED CONSENT DOCUMENT

Title of Study: Stability of gait in persons with Parkinson's disease under normal conditions and with visual or verbal cues.

Investigators: Ann L. Smiley-Oyen, PhD (asmiley@iastate.edu); Kristin Lowry, PhD candidate, PT (klowry@iastate.edu); Andrew Carrel, BS (acarrel@iastate.edu); Jessica Russell, undergraduate honors student (russellj@iastate.edu)

Contact information: Motor Control and Learning Research Laboratory, 178S Forker Building, Department of Health & Human Performance, Iowa State University, Ames, IA 50011; telephone: 515-294-3288

***************************************************************************

**

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION
Parkinson’s disease is characterized by several gait disturbances including small, shuffling steps, and slow walking speed. Cues, such as lines on the floor or auditory rhythms, are often given to persons with Parkinson’s disease (PD) in clinical settings to increase their stride length while walking. These techniques have been shown to increase walking velocity, stride length, and to somewhat normalize gait. However, the effects of these treatments on overall coordination of walking in people with PD have not been investigated. If increasing stride length actually disrupts overall coordination, then it may not be the best method of treatment. Such a disruption could result in imbalance and an increased risk of falling while walking. The purpose of this study is to determine the effect of visual and verbal cues on coordination of the walking pattern in people with PD and age-matched controls. The results may be useful in designing future physical therapy methods.

DESCRIPTION OF PROCEDURES
You are volunteering to participate in one testing session lasting about 1.5 to 2 hours aimed at assessing the effect of verbal and visual cues on walking. First you will be asked to fill out several questionnaires: a balance confidence scale, a measure of depression, and some questions about your level of physical activity. In addition, we will ask you some cognitive questions (like, what state do you live in) and some questions about your health, and for those with Parkinson’s disease, information about your movement symptoms from the disease. We will conduct a short balance test (Berg Balance Scale) and will measure your
height and weight. Then, you will be asked to put on a belt that has an instrument that will measure your motion (an accelerometer), and you will be asked to walk under three conditions: 1) normal walking; 2) walking with visual cues; and 3) walking with verbal cues. The visual cues condition will involve matching your step size to lines placed on the floor. The verbal cues condition will involve walking while you say "big steps" to yourself or the experimenter states “big steps” while you walk. For some trials you may be asked to wear a small inked pad on the sole of your shoe to track your step size.

RISKS
There are no known risks of participating in this study. If you lose your balance while walking an experimenter will be at your side to help stabilize you. To make sure you do not tire during testing we will have several rest breaks during which time you will be asked to be seated.

BENEFITS
There is no direct benefit to you, but there may be direct benefit to society in general. The results of this study will expand current knowledge about the effects of external cues on walking coordination in Parkinson's disease. Future research may build on this study by examining other aspects of physical therapy interventions aimed at improving walking in persons with Parkinson's disease.

COSTS AND COMPENSATION
You will not have any costs from participating in this study. You will not be paid to participate in this study.

PARTICIPANT RIGHTS
Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled. At any time during the study, you may withdraw your consent to participate without prejudice toward you. Such withdrawal can be for any reason you choose.

TREATMENT AND COMPENSATION IN CASE OF INJURY
If you experience an injury or adverse event, please call Dr. Smiley-Oyen immediately at 294-8261. Dr. Smiley-Oyen will help you contact your physician. If the injury or adverse event is due to your participation in this research, the sponsor of the study will not provide compensation for any medical costs you incur. It should be restated that the likelihood of injury in this study is very low.
Emergency treatment of any injuries that may occur as a direct result of participation in this research is available at the Iowa State University Thomas B. Thielen Student Health Center, and/or referred to Mary Greeley Medical Center or another physician or medical facility at the location of the research activity. Compensation for any injuries will be paid if it is determined under the Iowa Tort Claims Act, Chapter 669 Iowa Code. Claims for compensation should be submitted on approved forms to the State Appeals Board and are available from the Iowa State University Office of Risk Management and Insurance.

CONFIDENTIALITY
Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

All data will be coded numerically by subject and no names, initials, or other identifying characteristics will be reported in publication or presentation. Hardcopies of all data will be kept in a locked file cabinet in the Motor Control Lab. Computer files of data will be stored on a password protected computer in the Motor Control Lab.

Offer to Answer Questions
You are encouraged to ask questions at any time during this study. For further information contact Dr. Ann Smiley-Oyen at 294-8261. If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, jcs1959@iastate.edu, or Diane Ament, Director, Office of Research Assurances (515) 294-3115, dament@iastate.edu. You are encouraged to ask questions at any time during this study.

***************************************************************************
***
SUBJECT SIGNATURE

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the signed and dated written informed consent prior to your participation in the study.

Subject’s Name (printed)  

(Subject’s Signature)  (Date)
INVESTIGATOR STATEMENT

I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.

(Signature of Person Obtaining Informed Consent)  (Date)
APPENDIX C.

PD AND GAIT DATA SHEET

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Date</th>
<th>Order #</th>
<th>Room</th>
<th>Lead Exp</th>
<th>Preferred card</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pre-subject: Subject folder ______ stopwatch, step stool, ruler ______ glass of water ______
Battery in logger & checked ______ 2 clipboards, 2 pens ______
In gym: Paper and strips down ______ Chair with arms ______ 2nd chair ______ calculator, level ______
Extra strips ______ several pencils or pens ______ activity pages for PASE ______

Administer in lab (in following order):

1. Informed Consent (give a copy to the participant and keep a copy) ____________
2. Measure height (in cm) ____________
3. Measure leg length (in cm) Top of GT to Top of LM ______ GT to floor ______
4. Reciprocal Tap (12 sec) Trial 1 ______ Trial 2 _______ Trial 3 ______
5. Purdue Pegboard (30 sec) Trial 1 ______ Trial 2 _______ Trial 3 ______
6. ABC (read first item, then walk away) ____________
7. MMSE ____________
8. Berg Balance ____________

Administer in walking area:

Place data logger on subject (waist and head) and level waist accelerometer.
Break 1: after fast start, administer ½ of PASE; Break 2

---

**Orders for Testing**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Preferred</td>
<td>1) Preferred</td>
<td>1) Preferred</td>
<td>1) Preferred</td>
</tr>
<tr>
<td>2) Fast</td>
<td>2) Fast</td>
<td>2) Fast</td>
<td>2) Fast</td>
</tr>
<tr>
<td><strong>BREAK</strong></td>
<td><strong>BREAK</strong></td>
<td><strong>BREAK</strong></td>
<td><strong>BREAK</strong></td>
</tr>
<tr>
<td>3) 40% of Height</td>
<td>3) Internal</td>
<td>3) External</td>
<td>3) Pref+20%</td>
</tr>
<tr>
<td>4) Internal</td>
<td>4) Pref+20%</td>
<td>4) 40% of Height</td>
<td>4) External</td>
</tr>
<tr>
<td><strong>BREAK</strong></td>
<td><strong>BREAK</strong></td>
<td><strong>BREAK</strong></td>
<td><strong>BREAK</strong></td>
</tr>
<tr>
<td>5) Pref+20%</td>
<td>5) External</td>
<td>5) Internal</td>
<td>5) 40% of Height</td>
</tr>
<tr>
<td>6) External</td>
<td>6) 40% of Height</td>
<td>6) Pref+20%</td>
<td>6) Internal</td>
</tr>
<tr>
<td>7) Preferred</td>
<td>7) Preferred</td>
<td>7) Preferred</td>
<td>7) Preferred</td>
</tr>
<tr>
<td>8) Arm Swing</td>
<td>8) Arm Swing</td>
<td>8) Arm Swing</td>
<td>8) Arm Swing</td>
</tr>
</tbody>
</table>

**Responsibilities of experimenters:**

Experimenter 1 | Experimenter 2 | Experimenter 3
**Instructions**

<table>
<thead>
<tr>
<th>Count steps</th>
<th>Spotting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill in sheet</td>
<td>Placement of strips</td>
</tr>
<tr>
<td>Calculate step length</td>
<td>Count steps (report to Exp 2)</td>
</tr>
<tr>
<td>Placement of strips</td>
<td>w/fingers – no verbal report</td>
</tr>
<tr>
<td>Record sequence on data sheet</td>
<td></td>
</tr>
</tbody>
</table>

**Instructions for preferred:**

To subject: “In this condition you are asked to walk at your normal, comfortable pace.”

**Preferred Beginning of Testing (No Cue)**

<table>
<thead>
<tr>
<th>Number of Steps:</th>
<th>Step Length: (18m/ #steps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice ________</td>
<td>Practice __________</td>
</tr>
<tr>
<td>Trial 1 _________</td>
<td>Trial 1 __________</td>
</tr>
<tr>
<td>Trial 2 _________</td>
<td>Trial 2 __________</td>
</tr>
</tbody>
</table>

Comments:________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

**Preferred End of Testing (No cue)**

<table>
<thead>
<tr>
<th>Number of Steps:</th>
<th>Step Length: (18m/ #steps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice ________</td>
<td>Practice __________</td>
</tr>
<tr>
<td>Trial 1 _________</td>
<td>Trial 1 __________</td>
</tr>
<tr>
<td>Trial 2 _________</td>
<td>Trial 2 __________</td>
</tr>
</tbody>
</table>

Comments:________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
**Instructions for Fast**: To subject: “In this condition you are asked to walk faster than your normal pace.”

<table>
<thead>
<tr>
<th>Number of Steps:</th>
<th>Step Length: (18m/ #steps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence #_____ Practice _______</td>
<td>Practice_________</td>
</tr>
<tr>
<td>Sequence #_____ Trial 1_________</td>
<td>Trial 1___________</td>
</tr>
<tr>
<td>Sequence #_____ Trial 2_________</td>
<td>Trial 2___________</td>
</tr>
</tbody>
</table>

**Comments:**
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

**Arm Swing**: To subject: “In this condition, really focus on swinging your arms as you walk.”

<table>
<thead>
<tr>
<th>Number of Steps:</th>
<th>Step Length: (18m/ #steps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence #_____ Practice _______</td>
<td>Practice_________</td>
</tr>
<tr>
<td>Sequence #_____ Trial 1_________</td>
<td>Trial 1___________</td>
</tr>
<tr>
<td>Sequence #_____ Trial 2_________</td>
<td>Trial 2___________</td>
</tr>
</tbody>
</table>

**Comments:**
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
**Instructions for 40% of Height:** To subject: “In this condition you are asked to match your step size to the colored strips on the floor. Try to step on the strip, but without aiming, like this”…. (demonstrate.) (Make sure accelerometer is level)

40% of Height

<table>
<thead>
<tr>
<th>Number of Strips</th>
<th>Number of Steps</th>
<th>Step Length: (18m/ #steps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sequence #____ Practice ______ |
Sequence #____ Trial 1 ______ |
Sequence #____ Trial 2 ______ |

Comments:______________________________________________________________
________________________________________________________________________
________________________________________________________________________

Calculated Step Size= **height (cm)*0.4=________cm**

**Instructions for Preferred + 20% of Preferred:** To subject: “In this condition you are asked to match your step size to the colored strips on the floor. Try to step on the strip, but without aiming, like this”…. (demonstrate.) (Make sure accelerometer is level)

Preferred + 20% of Preferred

<table>
<thead>
<tr>
<th>Number of Strips</th>
<th>Number of Steps</th>
<th>Step Length: (18m/ #steps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sequence #____ Practice ______ |
Sequence #____ Trial 1 ______ |
Sequence #____ Trial 2 ______ |

Comments:______________________________________________________________
________________________________________________________________________
________________________________________________________________________
Conversion from step size in meters to cm for pref+20%:

preferred step size (m) * 100 * 1.2 = step size in cm

Calculated Step Size = ________ cm

**Instructions for Internal verbal:** To subject: “Now we want you to take bigger steps. In this condition you are asked to say ‘Big Step’ to yourself while you walk- like this” …. (demonstrate). Try to focus on taking bigger steps compared to your normal step size.

**Internal Verbal**

<table>
<thead>
<tr>
<th>Number of Steps:</th>
<th>Step Length: (18m/ #steps)</th>
</tr>
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<tr>
<td>Practice________</td>
<td>Practice________</td>
</tr>
<tr>
<td>Trial 1________</td>
<td>Trial 1________</td>
</tr>
<tr>
<td>Trial 2________</td>
<td>Trial 2________</td>
</tr>
</tbody>
</table>

**Comments:**

________________________________________________________________________

**Instructions for External verbal:** To subject: “Now we want you to take bigger steps. In this condition I will say ‘Big Step’ to you, out loud, while you walk - like this”…. (demonstrate). Try to focus on taking bigger steps compared to your normal step size.” “Big Step” statement should be spoken during the swing phase of each stride – not right at heel strike so the “metronome effect” is avoided.

**External Verbal**

<table>
<thead>
<tr>
<th>Number of Steps:</th>
<th>Step Length: (18m/ #steps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice________</td>
<td>Practice________</td>
</tr>
<tr>
<td>Trial 1________</td>
<td>Trial 1________</td>
</tr>
</tbody>
</table>
Sequence #____ Trial 2_________             Trial 2___________

Comments:______________________________________________________________

________________________________________________________________________
APPENDIX D.

FORMULAS FOR CALCULATIONS

1) Strip distance for 40% of height = height (in cm) * 0.4

2) Strip distance for 20% longer than preferred = preferred step size (in meters) * 100 * 1.2 = step size in cm

3) ES calculation = mean / (\sqrt{n} * standard error)

4) Coefficient of variation = mean standard deviation / mean
I would like to thank my advisor and mentor, Dr. Ann Smiley-Oyen, and my colleague and friend Kristin Lowry, for all of their help and time they gave me while I completed my first research project as a graduate student. I also want to thank my committee members, Dr. Tim Derrick and Dr. Tim Day, for serving on my committee and for their insightful advice. Last, I want to thank all the participants who volunteered for this study and the undergraduate and graduate students who helped me in many facets of the research project.