Cueing, feedback and directed attention embedded in a virtual environment modulate temporal and spatial bicycling features of healthy older adults and people with Parkinson's disease

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Abstract

Introduction: With age and disease, potential declines in function may result in barriers to participating in and adhering to an exercise program. There is a need for innovative, creative, and safe exercise programs that engage and motivate older adults and adults with neurological disease. Evidence based virtual environments (VE) that incorporate motor learning and compensatory strategies such cueing and feedback can change motor behavior while being engaging and motivating. Although VEs have been used for exercise promotion in healthy people and people with stroke, a specific understanding of embedding cueing and feedback in a cycling VE is absent. The purpose of this work was to investigate the short-term effect of cueing, feedback, and directed attention in a cycling VE on temporal and spatial parameters of cycling in people with PD and healthy age matched adults.

Methods A cross sectional design including people with Parkinson's disease (PD) (n=15) and age-matched healthy adults (n=13) was used. The protocol consisted of cycling on a stationary bicycle while interacting with a VE. Participants cycled under 4 conditions; auditory cueing, visual cueing, feedback, and directed attention. Outcomes include pedaling rate and trunk and hip kinematics. Data were analyzed by condition using factorial RMANOVAs with planned t-tests corrected for multiple comparisons. Kinematic data were further analyzed using Pearson Product Moment Correlations.

Results: Outcomes revealed that both groups increased their pedaling rate with external cues and augmented feedback. However, people with PD required attention directed to the visual cues in order to match the intensity of the stimulus. Simultaneous auditory and visual cue presentation also increased pedaling rate, and directing attention toward one or the other cue increased the magnitude of the effect. Changes in trunk and hip kinematics in both groups were found in the VE conditions.

Conclusions: These data serve as preliminary evidence that embedding auditory cues, visual cues, and feedback in a cycling VE alters pedaling rate and kinematics. It may be used as a strategy to increase exercise intensity that may promote fitness and address mobility changes with PD and normal aging.

Key Words: Virtual Environments, Bicycling, Cues, Feedback, Attention, Kinematics, Parkinson’s disease,

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Chapter 1

1 Introduction

1.1 *Context and Background*

Improvements in medical and preventive care have resulted in a growing number of Americans age 65 and older. With normal aging, deterioration in the central and peripheral nervous systems lead to slower execution of movement, decreased balance, and impaired coordination, resulting in changes in motor performance and skill acquisition (Seidler et al., 2010). These impairments can set off a chain of events leading to a sedentary lifestyle, resulting in further deterioration in mobility, function and decreased quality of life. This decline can be remediated in a variety of ways, including exercise.

Exercise has shown benefits in both cognitive and motor function in healthy older adults (Kraft, 2012; Seidler et al., 2010; Van Wegen, Hirsch, Juiskamp, & Kwakkel, 2014) and is thought to facilitate neuroplasticity, enabling a person to better learn and acquire skills (Hotting & Roder, 2013). In fact, lack of voluntary physical activity has been shown to inhibit neuroplastic effects (Van Wegen et al., 2014). Benefits of exercise include the ability to recruit additional brain regions during cognitive and motor tasks thus leading to improved performance, increases in brain volume in regions susceptible to atrophy over time, and enhanced function of prefrontal brain regions, which is thought to lead to enhanced motor function (Berchicci, Lucci, & Di Russo, 2013; Seidler et al., 2010). In middle age and older adults, exercise has been shown to improve muscle strength and endurance, flexibility, and contribute to overall good health and quality of life (Garber et al., 2011).

With age, increased disability and susceptibility to chronic disease such as Parkinson's disease (PD) are prevalent (Lill & Bertram, 2011). Parkinson's disease is a progressive neurological disorder primarily affecting people 60 years of age and older (Gazewood, Richards, & Clebak, 2013). It is the second most common progressive neurodegenerative disorder of adult onset after Alzheimers disease (Lill & Bertram, 2011) and can lead to significantly compromised quality of life. Despite prevalence of the disease, the current understanding of PD is limited and theory based. The current standard of care includes both medical and rehabilitation interventions (Tomlinson et al., 2012).

Medical management of the disease includes both pharmacological and non-pharmacological treatment (Tomlinson et al., 2012) but long-term pharmacological treatment, particularly with Levadopa, often results in adverse side effects such as dyskinesias, and the potential for the medication to become ineffective over time. Surgical interventions such as deep brain stimulation are considered only in specific patients and involve risks (Gazewood et al., 2013). The limitations in pharmacological and surgical approaches motivate the need for adjunct and/or alternative management of the disease (Tomlinson et al., 2012).

Rehabilitative interventions are a common tool used in the management of PD. The theoretical framework of rehabilitation for people with PD is based on a redundancy of neural circuits that allow for substitution, and the use of compensatory behavioral strategies such as cueing and directed attention (Van Wegen, et al., 2014). In addition, motor learning theories support the use of feedback for modifying performance and ultimately facilitating skill acquisition. Exercise has also been shown to be a viable method to manage the sequela of PD (Van Wegen et al., 2014).

Evidence to support exercise for people with neurological damage has been observed (Elsworth et al., 2009). Physical therapy, in the form of strengthening, functional training, and fitness, is a low cost and useful addition to standard medical treatment for people with PD (Koller, 2002). Referral early in the course of the disease has been shown to help delay the adverse effects of medications that are inevitable over time (Kues, Munneke, Nijkrake, Kwakkel, & Bloem, 2009). Exercise has also been shown to improve mobility, balance, and gait in people with PD (Van Wegen et al., 2014) and shows promise for neuroprotection, which may help decelerate the disease process (Alonso-Frech, Sanahuja, & Rodriguez, 2011; Goodwin, Richards, Taylor, Taylor, & Campbell, 2008; Morris, Martin, & Schenkman, 2010; Van Wegen et al., 2014).

1.2 *Problem Statement*

Despite known benefits to exercise, a large number of healthy older adults do not participate in exercise on a regular basis. Of those that do, the frequency, duration, and intensity of exercise often fails to meet recommended levels (Garber et al., 2011). This may be due to the many barriers to regular exercise in the older adult such as decreased strength and balance, pain, poor overall health, and a lack of convenient and safe exercise environments (Schutzer & Graves, 2004).

Exercise in people with PD has also been shown to be beneficial (Elsworth et al., 2009; Turnbull & Millar, 2006). Turnbull & Millar (2006) describe a proactive physical therapy management model of PD that suggests treatment strategies for 3 stages of disease progression (Turnbull & Millar, 2006). The first stage, when symptoms are mild, is that of *health awareness*, promotion of physical activity, and instilling a lifelong adherence to an exercise program. The second is one of *functional maintenance*, addressing problems as they arise and striving to maintain function. The last stage is considered *functional adaptation* in which steps are taken to assist the patient and caregiver in dealing with progressively debilitating symptoms. The first stage is ideal for promoting fitness and the second stage, even with the onset of symptoms that affect function, is also ideal for fitness interventions.

Compared to healthy older adults, barriers to exercise in people with PD are compounded and include aberrations in motor control and the progressive nature of the disease. Both result in difficulty negotiating public spaces and the potential loss of balance, which can lead to falls. The need to coordinate timing of medication with exercise adds additional barriers (Elsworth et al., 2009). Taken together, the low adherence to fitness programs in persons with PD is understandable. A need exists to engage both healthy older people and people with PD in safe, enjoyable, and effective exercise programs to improve and maintain fitness.

There are a variety of ways to construct an exercise program however, combining goal-based exercise, particularly aerobic exercise, with motor skill learning is thought to enhance motor performance by actively engaging cognitive processes (Petzinger et al., 2013). External cueing, feedback, and attention strategies can be incorporated into rehabilitation and fitness programs to engage cognitive processes and challenge participants (Petzinger et al., 2013). External cueing and feedback have resulted in immediate improvements in functional activities such as sit-to-stand, execution of activities of daily living, and gait in people with PD (Van Wegen et al., 2014). The manipulation of auditory and visual cues have also positively affected motor behavior in people with PD both in real-world settings (Mak & Auyeung, 2013; Nieuwboer et al., 2007; Rochester et al., 2010) and virtual environments (Mirelman, Patritti, Bonato, & Deutsch, 2010; Mirelman, Maidan, & Deutsch, 2013; van der Hoorn, Hof, Leenders, & de Jong, 2012).

Balance deficits in healthy older persons and people with PD can make walking safely a challenge. The high incidence of falls in these populations is an indication of this (Bautmans, Jansen, Van Keymolen, & Mets, 2011; Lewek, Poole, Johnson, Halawa, & Huang, 2010) and therefore, walking or running for exercise may not be a viable option for these populations. However, a stationary bicycle allows for the same repetitive cyclic motion of the lower extremities as walking, but is safer because it is less dependent on balance (Fowler et al., 2007b). Stationary bicycles are commonly found in rehabilitation centers, fitness facilities, and in the home setting, making them accessible to a large number of people. Cycling may be beneficial to disabled populations and those with chronic disease by improving strength, range of motion, and fitness, while minimizing joint stress (Johnston, 2007). Cycling, in particular forced use cycling, has shown benefits in mitigating symptoms of PD such as rigidity, tremor, and bradykinesia (Ridgel, Vitek, & Alberts, 2009). Bouts of passive cycling have also resulted in improvements in executive function in people with PD (Ridgel, Kim, Fickes, Muller, & Alberts, 2011).

People with PD present with deficiencies in motor control due to a reduction of dopamine in the nigrostriatal pathway (Gazewood, et al., 2013). A common manifestation of this is during gait where shortened stride length and velocity, freezing, and festination are common (Van Wegen et al., 2014). We postulate that deficiencies in motor control observed during gait may manifest during stationary cycling. Several factors affect cycling performance and include environmental, biomechanical, and physiological factors such as muscle length, joint angles, speed and type of contraction, and recruitment patterns (Too, 1990). Knowledge of trunk and lower extremity patterns of persons with PD during cycling may lead to more targeted use of the stationary bicycle in rehabilitation and fitness programs. For example, if an increase in pedaling rate increases excursion of the trunk, axial rigidity may be addressed. Or, if an increase in pedaling rate results in a more symmetric pattern of cycling, the asymmetric nature of the disease is addressed by using both sides equally. However, cycling kinematics is not well studied in people with PD,

Virtual environments and video games have been successful in improving mobility and physical activity in healthy people (Bateni, 2012; Warburton et al., 2007) and people with PD (Adamovich, Fluet, Tunik, & Merians, 2009; Griffin et al., 2011; Mirelman, Maidan et al., 2011; Pompeu et al., 2012a; van Wegen, de Goede et al., 2006; Warburton et al., 2007). Virtual environments have also been used to improve gait (Deutsch & Mirelman, 2007; Mirelman et al., 2010; Mirelman et al., 2011) with the possibility for use with other standard exercise equipment such as the stationary bicycle.

Virtual environments can incorporate cueing and feedback to promote changes in motor behavior in both healthy older adults and people with PD (Adamovich, et al., 2009; Mirelman, et al., 2013; Deutsch et al., 2006; Deutsch, Merians, Adamovich, Poizner, & Burdea, 2004; Deutsch, 2009) and therefore may provide a structure to optimize motor learning and fitness in a rehabilitation setting. However, there is limited evidence exists to support the efficacy of external cueing and feedback embedded in a cycling VE for rehabilitation or activity promotion in healthy older adults or persons with PD. This framework was used as the basis of the design for this study.

1.3 Operational Definitions

These definitions align with the aims and hypotheses of the study.

1. *Virtual Environments* are simulations of real-world environments (Adamovich et al., 2009). The VE used in this study consists of a road that

has grass and trees with mountains in the background. The road contained central white road markers similar to that in the real world. The view of the VE was in first person perspective looking at bicycle handlebars, front wheel, and upper extremities of an avatar, which represented the rider.

2. *Cueing* is the use of temporal or spatial stimuli to regulate movement (Spaulding et al., 2013; Van Wegen et al., 2014).
    a. Auditory cueing was in the form of a metronome set at a rate 20% faster than the cycling speed of the subject.
    b. Visual cueing was in the form of central road markers in the VE, similar to that seen on a real road. The markers were either present or absent. The speed of the markers were presented at a real-world distance apart (approximately 10') or presented at a 20% faster rate than real-world (the space between the markers will decrease by 20%).
3. *Feedback* includes intrinsic and extrinsic stimuli. Augmented, or extrinsic feedback, is external and provides information in addition to, or in place of intrinsic feedback (Shumway-Cook & Woollacott, 2012). Augmented feedback in this study was presented visually. When the participant cycled at a predetermined rate, feedback was generated in the form of the white central road markers changing color to purple when the participant cycled at a pre-specified range of speed.
4. *Directed Attention* is the action of focusing attention on a specific stimulus, typically in response to instruction. When both auditory and visual cues

were presented simultaneously (directed attention block), the first trial had no instructions to direct attention, in the next 2 trials, participants were instructed to: 1. Direct attention to the auditory cue, or 2. Direct attention to the visual cue.

5. *Pedaling Rate* was measured in revolutions per minute (rpm). Pedaling rate was collected via a Bluetooth sensor attached to the crankshaft of the pedal.

6. *Trunk and hip biomechanics* were collected using motion capture and included the following variables: excursion, symmetry, and variability of motion of the trunk and hip.

   a. *Trunk Excursion* was defined as the angular displacement of the trunk laterally in the coronal plane.

   b. *Hip Excursion* was defined as the angular displacement of the hip vertically, or, 'up and down' in the coronal plane.

   c. *Trunk Symmetry* was defined as the ratio of trunk excursion to the right compared to trunk excursion to the left.

   d. *Hip Intralimb Symmetry* was defined as the ratio of excursion of the 'hip up' to the 'hip down' motion of each hip.

   e. *Hip Interlimb Symmetry* was defined as the ratio of total excursion of the right hip compared to total excursion of the left hip.

   f. *Trunk to Hip Symmetry* was defined as the ratio of total trunk excursion to total right hip excursion and total trunk excursion to total left hip excursion.

g. *Trunk Variability* was defined as the lack of consistency of trunk excursion.

h. *Hip Variability* was defined as the lack of consistency of hip excursion

1.4 Aims and Hypotheses

The overall aim of this study was to determine whether cueing, feedback, and attention can be manipulated in a Virtual Reality augmented cycling system to modulate motor performance in healthy older adults and people with PD.

1.4.1 Aims

1. To determine if auditory cues embedded in a virtual environment will modulate pedaling rate in healthy age-matched adults and people with PD.

2. To determine if visual cues embedded in a virtual environment will modulate pedaling rate in healthy age-matched adults and people with PD.

3. To determine if visual feedback embedded in a virtual cycling environment will modulate pedaling rate in healthy age-matched adults and people with PD.

4. To determine if directing attention to relevant aspects of a virtual environment will modulate pedaling rate in healthy age-matched adults and people with PD.

5. To determine if there is a difference in response to cueing, feedback, and directed attention in pedaling rate between healthy age-matched adults and people with PD.

6. To explore the influence of pedaling rate on trunk and hip kinematics.

1.4.2 Hypothesis

The following hypotheses align with the goals of the study. The hypotheses are based on the expectation that in a cycling VE, auditory and visual cues, feedback, and directing a user's attention to a specific cue will result in an increase in pedaling rate in healthy age-matched adults and persons with PD. Secondarily, it was expected that trunk and hip kinematics would differ between healthy age-matched adults and people with PD.

Hypothesis 1: There will be an increase in pedaling rate between levels of the auditory condition within groups, healthy age-matched adults and people with PD.

Hypothesis 2: There will be an increase in pedaling rate between levels of the visual condition within groups, healthy age-matched adults and people with PD.

Hypothesis 3: There will be an increase in pedaling rate between levels of the feedback condition within groups, healthy age-matched adults and people with PD.

Hypothesis 4: There will be an increase in pedaling rate between the levels of the directed attention condition within groups, healthy age-matched adults and people with PD.

Hypothesis 5: There will be an increase in pedaling rate in all conditions for both groups but people with PD will pedal at a slower rate than healthy adults in all conditions. A more robust response is expected in people with PD compared to health age-matched adults in the visual cue and feedback conditions.

Hypothesis 6: The VE cycling conditions will influence trunk and hip kinematics. There will be a change in trunk and hip kinematics. Correlations will show a relationship between pedaling rate and excursion, symmetry, and variability of the trunk and hip.

1.5 Significance and need for the study

Evidence exists to show that moderate to intense physical exercise may be essential to stimulate neuroplasticity and that cueing interventions can elicit these required intensities (Van Wegen et al., 2014). External cueing techniques have proven effective to elicit behavioral changes such as improved motor performance and fitness in healthy people and people with PD. However, evidence is lacking as to the exact method of cue delivery, the most effective dosage of cue, and the frequency at which cues are presented (Van Wegen et al., 2014). External feedback has also been shown beneficial for motor acquisition in both the real and virtual world on healthy older adults (Sigrist, Rauter, Riener, & Wolf, 2013) and persons with PD (Mirelman et al., 2011; Pompeu et al., 2012). The use of virtual environments is a relatively new and novel approach to rehabilitation. However, limited evidence exists to support their use as a tool to promote exercise. In addition, a specific understanding of embedding cueing and feedback into VEs is absent.

Cycling kinematics has been studied in both healthy and patient populations. However, there is lack of information regarding cycling kinematics in people with PD. Due to the motor symptoms found in PD such as bradykinesia and axial rigidity, it may be expected that person with PD would exhibit kinematics during cycling that differ from their healthy counterparts. Knowledge of typical kinematics in healthy older adults and in people with PD may prove useful in fitness and rehabilitation programs to increase motion or promote symmetry of movement. These gaps in the literature form the basis for this proposal.

Described here is an experiment in which healthy age-matched adults and people with PD rode a stationary bicycle while interacting with a cycling VE. Auditory cues, visual cues, and feedback were embedded in the VE. Paper 1 investigated the influence of auditory and visual cueing on pedaling rate, Paper 2 investigated the influence of feedback and directing a user's attention to a specific cue in the VE on pedaling rate, and Paper 3 investigated the trunk and hip kinematics in the visual cueing and feedback conditions. The overall aim of the thesis was to determine if cueing, feedback, and directed attention embedded in a virtual environment modulated motor performance.

Chapter 2 Literature Review

2.1 Introduction

2.1.1 *Sensorimotor processing declines with age*

Age-related impairments in sensorimotor processing cause increased reliance on central, or cognitive, processes rather than peripheral mechanisms for proper motor performance. For example, during movement execution, older adults activate the same brain regions as their younger counterparts, but imaging studies show over-activation of these brain regions and the recruitment of additional brain regions compared to younger adults (Seidler et al., 2010). Two theories regarding this phenomenon exist. The first relates overactivity in brain regions to a loss of neural specialization that occurs with age. The result is inefficiency in the system. Conversely, a second theory describes increased brain activity as a compensatory mechanism designed to make up for age-related structural changes, such as atrophy of the primary motor cortex, somatosensory cortex, cerebellum, and parts of the basal ganglia, and may be considered a function of healthy aging (Seidler et al., 2010).

2.1.2 Sensorimotor processing declines in Parkinson's disease

In PD, the basal ganglia, in particular the striatum, no longer produce dopamine, which results in progressive disabling of movement and cognition (Kandel, Schwartz, & Jessell, 2000) that can profoundly affect function and independence. Four cardinal features predominate: resting tremors, postural instability, rigidity, and bradykinesia. Additional symptoms include flexed posture, axial rigidity, shuffling and freezing of gait, dyskinesias, hypophonia, autonomic dysfunction, and cognitive deficits (Jankovic, 2008).

The basal ganglia play an integral role in internally guided and automatic movements and influence such qualities as the amplitude, velocity, and direction of movement (Mink, 1996). They also play a role in postural adjustments, initiation of voluntary movement, and motor learning (Wichmann & DeLong, 2003; Young, Young, & Tolbert, 2008). Briefly, the basal ganglia involve input nuclei, the striatum and subthalamic nucleus, which gather information from the cortex, and output nuclei that influence the thalamus and frontal cortex. In the basal ganglia, there are two pathways, the direct and indirect, which act to facilitate and disfacilitate movement. This reciprocal regulation by the basal ganglia aids in the control of amplitude and velocity of movement. Overactivity in the indirect pathway is a major factor in this disease (Kandel et al., 2000). Within the striatum, incoming information from the cortex must be properly integrated and linked to appropriate output. In Parkinson's disease, this processing is severely compromised causing improper integration and activation of this information, which results in aberration of motor output (Albin, Young, & Penney, 1989). While there are many complexities that remain, this broad outline of PD is generally accepted.

Management of the disease is both medical and rehabilitative. While the ultimate aim of medical management is to modify the disease process with neuroprotective medications, currently, treatment is symptomatic (Meissner et al., 2011). Rehabilitation interventions in people with PD employ strategies that make use of alternate neural pathways, ultimately leading to changes in motor behavior (Van Wegen et al., 2014). The use of compensation and motor learning techniques for rehabilitation and fitness have been used to promote changes in motor behavior in healthy older adults and people with PD (Thaut, 2003; Powell, Stevens, Hand, & Simmonds, 2010; Hausdorff et al., 2007; Willems et al., 2006; Chiviacowsky, Wulf, & Wally, 2010; Landers, Wulf, Wallmann, & Guadagnoli, 2005). These techniques, as well as a novel use of technology to that incorporate these techniques i.e. virtual environments, will be discussed in the following review of the literature.

2.2 Literature Search Methods

An electronic search was conducted using Medline and CINAHL. The search was restricted to English only articles with no limitation on date of execution. The following terms were mapped and combined: Parkinson's disease, Basal ganglia, neural mechanisms, neural substrates motor learning, motor performance, motor behavior, spatio-temporal measurements, rehabilitation, physical therapy, exercise, cueing, auditory cueing, rhythmic auditory cueing, visual cueing, feedback, visual feedback, bandwidth feedback, directed attention, virtual reality, virtual environments, stationary bicycling, bicycling kinematics.

A study was deemed acceptable if it investigated the neural mechanisms of PD, virtual environments, cycling, cueing, feedback, directed attention, bicycling kinematics, and movement in healthy adults and people with PD. Studies were excluded if they were not directly related to a cueing paradigm, used feedback as a tool to effect motor behavior, or related to bicycling kinematics. Subsequent studies were gleaned from the reference lists of studies from the original search. Article selection focused on the primary topics that align with the goals and hypotheses of this proposed study:

1. Cueing in exercise and rehabilitation interventions in healthy older adults and people with Parkinson's disease.
2. Feedback in exercise and rehabilitation interventions in healthy older adults and people with PD.
3. Virtual Environments

2.3 Cueing

2.3.1 Introduction

Successful movement execution relies on an internal cue relayed from the basal ganglia to the supplementary motor area of the cerebral cortex. This internal cue prepares for movement by activating and deactivating each submovement within the movement sequence i.e. the motor set, (Kandel et al., 2000; Rubinstein, Giladi, & Hausdorff, 2002) thus leading to learning of movement sequences. The basal ganglia therefore, are integral in shifting movement execution from conscious control to one of automaticity (Morris, Iansek, Matyas, & Summers, 1996; Morris et al., 2010). In PD, this internal cue is absent or deficient, leading to aberration of self-generated movements resulting in freezing of gait, and/or paucity of movement. However, a substitute cue, an external cue, may compensate for the disrupted sequence between the basal ganglia and the supplementary motor area and result in more normal execution of movement (Morris et al., 2010). This is explained by a shift of attention to the movement due to the influence of the external cue. This results in conscious control of the movement and becomes under the control of brain regions other than the basal ganglia (Van Wegen et al., 2014).

The use of external cueing in patients with PD was first proposed by J. Purdon Martin in a 1963 address to the Royal College of Physicians and Surgeons on the topic of the basal ganglia and locomotion. He found that visual spatial stimuli in the form of transverse lines placed in the walking path, enabled patient to take longer steps, and obstacles, such as small blocks or bricks, produce a similar effect and even assisted in the initiation of gait. As a result, several of his patients could continue gait uninterrupted, even with the removal of these visual cues (Martin, 1963).

A variety of external cueing paradigms are currently used in rehabilitation (Rocha, Porfirio, Ferraz, & Trevisani, 2014; Alonso-Frech, Sanahuja, & Rodriguez, 2011). Rhythmic auditory cues, or, rhythmic auditory stimulation, are the most widely studied of the cueing techniques. Common examples include the use of a metronome or an underlying beat embedded in music (Ford, Malone, Nyikos, Yelisetty, & Bickel, 2010; Willems et al., 2006; Zijlstra, Rutgers, & Van Weerden, 1998).

Studies employing visual cues typically use stripes, or lines, placed on the floor (Morris, Iansek, Matyas, & Summers, 1994; van Wegen, et al., 2006), but the projection of laser lines on the floor (Lebold & Almeida, 2011) and the use of LED glasses to project a flashing light (Alonso-Frech et al., 2011; van Wegen et al., 2006) have also been employed. Somatosensory cueing may involve such techniques as the use of a portable vibration device attached to the body (El-Tamawy, Darwish, & Khallaf, 2012; Nieuwboer et al., 2007).

The integration of afferent sensory input is necessary for the proper execution of movement (Abbruzzese & Berardelli, 2003; Romanelli, Esposito, Schaal, & Heit, 2005) and is reliant on the integrity of the basal ganglia -motor cortex circuits (Morris et al., 2010). In healthy people, visual and somatosensory input are integrated in the basal ganglia (Azulay, Mesure, & Blin, 2006; Konczak et al., 2009). In people with PD, incoming sensory stimuli, in particular proprioception, is improperly integrated due to damage to the basal ganglia, which results in an increased reliance on external cues for proper motor output (Azulay et al., 2006; Konczak et al., 2009).

Several studies have been conducted investigating the use of external cueing to improve gait and function in people with PD. A large multi-center trial, the RESCUE trial, studied the effect of different sensory modalities on a variety of measures in the home setting in people with PD (Nieuwboer et al., 2007). A cueing device, which provided three types of external rhythmic cueing signals, auditory (tone delivered through earpiece), visual (flash of light), and somatosensory (pulsed vibration on wrist) was used. Patients experimented with all three cueing modalities during the first week, but were required to choose only one to train with during the next two weeks. At the conclusion of the intervention, all subjects were tested with all three devices. Interestingly, the majority of patients chose the auditory cueing device to train with, only a handful chose the somatosensory cueing device, and none chose the visual cueing device. Cueing practice consisted of performing of a variety of gait tasks including dual tasking and walking various distances (Nieuwboer et al., 2007). While all patients showed improvement, auditory cues resulted in the most significant improvement across all measures. The results of the RESCUE trial provide evidence that training with external rhythmic cueing in a home environment had a positive effect on gait parameters, freezing of gait, motor learning, and quality of life.

A recent meta-analysis by Spaulding et al., in 2013, compared studies using cueing in gait to determine the efficacy of cue type on stride length, cadence, and velocity in people with PD. Findings show that although both visual and auditory cues significantly improved kinematic gait parameters, auditory cues were more effective in improving cadence and velocity in people with PD (Spaulding et al., 2013).

The nature of the sensory stimuli dictates the type of neural activation that ultimately results in audio or visuomotor synchronization. For example, it is easier to synchronize with a discrete auditory sound than a continuous tone due to a strong phasic response in the neural system. For visual temporal stimuli, i.e. a flashing light, neural processing is slow. The visual system is better able to synchronize with a moving visual stimulus due to its preference for tracking the spatial aspects of a visual stimulus (Hove, Fairhurst, Kotz, & Keller, 2013). These findings support our choice of an auditory cue consisting of a metronome (discrete sound) and a visual cue of vertical central road markers (continuous visual stimuli) for use in this current study.

The processing of external cues involves a multimodal system that integrates incoming cues from the somatosensory, auditory, and visual systems. Of primary interest to this current study are auditory and visual cues. Hence, the subsequent review will discuss studies that examine auditory and visual cueing and their relative efficacy in altering behavior. This review provides the basis for the cueing aspect of the study, which compares the effects of auditory and visual cueing, embedded in a VE, on cycling behavior in healthy age-matched adults and people with Parkinson's disease.

2.3.2 Auditory Cueing

Healthy Older Adults

Rhythmic auditory stimulation (RAS), delivered at the appropriate time is known to facilitate internal timekeeping mechanisms in healthy adults (Repp, 2005; van Noorden & Moelants, 1999). The use of a metronome, or accents embedded in music, act as an external auditory cue to synchronize movements by integrating information between the auditory and motor systems (Chen, Penhune, & Zatorre, 2009).

A study by Heunickx et al., in 2008, investigated motor execution in healthy older and healthy young adults (Heuninckx, Wenderoth, & Swinnen, 2008). Subjects were required to synchronize their movement to an auditory rhythm (metronome) during an interlimb coordination task. In the healthy older adults, an overall increased use of cognitive processes, increased activation in auditory processing, and increased activity in visual neural circuits was found compared to healthy young adults, indicating an increased use of external stimuli in older subjects. This over-activation and activation of additional brain regions during a motor task, including activation of non-motor regions, is attributed to a compensatory mechanism used for motor processing in healthy elderly. Interestingly, this over-activation was found in elderly subjects who successfully completed the task, but not in elderly who were unsuccessful, indicating that over-activation of brain regions may be a marker for successful aging. These findings are in agreement with the compensation theory of increased brain activation in older adults (Seidler et al., 2010). Importantly, these results indicate potential for the use of external cueing as a compensation strategy to improve motor execution in the healthy older adult (Heuninckx et al., 2008).

In the laboratory setting, synchronization of movement to an external stimulus is often examined using a tapping paradigm. Neuroimaging of healthy adults show the use of multiple pathways for temporal processing, including cortical and subcortical brain activation, when synchronizing to auditory rhythms. Evidence from the tapping literature point to the potential use of auditory rhythms in the rehabilitation of patients with neurological and movement disorders for upper extremity movements (Thaut, 2003).

Movement synchronization has also been investigated in studies of gait resulting in the importance of the rate of cue presentation (Dickstein & Plax, 2012; Hausdorff et al., 2007; Powell, et al., 2010). Briefly, subjects are asked to match their walking speed to a beat set at a rate higher or lower than individual baseline values. Hausdorff et al., found that healthy older adults instructed to synchronize their gait to a metronome beat set at 100% and 110% of their baseline cadence resulted in an increase in gait variability (Hausdorff et al., 2007). One explanation may be the rate of stimulus was too high, or the metronome interfered with their internal cueing mechanism, which disrupted automaticity of the movement.

Dickstein and Plax examined the ability of 10 healthy young women to match their step rate to a metronome beat set at 60, 110, and 150 bpm. The ability to synchronize their steps was rate dependent, resulting in subjects' better able to time their footsteps to the metronome set at 60 bpm than at 150bpm. The inability to synchronize at the 150bpm rate may indicate a physiological upper limit for synchronization with a physical inability to time footsteps at the higher rate. Alternatively, since the 150bpm rate is not a multiple of the natural walking rate of 120bpm (Styns, van Noorden, Moelants, & Leman, 2007), it may have caused disturbance of gait as well. The ability to time walking to a musical tempo is most successful at rates between 106-130 bpm. Rates above 134bpm resulted in decreased ability to synchronize gait (Dickstein & Plax, 2012). In this study, physical capacity was taken into account when choosing the cue rate to determine if either group presented with a decreased physiological capacity to synchronize to a fast cue rate.

A virtual environment is an ideal medium to measure how auditory cues affect motor behavior. However, the rate of optic flow from a virtual environment can influence motor behavior as shown in treadmill walking studies in healthy adults (Prokop, Schubert, & Berger, 1997). Questions remain therefore, whether optic flow would interfere with, or enhance the effects, of an audio cue embedded in a virtual environment. Powell et al. (2010) investigated the effect of an audio cue rate set at baseline, 75%, 100% and 125% of baseline speed on walking speed in healthy young adults on a treadmill with and without a virtual environment. The purpose was to determine if an audio cue would influence walking speed and if the presentation of a virtual environment in addition to the auditory cue would influence the modulating effect of the audio cue. Findings showed an increase in speed and cadence with the audio cue set at 125% of baseline speed thus demonstrating that auditory cues do have an effect on walking speed in healthy adults (Powell et al., 2010). Interestingly, the addition of a virtual environment in the fast (125%) and slow (75%) audio cue conditions resulted in significantly slower walking speeds compared to the audio cue only condition. Therefore, although there was a significant effect of audio cues on walking speed, the addition of a virtual environment resulted in a subtractive effect. Powell et al. (2010) interpreted these findings as the addition of a virtual environment may require increased use of cognitive resources and therefore resulted in a subtractive effect, or, reflect the need to recalibrate incongruent sensory input between visual and motor information in the central nervous system, which may have slowed the walking pace.

In summary, discrepancies in the literature regarding the efficacy of auditory cues to influence movement in healthy older adults exist. In the tapping literature, auditory cues enabled the healthy older adult to synchronize their movements to the rate of cue. In walking, auditory cueing resulted in increased gait variability but the role that cue rate and physical capability plays in synchronizing footsteps must be taken into account as well. In addition, while auditory cues have been found to change walking speed on a treadmill, the addition of optic flow from a virtual environment interfered with the effect of the auditory cues. The method of presentation of a stimulus, e.g. continuous or discrete, has also been shown to influence motor response and should be addressed.

A discrete auditory cue was found to result in the most optimal synchronization during gait. The results of these studies offer important information and helped to inform the choice of audio cue type, rate, and presentation in the current study

Parkinson's disease

Rhythmic auditory stimulation is a common form of cueing used in the rehabilitation of individuals with PD. It consists of synchronizing to rhythmic sounds such as music or a metronome (Alonso-Frech et al., 2011). Studies have been conducted investigating the effect of auditory cues on velocity, cadence, stride length and freezing of gait (Ford et al., 2010; Hausdorff et al., 2007; McIntosh & Rice, Thaut, 1997; Willems et al., 2006) with improvements in all parameters, indicating that rhythmic auditory stimulation is a viable treatment option to improve gait in people with PD.

A single session study performed by McIntosh and colleagues evaluated the effect of rhythmic auditory stimulation 10% above baseline speed on gait velocity, cadence, and stride length in patients with PD both on and off medications then compared to healthy age-matched controls (McIntosh, et al., 1997). All subjects significantly improved in all gait measures.

Willems and colleagues also conducted a single session study in which 20 people with PD, 10 freezers and 10 non-freezers, and 10 age matched controls walked under auditory cued conditions delivered at 10% and 20% above and below baseline speed. Step velocity was modulated in all subjects under all cued conditions. Freezers and non-freezers responded similarly in respect to speed but differentially in respect to stride length. A significant increase in walking speed in all subjects occurred in all but the +20% condition. Stride length was not affected in controls, but significantly increased in the -10% condition in people with PD.   A decreased stride length in the +20% condition may have been the result of an inability to increase walking speed in participants.   The latter finding may reflect a limit in which subjects could take advantage of a speed-accuracy trade off, one that they were able to take advantage of in slower speeds (Willems et al., 2006).

Other studies investigated the effect of audio cue frequency on gait in people with PD. Picelli and colleagues investigated the effect of auditory cues set at three levels: 90%, 100% and 110% of baseline speed. Significant changes in spatiotemporal, kinematic and kinetic gait parameters as well as changes in cadence in response to the auditory rhythm occurred. Walking speed and stride length also increased as the cueing frequency increased, but the findings were not significant (Picelli, Camin, Tinazzi, Vangelista, Cosentino, Fiaschi, & Smania, 2010). Ford et al. (2010) conducted an intervention study over 8 weeks with 12 subjects with PD (Ford et al., 2010). The effect of progressively increasing the speed of rhythmic auditory stimulation on velocity, cadence, and stride length was assessed. An improvement in all gait parameters with increasing frequency of cues was found.

The ability to adjust walking speed to an external cue is dependent upon the cue rate. The modulation of cue rate in these studies was typically 10% to 20% above and/or below baseline speed. Unfortunately, there is a paucity of studies regarding optimal cue rate in stationary cycling, which resulted in reliance on choice of cue rate for this study based on the walking literature. The cueing rate decision for the current study was also based on a screening of people with PD and healthy subjects' ability to respond to cue type and rate on a stationary bicycle. In this screening, auditory and visual cues were set at rates 10%, 20%, and 30% faster than baseline cycling speed to assess their ability to adapt to an outside rhythm. A secondary objective of this screening was to determine the reasonable physiological upper limit of cycling speed of the participants, which was found to be in the 20% range for the majority of participants.

2.3.3 Visual Cueing

Specific studies using visual cues in healthy older adults are limited, however, several of the studies examining the role of visual cueing in people with PD compared to a group of healthy older adults. The results of these studies indicate that healthy elderly and people with PD may benefit from the use of visual cues for proper motor execution.

Visual cues have been used in an attempt to bypass defective internal cueing mechanisms in people with PD to improve gait. For example, when asked to walk on a surface with transverse stripes, people with PD were able to improve spatial and temporal gait parameters despite having decreased or absent ability to use internal cueing processes (de Melo Roiz, Cacho, Cliquet, & Quagliato, 2011; Lebold & Almeida, 2011; Lewis, Byblow, & Walt, 2000; Luessi, Mueller, Breimhorst, & Vogt, 2012; Morris, 2000).Visual cues may also improve gait by drawing the attention of the subject to the spatial aspects of the movement by simply focusing attention on correct size of stride length (Morris, Iansek, Matyas, & Summers, 1996; Morris, Martin, & Shenkman, 2010).

A variety of virtual visual cue presentations have been used in rehabilitation interventions including the use of virtual viewing spectacles to improve freezing of gait and overall mobility (Kaminsky, Dudgeon, Billingsley, Mitchell, & Weghorst, 2007), virtual glasses projecting freezing of gait triggers (Griffin et al., 2011) and flashing lights and virtual stripes projected on the floor in an attempt to modulate stride frequency (van Wegen et al., 2006). Only the virtual viewing spectacles in the study by Kaminsky and the lights/stripes projected on the floor by van Wegen showed significant results in reducing freezing of gait and modulating stride frequency.

van Wegen et al. (2006) examined the effect of external rhythmic visual cues and optic flow on velocity and stride frequency (van Wegen et al., 2006). Healthy adults and people with PD (either on medications or drug naïve) walked on a treadmill under 5 conditions ranging from a blank screen with no visual cues, to projection of a virtual corridor only, to projection of a virtual corridor with rhythmic spatial cues (transverse lines), to a blank screen with rhythmic temporal cues (flashing light) and finally projection of virtual corridor with rhythmic temporal cues. Results show that both transverse lines and a flashing light modulated stride frequency while maintaining walking velocity in people with PD and healthy controls. The investigators explained that the visual cues may have compensated for a deficient internal cue usually sent by the basal ganglia, or, alternatively, through the use of an alternate visuo-motor pathway that bypasses the basal ganglia. In this study, the presence of a virtual environment yoked to the speed of the treadmill did not impair or facilitate the ability to respond to visual cues. The authors feel this may be due to the subjects' attention being drawn to the cues and not to the presence of optic flow in the virtual environment.

Griffin et al. (2011) in a study involving 26 mid-stage people with PD both on and off medications investigated the effect of real and virtual cues (via virtual cueing spectacles) on walking (Griffin et al., 2011). Participants were exposed to 6 different conditions ranging from no cues, to a static image, horizontal visual flow 'stripes' that moved with or in a reversed motion to the projected visual flow, a flashing stimulus set at a rate at the participant's preferred cadence, transverse lines on the floor, and finally, a no cue condition. Only the transverse lines on the floor resulted in improved walking, as shown by increased stride length and decreased cadence.

Each of the above studies resulted in positive outcomes on gait in a clinical setting and in the community using visual cues, indicating that gait in people with mid-stage PD may be modified by the use of visual cues with and without a virtual environment.

2.3.4 Combined Cueing

Several studies investigated the effect of the concurrent presentation of two cue modalities in healthy people and people with PD (Baker, Rochester, & Nieuwboer, 2008; Espay, Baram, Dwivedi, Shukla, Gartner, Gaines, et al., 2010; Koelewijn, Bronkhorst, & Theeuwes, 2009; Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004). The primary concern is that one modality will compete with the other in terms of attentional costs, particularly in neurologically impaired populations.

Koelewijn et al. conducted two studies in which young healthy subjects participated in a visual cueing task and were asked to make elevation judgments regarding auditory or visual targets presenting to the left or right side of their visual fixation (Koelewijn et al., 2009). Auditory cues, in the form of a white noise burst and/or visual cues in the form of a gray horizontal bar on the screen were presented just prior to the target appearance. Trials consisted of audio cue only, visual cue only, or a combination of audio and visual cues presented simultaneously. Results show that although there was a summative effect when audio and visual cues were presented simultaneously in some conditions, the auditory effect was weaker overall than the response to the visual stimuli. Subjects tended to respond more strongly to the visual cue when both cues were presented simultaneously. These results indicate that competition exists between auditory and visual stimuli for the same attentional resources.

In studies of gait in people with PD, it was found that the simultaneous presentation of cues resulted in a summative effect on gait parameters. An early study by Suteerwattaanon et al., in 2004 sought to discern if the combination of cueing modalities had a greater effect on gait in people with PD (off meds) than the presentation of each cue individually (Suteerawattananon et al., 2004). Visual cues consisted of bright yellow strips of tape placed on the floor of the walkway. Distance between the strips was at 40% of the subjects' height. Auditory cues were in the form of a metronome set at a rate 25% higher than their baseline walking speed. Subjects walked at their fastest speed along a 7.6 m walkway under three conditions; visual cues only, auditory cues only, and both visual and auditory cues. Results show that both visual and auditory cues presented alone had a positive effect on gait parameters. Visual cues influenced spatial aspects of gait i.e. stride length, whereas auditory cues influenced temporal aspects of gait i.e. gait speed and cadence. The combination of cues also resulted in a significant effect on gait speed compared to the uncued condition, but no additive effects to improve stride length or cadence occurred. Rather, the simultaneous presentation of cues improved gait speed in a similar manner to that in the auditory cue only condition. The simultaneously presentation of cues in this study may have caused an interference effect by dividing the attention between the two cues (Suteerawattananon et al., 2004) and causing a competition for limited attentional resources.

Baker et al. (2008) in a study investigating the influence of internally vs externally generated cues on gait variability in people with PD, asked subjects to walk on a walkway under 4 conditions; no cue, auditory cue only, attentional cue only, or auditory plus attentional cue (Baker et al., 2008). Auditory cues were temporal in nature and consisted of a metronome set at 10% below preferred stepping speed. Attentional cues focused on spatial aspects of gait and instructed subjects to focus on 'taking big steps'. It was found that the simultaneous presentation of cues resulted in more effective reduction of gait variability compared to the presentation of auditory or attentional cues alone.

To determine the effects of visual and auditory cues presented simultaneously on spatial and temporal parameters of gait, Espay and colleagues (2010)attached a small visual-auditory cueing device containing the ability to emit visual (a life-size virtual checkerboard floor) and rhythmic auditory cues (auditory tone) to the clothing of subjects with PD (Espay et al., 2010). Visual and auditory cues were presented simultaneously and were controlled by an accelerator that linked the rate of presentation of the stimuli directly to the walking speed of the user. Patients wore the device for 2 weeks for twice-daily 30-minute sessions within the home. Patients were asked to step with long strides on each tile. The auditory tone became and remained continuous, provided the patients were walking steadily, thus providing a 'reward' for making an effort to synchronize their steps with the virtual tiles and auditory cue. Patients were assessed at baseline and after the 2-week intervention. Results show that training with concurrent visual/auditory cues resulted in improved gait velocity up to 18-20%, with some patients reaching 30% improvement when tested immediately following training. Although limitations exist and include absence of a control group, lack of blinding, potential order effect of testing protocol, lack of monitoring of device use at home, and lack of long term follow-up, among others, the authors feel these preliminary results show promise in the presentation of concurrent auditory and visual cues using this device to improve gait velocity and stride in patients with PD (Espay et al., 2010). In the meta-analysis by Spaulding et al. (2013) mentioned previously, it was found that the combination of visual and auditory cues resulted in a significant improvement in cadence but not stride length or velocity in people with PD (Spaulding et al., 2013).

In the studies noted here regarding people with PD, the simultaneous presentation of cues has generally shown a summative but selective effect on gait. The efficacy of external cueing in the treatment of people with PD is well known (Spaulding et al., 2013; Van Wegen et al., 2014), however, the findings in these studies are interesting in light of known limited cognitive resources in people with PD (Watson & Leverenz, 2010) and the possibility for competition of attention. Perhaps the focus of each of the cue types, visual cues relating to primarily to spatial parameters, and auditory cues relating primarily to temporal parameters, may explain the findings.

This method of combining visual and auditory cues has important clinical implications for designing effective rehabilitation programs for people with PD and was important to consider in the current study where visual and auditory cues were combined to effect a change in motor behavior. In the current study, the effect of simultaneous presentation of auditory and visual cues prior to conducting the study was unknown due to the inconsistent results of studies in the walking literature and the absence of studies in the cycling literature.

2.3.5 Summary

Clearly, the above review outlines a complex picture for how cues are related to behavior in both healthy older adults and people with Parkinson's disease. However, a number of findings can be drawn from this material and used to guide the design of this study. Foremost, in Parkinson's disease, damage to the basal ganglia results in dysfunctional motor output due to a deficient internal cueing mechanism resulting in increased reliance on external stimuli for proper movement execution. Secondly, both auditory and visual cueing paradigms, with and without a virtual environment, have shown to be effective in modifying motor execution in healthy older people and people with Parkinson's disease. However, auditory cueing appears to have more of an influence on temporal and spatial aspects of gait, with visual cues influencing spatial aspects of gait.

More evidence with long-term follow-up is needed to ascertain the efficacy of the two types of cue delivery. The simultaneous presentation of visual and auditory cues have been shown to have an additive effect in improving specific gait parameters, but may also produce an interference effect by causing competition for limited attentional resources. In addition, the choice of cue rate and presentation of cue (discrete or continuous) are important factors that can influence motor behavior. The current study incorporated these findings in order to investigate the ability of auditory and visual cues to modulate cycling speed and kinematics in a virtual environment in people with PD.

2.4 Feedback

2.4.1 Introduction

Complex neural processes are involved in the acquisition and reacquisition of motor tasks, including the use of feedback. Feedback is essential for learning to take place and is used to correct mistakes and monitor and improve performance and learning. Feedback includes intrinsic processes e.g. sensory input produced as a result of movement, and extrinsic processes e.g. input from the environment (Shumway-Cook & Woollacott, 2012).

A number of brain regions have been associated with feedback and motor learning and include the prefrontal, parietal, occipital, and temporal lobes. The striatum is also associated with motor learning through feedback (Eliassen, Lamy, Allendorfer, Boespflug, Bullard, Smith, et al., 2012). The basal ganglia in particular, play an integral role in internally guided and automatic movements and influence such qualities as amplitude, velocity, and direction of movement (Mink, 1996). In addition, the basal ganglia are involved in sensorimotor integration (Konczak et al., 2009) and are therefore highly involved in the processing of intrinsic feedback (Cincotta & Seger, 2007; Debaere, Wenderoth, Sunaert, Van Hecke, & Swinnen, 2003; Foerde & Shohamy, 2011b).

In PD, depletion of dopaminergic neurons in the basal ganglia lead to widespread deficits, including an inability to utilize intrinsic feedback to correct and modify motor behavior (van Dijk, Jannink, & Hermens, 2005a; van Dijk, Jannick & Hermens, 2005b) thus causing increased reliance on external feedback. External feedback processing involves parietal-premotor networks, which bypass deficient internal networks (the basal ganglia and the basal ganglia projections to the motor cortex) by using an external strategy for execution of movement (Debaere et al., 2003). Taking advantage of external feedback processing networks provides rehabilitation specialists with options to optimize treatment programs for their patients with PD.

2.4.2 Domains of Feedback

Here we review the literature regarding 5 domains of feedback-based learning to explain the motivation behind the choice of experimental design in the proposed study. The type of feedback chosen for the proposed study is extrinsic feedback with an external focus of attention. This feedback will be provided using knowledge of results regarding cycling speed. It will be signaled to the rider in the form of a change in color of central road markers when the rider attains a pre-specified range of speed. See Table 1 for a description of type of feedback and its efficacy on skill acquisition in healthy adults.

Table 1. Domains of feedback

Domain of Feedback	**Type of Feedback**	**Definition**	**Efficacious in Healthy for skill acquisition**	**Efficacious in PD for skill acquisition**
Locus	Intrinsic	Input through sensory systems as a result of movement	Yes (Van Vliet & Wulf, 2006)	No (Konczak et al., 2009)
	Extrinsic	Information from the environment that supplements intrinsic feedback	Yes (Van Vliet & Wulf, 2006; Van Vliet & Wulf, 2006)	Yes (Konczak et al., 2009)
Focus of attention	**External focus**	Draws attention extrinsically	Yes (Van Vliet & Wulf, 2006) (Wulf, Shea, & Lewthwaite, 2010)	Yes (Wulf, Landers, Lewthwaite, & Tollner, 2009)
	Internal focus	Draws attention intrinsically	Able to use internal focus but not as effective as external focus (Van Vliet & Wulf, 2006; Wulf et al., 2010)	No (Wulf et al., 2009)
Modality	**Visual**	Video, flashing lights, lighted bar graph, words of encouragement	Yes (Van Vliet & Wulf, 2006)	Yes (van Wegen et al., 2006)
	Auditory	Beeping, ringing, etc. to	Yes	Yes

		denote success or failure	(Van Vliet & Wulf, 2006)	(Hove et al., 2013)
	Haptic	Proprioceptive information i.e. in the form of forces or vibrations	Yes (Van Vliet & Wulf, 2006)	Unknown- deficiencies in proprioceptive integration in PD suggest No
Scheduling	Summary	Provided at the end of a set of trials	Yes (Van Vliet & Wulf, 2006)	Unknown-no evidence from the PD literature (Van Vliet & Wulf, 2006)
	Concurrent	Provided at the time the movement is being performed	Yes (R. A. Schmidt & Wulf, 1997; Van Vliet & Wulf, 2006)	Yes (Wulf & Weigelt, 1997)
	Immediate	Provided immediately after the movement is performed	Improves performance but is detrimental to learning (Van Vliet & Wulf, 2006)	No (Foerde & Shohamy, 2011b)
	Delayed	Provided after a delay, often only a few seconds, after the movement is performed	Yes (Van Vliet & Wulf, 2006)	Yes (Foerde & Shohamy, 2011b)
	Bandwidth	Indicates when a response is within a specified range of tolerance	Yes (Sherwood, 1988; Van Vliet & Wulf, 2006)	Unknown-no evidence from the PD literature (Sherwood, 1988; Van Vliet & Wulf, 2006)
Quality	Error correction feedback	Provides finely graded and specific information regarding not only that there was an error, but also how to correct it	Yes (Van Vliet & Wulf, 2006)	Yes (Di Bernardi Luft, 2014)
	Error-based feedback	More general feedback indicating success or failure, is typically in the form of reward/absence of reward	Yes (Van Vliet & Wulf, 2006)	Yes (Di Bernardi Luft, 2014)

2.4.3 Locus: Intrinsic vs Extrinsic Feedback

The origin of feedback can be intrinsic or extrinsic (Shumway-Cook & Woollacott, 2012; van Dijk et al., 2005). Intrinsic, or internal, feedback refers to one's own sensory-perceptual information generated as a result of a movement being performed. Examples include proprioceptive, auditory, and visual feedback (Van Vliet & Wulf, 2006). Intrinsic feedback helps form an internal representation of a movement goal and is received and processed in all persons, provided that sensory pathways and related mechanisms are intact (Greenwald, 1970). However, in the presence of sensory processing deficits, for example in those with neurological disorders, full awareness of movement through internal mechanisms may not be possible. Therefore, extrinsic feedback can provide information that cannot be obtained or processed intrinsically (van Dijk et al., 2005; Van Vliet & Wulf, 2006).

Extrinsic feedback is comprised of information gathered from the surrounding environment as a result of movement, and serves to augment intrinsic feedback (Shumway-Cook & Woollacott, 2012; Van Vliet & Wulf, 2006). The purpose of extrinsic feedback is to provide information about a person's performance. This information can relate to the outcome of the movement, i.e. knowledge of results, or to the quality of the movement, i.e. knowledge of performance (Wulf, Shea, & Lewthwaite, 2010).

2.4.4 Focus of Attention: External vs Internal

Feedback with an external focus of attention has been proven to be more beneficial in learning motor skills than an internal focus of attention (Wulf, 2013). Focusing internally during learning has been found to interrupt automatic processes while an external focus enhances learning by focusing on the movement outcome (Wulf, Shea, & Park, 2001). Benefits of an external focus of attention include improved accuracy, consistency, balance, force production, speed, endurance, and kinematics of movement, all which enhance performance. It is also believed to hasten the learning process by promoting automaticity of movement and shortening the initial stages of learning (Wulf, 2013).

Chiviacowski et al. (2010) compared the use of an external focus of attention to an internal focus on the ability of healthy older adults to learn a balance task (Chiviacowsky, Wulf, & Wally, 2010). Two groups of subjects were asked to stand on a balance platform and maintain its position as close to horizontal as possible. One group received instructions with an internal focus, ‘keep your feet horizontal’ the other group was instructed to focus on keeping the markers on the platform horizontal, an external focus. Although both groups increased their length of success during practice, the group with the external focus instructions outperformed the internal focus group on retention tests.

Focus of attention has also been studied in neurologically impaired populations. Based on findings in healthy people that an external focus of attention enhances learning, Landers et al. (2005) tested subjects with PD: fallers and non- fallers, using computerized posturography, under external, internal, and no focus conditions (Landers, Wulf, Wallmann, & Guadagnoli, 2005). The group of fallers in the external focus group exhibited greater improvements in balance than those in the internal and no focus conditions on retention tests. A study by Wulf et al. (2009) also sought to extend findings from the healthy literature regarding an external focus of attention. People with PD were instructed to balance on an unstable surface (an inflated rubber disc) while postural sway measurements were recorded. Subjects were given internal ('focus on minimizing movements of your feet'), external ('focus on minimizing movements of the disc'), or no focus ('stand still') instructions. Although no significant differences in the average time each group was able to maintain their balance was found, subjects in the external focus condition exhibited less postural sway compared to the internal and no focus groups (Wulf et al., 2009).

Results of these studies helped to inform this current study in the choice of feedback with an external focus, i.e. 'cycle at a rate that will make the markers turn color', which directs attention externally.

2.4.5 Modality: Visual, Auditory, Haptic

Studies have been conducted investigating a variety of feedback modalities to improve motor skill learning in healthy people and people with PD with comparisons made to healthy older adults. The use of visual feedback, audio biofeedback, and haptic feedback, has been shown to positively affect movement and balance in people with PD (Levy-Tzedek, Krebs, Arle, Shils, & Poizner, 2011; Mirelman, Herman, Nicolai, Zijlstra, Zijlstra, Becker,…Hausdorff, 2011; Rabin, Chen, Muratori, DiFrancisco-Donoghue, & Werner, 2013). Levy-Tzedek et al., in 2011 conducted a study to assess if rhythmic continuous movements of the forearm in healthy older adults and people with PD are influenced by the availability of visual feedback and/or dopamine therapy (Levy-Tzedek et al., 2011). Healthy subjects and subjects with PD tested on and off medications, were asked to follow a trace of their forearm motion. No explicit timing cues were given. Trials consisted of no vision trials followed by visual feedback trials. Speed and amplitude of upper extremity movements were measured. When visual feedback was not available, both healthy controls and people with PD executed faster movements. These results support the role of the basal ganglia in visuomotor integration with resultant deficits in sensory processing. This resulted in an inability to process both visual and proprioceptive input simultaneously thereby resulting in rhythmic movements that did not meet the speed or accuracy requirements of the task (Levy-Tzedek et al., 2011). The results of this study provided important information regarding the presentation of feedback in our VE. Visual feedback was provided simultaneously with proprioceptive feedback from the cycling motion and may have potentially resulted in a slower cycling speed due to difficulties in sensory integration.

Mirelman and colleagues conducted a study to investigate the feasibility of using an audio-biofeedback device to train postural stability in patients with PD (Mirelman et al., 2011). Seven people with PD participated in a 6-week intervention that required performance a variety of exercises relating to posture and balance, with the objective of improving posture, static and dynamic balance, and improving sit-to-stand and reaching activities. Participants wore a head set that emitted auditory feedback in differing frequencies and amplitudes depending on the participants' movement. Two types of feedback were provided, positive and negative, in the form of a tone in a target range when a proper posture/activity occurred, and a higher pitch tone when an improper posture/activity occurred. Positive trends in all of the balance measures, including the Berg Balance scale, were found. In addition, participants reported enjoying the activity (Mirelman et al., 2011). Adherence to an exercise program may be due to the improvements in balance, gait, etc., but may also be due to the social factors and enjoyment of participating in the exercise. It is important in the design of interventions to incorporate variables that will increase enjoyment and potentially lead to adherence in an exercise program. Extrinsic feedback is one way of accomplishing this.

Haptic feedback has also been used to improve balance in people with PD (Rabin, et al., 2013) investigate if haptic feedback provided though non-supportive fingertip touch could improve balance in people with PD. People with PD and healthy adults stood still for 25s in a sharpened Rhomberg stance under 4 conditions- eyes closed with no manual contact, eyes closed with light-touch contact, eyes closed unrestricted contact, eyes open no contact. Participants with PD exhibited greater postural sway compared to healthy controls, but manual contact reduced sway in people with PD. Non-supportive manual contact reduced sway more than vision. Findings show haptic cues can improve postural instability, providing yet another feedback modality to utilize in people with PD (Rabin et al., 2013).

The type of feedback used should take into account participant characteristics, the goal of treatment, and access to technology. Feedback can be presented in a virtual environment. Virtual environments have the ability to provide complex sensory stimulation for the user through visual, somatosensory, and auditory feedback (Adamovich, et al., 2009). In addition, the incorporation of proprioceptive, tactile, and force feedback from the VE in response to the user's actions increases the sense of presence in a VE and improves the interaction of the participant with the VE (Deutsch, Latonio, Burdea, & Boian, 2001). This increased interaction with the environment may lead to increased compliance (Merians, Fluet, Qiu, Lafond, & Adamovich, 2011) and therefore increased adherence to an exercise program.

2.4.6 Scheduling: Summary, Concurrent, Immediate, Delayed

Feedback is useful in early learning but if provided too often, can produce negative results (Van Vliet & Wulf, 2006). Therefore the timing of feedback is an important consideration in designing effective treatment programs. Studies investigating timing of feedback include those examining the effects of summary, concurrent, immediate, and delayed feedback on performance and learning.

Summary feedback is that which is provided at the end of a set of trials (Schmidt & Wulf, 1997; Van Vliet & Wulf, 2006). It provides information about an entire set of trials and has been found to be more effective than feedback after each and every trial (Schmidt & Wrisberg, 2008; Van Vliet & Wulf, 2006). Summary feedback typically results in poorer performance during practice, but results in better performance on retention tests when the feedback is removed (Schmidt & Wrisberg, 2008).

Conversely, concurrent feedback, provided at the same time a movement is being performed (Van Vliet & Wulf, 2006), is typically believed to improve performance, but a detriment to learning, in healthy adults (Schmidt & Wulf, 1997). The benefits of concurrent feedback on motor performance can be found in the following studies (Sanderson & Cavanagh, 1990; Verschueren, Swinnen, Dom, & De Weerdt, 1997) which are discussed below.

Stroke mechanics are essential to maximizing cycling performance. Sanderson & Cavanagh, (1990) sought to determine if real-time visual feedback regarding pedaling force, in addition to cadence feedback, would result in effective alteration of pedal forces compared to a group of cyclists who received only the digital display of cadence (Sanderson & Cavanagh, 1990). Six healthy young subjects rode a 10-speed bicycle mounted on a platform while observing a screen displaying visual feedback regarding pedal forces. The objective was to decrease forces during the recovery phase of the pedal stroke (from 180- 360 degrees of the pedal rotation). At the end of the training period, the group of cyclists receiving the augmented force feedback made significant reductions in pedaling force compared to the cadence only group. These results suggest that concurrent augmented visual feedback significantly affected the riders' ability to modify their pedaling forces.

Verschueren et al. (1997) also utilized concurrent feedback to investigate the ability of healthy older people and people with PD to learn an upper extremity interlimb coordination task and to transfer that learning to conditions with no visual feedback (Verschueren et al., 1997). Specifically, the ability to coordinate upper extremity movements at 90 degrees relative to each other by moving two horizontal levers in cyclical motions in time with a metronome was tested. In the practice phase, augmented concurrent visual feedback was provided for all trials with summary feedback provided after every 5th trial. Testing consisted of 3 conditions; reduced vision (blindfolded), normal vision, and augmented vision (concurrent feedback). Healthy older people performed well under all testing conditions, and in fact, in the no-feedback condition attained levels of performance near to those in the feedback condition. People with PD performed well in the feedback condition, but performance deteriorated in the blindfolded and normal vision conditions thus indicating the preference for visual information to guide upper extremity movements (Verschueren et al., 1997). Results from these studies are interesting in light of the common acceptance that concurrent feedback degrades learning in healthy adults (Schmidt & Wulf, 1997) but has been shown to improve performance. Implications for the current study were that the use of concurrent feedback would result in improved performance in both healthy older adults and people with PD but result in a more robust response in people with PD.

Immediate feedback, similar to concurrent feedback, can be detrimental to learning in healthy adults. Intrinsic processing is necessary for learning; immediate feedback does not allow for intrinsic processes to take place (Van Vliet & Wulf, 2006) however, the delay of feedback, even for a few seconds, has been shown to enhance learning (Swinnen, Nicholson, Schmidt, & Shapiro, 1990). Swinnen et al. (1990) tested healthy young adults in a timed task that required moving a slide along a linear track with their upper extremity (Swinnen, et al., 1990). Three feedback conditions were presented: immediate feedback, delayed feedback (8 seconds), and an estimation condition in which subjects were required to estimate their movement time within an 8 second delayed feedback interval. Learning was evaluated in immediate and delayed retention tests. The authors postulated that immediate feedback would delay learning and delayed feedback would be beneficial to learning. Findings show that compared to delayed feedback, instantaneous feedback degraded learning as shown on retention tests. This further supports the hypothesis that immediate feedback interferes with error detecting mechanisms, i.e. internal feedback processes that enhance learning. Delayed feedback on the other hand, is thought not only to enhance error detection capabilities but to also enhance learning of the movement itself (Swinnen et al., 1990).

The relationship between timing of external cues and learning was investigated in people with PD compared to healthy controls (Foerde & Shohamy, 2011b) in people with PD on and off medications (Foerde, Braun, & Shohamy, 2012) and in people with PD compared to people with amnesia (Foerde, Race, Verfaellie, & Shohamy, 2013). In a learning paradigm based on trial-by-trial feedback, results from fMRI analysis in healthy controls were consistent with activation in the striatum when feedback was immediate and activity in the hippocampus when feedback was delayed (Foerde & Shohamy, 2011b; Foerde, Braun, & Shohamy, 2013). Healthy controls were able to learn with both immediate and delayed feedback, people with amnesia, in which the basal ganglia are intact, learned from immediate but not delayed feedback. In contrast, people with PD were able to learn when feedback was delayed but impaired when feedback was immediate. This held true both on and off medications. The basal ganglia have been implicated in the processing of immediate feedback and the hippocampus in delayed feedback processing (Foerde & Shohamy, 2011a), which may explain the learning deficits with immediate feedback in people with PD.

The above mentioned studies emphasize the importance of the timing of feedback and that small delays, even a few seconds, can shift learning from one brain system to another. This is an important concept that should be addressed when designing treatment programs for people with PD (Foerde & Shohamy, 2011a).

The effect of frequency of feedback i.e. high or low, on learning is influenced by the focus of the feedback, i.e. internal or external. High frequency of feedback with an external focus does not necessarily detract from learning and may even benefit the learning process because it prevents the person from focusing internally. However, if given too frequently, external feedback can create dependency and result in detrimental effects on learning (Van Vliet & Wulf, 2006).

The purpose of a study by Guadagnoli et al. (2002) was to assess the relationship between frequency of feedback and motor learning in people with PD compared to healthy age matched controls (Guadagnoli, Leis, Van Gemmert, & Stelmach, 2002). Participants were randomly assigned to either a 100% rate of feedback or a 20% rate of feedback group and were asked to make fast and accurate arm pointing movements in relation to a specified movement time. During practice, all participants decreased their error rate, but those receiving 20% rate did so at a slower rate than those receiving

100% rate. Overall, people with PD performed better in practice with 100% feedback compared to healthy subjects. In retention tests, people with PD again performed better with more frequent feedback whereas controls performed better with less frequent feedback. Less frequent feedback is thought to enhance the use of sensorimotor integration, which supports learning through use of intrinsic error detecting processes. However, due to abnormalities in the use of internal feedback in people with PD, there is an increased reliance on more frequent feedback for successful learning (Guadagnoli et al., 2002). The current study employed the use of concurrent feedback to enhance motor performance, which is a form of 100% feedback. In light of the findings in the literature, it was expected that people with PD would respond similarly to healthy older adults in the feedback condition in regard to the frequency of feedback.

2.4.7 Quality: Error Correction vs Reinforcement Learning

Error based feedback and reinforcement learning are two methods of feedback that can be used in the learning of a motor skill. Error-based feedback provides information that not only informs that an error has been made but how the error occurred (Di Bernardi-Luft, 2014). It involves feedback that is finely graded and more exact. Error-based feedback learning has been studied extensively and has been shown to be beneficial in adapting behaviors to a changing environment (Diedrichsen, White, Newman, & Lally, 2010). Reinforcement learning uses categorical feedback, which is more general in nature, such as whether one was successful or not in achieving a desired result. It involves trial and error in which the participant learns how to perform the correct action. This feedback can be in the form of a reward (correct response) or absence of reward (incorrect response). Participants learn which actions lead to rewards, which is crucial in achieving the goal (Di Bernardi-Luft, 2014). It has been reported that people with PD off medications learn better with negative feedback but people with PD on medications learn better with positive feedback, or rewards (Di Bernardi-Luft, 2014). This current study used a reward-based reinforcement learning paradigm in the form of bandwidth feedback. However, there is limited recent evidence involving the use of bandwidth feedback in healthy older adults and little evidence in neurologically impaired populations, therefore it was difficult to predict participant behavior in this regard. In addition, studies are needed that provide a 'true' no feedback condition versus a bandwidth condition to accurately assess the effect of bandwidth feedback on learning (Butler & Fischman, 1996).

Bandwidth feedback is qualitative in nature in that it indicates when a response is within a pre-specified range of correctness, or tolerance (Lee & Carnahan, 1990; Sherwood, 1988). It can also provide quantitative feedback by indicating the amount of error outside the bandwidth, for example by indicating by a percentage if performance is above or below a desired range (Van Vliet & Wulf, 2006). Bandwidth feedback is useful to enhance motor skill learning, (Sherwood, 1988) and is the type of feedback most used by therapists in a rehabilitation setting. In general, an accepted range of behavior by a patient will be tolerated. If behavior is outside of the acceptable range, feedback is provided. The primary advantage of bandwidth feedback is that it promotes movement stability during practice and typically results in more stable retention (Van

Vliet & Wulf, 2006) due to its informative and motivating qualities. However, it has the potential to be detrimental to learning by providing too much guidance (Lee & Carnahan, 1990).

The size of bandwidth feedback and its effect on acquisition and learning has been investigated. In a study by Sherwood, the effects of narrow and wide bandwidth feedback when behavior was outside a range of tolerance was investigated. A wide bandwidth, within 10% of the desired speed of elbow flexion, or less frequent feedback, resulted in less variability of movement than a narrow bandwidth (within 5% of the desired speed of elbow flexion) and ultimately better learning (Sherwood, 1988). Bandwidth feedback can also be provided when a person is performing within a range of tolerance as in this proposed study. In this case, a wide bandwidth would result in more correct responses and therefore more frequent feedback. Based on knowledge of the effect of frequency of feedback on learning and performance, it would be expected that more frequent feedback would result in a greater change in the next response i.e. better performance, but decreased retention. To improve cycling performance, increase pedaling rate, the current study provided feedback at a wide bandwidth (+/- 3 rpms of a preset pedaling target rate), which provided more frequent feedback for the purpose of improving cycling performance.

2.4.8 Summary

In summary, the basal ganglia are integral to feedback processing. Although healthy older adults may present with deficits due to normal age-related declines in executive and motor function, in general they exhibit proper use of internal and external feedback mechanisms. People with PD are unable to respond to internal feedback due to dysfunction of the basal ganglia. However, the use of external feedback can bypass deficient neural pathways and result in improved motor performance and learning in people with PD. The clinical implications of these findings are important as they support a scientific foundation for the use of external feedback to change motor behavior in healthy older people and people with PD, and support the use of a feedback paradigm involving concurrent visual feedback of a bandwidth nature, with an external focus of attention, in this experimental design.

2.5 Virtual Environments

2.5.1 Introduction

Virtual environments are simulations of real world environments that provide complex multisensory information to the user (Adamovich et al., 2009; Holden, 2005) in a safe, engaging, and motivating environment (Merians et al., 2011). Virtual environments have been used successfully in healthy people and patient populations to promote activity and to address impairments and functional deficits such as impaired coordination, decreased strength, impaired postural control, and gait abnormalities (Adamovich et al., 2009; Deutsch et al., 2004; Deutsch, 2009; Hurkmans, Ribbers, Streur-Kranenburg, Stam, & van den Berg-Emons, 2011; Kaminsky et al., 2007; Lohse, Hilderman, Cheung, Tatla, & Van der Loos, Machiel, 2014; Lohse, Shirzad, Verster, Hodges, & Van der Loos, 2013; Merians, Tunik, Fluet, Qiu, & Adamovich, 2009;

Mirelman et al., 2013; Warburton et al., 2007). Evidence-based designs of VEs can be tailored to specifically address these deficits by incorporating compensatory techniques such as external cueing, and motor learning principles such as repetition, high intensity, and the provision of feedback, and therefore make an ideal medium for neurorehabilitation interventions.

Studies conducted in people with PD using virtual environments include the investigation of accuracy in reaching and improving balance and gait (Badarny, Aharon-Peretz, Susel, Habib, & Baram, 2014; Griffin et al., 2011; Jeong, Piao, Chong, Kim, Lee, Kwon, . . . Kim, 2005; Mirelman et al., 2011; Shine, Matar, Bolitho, Dilda, Morris, Naismith et al., 2013; van Wegen et al., 2006; Wang, Hwang, Fang, Sheu, Leong, & Ma, 2011). Although no studies were found in people with PD, studies have also been conducted on the efficacy of video games in improving balance, gait, function and energy expenditure and fitness in healthy people and people post-stroke, (Deutsch, 2009; Galna, Murphy, & Morris, 2010; Hurkmans et al., 2011; Nitz, Kuys, Isles, & Fu, 2010; Pompeu et al., 2012b) .

The use of virtual reality to promote fitness, are commonly in the form of video games such as the Nintendo Wii™ and Microsoft Kinect™. In a pilot study investigating the feasibility of the Wii to promote improved balance, strength, flexibility and overall fitness, Nitz et al. (2010) conducted a study on healthy young and middle-aged females (Nitz, et al., 2010). Subjects participated in twice-weekly unsupervised 30-minute sessions for 10 weeks using the Wii with a predetermined set of activities that addressed fitness, balance and strength. Results showed a significant improvement in balance and strength, with non-significant improvements in functional mobility and fitness measures. Limitations of the study include low compliance (70% adherence rate) and small sample size (10 subjects). Suggestions for future research include a larger sample size to confirm or refute the findings.

In light of the increased use of gaming technology in the long-term care setting, Marsten, in 2013, conducted a review of studies using video games in healthy older adults.. However, a wide variety of games, as well as non-conformity regarding duration of intervention in the studies, made it difficult to make comparisons. Despite these limitations, results suggest that video gaming technology may have a beneficial effect on fitness but a need for larger and longer-term studies exist (Marston, 2013).

The feasibility of an evidenced based VE to promote fitness in people post-stroke was conducted by Deutsch and colleagues in 2013 (Deutsch et al., 2013). Five participants were enrolled in the study, 4 with stroke and one healthy control. Participants attended 2 sessions of stationary cycling each week for 8 weeks. Cycling times increased over the course of the intervention from 20 minutes to 60 minutes. At the conclusion of the intervention, an increase in fitness levels, as indicated by improvement in peak VO2, was found, as well as a transfer of training from cycling to walking endurance, as shown by a meaningful change in the 6-Minute Walk test for two of the participants post-stroke (Deutsch et al., 2013). The preliminary findings of this study suggest that a cycling in a VE is efficacious in promoting fitness in people post-stroke. Future studies with a larger sample size and implementation in a clinical or community based environment may prove its benefit for mobility and fitness in people post-stroke. Studies using VEs in people with neurological disorders other than stroke may also prove beneficial.

Studies utilizing a virtual environment to improve gait are by far the most numerous and include those addressing stride length, freezing of gait, gait speed, improvement of dual tasking abilities, and obstacle negotiation (Griffin et al., 2011; Kaminsky et al., 2007; Mirelman et al., 2011; Van Wegen et al., 2014). A variety of virtual presentations were employed in these studies such as the projection of virtual stripes on the floor while walking in a virtual corridor, visual cues delivered via virtual viewing spectacles, walking in a virtual environment while wearing virtual glasses that presented freezing of gait triggers, and the combination of treadmill walking with virtual reality.

These studies support the benefit of using virtual reality to augment traditional rehabilitation interventions for patients with mid-stage PD and the potential use of VEs to promote fitness in other neurologically impaired populations, including people with PD. However, the use of VEs in people with movement disorders has developed more slowly than in other areas of rehabilitation (Adamovich et al., 2009). Future research with large sample sizes and participants with varying levels of physical and cognitive abilities due to PD would prove beneficial.

2.5.2 Optic flow

The term optic flow was first used in the 1950's by James Gibson, a pioneer in the field, to describe visual flow patterns that contain information about self-motion, moving objects, and the layout of the environment (Warren, 2003). Optic flow is the visual perception of movement produced by a subject's own actions (Azulay et al., 2006). It provides a powerful visual cue that can influence a person's speed and direction (Chou, Wagenaar, Saltzman, Giphart, Young, Davidsdottir, & Cronin-Golomb, 2009; Lamontagne, Fung, McFadyen, & Faubert, 2007; Lebold & Almeida, 2011; Powell, Hand, Stevens, & Simmonds, 2006; Prokop et al., 1997; Warren, Kay, Zosh, Duchon, Sahuc, 2001).

Walking velocity modulations in response to changes in optic flow have been studied in healthy people and people with PD (Chou et al., 2009; Prokop et al., 1997; Schubert, Prokop, Brocke, & Berger, 2005). Evidence from the walking literature in healthy adults shows that optic flow set at a rate faster than a subjects' walking speed causes a decrease in walking velocity, while slower optic flow causes an increase in walking velocity (Prokop et al., 1997). This reaction has also been found in people with PD (Schubert et al., 2005).

It is proposed that people with PD have an inability to properly use incoming sensory stimuli due to deficient neurological connections that pass through the basal ganglia in particular proprioception, which ultimately influence motor decisions (McAuley, 2003). However, visual input activates alternate visuomotor circuits that pass through the cerebellum and thereby bypass the defective basal ganglia. This may explain the increased reliance on vision in people with PD (Azulay et al., 2006; Kandel et al., 2000) and the ability to respond to optic flow.

Schubert et al. (2005) examined the effect of optic flow manipulations on walking velocity, stride length, and stride frequency while walking on a treadmill in healthy older adults and people with PD (Schubert et al., 2005). Participants were instructed to maintain a preferred walking velocity throughout the experiment while the speed of optic flow was modified. A decrease in optic flow speed resulted in an increase in walking velocity, and vice versa, in all subjects. However, people with PD reacted more strongly to these modulations compared to healthy subjects. The more robust findings in people with PD may be due to the increased reliance on visual information due to impaired processing of proprioceptive information (Azulay et al., 1999).

Both the treadmill and the stationary bicycle are common tools used in the physical therapy setting for fitness and rehabilitation (Johnston, 2007), and both are well suited for virtual reality interventions. Limited evidence exists on the efficacy of a cycling VE for fitness or rehabilitation. However, studies have been conducted to determine the degree to which visual information contributes to speed estimation while riding a bicycle (Sun, Lee, Campos, Chan, & Zhang, 2003; van Veen, Distler, Braun, & Bulthoff, 1998), the use of VEs to influence equilibrium (Jeong et al., 2005), the determination of the effect of optic flow on perceived exertion (Parry, Chinnasamy, & Micklewright, 2012), and to determine the effect of optic flow speed manipulations on cycling velocity in healthy adults and people post stroke (Gade, Gallagher, Maiden, Patel, & Deutsch, 2013).

Specific elements such as real world scaling of objects, elements in the periphery, and high visual contrast, can be embedded in a virtual environment. These elements provide velocity cues that affect a rider's immersion and self-speed estimation (Powell & Stevens, 2013). In an early study investigating self-speed estimation in a virtual cycling environment, subjects cycled through a virtual geometric model of a real city then provided subjective feedback regarding cycling effort (van Veen et al., 1998). In general, participants underestimated their cycling speed, which may have been due to the absence of important velocity cues such as high visual contrast, or a narrow field of view (Powell & Stevens, 2013). A limitation of this study is that it was not stated if the speed of optic flow presentation was manipulated, a factor that also influences a rider's speed and estimation of self-motion.

Later studies investigating the ability to estimate speed of self-motion while cycling in a virtual environment have also been performed (Sun et al., 2003). Young healthy adults wore a head mounted display to view a seemingly infinite virtual hallway. Participants were asked to estimate their speed based on a standard and comparison speed. When visual cues in the form of optic flow, or proprioceptive cues, supplied by the movement of the rider, were available either alone or in combination, participants were successful in estimating their speed, thus indicating that either cue alone is sufficient. However, when the speed of visual flow was made incongruent with proprioceptive information, proprioceptive information dominated the contribution to speed estimation over and above that of the visual information.

Gade et al. (2013) investigated the effect of optic flow gain manipulation on young, older healthy, and people post stroke (Gade et al., 2013). Subjects rode a stationary bicycle while viewing a virtual environment of a mountain scene with an avatar riding a bicycle on a dirt path. The scene was viewed on a TV monitor placed approximately 5 feet in front of the bicycle. Four levels of optic flow gain were determined for each individual, followed by a randomized order of cycling trials that included manipulation of optic flow gain, path width (narrow/wide) and path difficulty (mud patches/no mud patches). Subjects were asked to cycle in response to the display on the screen. Results showed no significant difference between groups in response to optic flow manipulation, but within group differences for gain contrast, path width, and path difficulty were found. These differences did not reach significance, which may be due to small sample size. Interesting to note is that unlike the walking literature, as speed optic flow increased, cycling velocity increased, and as speed of optic flow decreased, cycling speed decreased. An important limitation of this study was the small field of view, which may have reduced the influence of the optic flow. Additionally, multiple variables were tested simultaneously making the interpretation of the role of optic flow difficult. These limiting factors were addressed in the current study by using single stimuli and larger field of view.

Together, these studies found that cycling in a VE does influence riding behavior. The study by Gade et al. (2013) found that modulations in cycling speed were in direct proportion to modulations of optic flow speed. This is in contrast to the walking literature where modulations of optic flow speed resulted in out of phase velocity of gait.

2.5.3 Elements in a virtual environment and their effect on the user

Content in a VE has a direct effect on the behavior of the user. Therefore, it is important when designing a virtual environment for rehabilitation or fitness to ensure that the effect of the content results in behavior that is aligned with treatment goals. The design of the VE in this study was determined after careful scrutiny of the literature pertaining to the influence of visual and auditory content in a VE, to ensure alignment with the goals of the study. Justification for the selection of content in the VE of the proposed study is outlined in Table 2.

Table 2. Effect of content in a virtual environment on the user

Content in the virtual Environment	Effect on the user	Content chosen for the proposed study
Type of presentation	An abstract presentation typically consists of a dot or line pattern and is used often in early studies of optic flow and in research settings A realistic presentation is more often used in the clinical setting (Powell & Stevens, 2013)	The setting of the VE is an outdoor mountain scene
Audio	Music tempo can affect movement timing (Chen et al., 2009; Powell & Stevens, 2013). Ambient sounds may improve immersion	Ambient sounds of nature i.e. birds chirping will be embedded in the VE. There will be no music in the VE to limit the influential effect of tempo on cycling speed.
Optic Flow	Optic flow matched to the speed of walking does not interfere with the ability to respond to external cues (van Wegen et al., 2006).	The general design of the road and trees will provide optic flow information. The rate of optic flow will be matched to the speed of the rider.
Spatial Frequency	Increasing the spatial frequency between objects, such as central road markers, gives the user the perception of slowing down and vice versa. (Banton, Stefanucci, Durgin, Fass, & Proffitt, 2005; Holden, 2005).	The rate of presentation of the visual cues will start with central road markers presented at 20% above the frequency of the baseline RPM
Contrast	High color contrast between objects in the environment gives the impression of faster visual flow (Stone & Thompson, 1992).	There is high color contrast between the grass, road, mountains and sky

Texture	Textured or cluttered environment improves perceived speed of self-motion (Durgin, Gigone, & Scott, 2005)	The environment includes grass textured with flowers and blades of grass
Size of objects	Elements that appear realistic in size and in proportion to each other likely influences speed perception (Banton et al., 2005; Powell & Stevens, 2013)	Bicycle and rider are in normal proportion to the surrounding landscape
FOV	A wider FOV (ideal 80-200 degrees) improves estimation of self-motion perception due to the presence of peripheral visual cues (Banton et al., 2005; Powell & Stevens, 2013)	The VE will be front-projected onto a flat 104-inch screen (68 X 79 inches) positioned approximately 5 feet in front of the participant with a horizontal field of view of 80 degrees.

2.5.4 Cueing and Feedback in Virtual Environments

Virtual reality systems have the ability to present complex multimodal sensory information to the user, which can include the use of audio and visual cues, as well as the manipulation of auditory and visual feedback (Holden, 2005). The presentation of this sensory information can be used to augment motor performance in both walking and cycling in a virtual environment. However, the presence of optic flow has been shown to influence the behavior of the user with concern that it may interfere with the ability to attend to cues or feedback (Powell et al., 2010; van Wegen et al., 2006).

In a study by Powell et al in 2010, gait speed in healthy adults was influenced by the presentation of auditory cues while walking on a treadmill (Powell et al., 2010). Audio cue rates were set at 75%, 100% and 125% of baseline speed. Although walking speed increased in all audio cue conditions, significance was found only in the 125% cue condition. The addition of visual flow to the fast and slow audio cue conditions resulted in a significant decrease in walking speed compared to the audio cue only condition. This indicates that the presence of the VE influenced walking speed when audio cues were incongruent with preferred walking speed. This suggests an increased demand on cognitive resources for motor execution in the presence of a VE. The authors felt that the conflict of cue rate and preferred walk speed may have required more conscious attention and therefore interrupted the automatic nature of walking resulting in a slower walking speed. In light of these findings, it was expected that in the current study, both healthy older and people with PD would respond with a decrease in pedaling rate when presented with audio cues in conjunction with the virtual environment.

van Wegen et al. (2006) investigated the influence of visual cues on stride frequency and walking velocity in people with PD while on a treadmill. Briefly, subjects were exposed to a stepwise progression of trials consisting of a blank screen, projection of a virtual corridor, the virtual corridor with visual spatial cues (transverse lines), a blank screen with audio cues only, and the virtual corridor with visual temporal cues (a flashing light). Optic flow speed was matched to the walking speed of the subject in all trials. Results showed that participants were able modulate their walking, in particular their stride frequency, in response to the visual cues in all trials. Importantly, results of this study indicate that the presence of a VE while walking on a treadmill did not interfere with the ability of people with PD to respond to external cues (van Wegen et al., 2006).

In both of these studies, optic flow speed was linked to treadmill speed. However, the differences of the two studies lie in the choice of cue; audio or visual, and subject characteristics; healthy or people with PD. In the study by Powell, healthy subjects were influenced not only by audio cues, but the addition of visual flow as well. This flow resulted in a subtractive effect on speed, most likely due to an increased demand on attentional resources. Van Wegen et al. (2006) found a response to visual cues in people with PD, but found no conflict when both visual cues and visual flow were presented. The difference in results in these two studies may be due to the difference in cue type i.e. audio versus visual, or the increased reliance on vision in people with PD.

2.5.5 Gap in the literature and goal of study

Virtual environments are more versatile than the real-world in their ability to closely control content provided to the user, and thereby more aptly meet the patients' needs (Adamovich et al., 2009). They provide clinicians with a powerful tool in which to train and rehabilitate patients with a variety of pathologies. The use of virtual reality in exercise and rehabilitation is relatively new, with progress in the design of VEs and interventions best suited to promote optimal outcomes. Although VEs have been used for exercise promotion in healthy people and people with stroke, its use for fitness in people with PD has not been investigated. In addition, a specific understanding of embedding cueing and feedback in a VE is absent. Therefore, the purpose of the current study was to investigate the short-term effect of cueing, feedback, and directed attention in a VE on motor performance.

Chapter 3 Methods and Procedures

Two preliminary studies were conducted prior to proposing this project. The first study compared lower extremity kinematics during stationary upright and recumbent cycling in people with PD and healthy age-matched adult (Gallagher et al., poster presentation CSM, 2013). Results from this observational study showed greater excursions in the trunk and hip in healthy adults while riding the upright bicycle. No kinematic differences between bicycles for people with PD were found, but this was interpreted as a result of a (low) self-selected seat height in this population.   Since greater options for movement were desired in the current study, a standardized seat height and an upright bicycle were chosen. Results from the second study informed the design and power analysis of this study and can be found in Appendix A.

3.1 Research Design

This study used a cross sectional design. Two groups of participants were included: healthy older adults and people with PD. Data were collected in one experiment, but analyzed separately.

3.2 Variables

The following measures were collected to define the cohort: age, gender, weight, height, cognitive function, and lower extremity range of motion. Additional measures for people with PD included: disease duration, Hoehn and Yahr stage (H&Y) (Hoehn

& Yahr, 1967), and the motor subsection (part III) of the Unified Parkinson's Disease Rating Scale (Goetz et al., 2008).

Each analysis of the cycling data included two independent variables analyzed separately for the two types of dependent variables. The first independent variable of group had two levels: healthy older adults and people with PD, the second independent variable, condition, had 3-5 levels: Auditory (4 levels), Visual (5 levels), Feedback (3 levels), and Directed Attention (5 levels). Dependent variables for each condition were pedaling rate (RPMs) and kinematics (trunk and hip). See Table 3 for a description of the independent variables by condition and levels within each condition.

Table 3. Independent Variable of Condition

Condition	Levels	Design
Auditory Block (4 levels)		Auditory and Visual blocks counterbalanced between subjects
	Warm up and Baseline	
	Auditory Cues only	
	Virtual Environment only	
	Auditory Cues + Virtual Environment	
Visual Block (5 levels)		Auditory and Visual blocks counterbalanced between subjects
	Baseline	
	Virtual Environment only	
	Virtual Environment + Visual Cues (Visual Cues at real world distance apart)	
	Virtual Environment + Visual Cues (Visual Cues presented at 20% faster speed.	
	Virtual Environment + Visual Cues (Visual Cues presented at 20% faster speed. Cues to attend to visual cues)	

Feedback Block (3levels)		Trials presented in the order indicated
	Baseline	
	Virtual Environment only	
	Virtual Environment + Feedback Visual Cues presented at 20% faster speed. (Visual Cues change color if target cycling speed is achieved)	

Directed Attention Block (5 levels)		The last two trials were counterbalanced within the block
	Baseline	
	Virtual Environment only	
	Auditory Cues + Visual Cues no directed attention	
	Auditory Cues + Visual Cues attention directed to AC	
	Auditory Cues + Visual Cues attention directed to VC	

3.2.1 Independent Variables

The independent variables are described as they relate to each hypothesis:

Hypothesis 1 (effect of auditory cues)

<u>Rhythmic auditory cueing (AC)</u>

Rhythmic auditory cues consisted of a computer generated metronome beat provided through a pair of speakers placed on a table in front of the bike. The metronome rate was based on the walking literature and also on trials of 3 healthy adults and 3 people with PD. The metronome rate was set 20% above baseline speed of each participant. Cues were based on 2 bpm = 1 RPM. For example, if a person had a baseline pedaling rate of 60 RPMs, the matched metronome rate was 120 bpm. A 20% increase in metronome rate would then be 144 bpm with a corresponding pedaling rate of 72

RPMs. Instructions to participants were '*Every time you hear a beat, push down on the pedal with your right, left, right, left, etc.*'

Hypothesis 2 (effect of visual cues)

<u>Visual Cues (VC)</u>

Visual cues consisted of central road markers that were either present or absent (Fig. 1). Each road marker was a fixed length of 1.5m. The rate of presentation of the markers started at a 'real world" distance apart (10 feet). This was the baseline VC condition. The rate of presentation of these markers when increased, were 20% faster, e.g. the distance between the markers decreased by 20%; optic flow is unchanged, the markers just appear more frequently. Road markers were first presented with no specific instructions, and in the next trial received the following instructions, "*Try to decrease the gray space between the markers*". The instruction for the latter trial was intended to get participants to pedal at a faster rate; they could not actually decrease the spacing of the markers.

The edge of the road marker closest to the rider was used to determine the start point of a road marker. The distance covered by the wheels on the road with a single revolution of the wheel times the RPM of the rider gives the linear distance covered in a minute: Linear distance covered in the virtual world/minute = circumference of the wheel times the RPM = $(2\pi * R) * RPM$. The relationship is 6 meters in the real world equals 3 meters in the virtual world.

Fig. 1: Virtual environment a. with visual cues and b. without visual cues

Hypothesis 3 (effect of visual feedback)

Feedback was presented in the VE using a bandwidth format. It consisted of a change in color from white to purple of the central road markers when pedaling speed was +/- 3 RPM of the speed of the road markers. Participants were instructed to "*Cycle at a rate that will make the maker turn color and keep that change in color throughout the entire trial*".

Hypothesis 4 (effect of directed attention)

When both auditory and visual cues were presented simultaneously, participants initially received no instructions on where to direct their attention, then received instruction to direct their attention to the auditory cues "*Match your cycling speed to the metronome*", or to direct their attention to the visual cues "*Try to decrease the gray space between the markers*". See above descriptions for visual and auditory cueing.

Hypothesis 5 (Between group)

For all participants, a difference in RPM between groups will be determined for each condition.

Hypothesis 6 (Trunk and Hip kinematics)

For all participants, a difference in trunk and hip kinematics will be determined within and between groups.

3.2.2 Dependent Variables

RPM's: The number of revolutions of the crank per minute.

Trunk and hip kinematics: Kinematics of the trunk and hip were obtained using the Vicon Peak Motus motion capture system sampled at 120 Hz (Vicon Motion Systems Ltd., Denver, CO, USA). Relative joint angles were calculated for the trunk and hip in the coronal plane.

Table 4a and 4b provide a summary of the variables used in this study.

Table 4a. Independent Variables

Independent Variable	Purpose
Auditory Cues	Metronome beat set 20% above baseline speed. Purpose is to increase pedaling rate
Visual Cues	Central road markers set at a rate 20% faster than baseline speed. Purpose is to increase pedaling rate.
Feedback	The central road markers will turn color from white to purple. Purpose is to give visual feedback pertaining to pedaling rate and to increase pedaling rate.
Directed Attention	Auditory and visual cues will be presented simultaneously with instruction to attend to either the auditory or visual cue. Purpose is to determine if the simultaneous presentation of cues will result in an increase or decrease in pedaling rate, and also to determine if there is a preference for cue type.
Between Groups	Purpose is to determine if there are differences in RPM and kinematics between groups

Table 4b. Dependent Variables

Dependent Variable	Purpose
RPM	RPM was used to determine if participants modulated their pedaling rate in response to the independent variables and if there was a difference in pedaling

	rate between groups.
Trunk kinematics	Kinematics of the trunk were collected to determine if a change in pedaling rate led to changes in trunk motion within and between groups.
Hip kinematics	Kinematics of the hip were collected to determine if a change in pedaling rate led to a change in hip motion within and between groups

3.3 Subjects

A sample of convenience was used. Participants were recruited through flyers posted at the NYIT and Rutgers campuses as well as on the Research in Virtual Environments and Rehabilitation Sciences (RIVERS) Lab website and by phone (see script section 3.6). Control subjects were recruited from the community and from spouses of the participating PD population. All participants signed informed consent prior to participating in the study.

Suitability for inclusion in this study was determined according to the following criteria:

Common Inclusion Criteria

- Age between 50 and 85 years inclusive.
- Males and females were included in the study.
- Able to ride a stationary upright bicycle
- Able to provide informed consent

Common Exclusion Criteria

- Significant cognitive deficits as defined by the Montreal Cognitive Assessment

(MoCA) < 24 (Hoops, Nazem, Siderowf, Duda, Xie, Stern, & Weintraub, 2009).

- Severe hearing or visual deficit including color blindness
- History of stroke, traumatic brain injury or other neurological disorder other than PD
- Unstable medical condition including musculoskeletal disorders such as severe arthritis, knee surgery, hip surgery, or any other condition that the investigators determine would impair the ability to ride a stationary bicycle

Specific Criteria for participants with PD

Inclusion

- Parkinson's Disease diagnosed by a neurologist
- Hoehn and Yahr stage II-III (Hoehn & Yahr, 1967)

Exclusion

- Incapacitating tremors or dyskinesias that would limit ability to ride a stationary bicycle and interfere with kinematic data collection
- Severe freezing of gait that would interfere with cycling as seen on the UPDRS and/or by participant history

3.4 Sample Size

Sample size was derived based on previous reported related research (Powell et al., 2010; van Wegen et al., 2006) and data from a related project that used similar measures (Gade, Gallagher, Maiden, Patel, & Deutsch, 2013). Twenty-eight participants were included in the study, 13 age-matched healthy adults and 15 people with PD.

3.5 Instrumentation

The virtual reality cycling system consisted of a custom designed (VE), computer, projector display of the VE on a screen, speakers, upright stationary bicycle, RPM sensor, and motion capture system. Data were collected from the RPM counter and motion-capture system (Fig, 2).

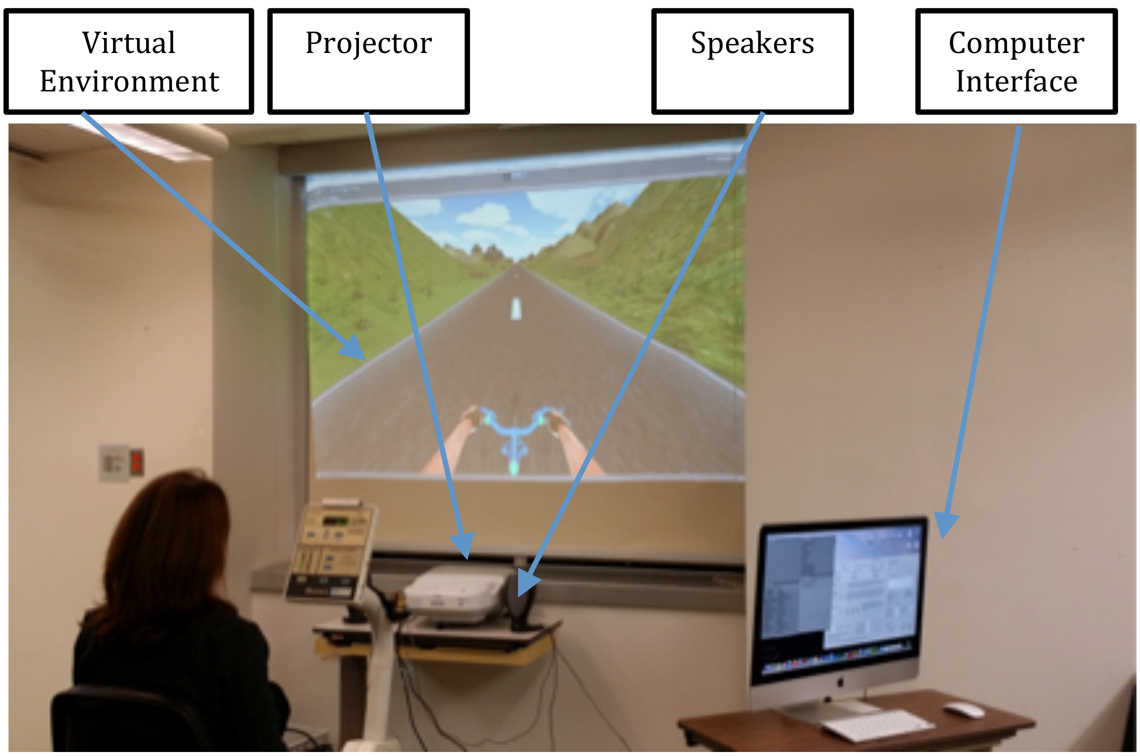

Fig. 2: System set up

Virtual environment (VE)

The virtual environment was front-projected onto a flat wall approximately 5 feet in front of the participant. The monoscopic projection of the environment was equivalent to 94-inches (43 X 83 inches) with a horizontal field of view of 80 degrees. The environment was designed in a free-to-download version of Unity 3D gaming engine. The VE consisted of a straight road surrounded by grass, trees, plants shrubs, and mountains. The participant viewed the VE from a first person perspective (Fig. 3).


Fig. 3: The virtual environment

Upright Stationary Bicycle

Cybex Upright Bicycle, Model #750C was used for all participants. Bike parameters were set at 20 Watts and constant power.

RPM Sensor

A Wahoo RPM cadence sensor attached to the crankshaft of the bicycle measured the RPM of the participant at 60Hz. A custom C-sharp (C#) code on the computer communicated with the Bluetooth sensor and transferred RPM data to the Unity gaming environment. The RPM was then translated into the speed of the rider in the VE.

Motion Analysis system

Body segment kinematics were measured at 120 Hz, using a nine-camera motion capture system (Vicon PeakVicon Motion Systems Ltd., Denver, CO, USA) to track 16 reflective markers placed on the subject. Data was processed using a simple algorithm implemented in Matlab. Retroreflective markers with adhesive backing were place on bilateral lateral acromion, suprasternal notch, sternal angle, C7 spinous process, T10 spinous process, and bilateral greater trochanters, lateral femoral condyles, ankle (inferior tip of lateral malleolus), heel, and webspace between 1st and 2nd metatarsal heads.

Polar Heart Rate Monitor

A Polar HR7 Bluetooth heart rate monitor was read via a mobile device (Android/iOS) to check the heart rate of the participant. Heart rate was monitored throughout. When the participants' heart rate returned to +/-10 beats of resting heart rate, a new trial was begin.

Borg Scale

The Borg scale (Borg, 1970) is a measure of rate of perceived exertion. Rating of perceived exertion was taken immediately after completion of each trial and was used to monitor the exertion level. The lowest measure on the scale is 6: no exertion at all, and the highest is 20: maximal exertion.

Visual Analogue Scale (VAS)

A 5 level VAS scale was used to determine the perceived difficulty of adhering to instructions for selected trials. For example: "*On a scale of 1(not difficult) to 5(very difficult), how hard was it to keep pace with the metronome in this trial?*

3.6 Research Protocol

The study was conducted at the Biomechanics lab located in the Academic Health Care Center at the New York Institute of Technology's Old Westbury campus. Screening via telephone or in person took place to determine subject eligibility. Participants attended two testing sessions lasting approximately 1 hour each (Table 5).

Table 5: Protocol Timetable

Prior to study visit	Testing sessions: Total approximate time: 120 minutes	
Screening (10 min)	Session 1: Consent MoCA Motor Assessment (UPDRS) Disease Severity (H&Y) ROM/LE measurements (50 minutes)	Session 2: Marker placement (10 min) Cycling Protocol (50 minutes)

Testing sessions were conducted during the ON state of medication for all participants with PD. Informed consent, cognitive assessment using the Montreal Cognitive Assessment (MoCA) (Hoops et al., 2009), motor assessment using Part III of the Unified Parkinson's Disease Rating Scale (UPDRS) (Goetz et al., 2008), and disease severity, using the Hoehn and Yahr scale (Hoehn & Yahr, 1967) were performed to determine eligibility for the study. Lower extremity range of motion was collected using a standard goniometer (Fig. 5). All assessments were performed by the principle investigator (RG). See section 3.6.2. for a description of these measures.

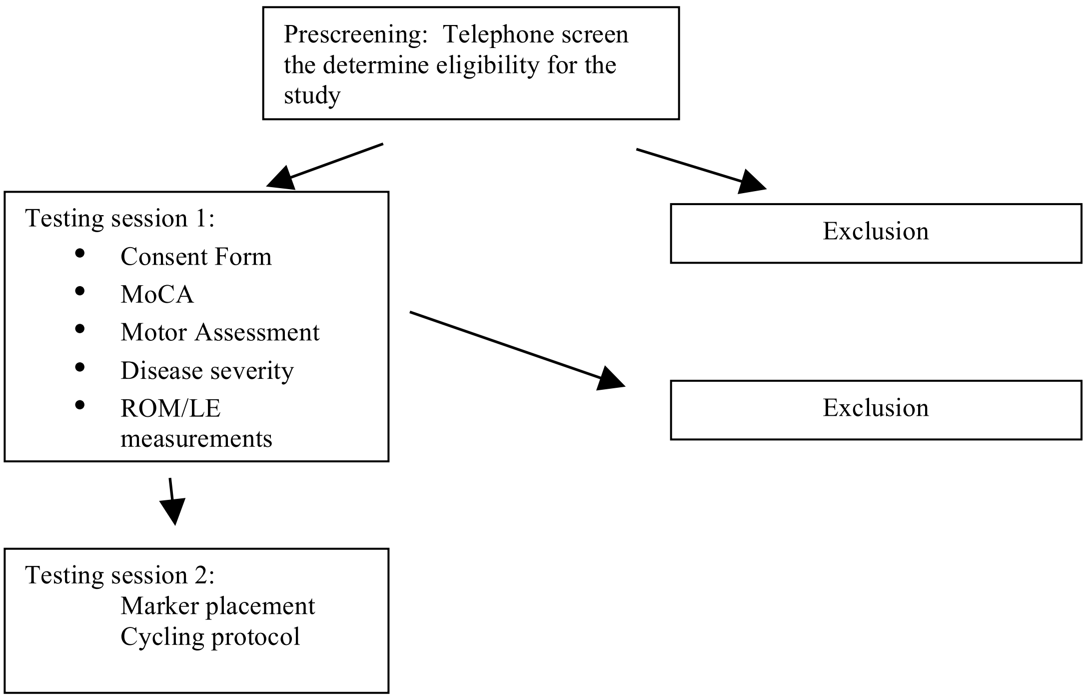

Fig. 5: Study Procedure

3.6.1 Pre-screening

To determine eligibility for participation in the study, participants underwent a screening either in person or on the phone. Subjects deemed eligible were scheduled for the testing session. The script for the phone screen was as follows: "*I am conducting a study that will look at the cycling behavior of people while they ride a stationary bicycle and watch a mountain scene on a screen. The type of people I'm looking for are healthy adults with and without Parkinson's disease. The study will be* *conducted in two visits each lasting approximately one hour. If this study sounds like something you'd like to participate in, I'd like to ask you some questions to make sure you fit the criteria."*

3.6.2 First Testing session

Informed Consent

Participants read and signed the informed consent.

Cognitive Assessment

After a participant was consented, the MoCA was administered (Hoops et al., 2009). The MoCA is a cognitive assessment tool proven to have strong psychometric properties for the detection of mild cognitive impairments and dementia in people with PD. Only those participants scoring 24 or above on the MoCA were included in the study.

Motor Assessment

The MDS-UPDRS is a comprehensive assessment designed to monitor the burden and extent of Parkinson's disease across the longitudinal disease course and provide a clinical endpoint in therapy trials. It is the most widely used clinical rating scale for Parkinson's disease (PD). The MDS-UPDRS, developed in 2007 by the Movement Disorder Society, is a new version of the scale that retains the strengths of the original scale but resolved such problems as a lack of consistent anchors among subscales and low emphasis on non-motor features of PD (Goetz et al., 2008).

The MDS-UPDRS has 4 parts with a total summed score. Part I examines non-motor experiences of daily living. Part II examines motor experiences of daily living and is a self-administered questionnaire. Part III is the motor examination, administered by a trained practitioner. Part IV addresses motor complications by integrating patient derived information with the rater's clinical observations and judgments. Part III, the motor subscore, was used in this study. The administration of Part III takes approximately 20 minutes to administer (Goetz et al, 2008).

Disease Severity

Hoehn and Yahr classification (Hoehn & Yahr, 1967) was used to determine Disease severity. Only those participants in stage II or III of the Hoehn and Yahr classification were included in the study

Lower Extremity Anthropometrics

Lower extremity passive range of motion was assessed using a goniometer (Sammons Preston model #7514). The following motions were measured: hamstring length via a straight leg raise test, hip extension, knee extension, and dorsiflexion (Kendall, McCreary, & Kendall, 1983). In addition, gross assessment of hip flexion and plantarflexion were performed.

3.6.3 Second Testing Session: Participant set up and bicycling protocol

Subjects wore a Bluetooth enabled Polar Heart Rate monitor™. Retroreflective markers were placed on the participant and they were then seated on the bicycle. Participants were oriented to the protocol. Seat height was positioned at 100% of greater trochanter length (measured from the ground while standing barefoot) (Gregor, Broker, & Ryan, 1991). The foot was positioned with the ball of the foot on the pedal surface.

Bike parameters were set at 20 watts and constant power. Resting heart rate, respiratory rate and blood pressure was recorded prior to beginning the cycling protocol. Heart rate was monitored throughout. Subjects performed a warm-up on the bike for approximately 2 minutes to establish a stable rate that was consistently within +/-5 RPM. To establish their upper threshold of speed, at the end of the warm-up, the participant was asked to pedal as fast as they could for 20 seconds. After riding at the fast pace, participants were asked to return to a comfortable pace for approximately 2 minutes to establish the baseline rate.

Bicycle Trial Conditions

Participants performed 15 trials (1 minute each) of cycling divided into three blocks. The Feedback condition was included as the last trial of the visual cue condition. The auditory and visual blocks were counter balanced between subjects and trials 4 and 5 in the directed attention block were counterbalanced within the block. Counterbalancing of blocks and trials were used to minimize fatigue and learning effects. After each trial a VAS was used to gauge subject fatigue and ability to execute the cycling task, using the following sample question: *On a scale of 1(not difficult)-5(very difficult), how difficult was it to keep pace with the metronome in this trial? The same instructions, specific for each trial, were provided to each participant* (Tables 6-9).

Table 6. Cycling Trials: Auditory Condition

Trial	Description	Instructions to participant
Warm up Baseline	No AC No VE	*Look ahead of you. Start pedaling until you reach a comfortable speed.* *Continue pedaling until you are asked to stop.* **To establish subjects' capacity: after approximately 2 minutes, was ask to ride at the fastest pace they can for 20 seconds then return to a comfortable pace for approximately 2 minutes.*
Audio Cues	AC No VE	*Look ahead of you. Match your pedaling rate to the metronome beat. For example, every time you hear the beat, push down on the pedal with your right, left, right, left, etc.* *Continue to pedal until you are asked to stop.*
VE	No AC VE	*Look ahead of you at the road.* *Continue to pedal until you are asked to stop.*
Audio Cues + VE	AC (20% above baseline) VE	*Look ahead of you at the road.* *Match your pedaling rate to the metronome* *Continue to pedal until you are asked to stop.*

VE= virtual environment, AC= auditory cues

Table 7. Cycling Trials: Visual Cueing and Visual Feedback Conditions

Trial	Description	Instructions to participant
Warm up	No VE	*Look ahead of you* *Ride at a comfortable pace, one that you can keep up for a while* *Continue to pedal until you are asked to stop*
VE no VC	No VC VE	*Look ahead of you at the road. Continue to pedal until you are asked to stop.*
VE+VC20%	VC (real world placement) VE	*Look ahead of you at the road.* *Continue to pedal until you are asked to stop.*
VE 20% faster	VC (20% faster) VE	*Look ahead of you at the road. Continue to pedal until you are asked to stop.*

VC20% with instruction	VC (20% faster-cue to attend to VC) VE	*Look ahead of you at the road. Try to decrease the gray space between the markers. Continue to pedal until you are asked to stop*

VE= virtual environment, VC= visual cues, FB=visual feedback

Table 8. Cycling Trials: Feedback Condition

Warm up	No VE	*Look ahead of you* *Ride at a comfortable pace, one that you can keep up for a while* *Continue to pedal until you are asked to stop*
VE no VC	No VC VE	*Look ahead of you at the road. Continue to pedal until you are asked to stop.*
Feedback	FB VE	*Look ahead of you at the road. Your goal in this trial is to cycle at a rate that will make the marker turn from white to purple and to keep the change in color throughout the entire trial.* *Continue to pedal until you are asked to stop.*

VE= virtual environment, VC= visual cues, FB=visual feedback

Table 9. Cycling Trials: Directed Attention Condition

Trial	**Description**	**Instructions to participant**
Warm up	No VE	*Look ahead of you. Continue to pedal until you are asked to stop.*
VE	No cues VE	*Look ahead of you. Ride at your comfortable pace. Start pedaling and continue to pedal until you are asked to stop.*
AC +VC no instruction	AC +VE	*Look ahead of you. Continue to pedal until you are asked to stop.*
AC +VC attention to AC	AC +VC Attention directed to auditory cues.	*Look ahead of you. Match your cycling speed to the metronome beat. Continue to pedal until you are asked to stop.*
AC +VC attention to VC	AC+VC Attention directed to visual cues.	*Look ahead of you at the road. Look at the road markers. Continue to pedal until you are asked to stop.*

VE= virtual environment, AC= auditory cues, VC= visual cues, DA=directed attention

3.7 Data Analysis

To test for group differences on clinical tests and subject characteristics, a 1-way ANOVA was conducted. Means and standard deviations were calculated for dependent variables. Histograms were constructed to evaluate for normalcy and homogeneity of the distribution. A repeated measures factorial analysis of variance was performed separately for each condition (auditory, visual, feedback, and directed attention) to determine within and between group differences. When a significant effect was found, post hoc analysis was performed using a Bonferroni correction for multiple comparisons. Hypotheses were tested with either a one-tailed or two-tailed significance based on the evidence to support directionality. SPSS for Mac (Version 22) was used for all data analysis (Table 10).

Table 10. Statistical Comparisons

	Comparisons
1. Auditory Condition/ 4 levels	1a. VE only to AC only 1b. Baseline to AC +VE 1c. AC only to AC+VE 1d. VE only to AC +VE
2. Visual Condition/ 5 levels	2a. VE only to VE+VC 20% 2b. VE only to VE+VC 20% (instruction to attend to the visual cues) 2c. VE+VC 20% to VE+VC 20% (instruction to attend to the visual cues)
3. Feedback Condition/ 3 levels	3a. FB to Baseline 3b. FB to VE only 3c. FB to VE+VC 20% (instruction to attend to the visual cues)
4. Directed Attention Condition/4 levels	4a. VE only to AC +VC (no instructions to direct attention) 4b. VE only to AC +VC (attention directed to AC) 4c. VE only to AC +VC (attention directed to VC) 4d. AC +VC (attention directed to AC) to AC +VC (attention directed to VC)
5. Between Groups Comparisons	5a. Auditory Condition: To determine *between group* differences in mean rpm and kinematics for auditory condition, a 2 x 4 repeated measures ANOVA was conducted. 5b. Visual Condition: To determine *between group* differences in the mean rpm

	and kinematics between groups in the visual block, a 2 x 5 repeated measures ANOVA was conducted. 5c. Feedback Condition: To determine *between group* differences in the mean rpm and kinematics between groups in the feedback block, a 2 x 3 repeated measures ANOVA was conducted. 5d. Directed Attention Block: To determine *between group* differences in mean rpm and kinematics in the Directed Attention block, a 2 x 4 repeated measures ANOVA was conducted.

AC= auditory cues, VC= visual cues, FB=visual feedback, VE= virtual environment

3.7.1 Hypotheses and Statistical Analysis

Auditory Condition (AC)

Hypothesis 1: There will be an increase in pedaling rate between levels of the auditory condition within groups, healthy older adults and persons with PD.

Analysis: A repeated measures ANOVA followed by planned comparisons (Bonferroni) to explore within group differences in RPM for the following conditions:

Hypothesis1.a. AC only to VE only

Hypothesis1.a.1. The presentation of audio cues with no VE will result in an increase in pedaling rate in healthy older adults compared to the virtual environment alone.

Hypothesis1.a.2. The presentation of audio cues with no VE will result in an increase in pedaling rate in people with PD compared to the virtual environment alone.

Hypothesis 1.b. Baseline to AC+VE

Hypothesis 1.b.1. The presentation of auditory cues in a virtual environment will result in an increase in pedaling rate in healthy older adults compared to no VE and no auditory cues (baseline).

Hypothesis 1.b.2. The presentation of auditory cues in a virtual environment will result in an increase in pedaling rate in people with PD compared to no VE and no auditory cues (baseline).

Hypothesis1.c. AC only to AC+VE

Hypothesis1.c.1. The presentation of auditory cues in a virtual environment will result in an increase in pedaling rate in healthy older adults compared to auditory cues alone.

Hypothesis 1.c.2. The presentation of auditory cues in a virtual environment will result in an increase in pedaling rate in people with PD compared to auditory cues alone.

Hypothesis1.d. VE only to AC+VE

Hypothesis1.d.1. The presentation of auditory cues in a virtual environment will result in a increase in pedaling rate in healthy older adults compared to projection of the virtual environment alone.

Hypothesis1.d.2. The presentation of auditory cues in a virtual environment will result in a increase in pedaling rate in people with PD compared to projection of the virtual environment alone.

Visual Condition (VC)

Hypothesis 2: There will be an increase in cycling velocity between levels of the visual block within groups, healthy older adults and people with PD.

Analysis: A repeated measures ANOVA followed by planned comparisons (Bonferroni) to explore within group differences in RPM for the following conditions:

Hypothesis 2.a. VE only to VC 20% faster rate

Hypothesis 2.a.1. The presentation of visual cues at a 20% faster rate will result in an increase in pedaling rate in healthy older adults compared to presentation of the VE with no visual cues.

Hypothesis 2.a.2. The presentation of visual cues at a 20% faster rate will result in an increase in pedaling rate in people with PD compared to presentation of the VE with no visual cues.

Hypothesis 2.b. VE only to VC 20% faster rate (attend to the VC)

Hypothesis 2.b.1. The presentation of visual cues at a 20% faster rate with cueing to attend to the visual cues will result in an increase in pedaling rate in healthy older adults compared to presentation of the VE with no visual cues.

Hypothesis 2.b.2. The presentation of visual cues at a 20% faster rate with cueing to attend to the visual cues will result in an increase in pedaling rate in people with PD compared to presentation of the VE with no visual cues.

Hypothesis 2.c. VE 20% faster rate to VC 20% faster rate (attend to the VC)

Hypothesis 2.c.1. The presentation of visual cues at a 20% faster rate with cueing to attend to the visual cues in a virtual environment will result in an increase in pedaling rate in healthy older adults compared to presentation of the VE with visual cues presented at a 20% faster rate with no directed attention.

Hypothesis 2.c.2. The presentation of visual cues at a 20% faster rate with cueing to attend to the visual cues in a virtual environment will result in an increase in pedaling rate in people with PD compared to presentation of the VE with visual cues presented at a 20% faster rate.

Feedback Condition (FB)

Hypothesis 3: There will be a difference in cycling velocity and trunk and hip kinematics between levels of the Feedback condition within groups, healthy older adults and people with PD.

Analysis: A repeated measures ANOVA followed by planned comparisons (Bonferroni) to explore within group differences in RPM for the following conditions:

Hypothesis 3.a. FB to Baseline

Hypothesis 3.a.1. The presentation of visual feedback in a virtual environment will result in an increase in pedaling rate in healthy older adults compared to baseline.

Hypothesis 3.a.2. The presentation of visual feedback in a virtual environment will result in an increase in pedaling rate in people with PD compared to baseline.

Hypothesis 3.b. FB to VE only

Hypothesis 3.b.1. The presentation of visual feedback in a virtual environment will result in an increase in pedaling rate in healthy older adults compared to presentation of the VE with no visual cues.

Hypothesis 3.b.2. The presentation of visual feedback in a virtual environment will result in an increase in pedaling rate in people with PD compared to presentation of the VE with no visual cues.

Hypothesis 3.c. FB to VE+VC (20% faster rate with cueing to attend to the VC**)**

Hypothesis 3.c.1. The presentation of visual feedback in a virtual environment will result in a increase in pedaling rate in healthy older adults compared to visual cues presented at a 20% faster rate with cueing to attend to the visual cues.

Hypothesis 3.c.2. The presentation of visual feedback in a virtual environment will result in an increase in pedaling rate in people with PD compared to visual cues presented at a 20% faster rate with cueing to attend to the visual cues.

Directed Attention Condition

Hypothesis 4: There will be a difference in pedaling rate between levels of the directed attention condition within groups, healthy older adults and people with PD.

Analysis: A repeated measures ANOVA followed by planned comparisons (Bonferroni) to explore within group differences in RPM for the following conditions:

Hypothesis 4.a. VE only to AC+VC (no instructions to direct attention)

Hypothesis 4.a.1. The simultaneous presentation of both auditory and visual cues, will result in a difference in pedaling rate in healthy older adults compared to projection of the virtual environment alone.

Hypothesis 4.a.2. The simultaneous presentation of both auditory and visual cues will result in a difference in pedaling rate in people with PD compared to projection of the virtual environment alone.

Hypothesis 4.b. VE only to AC+VC (attention directed to AC)

Hypothesis 4.b.1. The simultaneous presentation of both auditory and visual cues, with attention directed to auditory cues, will result in an increase in pedaling rate in healthy older adults compared to projection of the virtual environment alone.

Hypothesis 4.b.2. The simultaneous presentation of both auditory and visual cues, with attention directed to auditory cues, will result in an increase in pedaling rate in people with PD compared to projection of the virtual environment alone.

Hypothesis 4.c. VE only to AC+VC (attention directed to VC)

Hypothesis 4.c.1. The simultaneous presentation of both auditory and visual cues, with attention directed to visual cues, will result in an increase in pedaling rate in healthy older adults compared to projection of the virtual environment alone.

Hypothesis 4.c.2. The simultaneous presentation of both auditory and visual cues, with attention directed to visual cues, will result in an increase in pedaling rate in people with PD compared to projection of the virtual environment alone.

Hypothesis 4.c. AC+VC (attention directed to AC) to AC+VC (attention directed to VC)

Hypothesis 4.c.1. The simultaneous presentation of auditory and visual cues, with attention directed to auditory cues, will result in an increase in pedaling rate in healthy older adults compared to the simultaneous presentation of both auditory and visual cues, with attention directed to visual cues.

Hypothesis 4.c.2. The simultaneous presentation of auditory and visual cues, with attention directed to auditory cues, will result in an increase in pedaling rate in people with PD compared to the simultaneous presentation of both auditory and visual cues, with attention directed to visual cues.

Hypothesis 5: (Between Group Comparisons)

Hypothesis 5a. The response to the presentation of auditory cues in a virtual environment will be less robust for pedaling rate in people with PD compared to healthy older adults.

Analysis: To explore between group differences, a 2 x 4 repeated-measures factorial ANOVA will be conducted.

Hypothesis 5.b. The response to the presentation of visual cueing in a virtual environment will result in a more robust response for pedaling rate in people with PD compared to healthy older adults.

Analysis: To explore between group differences condition, a 2 x 5 repeated-measures factorial ANOVA will be conducted.

Hypothesis 5.c. The response to the presentation of visual feedback in a virtual environment will result in a more robust response for pedaling rate in people with PD compared to healthy older adults.

Analysis: To explore differences between groups according to condition, a 2 x 3 repeated measures factorial ANOVA will be conducted.

Hypothesis 5.d.1. The simultaneous presentation of auditory and visual cues with attention directed to the auditory cues will result in an increase in pedaling rate in people with PD compared to healthy older adults.

Hypothesis 5.d.2 The simultaneous presentation of auditory and visual cues with attention directed to the visual cues will result in an increase in pedaling rate between people with PD compared to healthy older adults.

Analysis: To explore differences between groups according to condition, a 2 x 3 repeated measures factorial ANOVA will be conducted.

Hypothesis 6: Modulation of trunk and hip kinematics will be found in the 20% faster and feedback conditions for people with PD and healthy age-matched adults.

Analysis: Separate 2 x 3 repeated measures factorial ANOVAs followed by planned comparisons (Bonferroni) will be conducted to explore within and between group differences in kinematics for the following conditions: Baseline, 20% faster, and feedback.

Hypothesis 6a: There will be a relationship between some kinematic changes and RPM. There will be no relationship between some variables and RPM.

Analysis: To dissociate speed-related versus VE related changes in kinematics in people with PD and healthy age-matched adults, exploratory correlational analysis will be performed.

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Chapter 4: Paper 1

Auditory and visual cueing modulate cycling speed of older adults and person's with Parkinson's disease in a Virtual Cycling (V-Cycle) system

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Title: Auditory and visual cueing modulate cycling speed of older adults and persons with Parkinson's disease in a Virtual Cycling (V-Cycle) system

Abstract

Background: Evidence based virtual environments (VEs) that incorporate compensatory strategies such as cueing may change motor behavior and increase exercise intensity while also being engaging and motivating. The purpose of this study was to determine if people with Parkinson's disease and aged matched healthy adults responded to auditory and visual cueing embedded in a bicycling VE as a method to increase exercise intensity.

Methods: We tested two groups of participants, people with Parkinson's disease (PD) (n=15) and age-matched healthy adults (n=13) as they cycled on a stationary bicycle while interacting with a VE. Participants cycled under 2 conditions: auditory cueing (provided by a metronome) and visual cueing (represented as central road markers in the VE). The auditory condition had four trials in which auditory cues or the VE were presented alone or in combination. The visual condition had 5 trials in which the VE and visual cue rate presentation was manipulated. Data were analyzed by condition using factorial RMANOVAs with planned t-tests corrected for multiple comparisons.

Results: There were no differences in pedaling rates between groups for both the auditory and visual cueing conditions. People with PD increased their pedaling rate in the auditory (F 4.78, $p=0.029$) and visual cueing (F 26.48, $p<0.000$) conditions. Age-matched healthy adults also increased their pedaling rate in the auditory ($F=24.72$, $p<0.000$) and visual cueing ($F=40.69$, $p<0.000$) conditions. Trial-to-trial comparisons in the visual condition in age-matched healthy adults showed a step-wise increase in pedaling rate ($p=0.003$ to $p<0.000$). In contrast, people with PD increased their pedaling rate only when explicitly instructed to attend to the visual cues ($p<0.000$).

Conclusions: An evidenced based cycling VE can modify pedaling rate in people with PD and age-matched healthy adults. People with PD required attention directed to the visual cues in order to obtain an increase in cycling intensity. The combination of the VE and auditory cues was neither additive nor interfering. These data serve as preliminary evidence that embedding auditory and visual cues to alter cycling speed in a VE as method to increase exercise intensity that may promote fitness.

Keywords—Virtual environments, virtual reality, motor learning, cueing, bicycling, exercise intensity, Parkinson Disease, older adults

Introduction

Exercise is essential for people with Parkinson's disease (PD) and older adults to maintain optimal health (Garber et al., 2011). However, barriers to exercise such as poor health and unsafe exercise environments (Elsworth et al., 2009; Schutzer & Graves, 2004) an affect motivation and result in an overall decrease in physical activity (Turnbull & Millar, 2006). Therefore, there is a need to find safe, available, and engaging exercise programs for these populations.

The American College of Sports Medicine recommends that adults of all ages, including those with chronic disease or disabilities, engage in continuous moderate or vigorous exercise on a regular basis to ensure optimal health (Garber et al., 2011). Regular physical activity is associated with numerous health benefits in all adults including improvements in cardiovascular, motor, and cognitive function (Van Wegen, Hirsch, Juiskamp, & Kwakkel, 2014; Hotting & Roder, 2013; Kraft, 2012; Seidler et al., 2010; Hirsch & Farley, 2009; van Praag, 2009). In people with PD, exercise may also be neuroprotective, and help decelerate the disease process (Van Wegen et al., 2014; Alonso-Frech, Sanahuja, & Rodriguez, 2011; Morris, Martin, & Schenkman, 2010).

Many factors, such as exercise timing, type, and intensity, determine the extent of benefit of exercise (Garber et al., 2011; Van Wegen et al., 2014). High intensity exercise when compared to low intensity exercise has been shown to promote greater cardiovascular, metabolic and musculoskeletal health for older adults and greater motor function for people with PD (Petzinger et al., 2013). Specifically for people with PD, high intensity treadmill training studies have demonstrated improvements in muscle activation, motor function, mobility, gait, and quality of life (Rose, Lokkegaard, Sonne-Holm, & Jensen, 2013b; Rose, Lokkegaard, Sonne-Holm, & Jensen, 2013a; Herman, Giladi, Gruendlinger, & Hausdorff, 2007), as well as evidence of neuroplastic changes when cognitive challenges were introduced (Fisher et al., 2008). Importantly, these studies also show that people with PD can tolerate exercise at high intensities (Rose et al., 2013b; Fisher et al., 2008).

Stationary cycling is a viable form of aerobic exercise that is safe and commonly used in healthy and patient populations, including people with PD, to improve cardiovascular fitness while minimizing joint stress (Hirsch & Farley, 2009; Johnston, 2007). In fact, people with PD can often ride a bike even after their ability to walk is compromised (Snijders, van Kesteren, & Bloem, 2012).

High intensity cycling studies in people with PD are based on studies in animal models that show high intensity exercise improves motor function, and is also neuroprotective (Ridgel, Vitek, & Alberts, 2009; Ridgel, Peacock, Fickes, & Kim, 2012). Early studies by Ridgel and colleagues investigated 'forced-use', or high intensity cycling that employed a tandem bicycle to force a pedaling rate an average 30% faster than the voluntary pedaling rate of participants with PD. Mitigation of symptoms such as tremor, rigidity, and bradykinesia were found (Ridgel et al., 2009). More recent studies found that a single session of high intensity active assisted cycling reduced tremors and improved bradykinesia in persons off medication (Ridgel et al., 2012). In a 2015 study, 3 sessions of high intensity cycling improved motor symptoms in not only the lower, but the upper extremities as well. In addition, a decrease in Timed Up and Go scores brought participants from a high fall risk to a no fall risk range (Ridgel, Phillips, Walter, Discenzo, & Loparo, 2015). These results suggest that pedaling at a high rate may improve symptoms of PD and supports the use of high intensity exercise as an alternative to medication to manage symptoms.

Virtual environments (VE) are simulations of real world environments that provide complex multisensory information to the user (Adamovich, August, Merians, & Tunik, 2009; Holden, 2005) in a safe, engaging, and motivating context (Merians, Fluet, Qiu, Lafond, & Adamovich, 2011). Virtual environments and serious games (using game theory and game mechanics to address a serious purpose such as education or rehabilitation, in contrast to recreation) have been successful in improving mobility and physical activity in healthy people and people with PD (Pompeu et al., 2012; Mirelman et al., 2011; Griffin et al., 2011; Adamovich et al., 2009; van Wegen et al., 2006). People with PD have difficulty generating appropriate effort when moving and show reduced amplitude of movement compared to their healthy counterparts (Jankovic, 2008). External cues may compensate for defective internal mechanisms that cause these deficiencies and result in more normal execution of movement (Morris et al., 2010). Virtual environments can be tailored to incorporate compensatory techniques such as cueing, and motor learning principles such as the provision of feedback, repetition, and high intensity training. For example, an 8-week training program using a cycling VE developed by Deutsch et al. (2013) successfully improved fitness levels in people post-stroke (Deutsch et al., 2013).

External cueing, both auditory and visual, have been found to positively affect motor behavior in healthy people and in people post-stroke and with PD not only in real-world settings (Mak, Yu, & Hui-Chan, 2013; Rochester et al., 2010; Nieuwboer et al., 2007) but also in VEs (Mirelman et al., 2011; Mirelman, Patritti, Bonato, & Deutsch, 2010). An important consideration when studying the influence of a VE on motor behavior is the role of optic flow, the visual perception of movement produced by a person's own actions (Azulay, Mesure, & Blin, 2006). Optic flow provides powerful information that influences the speed and direction of movement during walking in older adults (Prokop, Schubert, & Berger, 1997; Warren, 2001; Powell, Hand, Stevens, & Simmonds, 2006; Chou et al., 2009), in people post-stroke (Lamontagne, Fung, McFadyen, & Faubert, 2007), and people with PD (Lebold & Almeida, 2011), and also in cycling in older adults (van Veen, Distler, Braun, & Bulthoff, 1998; Sun, Lee, Campos, Chan, & Zhang, 2003) and people post-stroke (Gade, Gallagher, Maiden, Patel, & Deutsch, 2013).

Visual cueing in a VE has been shown to modulate and be independent of optic flow (van Wegen et al., 2006). Van Wegen et al. (2006) investigated the influence of visual cues on stride frequency and walking velocity in healthy older adults and people with PD on a treadmill (van Wegen et al., 2006). Due to an increased reliance on vision in people with PD (Schubert, Prokop, Brocke, & Berger, 2005; Azulay et al., 1999), the possibility of a suppressive effect when the VE was presented with the visual cue (a rhythmic flashing light) existed. However, participants were able modulate their stride frequency when the visual cues were presented with the VE, indicating that the presence of the VE did not interfere with the ability to respond to the external cues

(Adamovich et al., 2009).

Coupling auditory cues and optic flow in a VE has been studied in walking (Powell, Stevens, Hand, & Simmons, 2010). Powell et al., sought to determine if auditory cueing presented in a VE would influence gait speed in healthy adults while walking on a treadmill (Powell et al., 2010). The VE and auditory cues were presented alone and in combination; three audio cue rates were used: 75%, 100% and 125% of baseline speed. The addition of optic flow to the fast and slow audio cue conditions resulted in a significant decrease in walking speed compared to the audio cue only condition, suggesting an increased demand on cognitive resources for motor execution in the presence of a VE. The influence of auditory or visual cueing embedded in a cycling VE has not been investigated. Therefore, it is unknown if there will be a suppressive or additive effect. Investigating these potential interactions is one of the purposes of this study.

In summary, VEs provide clinicians with a tool to train and rehabilitate people with PD and healthy older adults, and may serve to optimize motor learning and fitness in a rehabilitation setting. However, despite the evidence to support the use of VEs to improve gait and for exercise promotion, there is no direct evidence to support the efficacy of external cueing embedded in a virtual cycling environment for fitness and activity promotion. Therefore, an evidence-based virtual cycling environment embedded with auditory and visual cues was developed to determine if pedaling rate would increase in people with PD and age-matched healthy older adults. While between-group comparisons were measured, our primary interest was comparisons within-groups. We also sought to determine if there would be interference or an additive effect between auditory cues and the VE, and if people with PD would show a stronger response than the age-matched healthy adults to the visual cues. Secondarily we confirmed the validity of the VE by measuring if the percent increase in cycling was proportional to the augmented cues.

Based on evidence from the literature, we hypothesized that both groups would respond to the auditory and visual cueing by increasing pedaling rate, and that age-matched healthy adults would pedal at a faster rate under all conditions compared to people with PD. We also hypothesized that people with PD would respond more strongly to visual cues than age-matched healthy older adults. When auditory and visual cueing were combined, we proposed a non-directional hypothesis due to the possibility of either an interference or additive effect. We also expected that the increase in pedaling rate for both groups would be proportionate to cue rate.

Methods

Study Design

This study used a cross sectional design. Eligible participants consisted of people with PD and age-matched healthy adults. The Institutional Review Board at the New York Institute of Technology and Rutgers University School of Health Professions approved this work. All participants provided written informed consent prior to participation.

V-CYCLE System

The virtual reality cycling system, V-CYCLE, consists of an evidenced-based custom designed VE, computer, projector display of the VE on a screen, desktop speakers, upright stationary bicycle, revolutions per minute (RPM) sensor, and heart rate monitor.

A. Unity Game Design

The VE was built specifically for this study using the free version of Unity 4.3™. Factors embedded in a VE can facilitate or hinder motor behavior (Powell & Stevens, 2013). Therefore elements in the V-CYCLE environment were chosen after careful review of the literature and based on their ability to influence self-perception of motion.

- **Field of view**: a wide field of view incorporates visual cues in the periphery, thereby improving perception of self-motion and immersion. The ideal field of view is between 80 and 200 degrees (Powell & Stevens, 2013). The field of view in the V-CYCLE environment was 80 degrees.
- **Spatial frequency between objects**: Manipulating the spatial frequency between objects in the environment gives the user a sense of moving faster or slower through the environment (Holden, 2005; Banton, Stefanucci, Durgin, Fass, & Proffitt, 2005). We decreased the spatial frequency between the central road markers (our visual cue) from a real-world distance apart to a 20% faster presentation rate.

- **Color contrast and texture:** A high color contrast and the inclusion of texture in the environment improve the user's self-perception of motion (Stone & Thompson, 1992). We ensured a high color contrast between the road, sky and grass, and movement of the foliage supplied texture.
- **Scale of objects:** Objects scaled to real-world proportions influence self-perception of motion (Nieuwboer et al., 2007; Powell & Stevens, 2013). The objects in our environment were scaled to real-world proportions.

The scenery, consisting of a road, mountains, trees and sky, was designed using the default terrain editor of Unity 4.3 with a first person perspective view (Figure 1). The goal of the design process was to create an open straight road surrounded by mountains with an adequate field of view and variability in the scenery.

The models and avatars used during the design were purchased or downloaded from the Unity asset store. Rendering was done using the built in renderer for terrain, and Skybox for the clouds and sky. The input manager was used to accept keyboard controls for pausing, quitting, and manual override functions for control of the avatar. Scripts within Unity were written in C++ to customize and have control over the VE during the trial. The RPM (Wahoo RPM sensor) and heart rate (Polar HR7) data were collected and recorded independent of Unity using a Wahoo SDK and saved as a .CSV file. This file was used to read the pedal RPM data from the Wahoo sensor to control the speed of the rider. The linear distance covered by the bike/minute in the VE was calculated as (2π * radius of wheel) * RPM. The status of data collection and timer was controlled using a C++ script. The virtual environment utilized the RPM data from the .CSV output file to control the speed of the avatar in the VE. A real-world two lane road is approximately 24 feet wide. The base of the road in this VE was 7 feet, 10 inches. This resulted in a scaled down factor of approximately 3.5

Insert Figure 1

Auditory and Visual Cueing

Auditory cueing was provided by a metronome set at a rate 20% faster than the pedaling rate of the subject. The 20% rate was based on the walking literature (Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004; McIntosh & Rice, 1997) as well as preliminary trials performed by the investigators on 3 healthy and 3 people with PD to determine a physiological upper limit of pedaling rate. Visual cueing was in the form of central road markers in the VE, scaled to represent a real road.

B. V-Cycle set up

An upright stationary bicycle (Cybex model #750C) was used in this study. A Wahoo cadence sensor attached to the crank of the bike pedal measured the pedal RPM and transferred the data via Bluetooth™. An Epson (Model 485Wi) short throw projector was used to project the environment onto a flat wall, approximately 5 feet in front of the bicycle, resulting in an equivalent screen size of 94-inches (43 X 83 inches) with a horizontal field of view of 80 degrees (Figure 2). A pair of Logitech desktop speakers connected to an IPhone metronome application was used for trials with audio cueing.

Insert Figure 2

C. **Participants**

Twenty-eight participants, 15 people with PD (66.3 +/- 9.6 years; Hoehn &Yahr (H&Y) stages II and III) (Hoehn & Yahr, 1967) and 13 age-matched healthy adults (66.7 +/- 9.1, years), voluntarily participated in the study. Participants were recruited through flyers, referral, and exercise groups. Age-matched healthy adults were spouses or friends of participants with PD. Telephone or in-person interviews were used to screen for eligibility. Participants were included if they were 50 to 85 years inclusive, able to ride a stationary upright bicycle and had a Montreal Cognitive Assessment (MoCA) (Hoops et al., 2009) score >/= 24. Participants with PD were included if they were diagnosed by a neurologist as having PD and were in stage II-III H&Y (Hoehn & Yahr, 1967). Participants were excluded if they had: 1. severe hearing or visual deficit including color blindness; 2. history of stroke, traumatic brain injury or neurological disorder other than PD; 3. unstable medical condition including musculoskeletal disorders such as severe arthritis, knee surgery, hip surgery; or any other condition that the investigators determine would impair the ability to ride a stationary bicycle; 4. medical or musculoskeletal contraindications to exercise. Participants with PD were excluded if they had incapacitating tremors or dyskinesias that would limit ability to ride a stationary bicycle.

D. Procedure

Participants attended two testing sessions lasting approximately 1 hour each. The first characterized the participants by measuring: age, gender, mental status, and lower extremity range of motion. Participants with PD were clinically rated by a trained examiner on the H&Y scale (Hoehn & Yahr, 1967) and the Motor subsection (part III), of the Unified Parkinson's Disease Rating Scale (UPDRS) (Goetz et al., 2008).

The second session consisted of the bicycling protocol. Participants were seated on the bicycle with the seat height adjusted between 100% and 110% of the length from the greater trochanter to the floor (measured without shoes) (Gregor et al., 2002). After a 5-minute warm-up, participants performed 9 trials (1 minute each) of cycling divided into 2 blocks, Auditory (4 trials) and Visual (5 trials) (See Tables 1 and 2 for the description of trials). Each block included a baseline condition (cycling without a VE or cues) to ensure that pedaling rate changes were assessed relative to each block. Block order was counterbalanced between participants. To ensure the same frame of reference from one trial to the next, the order of trials was maintained within each block. This method of trial presentation has been used in similar studies (van Wegen et al., 2006).

The 1-minute trial length was chosen to capture short-term changes in cycling behavior while minimizing the effects of fatigue on cycling rate. The Borg scale (Borg, 1970) was used as a rate of perceived exertion and was shown to participants immediately after completing a trial. Heart rate was monitored throughout. Readiness to continue to the next trial was determined when heart rate returned to no more than 10 beats above the warm up rate. Rest between trials ranged from 1 to 3 minutes.

Insert Table 1 and Table 2

Outcome measures

The primary outcome measure was pedaling rate measured as RPMs. Pedaling rate was continuously recorded via a Bluetooth cadence sensor attached to the crankshaft of the pedal. Average cadence over the 1-minute trial was calculated and used for data analysis. The first 5 seconds of each trial were not included in the analysis to allow participants to stabilize their cycling rate.

E. Data Analysis

Descriptive analyses were performed on patient characteristics: age, gender, cognitive status, disease stage, and motor assessment. Differences between groups for baseline characteristics were tested with independent t-tests. Means and standard deviations were calculated for RPM with an alpha level of 0.05 and corrected for multiple planned comparisons using a Bonferroni correction.

Auditory Condition:

A 2x5 (group x condition) repeated measures factorial ANOVA was conducted to determine between and within group differences for the auditory condition. The alpha level was corrected based on the following 5 planned comparisons: baseline to auditory cues, baseline to VE, baseline to auditory cues + VE, auditory cues to auditory cues + VE, VE to auditory cues + VE. To determine if the change in pedaling rate was proportional to the auditory cue rate (a 20% increase) the percent change from baseline to each condition was calculated.

Visual Condition:

A 2x4 repeated measures factorial ANOVA was conducted to determine between and within group differences for the visual condition. The corrected alpha level in the visual condition was based on the following 4 planned comparisons: baseline to VE, VE to VE with visual cues, VE to VE with visual cues to 20% faster visual cues, 20% faster visual cues to VE with instruction. To determine if the change in pedaling rate was proportional to the visual cue rate (a 20% increase) the percent change from baseline to each condition was calculated. IBM SPSS (Version 22) was used for all analyses.

Results

Participants

Fifteen people with PD and 13 age-matched healthy adults participated in the study. There were no significant differences in age or cognitive status between the two groups (Table 3). Participants with PD were in stage II or III on the H&Y scale (Hoehn & Yahr, 1967).

Insert Table 3

E. Auditory Condition

There was a significant main effect for cue, with no group or interaction effects. Age-matched healthy adults pedaled at a faster, albeit non-significant, rate than persons with PD in all conditions. Within group comparisons showed that both groups significantly increased their pedaling rate in the Auditory Condition ($F=24.72$, df 1.7 $p<0.000$). Compared to baseline, both groups increased their pedaling rate with the presentation of auditory cues; people with PD, $p<0.000$; age matched healthy adults, $p<0.000$, and when auditory cues were presented with the VE; people with PD: $p<0.000$; age matched healthy adults $p<0.002$. People with PD responded with an increase in pedaling rate to the presentation of the VE compared to baseline ($p<0.000$) whereas the age-matched healthy adults did not ($p=0.017$) (Figures 3 and 4). Expected and observed changes in cycling speed are presented in Table 4.

Insert Figures 3 and 4
Insert Table 4

F. Visual Condition

There was a significant main effect for cue, with no group or interaction effects. Age-matched healthy adults pedaled at a faster rate than people with PD in all conditions showing a trend toward significance ($F=4.00$, df 1, $p= .056$). Within group comparisons showed that both groups significantly increased their pedaling rate

(F=40.69, df 4, p< 0.000). Comparisons within trials exclusive of baseline revealed that age-matched healthy adults increased their pedaling rate with each successive trial, but people with PD increased their pedaling rate only when explicitly instructed to attend to the cues (p=0.000) (Figures 5 and 6).

The expected and observed changes in pedaling rate are presented in table 4. The largest increase in pedaling rate for both groups (PD, 35% and age-matched healthy adults, 25%) was in the VE +VC 20% with instruction condition.

Insert Figures 5 and 6
Insert Table 5

Discussion

The primary aims of this study were to develop and validate an evidenced based cycling VE (V-CYCLE) embedded with auditory and visual cues, and to determine if these cues influenced pedaling rate in people with PD and age-matched healthy adults. Validity of the V-CYCLE was demonstrated as persons with PD and age-matched healthy adults modified their cycling behavior in response to the manipulations in the VE. While the groups did not differ, both groups increased their pedaling rate when compared to baseline.

Auditory Condition

The main findings in the auditory condition are that people with PD and age-matched healthy adults increased their pedaling rate compared to baseline, and there was no interference effect when the auditory cues were presented with the VE. The increase in pedaling rate in both groups agrees with our hypothesis and aligns with the literature that healthy people can match their walking speed to an auditory cue (McIntosh & Rice, 1997; Dickstein & Plax, 2012; Hausdorff et al., 2007; Willems et al., 2006). However, in contrast to the walking literature, there was no interference for either group when the VE and auditory cues where presented simultaneously (Powell et al., 2010).

The lack of interference found in this study may be attributed to a variety of reasons. First, elements in the periphery of a VE provide important peripheral cues that help increase immersion of the user in the environment. These cues also are also known to increase self-perception of motion (Powell & Stevens, 2013). The stimulus in this environment may have been weak due to a lack of peripheral cues and thus no interference effect was found. Alternatively, this finding may be explained by general differences between walking and cycling. In walking, one receives proprioceptive information regarding position while translating through space. This information contributes to muscle coordination and plays a role in the automaticity of walking (Clark, Christou, Ring, Williamson, & Doty, 2014). During stationary cycling, there is no translation, and therefore proprioceptive inputs and response to these inputs may differ. A second explanation is that in cycling, angular momentum of the pedaling apparatus may keep the legs moving along (Snijders et al., 2012) thereby off-setting any slowing down in pedaling rate from the VE. Lastly, there may have been an order effect due to the non-randomization of trials within each block. Participants heard the auditory cue in the first trial and may have continued to attend to it when the VE was presented.

Visual Condition

Both people with PD and age-matched healthy adults increased their pedaling rate in most trials compared to baseline. Their patterns however, differed. People with PD significantly increased their pedaling rate with just the viewing of the VE but age-matched healthy adults did not. This is in agreement with our hypothesis and the literature that states people with PD are more reliant on visual stimuli (Schubert et al., 2005). The stimulus of the optic flow with the VE alone stimulated a higher cycling rate for people with PD and not age-matched healthy adults.

People with PD responded to the visual cues only when explicitly instructed to attend to the cues and not in the implicit cue conditions. The use of explicit instructions to augment motor performance is well demonstrated in the PD literature (Van Wegen et al., 2014; Morris, Iansek, Matyas, & Summers, 1996). Morris et al., in 1996 investigated the effects of visual cue training on the ability to walk to normal gait parameters (Morris et al., 1996). Normalization of gait was found when subjects were explicitly instructed to attend to the markers, "step over the markers and walk to the end of the walkway". Similarly, van Wegen et al. (2006) found that explicit instruction to attend to visual cues modulated stride frequency while maintaining walking velocity in people with PD (van Wegen et al., 2006). Our findings, and the evidence in the literature, have implications for adding explicit messages into a VE to increase the likelihood of achieving the target motor behavior.

As expected, age-matched healthy adults responded to progressively faster visual cues, while people with PD did not. This may be because the increase in optic flow speed preferentially influenced pedaling rate in age-matched healthy adults. This finding is in agreement with the literature that states that decreasing the spatial frequency between objects in a VE gives the impression of moving faster through the environment (Holden, 2005; Banton et al., 2005). This finding also suggests that stimuli in the VE alone may not have been salient enough to produce a response in people with PD. Alternatively, unless explicitly instructed to attend to a cue, people with PD were not able to process the stimuli fast enough.

Contrary to our hypothesis, age-matched healthy adults did not pedal significantly faster than people with PD in either the auditory or the visual condition. This may be explained in part by the high functioning persons with PD that were studied. The difference in the performance under the visual condition approached significance, with age-matched healthy adults pedaling faster than people with PD. However, the percent change from baseline was greater for people with PD.

Limitations

When designing a VE, embedded elements may facilitate or hinder motor behavior (Powell & Stevens, 2013). The following factors may have affected the degree of immersion that participants experienced and explain the lack of interference that is found in walking studies (Azulay et al., 1999). For example, the size of the field of view influences a participants' degree of immersion and perception of self-motion (Sun et al., 2003; Powell & Stevens, 2013), which can limit the ability to appropriately respond to elements in the environment. The field of view in the V-CYCLE was 80 degrees, which is at the lower limit of ideal size (80 to 120 degrees) (Powell & Stevens, 2013). However, our VE was designed for use in a clinical setting where space may be limited.

Using a monoscopic rather than a stereoscopic projection may have influenced behavior of our participants. A stereoscopic projection provides separate images to each eye thereby increasing depth perception. This in turn increases self-motion perception and sense of immersion in the environment (Powell & Stevens, 2013). A monoscopic projection was chosen for this study because of its ease of use and lower cost, and therefore more amenable to the clinical setting.

The use of horizontal rather than vertical lines as a visual cue may have also influenced cycling behavior. Our simulation was adapted from the walking literature, which typically use lines oriented perpendicular to the walking progression (van Wegen et al., 2006; Morris et al., 1996; Luessi, Mueller, Breimhorst, & Vogt, 2012; Morris, Iansek, Matyas, & Summers, 1994). The visual cues in the V-CYCLE were oriented vertical to the scene to make the environment ecologically valid. Although the vertical orientation of the cues did not appear to limit performance, future designs may specifically test if visual cues perpendicular to the line of progression augment the performance of people with PD.

An order effect cannot be ruled out because the trials within each block were administered in the same order. This is especially true for the visual block where the last condition in the block had the greatest increase in pedaling rate. However, in the auditory block, we did not observe a pattern of change that could be explained by order.

Other factors that may have influenced pedaling rate include that participants may have warmed up, resulting in a faster pedaling rate over time, or, the short trial length of one minute may not have given participants enough time to adjust to the stimulus. Future studies should include trials of longer length.

The auditory and visual blocks were not parallel comparisons. However, in designing the protocol, we were interested in the effects of optic flow without, then with, VCs in the visual condition resulting in an additional trial compared to the auditory condition. Regardless, an added trial in the auditory condition (auditory cues at baseline speed) would remedy this.

Feedback from participants as well as the investigators' observations suggested several additions to the existing VE in order to increase engagement and promote longer-term use. These include variations in scenes and terrain, with the addition of curves and obstacles. A few participants remarked that they would have enjoyed the scene more if the road had curves in it. Obstacles embedded in the environment such as an animal crossing the road, or children playing on the side of the road would have made navigating the environment more challenging. In fact, one participant remarked that they were "…waiting for an object to pop out in front of them on the road". For the purpose of this study however, the goal was to understand the role of visual and auditory cueing without confounding the response with other visual stimuli. The careful assessment of single features in a VE used in this study is a proposed strategy to progressively build evidence-based environments.

Conclusions

In this study, the walking literature was adapted to cycling to determine if short-term changes in motor behavior could be achieved by embedding auditory and visual cues in a cycling VE, with the ultimate goal of promoting long-term changes to promote fitness. Our findings validate that a virtual cycling environment embedded with auditory and visual cues can modulate pedaling rate in age-matched healthy adults and people with PD. Of clinical importance is the need to explicitly instruct persons with PD to attend to the visual cues to increase the response to the environment. This creates interaction between the clinician, patient, and VE, and indicates that VEs are not static but can be modified by the clinician by explicitly directing attention to a salient cue to modify a response.

The semi-immersive and simple environment that was created provided a strong enough stimulus to produce a response from both groups. This is important when choosing to implement this method in a clinic where space may be at a premium. In addition to the role of cueing in a cycling VE, the investigators have also assessed the role of feedback and directed attention, which complement the findings reported here.

Abbreviations

ANOVA: Analysis of variance; H&Y: Hoehn and Yahr; MoCA: Montreal cognitive Assessment; PD: Parkinson's disease; RPM: revolutions per minute; VE: Virtual environment; UPDRS: Unified Parkinson's disease Rating Scale

Declarations

Ethics approval and consent to participate

The Institutional Review Board at the New York Institute of Technology and Rutgers University School of Health Professions approved this work. All participants provided written informed consent prior to participation.

Consent for publication

Consent provided upon request

Availability of data and material

The data sets during and/or analyzed during the current study are available from the corresponding author upon request.

Competing interests

The authors declare that they have no competing interests

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Author's contributions

RG, JD, and HD conceived the study, developed and implemented the experimental design, defined the data analysis methodologies, collected the data, conducted the data and statistical analysis, interpreted the results, and drafted the manuscript. RG also selected the subjects and coordinated data collection. WW co-conceived the study, participated in the design, and assisted in coordination of data collection. WP participated in the design of the study and drafting of the manuscript. All authors read and approved the final manuscript.

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Tables

Table 1. Auditory Cueing: Description of trials

Trial	Instructions to participant
Baseline	*Look ahead of you. Start pedaling until you reach a comfortable speed.*
AC	*Look ahead of you. Match your cycling speed to the metronome.*
VE	*Look ahead of you at the road.*
AC + VE	*Look ahead of you at the road. Match your cycling speed to the metronome.*

Baseline=no VE, no cueing, VE= virtual environment without auditory cues AC= auditory cues without a VE

Table 2. Visual Cueing: Description of trials

Description	Instructions to participant
Baseline	*Look ahead of you.* *Ride at a comfortable pace.*
VE	*Look ahead of you at the road.*
VC	*Look ahead of you at the road.*
VC 20% faster	*Look ahead of you at the road.*
VC 20% faster with instruction	*Look ahead of you at the road. Try to decrease the gray space between the markers.*

Baseline=no VE, no cueing, VE= virtual environment, VC= visual cues, 20% faster (spacing between markers decreased by 20% compared to previous trial)

Table 3. Participant Characteristics (N=28)

	Parkinson's Disease n=15		Age-matched healthy n=13	
Characteristic	Mean (SD)	Range	Mean (SD)	Range
Age (y) mean (SD)	66.3 (9.6)	50-80	66.7 (9.1)	50-81
Gender (M/F)	13/2	------	7/6	------
MoCA	26.3 (1.9)	24-29	27.1 (2.3)	24-30
H&Y	2.3 (0.5)	2-3	------	------
UPDRS-Motor	35.5 (14.2)	8-56	------	------

MoCA: Montreal Cognitive Assessment. H&Y: Hoehn and Yahr Scale.
UPDRS III Unified Parkinson's disease Rating Scale Part III Motor subsection

Table 4. Auditory Condition: Expected and Observed RPM changes

Condition	Parkinson's Disease		Age Matched Healthy Adults	
	Expected (%)	Observed (%)	Expected (%)	Observed (%)
Baseline to AC	↑ 20	19	↑ 20	15
Baseline to VE	↑ baseline	14	↑ baseline	7
Baseline to AC+VE	unknown	18	↑ baseline	17
AC to AC+VE	unknown	-1	unknown	2

baseline: increase from baseline rate but of unknown magnitude
unknown: additive effect (positive) or interference effect (negative)

Table 5. Visual Condition: Expected and Observed RPM changes

Condition	Parkinson's Disease		Age Matched Healthy Adults	
	Expected (%)	Observed (%)	Expected (%)	Observed (%)
Baseline to VE	↑ baseline	13	↑ baseline	7
VE to VE + VCs	↑ baseline	9	↑ baseline	16
VE to VE + 20% faster VCs	↑ 20	15	↑ 20	12
VE to 20% faster VCs + instruction	↑ 20	35	↑ 20	25

baseline: increase from baseline rate but of unknown magnitude

Figure Captions:

1. Figure 1. The VE without (L) and with (R) road markers, which are the visual cues (VE+VC). Road markers were presented at the baseline cycling rate of the participant then increased by 20%.
2. Figure 2. V-CYCLE System set up. The virtual environment displayed via a short throw projector, was projected onto a flat wall approximately 5' in front of the participant.
3. Figure 3. Auditory condition, PD: Mean (SE) RPMs. There was a significant increase in pedaling rate from baseline to all conditions.
   *Corrected alpha p=/<0.01
4. Figure 4. Auditory condition, Older Adults: Mean (SE) RPMs. There was a significant increase in pedaling rate from baseline with ACs and ACs combined with the VE.
   *Corrected alpha p=/<0.01
5. Figure 5. Visual condition, PD: Mean (SE) RPMs. There was a significant increase in pedaling rate between trials when the VE was added and when instructed to attend to the VC.
   *Corrected alpha, p=/<0.01
6. Figure 6. Visual condition, Older Adults: Mean (SE) RPMs. There was a significant increase in pedaling rate between trials when VC were added to the VE, when the VC were presented at a faster rate, and when instructed to attend to the VC.

*Corrected alpha, p=/<0.01

Figures:

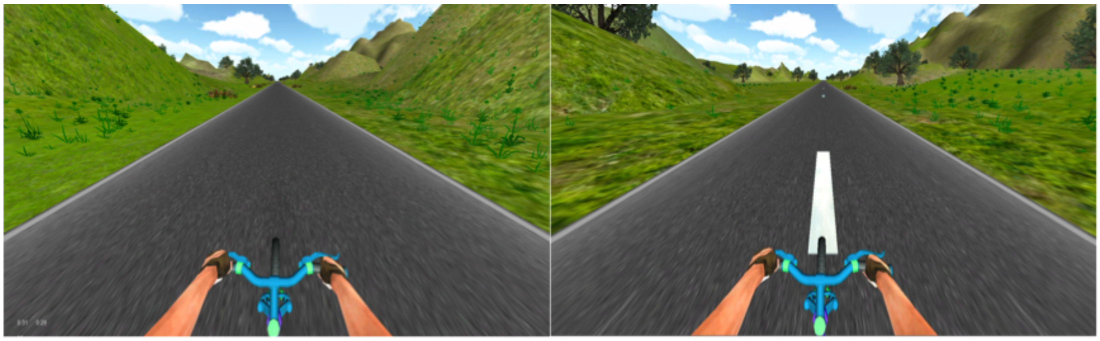

Figure 1. The VE without (L) and with (R) road markers, which are the visual cues (VE+VC). Road markers were presented at the baseline cycling rate of the participant then increased by 20%.

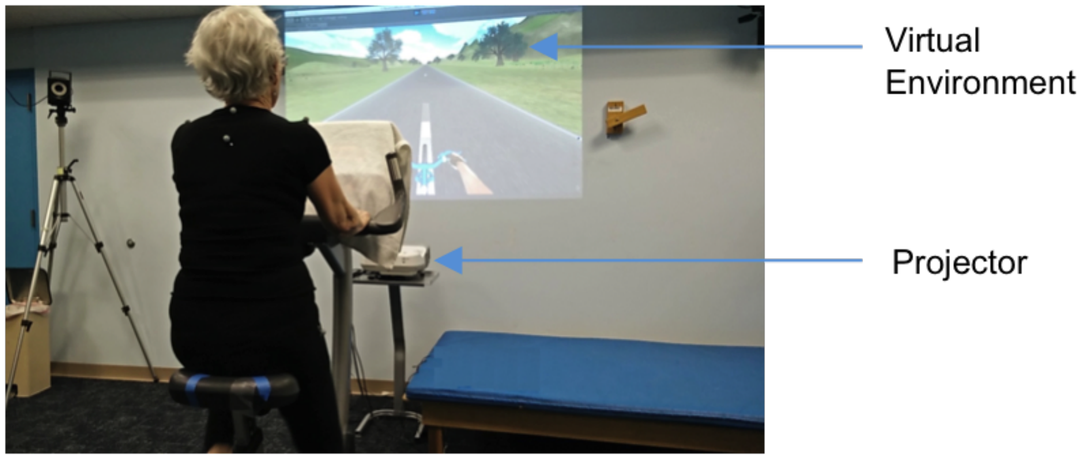

Figure 2. V-CYCLE System set up. The virtual environment displayed via a short throw projector, was projected onto a flat wall approximately 5’ in front of the participant.

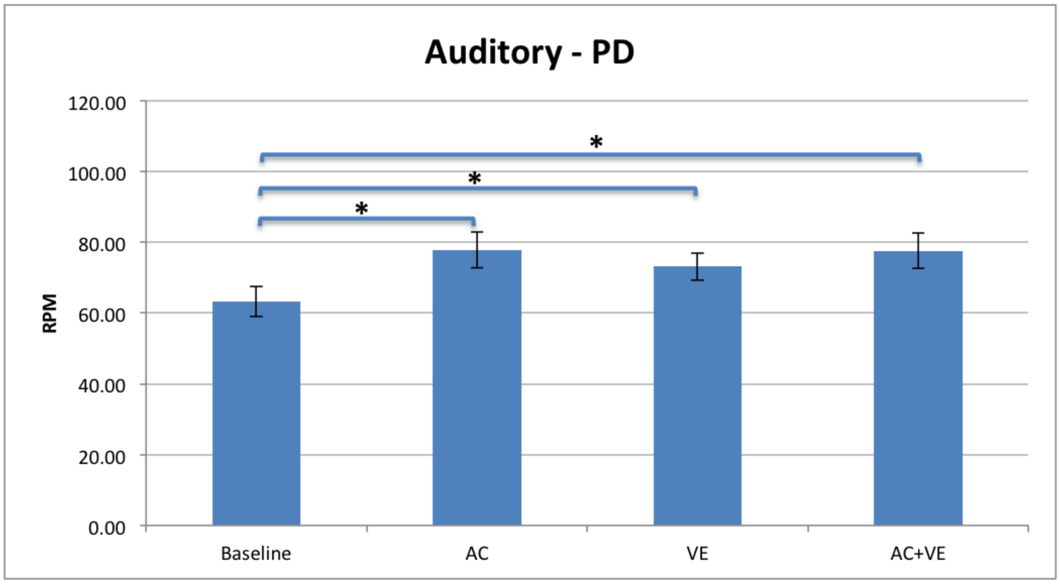

Figure 3. Auditory condition, PD: Mean (SE) RPMs. There was a significant increase in pedaling rate from baseline to all conditions.

*Corrected alpha p=/<0.01

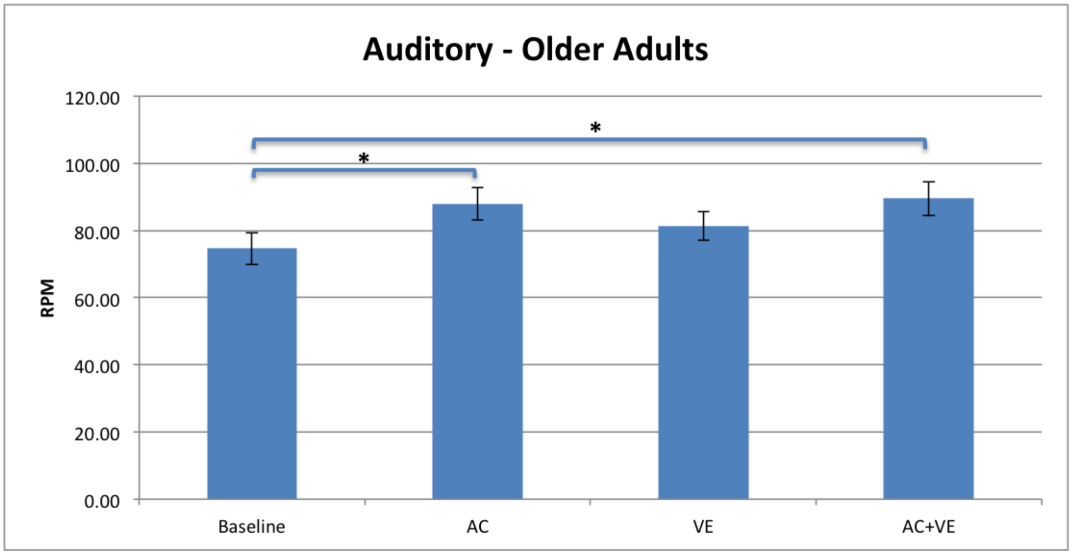

Figure 4. Auditory condition, Older Adults: Mean (SE) RPMs. There was a significant increase in pedaling rate from baseline with ACs and ACs combined with the VE.

*Corrected alpha p=/<0.01

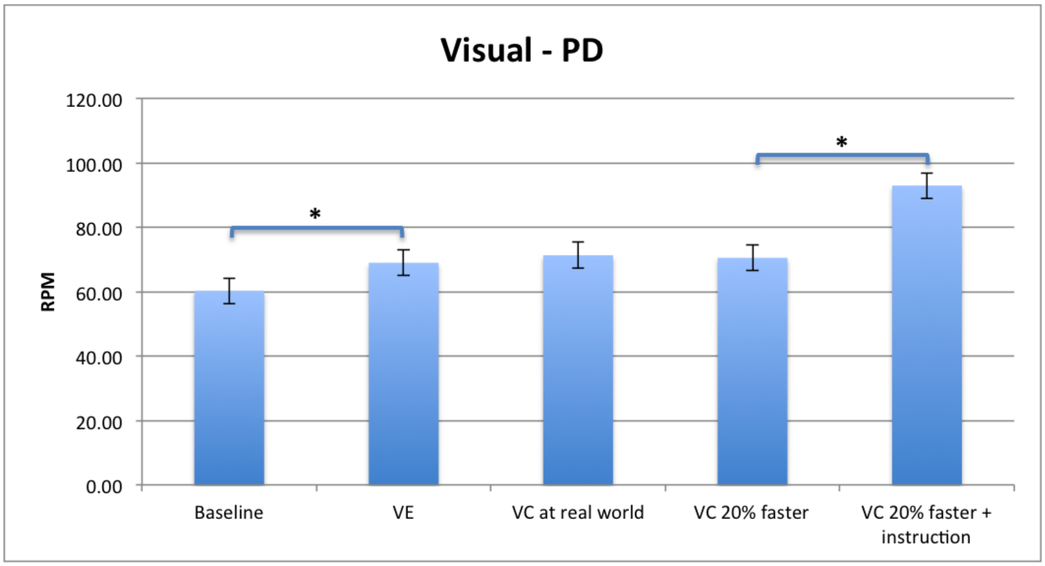

Figure 5. Visual condition, PD: Mean (SE) RPMs. There was a significant increase in pedaling rate between trials when the VE was added and when instructed to attend to the VC.

*Corrected alpha, p=/<0.01

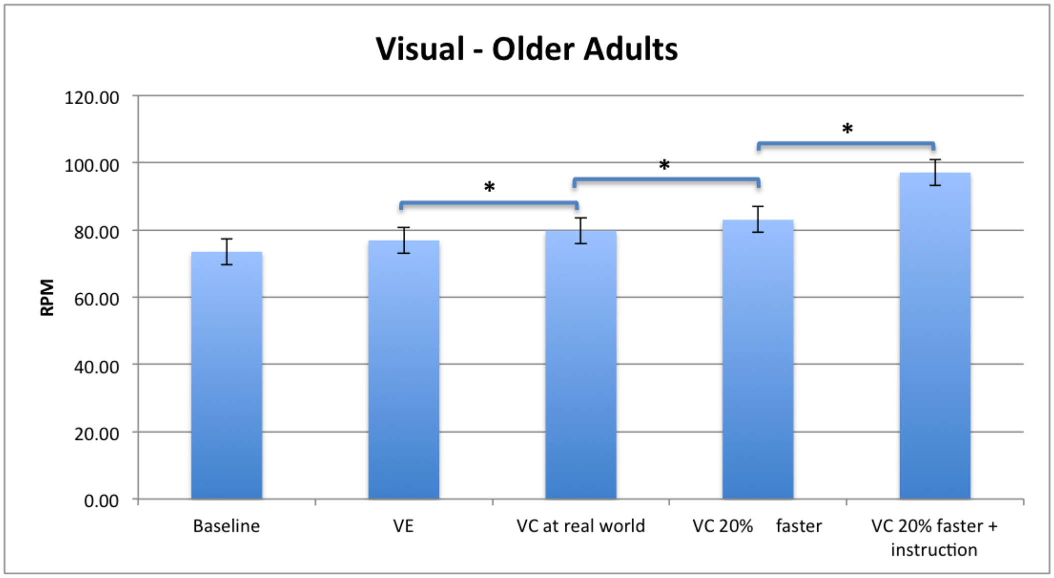

Figure 6. Visual condition, Older Adults: Mean (SE) RPMs. There was a significant increase in pedaling rate between trials when VC were added to the VE, when the VC were presented at a faster rate, and when instructed to attend to the VC.

*Corrected alpha, p=/<0.01

Chapter 5: Paper 2

Feedback Increases Exercise Intensity More than Directed Attention in a Cycling Virtual Environment in Persons with Parkinson's disease and Healthy Older Adults

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Title: Feedback Increases Exercise Intensity More than Directed Attention in a Cycling Virtual Environment for People with Parkinson's disease and Healthy Older Adults

Abstract

Objectives: To determine if people with PD and healthy age-matched adults modulate pedaling rate as a result of augmented external feedback and directed attention in a cycling virtual environment (VE).

Design: Cross-sectional

Setting: Outpatient physical therapy clinic.

Participants: People with PD (n=15), Hoehn and Yahr stages 2-3, age-matched healthy adults (n=13).

Intervention: Participants cycled on a sensorized stationary bicycle while interacting with a VE consisting of a road through a mountain scene. Participants cycled under 2 conditions: Feedback; central road markers changed color when cyclists were in the bandwidth of their pedaling rate in revolutions per minute (RPM), and Directed Attention; simultaneous presentation of auditory cues (provided by a metronome) and visual cues (road markers) with attention directed at one or the other cue.

Main Outcome Measure: Pedaling rate as measured in RPMs. Data were analyzed by condition using factorial RMANOVAs with planned t-tests and corrected for multiple comparisons.

Results: Both groups increased pedaling rate between 23 and 27%, in the feedback condition ($F=71.38$, $p<0.000$) and 11 to 14% in the directed attention condition ($F=18.08$, $p<0.000$). Simultaneous presentation of cues increased pedaling rate relative to baseline in people with

PD (t=-3.13, p=0.009); and age-matched healthy adults (t=-4.58, p=0.001). Directing attention to either auditory or visual cue allowed riders to approximate the rate of cue presentation.

Conclusions: As expected, people with PD and healthy age-matched adults modified cycling behavior in response to bandwidth speed feedback. Simultaneous auditory and visual cue presentation also increased cycling rate; directing attention increased the magnitude of the effect. These results suggest that incorporating these techniques into a virtual reality-based rehabilitation program may be used as a strategy to increase exercise intensity.

Key Words: Virtual environments, Bicycling, Feedback, Attention, Parkinson's disease

List of Abbreviations:

PD Parkinson's disease

RPM Revolutions per minute

VE Virtual Environment

V-CYCLE Virtual Reality Cycling System

Introduction

It has been suggested that virtual environments (VE) are more versatile than real-world scenarios in their ability to closely control content provided to the user, and thereby more aptly meet patients' therapeutic needs (Adamovich, Fluet, Tunik, & Merians, 2009). Virtual environments may provide clinicians with a useful approach to rehabilitate people with a variety of health conditions. Evidence based VEs are constructed by using concepts that work in the real world and embedding them into the environment. For example, the use of feedback is a common strategy used in the rehabilitation of people with Parkinson's disease (PD) and healthy adults to improve motor performance in real-world settings (Levy-Tzedek, Krebs, Arle, Shils, & Poizner, 2011; van den Heuvel et al., 2014; Rosati, Oscari, Spagnol, Avanzini, & Masiero, 2012). Feedback has also been implemented in VEs as a strategy to change motor behavior both in healthy and patient populations, including older adults, persons post stroke, and people with PD (Deutsch et al., 2004; Holden, 2005; Messier et al., 2007; Deutsch, 2009; Adamovich et al., 2009).

Feedback is essential for motor learning and includes both intrinsic and extrinsic processes (van Dijk, Jannink, & Hermens, 2005a; Winstein, 1991; Shumway-Cook & Woollacott, 2012). Feedback informs us about success in achieving a movement goal and therefore plays a key role in how we navigate in the world. Intrinsic, or internal, feedback is sensory input produced as a direct result of movement. It may be proprioceptive, auditory, or visual in nature (Shumway-Cook, 2012). External, or augmented, feedback is provided in addition to internal feedback. It originates from an outside source and can be in many forms including verbal, auditory or visual (Van Vliet & Wulf, 2006). The basal ganglia are critical in the processing of internal feedback (Van Vliet & Wulf, 2006) and play an important role in internally guided and automatic movements (Mink, 1996).

External feedback processing involves parietal-premotor networks that bypass internal networks (the basal ganglia and its projections to the motor cortex) by using an external strategy for execution of movement (Debaere, Wenderoth, Sunaert, Van Hecke, & Swinnen, 2003). Healthy older adults, despite normal age-related declines in executive and motor function, exhibit proper functioning of both internal and external feedback mechanisms (Schmidt, 2008). However, in the presence of sensorimotor processing deficits, as found in people with PD, an inability to utilize internal feedback to correct and modify motor behavior (van Dijk, Jannink, & Hermens, 2005b) results in an increased reliance on external feedback processes for proper movement execution (Abbruzzese & Berardelli, 2003).

Real-world use of external feedback in the form of audio biofeedback (Mirelman et al., 2011), haptic (Rabin, Chen, Muratori, DiFrancisco-Donoghue, & Werner, 2013), and visual feedback (Ehgoetz Martens, Ellard, & Almeida, 2015) has been shown to improve gait, functional activities, postural stability, and obstacle clearance in people with PD. The incorporation of external feedback has also been studied in VEs in persons post-stroke and people with PD to improve gait, obstacle negotiation, and activities of daily living (Deutsch & Mirelman, 2007; Galna, Murphy, & Morris, 2010)

In addition to the processing of internal feedback, the basal ganglia are also involved in attentional selection through connections to the prefrontal cortex (Abbruzzese & Berardelli, 2003). Simultaneous input from multiple sensory stimuli; proprioceptive, auditory, and visual, create competition for attention (Mozolic et al., 2008) and may result in improper and/or inefficient motor output in older adults and neurologically impaired populations (Watson & Leverenz, 2010). The primary concern is that one modality will compete with the other in terms of attentional costs, resulting in movement interference, particularly in people with PD who are known to have limited cognitive resources (Watson & Leverenz, 2010).

Studies in healthy older adults (Koelewijn, Bronkhorst, & Theeuwes, 2009) found improvements in motor behavior with simultaneous cue presentation. Guitard et al. (2013) found that in a group of community dwelling healthy older adults, simultaneous presentation of visual and auditory cues resulted in the highest frequency of grab bar use (76%). Auditory (60%) and visual cueing (58%) presented separately resulted in increased use of the grab bar, with the auditory cue less preferred but more powerful than the visual cue (Guitard, Sveistrup, Fahim, & Leonard, 2013).

In people with PD, the simultaneous presentation of cues has generally shown a summative effect on gait, with auditory and visual cues each influencing different aspects of gait such as stride length and gait speed (Suteerawattananon, Morris, Etnyre, Jankovic, & Protas, 2004; Spaulding et al., 2013; Baker, Rochester, & Nieuwboer, 2008; Baker et al., 2008; Espay et al., 2010). An early study by Suteerwattaanon et al., in 2004 sought to discern if the combination of cueing modalities had a greater effect on gait in people with PD than the presentation of each cue individually (Suteerawattananon et al., 2004). An increase in stride length and gait speed with simultaneous auditory and visual cues in people with PD were found, but the addition of auditory cues to the visual cues did not improve stride length above that found with visual cueing alone, and actually resulted in a slight decrement in stride length. In a meta-analysis by Spaulding et al. (2013) it was found that the combination of visual and auditory cueing resulted in a significant improvement in cadence but not stride length or gait speed in people with PD (Spaulding et al., 2013).

The efficacy of external cueing in the treatment of people with PD is well known (Spaulding et al., 2013; Van Wegen, Hirsch, Juiskamp, & Kwakkel, 2014) and in general, the results of these studies show benefit from simultaneously cue presentation. However, the stronger response to the visual cue and the slight decrement in stride length with simultaneous presentation of cues in the study by Suteerawattananon et al. (2004) may indicate a competition for limited attentional resources in people with PD (Watson & Leverenz, 2010) and the possibility for competition of attention. The focus of each of the cue types, visual cues relating primarily to spatial parameters, and auditory cues relating primarily to temporal parameters, may explain the findings. Perhaps explicitly directing the participant's attention to a specific cue would result in improved performance under simultaneous cue conditions.

The ability to present simultaneous stimuli is one of the advantages of using a VE for rehabilitation. Stimuli related to visual information inherent in a VE, include optic flow, as well as experimenter introduced cueing and feedback; all of which can be manipulated. Optic flow can be defined as the perception of movement as one moves through an environment (Azulay, Mesure, & Blin, 2006) and is a key element in a VE. It has been shown to modulate gait in healthy people (Prokop, Schubert, & Berger, 1997), persons post-stroke (Lamontagne, Fung, McFadyen, & Faubert, 2007), and people with PD, with more profound effects in people with PD compared with healthy older adults (Schubert, Prokop, Brocke, & Berger, 2005). However, the influence of simultaneous stimuli embedded in a cycling VE, combined with the response to optic flow, on motor performance is largely unknown and may have important clinical implications in designing rehabilitation and fitness programs that utilize a VE for healthy older adults and people with PD. Given the potential number and variety of elements in a VE, we propose that directing the user's attention to a specific stimulus in the VE may enhance their response and result in increased exercise intensity.

A variety of exercise modalities may be used to promote fitness in healthy older adults and people with PD, including stationary cycling. Studies using 'forced use' cycling show improvement in motor skills and cognitive function in people with PD (Ridgel, Kim, Fickes, Muller, & Alberts, 2011; Ridgel, Vitek, & Alberts, 2009; Ridgel, Phillips, Walter, Discenzo, & Loparo, 2015; Ridgel, Peacock, Fickes, & Kim, 2012). When combined with a VE, stationary cycling may be desirable for training intensity and duration. In a previous study, we showed that a novel virtual cycling environment embedded with auditory and visual cues increased exercise intensity by increasing pedaling rate (Gallagher, Damodaran, Werner, Powell, & Deutsch, 2016). The purpose of this investigation was to study the effect of external visual feedback and directing attention (during simultaneous cue presentation) on exercise intensity pedaling rate in people with PD and age-matched healthy adults. Our primary interest was comparisons within groups. We hypothesized that both groups would increase their pedaling rate in response to external visual feedback. We also hypothesized that during simultaneous presentation of cues, both people with PD and healthy age-matched controls would increase pedaling rate but at a lower rate than the cue presentation of 20%, and that directing attention would enhance the effect. We speculated that directing attention to the visual cue would result in a more pronounced effect on pedaling rate in people with PD than age-matched healthy adults due to the known reliance on vision in people with PD (Schubert et al., 2005; Azulay et al., 1999).

Methods

Study Design

This study used a cross sectional design. Eligible participants consisted of people with PD and age-matched healthy adults. The Institutional Review Board at the New York Institute of Technology and Rutgers University School of Biomedical and Health Sciences approved this work. All participants provided written informed consent prior to participation.

Experimental Setup

V-Cycle system and set up

The virtual reality cycling system, V-CYCLE, consists of an evidenced-based custom designed VE computer, projector display of the VE on a screen, upright stationary bicycle[a], a Bluetooth Wahoo cadence sensor[b] attached to the crank of the bike pedal to measure pedal revolutions per minute (RPM), a wireless Polar heart rate monitor[c], and a pair of Logitech desktop speakers[d] connected to an iPhone[f] metronome application for use in trials with audio cueing (Gallagher et al., 2016). The environment was projected onto a flat wall, approximately 5 feet in front of the bicycle resulting in a horizontal field of view of 80 degrees. It used a first person perspective of a cyclist riding on a straight road that had grass, trees, plants, mountains on either side, and a view of the sky and horizon at the end of the road.

Participants

The study included twenty-eight participants, 15 people with PD and 13 age-matched healthy adults aged 50-85 years old inclusive. Participants were included if they were able to ride a stationary upright bicycle, had no medical conditions that would preclude them from exercise, and a Montreal Cognitive Assessment (Hoops et al., 2009) score >/= 24. Participants with PD were in stages II-III on the Hoehn & Yahr scale (Hoehn & Yahr, 1967) and had no incapacitating tremors or dyskinesias that would limit their ability to ride a stationary bicycle.

Participants were recruited through flyers, referral, and a local exercise group. Age-matched healthy adults were spouses or friends of participants with PD. Telephone or in-person interviews were used for screening. After determining eligibility, participants attended two testing sessions lasting approximately 1 hour each.

Protocol

Clinical Tests

Baseline measures to define the cohort: age, sex, mental status, and lower extremity range of motion were collected. A trained examiner (RG) clinically rated participants with PD using the Hoehn & Yahr scale (Hoehn & Yahr, 1967) and the Motor subsection, (part III) of the Unified Parkinson's Disease Rating Scale (Goetz et al., 2008). All participants with PD were tested in the on-phase of medication.

Bicycle Protocol

Participants were seated on the bicycle with the seat height adjusted between 100% and 110% of the length from the greater trochanter to the floor (measured without shoes) (Gregor et al., 2002). After a 2-minute warm-up, a 30 second period of fast pedaling determined the participant's upper threshold of pedaling rate followed by 2 minutes of pedaling at a comfortable pace. The pedaling rate in the last 2 minutes of the warm-up was used as the baseline rate for the first set of trials.

Cycling trials were 1-minute in length. This time frame was chosen because our primary interest was a short-term change in cycling behavior, but also to minimize the effects of fatigue. Rate of Perceived of Exertion was measured immediately after each trial using the Borg scale (Borg, 1970) and heart rate was monitored throughout. Rest between trials ranged from 1 to 3 minutes. The criterion to begin a new trial was the return of heart rate to no more than 10 beats above the warm up rate.

Cycling Trials

This study is part of a larger trial. The results presented here are a subset of 9 trials from a total of 17 trials. The other 8 trials consisted of auditory and visual cue conditions; results are reported elsewhere (Gallagher et al., 2016). During this experiment, participants performed 1-minute trials of cycling divided into 2 blocks to address the following conditions: Feedback (4 trials), and Directed Attention (5 trials).

Specific features of a VE influence a users perception of self-motion. For example, a high color contrast, a textured environment, and the spatial frequency between objects can potentially influence pedaling rate (Powell & Stevens, 2013). The introduction of a VE (optic flow) from no VE (no optic flow) has been shown to influence motor behavior (Prokop et al., 1997). The addition of road markers, and the road markers with the spatial frequency decreased between them, as in this study, has the potential to further influence pedaling rate due to added optic flow in the environment.

Therefore, to account for the influence of optic flow in this study, a specific order of trial presentation was used (van Wegen et al., 2006). Both the Feedback and Directed Attention conditions began with a baseline trial of no VE, followed by the addition of the VE. In the Feedback condition, the VE trial was followed by the addition of visual cues, then the addition of feedback. The Directed Attention condition added 2 trials of simultaneous cues with and without directing attention to the cues.

Feedback Condition

Visual cues were white central road markers scaled to represent a real road (presented at a distance of 10 feet apart) and embedded in the VE. Feedback was presented when a participant cycled at a predetermined rate (20% faster than baseline) by having the white central road markers change to purple (Figure 1a and b).

The pre-determined rate of augmented visual feedback was presented at a bandwidth of 20% faster +/- 3 revolutions per minute (RPMs) of the baseline rate for the trial. Bandwidth feedback is a specific form of external feedback that is qualitative in nature in that it indicates when a response is within a pre-specified range of correctness, or tolerance (Lee & Carnahan, 1990; Sherwood, 1988) as was used in this study. The Feedback condition consisted of 4 trials, which are presented with the instructions to the participants in Table 1.

Insert Figure 1a and b here
Insert Table 1 here

Directed Attention Trials

The Directed Attention condition involved the simultaneous presentation of auditory and visual cues. Visual cues were in the form of white central road markers. The rate of presentation of the visual cues was set to appear at a 20% faster rate (8 feet apart) than the baseline rate of 10 feet apart. Auditory cues were provided by a metronome application on an iPhone, projected through desktop speakers, and also set at a rate 20%

higher than the baseline pedaling rate of each participant. The 20% faster rate was based on the walking literature (McIntosh & Rice, 1997; Suteerawattananon et al., 2004) and on informal trials of people with PD and healthy adults to determine pedaling rate threshold.

Participants were either given no instructions to direct their attention or, were given instructions to direct their attention to one or the other cue. Instructions to direct attention to the auditory or visual cue trials were counterbalanced between participants. The order of trials 1-3 was maintained to control for the potential influence of optic flow (Table 2).

Insert Table 2 here

Outcome measure

The primary outcome measure was pedaling rate measured in RPMs. Pedaling rate was continuously recorded using a cadence sensor attached to the crankshaft of the pedal and transferred to a laptop computer via Bluetooth^{TM} technology. Average pedaling rate over the 1-minute trial was calculated and used for data analysis. The first 5 seconds of each trial were excluded to allow participants to stabilize their cycling rate.

Data Analysis

Descriptive analyses were performed on patient characteristics: age, sex, cognitive status, disease stage, and motor assessment. Differences between groups for baseline characteristics were tested with independent t-tests. Normality was tested using the Shapiro-Wilk test. Means and standard deviations were calculated for RPM variables with an alpha level set at 0.05 and corrected for multiple planned comparisons using a Bonferroni correction. Statistical Package for the Social Sciences version 22.0 was used for all analyses. To confirm the validity of the VE, the actual change (increase) in pedaling rate was compared to the expected change. This was measured by calculating the percent increase in pedaling rate.

Feedback Condition

A 2x4 General Linear model for repeated measures was applied with group (PD, age-matched healthy adults) and condition (baseline, VE, Visual Cues, and Feedback) (see Table 1). When significant effects were found, alpha corrected planned comparisons were performed to determine the location of the effect. Statistical comparisons were as follows: Baseline to VE, VE to Visual Cues, VE to Feedback, and Visual Cues to Feedback. The choice of comparisons reflects the sequential addition of optic flow, visual cues, and FB to the environment, each of which has the potential to influence a users' behavior. Each comparison was tested with a one-tailed analysis. To determine if the change in pedaling rate was proportional to the feedback rate (20% increase), the percent change for each comparison was calculated.

Directed Attention Condition

A 2x3 general linear model for repeated measures was applied with group (PD, age-matched healthy adults) and condition; baseline, auditory plus visual cues (no directed attention), auditory plus visual cues (attention directed to auditory cues), auditory plus visual cues (attention directed to visual cues) (see Table 2). When significant effects were found, alpha corrected planned comparisons were performed to determine the location of the effect. Statistical comparisons were as follows: Baseline to auditory plus visual cues (no directed attention), auditory plus visual cues with no directed attention to auditory plus visual cues with attention directed to auditory cues, auditory plus visual cues (no directed attention) to auditory plus visual cues with attention directed to visual cues. To determine if the change in pedaling rate was proportional to the cues combined with directing attention, a 20% increase, the percent change for each comparison was calculated.

Results

Participants

Fifteen people with PD and 13 age-matched healthy adults participated in the study. There were no differences in age or cognitive status between the two groups. Participants with PD were in stage II or III on the Hoehn and Yahr scale (Hoehn & Yahr, 1967) (Table 3).

Insert Table 3 here

Feedback Condition

Significant main effects were found for condition and group, but no interaction effects. Healthy adults pedaled at a faster rate than people with PD in all conditions ($F=7.497$, $p=0.011$). Within group comparisons showed that both groups increased their pedaling rate in the Feedback condition ($F=71.38$, $p<0.000$). People with PD increased their pedaling rate from baseline (no VE) to presentation of the VE ($t=-3.90$, $p=0.002$), from VE to feedback ($t= -6.30$, $p<0.000$) and VC to feedback ($t= -5.70$ d14, $p<0.000$ (Figure 2). Age-matched healthy adults increased their pedaling rate from VE to VC ($t= -3.30$, $p=0.003$), VE to feedback ($t= -5.76$, $p<0.000$), and VC to feedback ($t=-5.62$, df12, $p>0.000$) (Figure 3).

Hypothesized and observed differences in cycling rate are presented in Table 4. The largest increases were found when feedback was presented.

Insert Figures 2 and 3 here
Insert Table 4 here

Directed Attention Condition

There was a main effect for the Directed Attention condition with no group or interaction effects. Age-matched healthy adults pedaled at a faster, albeit non-significant rate than people with PD in all conditions ($F=1.52$, $p=0.23$). Both groups responded by pedaling faster with directed attention ($F=18.08$, $p<0.000$). Within group comparisons showed that both people with PD ($t=-3.13$, $p=0.009$), and age-matched healthy adults ($t=-4.58$, $p=0.001$) increased their pedaling rate from baseline to simultaneous cue presentation with no directed attention (Figures 4 and 5).

When attention was directed to either the visual or auditory cue during simultaneous cue presentation, four and five percent increases in pedaling rate were found in people with PD and healthy older adults respectively. These changes were not significant. Hypothesized and observed differences in cycling rate are presented in Table 5.

Insert Figures 4 and 5 here
Insert Table 5 here

Discussion

The purpose of this study was to determine if external visual feedback in a cycling VE affected pedaling rate, and whether the simultaneous presentation of cues, and directing attention to a specific cue would increase pedaling rate in people with PD and age-matched healthy adults. The main findings are that the addition of feedback to a VE increased pedaling rate, the simultaneous presentation of cues in a VE increased pedaling rate, and directing attention to a specific cue increased, albeit not significantly, pedaling rate to approximate the frequency of cue presentation. Each of these findings is discussed separately below.

Feedback Condition

Although both groups increased their pedaling rate in response to feedback, the pedaling rate was slower for people with PD compared to age-matched healthy adults in all conditions. This finding was expected and may be explained by the bradykinesia commonly found in PD (Gazewood, Richards, & Clebak, 2013).

Only people with PD increased their pedaling rate from baseline to presentation of the VE. This finding aligns with findings by Azulay et al. (2002) who suggest that visual dependence in people with PD may be a strategy to compensate for deficits in kinesthetic feedback (Azulay, JP, Mesure, S, Amblard, B, & Pouget, J, 2002) and therefore may respond more strongly to visual stimuli compared to healthy adults (Schubert et al., 2005). In people with PD, visual input activates alternate visuomotor circuits that pass through the cerebellum and bypass the defective basal ganglia which may further explain the increased reliance on vision (Azulay et al., 2006; Kandel, Schwartz, & Jessell, 2000) and their ability to respond to optic flow (Schubert et al., 2005; Ehgoetz Martens et al., 2015). However, people with PD did not increase their pedaling rate when the visual cues were added to the VE. It is suspected that the visual cues were not salient enough to produce a response in people with PD.

Both groups responded by increasing their pedaling rate as a response to augmented external feedback and confirm our hypothesis that feedback embedded in a VE can influence motor behavior. These are short-term effects and would need to be tested further to see whether they endure with longer intervals of cycling to produce a training effect. Long term changes in motor behavior in studies where participants trained gait, coordination, strength, and balance using a VE augmented with feedback (Mirelman et al., 2011; Lewak, Feasel, Wentz, Brooks, & Whitton, 2012; Deutsch et al., 2013; Lohse, Hilderman, Cheung, Tatla, & Van der Loos, 2014) have shown enduring and positive results.

Both groups pedaling rate exceeded the 20% stimulus presentation for the Feedback condition. Age-matched healthy adults had a 27-30% increase from the VE alone to feedback, and the 27% increase from the VE with the road markers to the FB condition, were greater than the 20% (+/-3RPMs) stimulus from baseline pedaling rate. People with PD more closely matched the feedback stimulus (25% and 23% respectively). The investigators observed both over and under-shooting of the target speed in order to obtain the bandwidth feedback. It is unclear why there was a bias to over-shoot. A longer trial might result in greater congruency between the bandwith feedback and the cycling rate.

Directed Attention Condition

The primary finding is that compared to baseline, the presentation of simultaneous cues increased pedaling rate, however, the increases of 14% (PD) and 11% (healthy older adults), fell short of the 20% cue rate. It is possible that shifting attention between auditory and visual cues resulted in an inability to achieve the rate of cue presentation.

When attention was directed to either the auditory or the visual cue however, additional small increases in pedaling rate of 4% and 5% were found. These findings suggest that while simultanenous cue presentation does increase pedaling rate, the effect can be augmented with directing attention, thus supporting the use of this strategy to enhance motor performance in people with PD and healthy age-matched adults. In healthy adults, it has been shown that instruction to adopt an external focus of attention during motor skill learning results in more effective performance and learning (Wulf, Shea, & Lewthwaite, 2010). In a study by Canning in 2005, during dual task walking in people with PD, trials included those with no instruction to pay attention, instruction to pay attention to the tray and glasses they carried, or instructions to pay attention to their walking. Results show an improvement in walking speed when instructed to pay attention to their walking, suggesting that directing attention can be used to improve performance of motor tasks in people with PD (Canning, 2005). The findings in this study also support those from a previous study that showed an increase in pedaling rate when participants were instructed to pay attention to visual cues in a VE (Gallagher et al., 2016). The results of these studies show that directing attention during a motor skill can improve performance. Therefore, in the present study, although the presentation of simultaneous cues did increase pedaling rate, the full effect was not achieved until attention was specifically directed, re-enforcing the relevance of directing attention.

Limitations:

Limitations that may have affected our results are as follows. First, this study is part of a larger study that consisted of other trial conditions. Therefore, the trials reported in this study were not presented discretely and results may have been influenced by previous trials.

Second, in the feedback condition, it was observed that participants were both over and underestimating their speed (with a bias towards over estimation) in trying to determine at what rate they should pedal to make the feedback appear. Likely, the one-minute trial was too short for participants to stabilize their cycling speed to the bandwidth in which the feedback was presented. Future trials should be of longer length.

Conclusions

To our knowledge, this is the first study to embed feedback in a cycling VE with the purpose of increasing pedaling rate. The use of feedback consistently produced an increase in pedaling rate in this study. The presentation of simultaneous cues increased pedaling rate, but directing a user's attention to a specific cue resulted in a closer approximation of the cue rate.

These findings add to the body of knowledge surrounding the use of VEs for rehabilitation and fitness, and show an advance over prior studies through embedding feedback in a cycling VE, but also show the effects of simultaneous cue presentation and directing attention in a cycling VE. Importantly, these findings support the use of feedback in a VE to enhance performance, and provide new evidence on the effect of simultaneous cue presentation in a cycling VE and in explicitly directing a user's attention for a desired behavioral response, thus providing rehabilitation specialists with options to optimize treatment programs for their patients with PD.

These findings, together with those from a previous study on embedding auditory and visual cueing in a VE, show that evidenced based VEs may be used to change motor behavior in healthy adults and people with PD. Future studies will investigate if VEs yoked to exercise equipment can be used as a tool for fitness promotion.

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Supplier List:

a. Cybex upright stationary bicycle model #750C, Cybex International, Inc.
b. Bluetooth Wahoo cadence sensor
c. H7 Polar heart rate sensor
d. Logitech desktop speakers Model S120
e. iPhone 6s

Tables

Table 1. Feedback Condition: Description of trials

Trial	Instructions to participant
Baseline	*Look ahead of you.* *Ride at a comfortable pace.*
VE	*Look ahead of you at the road.*
VC 20%	*Look ahead of you at the road.*
Feedback	*Look ahead of you at the road. Your goal in this trial is to cycle at a rate that will make the marker turn from white to purple and to keep the change in color throughout the entire trial.*

Abbreviations: Baseline, no VE, no cueing; VE, virtual environment; VC 20%, VE with visual cues set to appear at a 20% faster rate (8 feet apart) than the baseline rate of 10 feet apart; FB, markers change color when pedaling at a predetermined rate.

Table 2. Directed Attention Condition: Description of trials

Description	Instructions to participant
Baseline	*Ride at a comfortable pace*
VE	*Look ahead of you at the road.*
AC + VC 20% No directed attention	*Look ahead of you at the road.*
AC + VC 20% Attention directed to AC*	*Match your cycling speed to the metronome*
AC + VC 20% Attention directed to VC*	*Look at the road markers*

Abbreviations: Baseline, no VE, no cueing; VE, virtual environment; AC, auditory cues*; VC, visual cues set to appear at a 20% faster rate (8 feet apart) than the baseline rate of 10 feet apart*

*trials counterbalanced between participants

Table 3 Participant Characteristics (N=28)

	Age-matched Healthy n=13		Parkinson's disease n=15	
Characteristic	Mean (SD)	Range	Mean (SD)	Range
Age (y) mean (SD)	66.7 (9.1)	50-81	66.3 (9.6)	50-80
Gender (M/F)	7/6	------	13/2	------
MoCA	27.1 (2.3)	24-30	26.3 (1.9)	24-29
H&Y	------	------	2.3 (0.5)	2-3
UPDRS III	------	------	35.5 (14.2)	8-56

Abbreviations: MoCA, Montreal Cognitive Assessment; H&Y, Hoehn and Yahr Scale; UPDRS III, Unified Parkinson's disease Rating Scale Part III Motor subsection.

Table 4. Feedback Condition: Expected and Observed rpm changes

Condition	PD			Age-matched healthy adults		
	Expected Increase (%)	Observed Increase (%)	*P*	Expected Increase (%)	Observed Increase (%)	*P*
Baseline to VE	↑ baseline	13	0.002*	↑ baseline	4	0.034
VE to VC	↑ greater than VE but magnitude unknown	3	0.023	↑20	3	0.003*
VE to FB	↑20	25	0.000*	↑ 20	30	0.000*
VC to FB	↑unknown	23	0.000*	↑unknown	27	0.000*

Corrected alpha p=/<0.01 based on multiple (4) comparisons.

Abbreviations: VE, virtual environment; VC, visual cues; FB, feedback

Key: Baseline, no VE, no feedback; VE, Virtual environment only; VC, virtual environment with VC at 20%; virtual environment with FB; ↑, expected change

Table 5. Directed Attention Condition: Expected and Observed rpm changes

Condition	PD			Age-matched healthy adults		
	Expected Increase (%)	Observed Increase (%)	*P*	Expected Increase (%)	Observed Increase (%)	*P*
Baseline to AC+VC (no directed attention)	↑Unknown	14	0.009*	↑Unknown	11	0.001*
AC+VC (no directed attention) *to* AC+VC (attention directed to AC)	↑Unknown	4	0.202	↑Unknown	5	0.122
AC+VC (no directed attention) *to* AC+VC (attention directed to VC)	↑Unknown	5	0.111	↑Unknown	4	0.096

Corrected alpha p=/<0.02 based on multiple (3) comparisons

Abbreviations: AC, auditory cues; VC, visual cues

Key: Baseline, no VE; AC +VC, simultaneous presentation of cues; VE, ↑, expected change

Figure Title and Legends:

1. **Fig 1a. and 1b.** The VE with road markers and the VE with augmented feedback.

2. **Fig 2.** Feedback Condition, Parkinson's disease: Mean (SE) RPMs.

   Corrected alpha p<0.01 based on multiple (4) comparisons.

   Abbreviations: VE, virtual environment; VC, visual cues; FB, feedback

   Key: Baseline, no VE no feedback; VE, Virtual environment only; VC, virtual environment with VC at 20%; virtual environment with FB

3. **Fig 3.** Feedback Condition, Older Adults: Mean (SE) RPMs.

   Corrected alpha p=/<0.01 based on multiple (4) comparisons.

   Abbreviations: VE, virtual environment; VC, visual cues; FB, feedback

   Key: Baseline, no VE no feedback; VE, Virtual environment only; VC, virtual environment with VC at 20%; virtual environment with FB

4. **Fig 4.** Directed Attention Condition, Older Adults: Mean (SE) RPMs.

   Corrected alpha p=/<0.02 based on multiple (3) comparisons.

   Abbreviations: AC, auditory cues; VC, visual cues.

   Key: Baseline, no VE; no directed attention, auditory and visual cues presented simultaneously with no instruction to attend to a specific cue; attention directed to AC, auditory and visual cues presented simultaneously with instruction to attend to the auditory cues; attention directed to VC at 20%, auditory and visual cues presented simultaneously with instruction to attend to the visual cues

5. **Fig 5.** Directed Attention Condition, Older Adults: Mean (SE) RPMs.

Corrected alpha p=/<0.02 based on multiple (3) comparisons.

Abbreviations: AC, auditory cues; VC, visual cues.

Key: Baseline, no VE; no directed attention, auditory and visual cues presented simultaneously with no instruction to attend to a specific cue; attention directed to AC, auditory and visual cues presented simultaneously with instruction to attend to the auditory cues; attention directed to VC at 20%, auditory and visual cues presented simultaneously with instruction to attend to the visual cues

Figures:

Fig 1a. and 1b. The VE with road markers and the VE with augmented feedback.

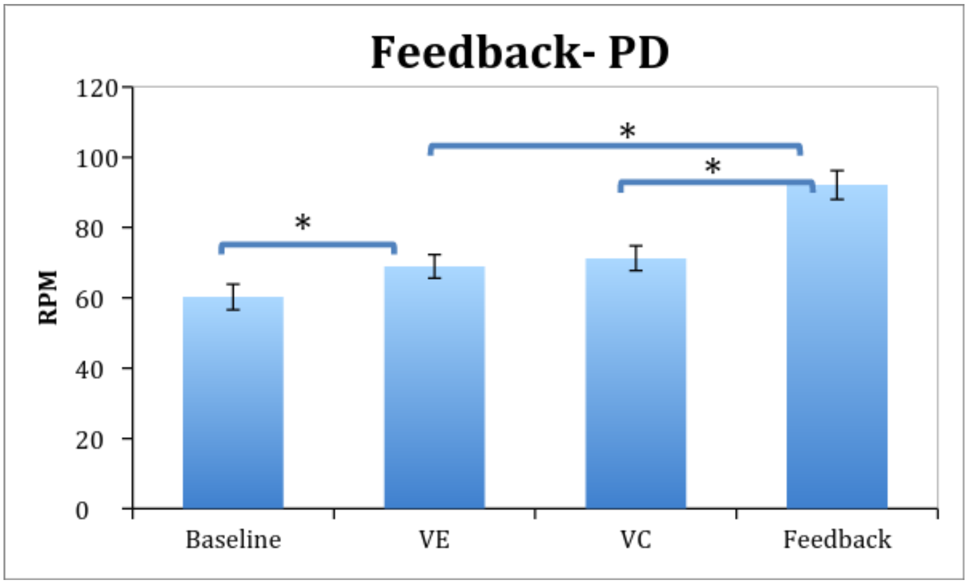

Fig 2. Feedback Condition, Parkinson's disease: Mean (SE) RPMs.

Corrected alpha p<0.01 based on multiple (4) comparisons.

Abbreviations: VE, virtual environment; VC, visual cues; FB, feedback

Key: Baseline, no VE no feedback; VE, Virtual environment only; VC, virtual environment with VC at 20%; virtual environment with FB

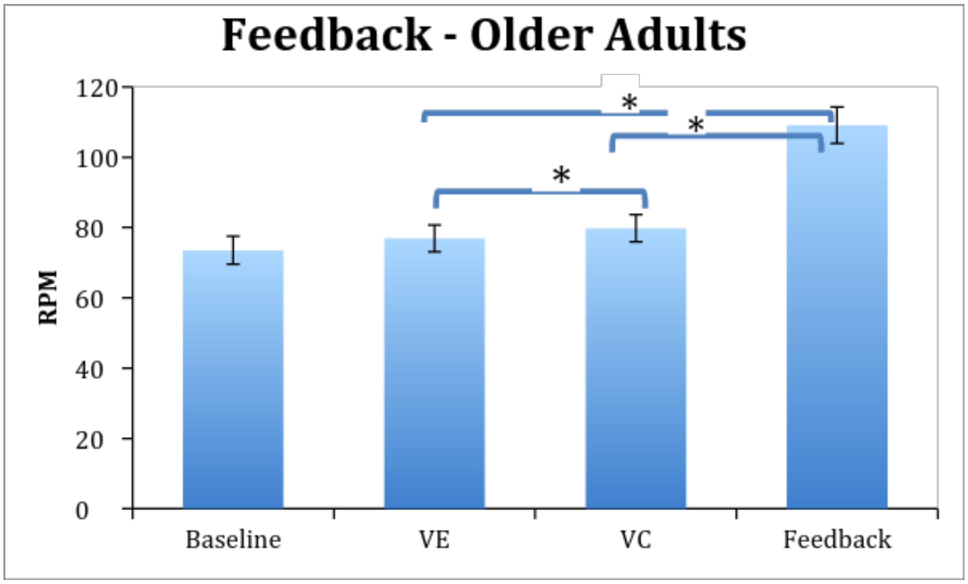

Fig 3. Feedback Condition, Older Adults: Mean (SE) RPMs.

Corrected alpha p=/<0.01 based on multiple (4) comparisons.

Abbreviations: VE, virtual environment; VC, visual cues; FB, feedback

Key: Baseline, no VE no feedback; VE, Virtual environment only; VC, virtual environment with VC at 20%; virtual environment with FB

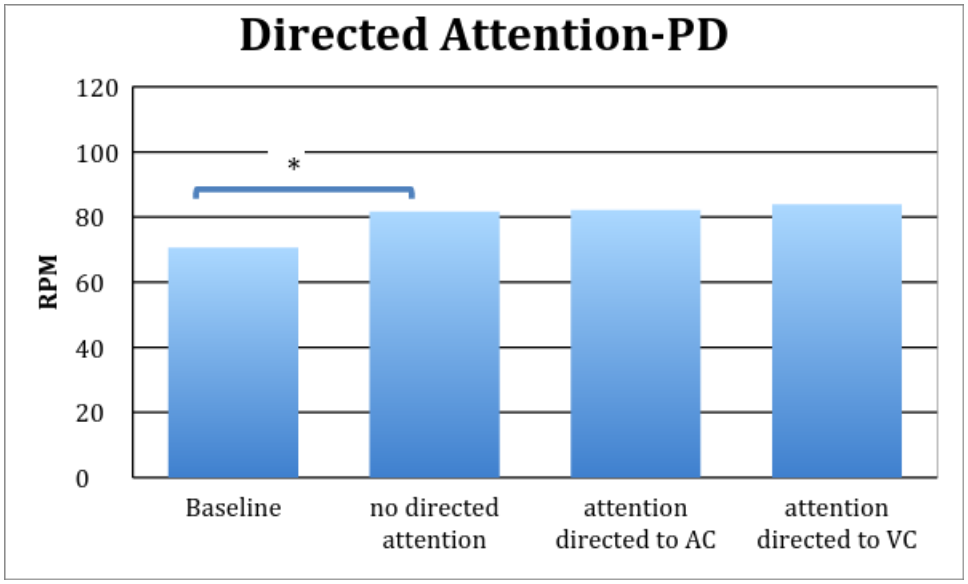

Fig 4. Directed Attention Condition, Older Adults: Mean (SE) RPMs.

Corrected alpha p=/<0.02 based on multiple (3) comparisons.

Abbreviations: AC, auditory cues; VC, visual cues.

Key: Baseline, no VE; no directed attention, auditory and visual cues presented simultaneously with no instruction to attend to a specific cue; attention directed to AC, auditory and visual cues presented simultaneously with instruction to attend to the auditory cues; attention directed to VC at 20%, auditory and visual cues presented simultaneously with instruction to attend to the visual cues

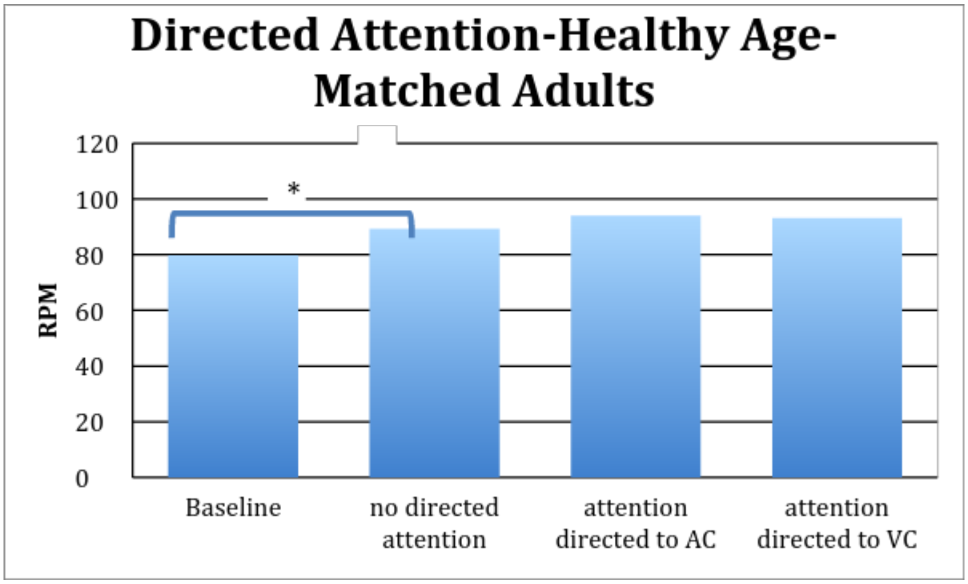

Fig 5. Directed Attention Condition, Older Adults: Mean (SE) RPMs.

Corrected alpha p=/<0.02 based on multiple (3) comparisons.

Abbreviations: AC, auditory cues; VC, visual cues.

Key: Baseline, no VE; no directed attention, auditory and visual cues presented simultaneously with no instruction to attend to a specific cue; attention directed to AC, auditory and visual cues presented simultaneously with instruction to attend to the auditory cues; attention directed to VC at 20%, auditory and visual cues presented simultaneously with instruction to attend to the visual cues

Chapter 6: Paper 3

Changes in Trunk and Hip Kinematics in a Cycling Virtual Environment in People with Parkinson's disease and Healthy Older Adults: An Exploratory Study

Paper 3. Changes in Trunk and Hip Kinematics in a Cycling Virtual Environment in People with Parkinson's disease and Healthy Older Adults: An Exploratory Study

Abstract

Background: People with Parkinson's disease (PD) present with motor symptoms such as rigidity, asymmetry, and increased variability of movement. Stationary cycling is a safe alternative to walking and may be used as a strategy to ameliorate motor symptoms. However, lack of evidence exists for cycling kinematics in people with PD. This exploratory study examined spatial changes of the trunk and hip in people with PD and healthy age-matched adults while in a cycling virtual environment (VE) to determine the contribution of pedaling rate and influence of the VE on these changes.

Methods: Participants cycled on a stationary bicycle while interacting with a VE (a road through a mountain scene). Participants cycled under 3 conditions: Baseline, Visual Cueing, and Feedback (central road markers changed color when bandwidth of pedaling rate, in revolutions per minute, was reached). Outcomes: trunk and hip excursion, symmetry, and variability. Data were analyzed by condition using factorial RMANOVAs with planned t-tests corrected for multiple comparisons. Pearson product moment correlation coefficients were used to determine if kinematic changes were due to an increase in pedaling rate or influence of the VE.

Results: Both groups increased pedaling rate in the feedback condition compared to baseline ($F= 52.782$, $p<0.000$), PD ($t= -5.130$, $p<0.007$), healthy adults ($t= -8.412$, $p<0.002$). Within condition differences for trunk symmetry ($F=4.907$, $p<0.028$), hip excursion, ($F=5.542$, $p<0.021$), and hip symmetry ($F=7.638$, $p<0.007$) were found in the feedback condition. People with PD showed increased trunk symmetry ($t=8.118$, $p<0.002$), increased hip excursion ($t= -4.362$, $p<0.011$) and decreased hip symmetry in the feedback condition ($t= -2.942$, $p<0.030$). Healthy adults pedaled with greater hip symmetry in the feedback condition ($t= -2.794$, $p<0.034$). There were no differences in variability of the trunk or hip for either group.

Conclusions: Changes in trunk and hip kinematics in people with PD and healthy age-matched adults in a cycling VE were found. These changes were due to the influence of the VE and an increase in pedaling rate. These results suggest that cycling in a VE can modify trunk and hip kinematics and that using a stationary bicycle, can be used as a strategy to change them.

Key Words: Virtual environments, Bicycling, Kinematics, Parkinson's disease, older adults

Introduction

In Parkinson's disease, loss of dopaminergic neurons in the basal ganglia results in both cognitive and motor symptoms (Petzinger et al., 2013) with tremors, postural instability, bradykinesia and rigidity as hallmarks of the disease (Jankovic, 2008). Rigidity, an increase in tone in the resting state of a muscle, is thought to have a central origin involving the tonic neck reflex mechanism (McAuley, 2003) and in people with PD affects both limb and axial musculature (Peterson & Horak, 2016). Rigidity has been reported as the greatest contributor of disability in people with PD (Post, Merkus, de Haan, Speelman, & Group, 2007).

Axial rigidity, characterized by loss of mobility of the trunk and neck, is greater in people with PD compared to age-matched healthy controls (Peterson & Horak, 2016). Rigidity affects both spatial and temporal aspects of gait for example, rigidity of axial muscles contributes to decreased step length. Decreased gait speed may be attributed to rigidity of hip musculature. Rigidity is also responsible for the decreased ability to dissociate the trunk from the hip, manifested in the 'en block' turning pattern, found in people with PD (Peterson & Horak, 2016).

Increased variability and asymmetry of motor output contribute to the gait impairment in people with PD (Galna, Murphy, & Morris, 2010). Variability of motor output has been found to affect spatial aspects of gait i.e. step width and step length, which in turn affects temporal components such as gait speed (Peterson & Horak, 2016). Asymmetry of motor symptoms in people with PD is common, particularly in the early stages (Jankovic, 2008), and continues throughout disease progression

(Djaldetti, Ziv, & Melamed, 2006). Asymmetry of spatial and temporal parameters have been found in the upper extremities; for example in decreased arm swing excursion (Peterson & Horak, 2016), and in the lower extremities, as manifested in variability in stride time (Hausdorff et al., 2003) and impairments in bilateral control of walking (Plotnik, Giladi, & Hausdorff, 2008). Asymmetries have also been found in cycling in people with PD (Penko et al., 2014). Pedaling force was examined in 25 people with PD under increasing resistance but constant pedaling rate. Asymmetry in average power output of the lower extremities increased as workload increased (Penko et al., 2014). Based on this evidence, we postulate that asymmetry and variability might be found in cycling kinematics in people with PD.

With age, loss of flexibility is common and can lead to limitations in mobility and function (Mahoney, Verghese, Holtzer, & Allali, 2014). In normal aging, denervation of the striatal pathways of the dopaminergic system that communicate with the basal ganglia occur (Mahoney et al., 2014). This denervation can cause Parkinsonian-like symptoms such as resting tremor, bradykinesia, and rigidity, which are associated with a decline in gait, balance, (Wilson, Schneider, Beckett, Evans, & Bennett, 2002) and quality of life (Cano-de-la-Cuerda, Vela-Desojo, Miangolarra-Page, Macias-Macias, & Munoz-Hellin, 2011). Wilson et al. (2002) using self-report and performance-based measures found that 1 in 4 (n=2000) community dwelling adults (>/= 65 years) showed mild Parkinsonian signs. The most prevalent of these was axial rigidity, which was reported as having the greatest impact on function (Wilson et al., 2002).

Pharmacological management may ameliorate motor symptoms in the early stages of Parkinson's disease, but medications lose effectiveness over time (Tomlinson et al., 2012). However, rehabilitation interventions may improve function by focusing on strength, cardiovascular conditioning, and flexibility (Morris, Martin, & Schenkman, 2010). Exercise may help to remediate the declines found in PD and normal aging, which can lead to improved overall health, and contribute to maintaining function (Morris et al., 2010). Aerobic exercise may lead to improvements in neuroplasticity, and strenuous exercise has been linked to a decreased risk for developing Parkinson's disease (Petzinger et al., 2013).

Stationary cycling is a common exercise used to improve fitness and for rehabilitation of both healthy and patient populations (Johnston, 2007). It is safer than walking because it places less demands on balance. Forced-use stationary cycling has been found to improve not only aerobic capacity (Ridgel, Vitek, & Alberts, 2009) and cognition (Ridgel, Kim, Fickes, Muller, & Alberts, 2011), but also to reduce motor symptoms, including bradykinesia and rigidity, in people with PD (Ridgel, Peacock, Fickes, & Kim, 2012). Improving trunk mobility and dissociation of the trunk and hip through exercise may improve function and prove desirable for people with PD. We suggest stationary cycling as a strategy to address axial rigidity and lack of trunk-to-hip dissociation found in people with PD. We also suggest that stationary cycling may promote more symmetric and less variable movements in this population.

Despite the prevalence of studies investigating cycling kinematics in healthy (Gregor et al., 2002; Bini, Hume, & Croft, 2011; Sauer, Potter, Weisshaar, Ploeg, &

Thelen, 2007; Ranky et al., 2014) and patient populations (Perell et al., 2002; Mimmi, Pennacchi, & Frosini, 2004; Trumbower & Faghri, 2005; Johnston, Barr, & Lee, 2007), a lack of evidence regarding kinematics, particularly of the trunk, during stationary cycling in people with PD exists. Trunk kinematics have been investigated during gait (Van Emmerik, Wagenaar, Winogrodzka, & Wolters, 1999; Smith & Kulig, 2016) but evidence regarding trunk kinematics during stationary cycling in people with PD or healthy older adults is lacking.

Previously, we reported that visual cueing (Gallagher, Damodaran, Werner, Powell, & Deutsch, 2016) and feedback (Gallagher, Damodaran, Cohen, & Deutsch, submitted April 2017) in a virtual cycling environment increased pedaling rate in healthy adults and people with PD. The purpose of this study was to investigate spatial changes in the trunk and hip that accompanied these increases, specifically, excursion, symmetry and variability, as a way to characterize cycling behavior in people with PD and older adults We propose the following hypotheses:

1. There will be less trunk excursion and greater hip excursion while cycling in the VE conditions compared to the baseline condition in people with PD and healthy age matched adults.
2. There will be greater symmetry and less variability in trunk and hip motion while cycling in the VE conditions compared to the baseline condition in people with PD and healthy age matched adults.

3. People with PD will have less trunk and hip excursion, less trunk and hip variability, and will show less symmetry in their movement compared to healthy age matched adults while in a cycling VE.

Methods

Participants

Twenty-eight participants, 15 people with PD and 13 age-matched healthy adults participated in the original study (Gallagher et al., 2016). The data here are a subset from the larger study and include four people with PD and four healthy aged-matched controls. A repeated measures ANOVA was performed to determine differences in pedaling rate with the VE for the total number of participants as well as the subset analyzed in the current study. The subset of 8 participants was found to have the same changes in pedaling rate as the larger group of 28 participants and was therefore deemed representative of the total sample.

Participants were recruited through flyers, referral, and a local exercise group from the Academic Health Care Center on the Old Westbury campus of New York Institute of Technology. The Institutional Review Board at the New York Institute of Technology and Rutgers University School of Biomedical and Health Sciences approved this work. All participants provided written informed consent prior to participation.

Eligibility criteria are described in detail elsewhere (Gallagher et al., 2016) and can be summarized as follows: All participants: between 50 and 85 years of age, male or female, able to ride a stationary upright bicycle, no medical conditions that would preclude them from exercise, a Montreal Cognitive Assessment score >/= 24, (Hoops et al., 2009). Participants with PD: stage II-III on the Hoehn & Yahr scale (Hoehn & Yahr, 1967) and no incapacitating tremors or dyskinesias that would limit ability to ride a stationary bicycle.

Descriptive clinical tests included the Montreal Cognitive Assessment and Part III Motor subscale of the Unified Parkinson's Disease Rating Scale (Goetz et al., 2008). All participants with PD were tested in the on-phase of medication.

Instrumentation

V-Cycle system and set up

The virtual reality cycling system, V-CYCLE, an evidenced-based custom designed VE, is described in detail elsewhere (Gallagher et al., 2016). Briefly, the system consists of a projector display of a mountain scene, upright stationary bicycle, a wireless cadence sensor, and wireless Polar Heart rate monitor. The VE was projected onto a flat wall, approximately 5 feet in front of the bicycle with a horizontal field of view of 80 degrees. The mountain scene consisted of a straight road with has grass, trees, flowers, with a view of the sky and horizon at the end of the road.

Bicycle

An upright stationary bicycle (Cybex model #750C) was used. Seat height was standardized between 100% and 110% of the length from the greater trochanter to the floor measured without shoes (Gregor et al., 2002). The starting position on the bicycle was with the ankle in a neutral position and the trunk upright when the crank was at 180 degrees (position farthest from the rider). A Bluetooth Wahoo cadence sensor attached to the crankshaft of the pedal monitored pedaling rate.

Experimental Protocol

Data were acquired as previously described (Gallagher et al., 2016). Briefly, Participants attended two testing sessions lasting approximately 1 hour each. The first session involved obtaining informed consent and collection of demographic and baseline data. The second session began with participants fitted with the reflective markers and seated on the bicycle. A 2-minute warm-up period allowed participants to develop a consistent pedaling rate and was followed by 1-minute of fast pedaling to determine maximum pedaling rate. The period of fast pedaling was used to determine the maximum pedaling rate of each participant. The warm-up concluded with 2 minutes of pedaling at a comfortable rate. One-minute cycling trials with 1-3 minutes rest between trials were performed by each participant. Kinematic data were collected for the middle 30 seconds of each trial to allow for adjustment to the trial condition. Rate of perceived of exertion was measured immediately after each trial using the Borg scale (Borg, 1970). Heart rate was monitored throughout with a Polar Heart Rate monitor (Polar HR7). Criteria to begin the next trial were determined by return of heart rate to no more than 10 beats above the warm up rate.

To answer the question if excursion, symmetry, and variability of the trunk and hip changed in response to cycling under different VE conditions, 3 conditions from a total of 15 were chosen for further analysis. These three conditions were chosen because they showed the greatest temporal changes. Conditions included were: baseline condition (no VE), 20% faster condition (VE with central road markers presented at a 20% faster rate than a real world distance apart), and a feedback condition in which the central road markers changed to purple when a pre-determined pedaling rate was achieved. Instructions to, *Ride at a comfortable pace* (baseline trial), *Look ahead of you at the road* (20% faster trial), or to *Pedal at a rate that will make the markers change color (feedback trial)*, were provided.

Kinematic Data Collection

Kinematic data were collected using a 9-camera digital motion capture system sampling at a frequency of 120Hz (Vicon Peak Motus, Vicon Motion Systems Ltd., Denver, CO, USA). Sixteen reflective markers with adhesive backing were placed on each participant on the following anatomical landmarks: suprasternal notch, sternal angle, C7 spinous process, T10 spinous process, and bilaterally on the lateral acromion, greater trochanter, knee (lateral joint line), ankle (inferior tip of lateral malleolus), heel, and webspace between 1st and 2nd metatarsal heads.

Definition of Trunk and Hip angles

Pedaling rate was recorded in revolutions per minute (RPM). Movement of the trunk and hip in the coronal plane was observed. Trunk and hip movement are of concern in people with PD because of known axial and limb rigidity which negatively affect quality of movement (Peterson & Horak, 2016). The choice of the coronal plane was determined by the observation that participants exhibited only a minimal amount of movement in the sagittal plane during data acquisition and subsequent review of participant videos. Movement of the trunk in the sagittal plane may be restricted due to riders holding onto the handlebars, thus restricting free movement of the trunk in the sagittal plane. The plane of movement therefore, was about the Y-Z axis, with Y along the coronal axis and Z along the vertical axis. The trunk segment was defined using the T10 marker and the midpoint of a segment drawn between the left and right greater trochanter markers (the global horizontal axis). Trunk angle was calculated as the angle deviation of the trunk segment in the coronal plane with respect to the global vertical axis (Fig. 1). The hip segment for the left and right were defined as the segment from the midpoint of the horizontal segment to the left or right greater trochanter markers respectively. The right and left hip angles were calculated as the angle formed between the hip segment and the global horizontal axis (Fig. 2). A positive hip value indicated the hip moved in a superior direction in the coronal plane, a negative value indicated the hip moved in the downward direction in the coronal plane.

Insert Figures 1 and 2 here

Kinematic Data Processing

Three-dimensional data were exported from the Vicon Motus motion capture system and processed using Matlab. The .3TD files were checked for missing markers and loss of data, and necessary gap filling was performed. The 3D coordinates of individual markers in the X, Y, and Z-axis were extracted and binned. A fourth order low pass Butterworth filter was applied on binned data prior to definition of individual segments and angle calculations. Trunk and hip angles were differentiated further as trunk lean right (positive) trunk lean left (negative), hip upward (positive) and hip downward (negative) movement respectively, based on the sign of the value.

Derivation of Dependent Variables

Trunk and hip kinematics included the following variables: excursion, symmetry, and variability.

a. <u>*Trunk Excursion*</u> was defined as the angular displacement of the trunk laterally in the coronal plane. It was derived by adding the average excursion of the trunk to the right of the global vertical axis to the average excursion of the trunk to the left of the global vertical axis.

b. <u>*Hip Excursion*</u> was defined as the angular displacement of the hip vertically, or, 'up and down' in the coronal plane. It was derived by adding the average excursion of the 'up' movement relative to the global horizontal axis, to the 'down' movement of the hip relative to the global horizontal axis.

c. Symmetry was used as a measure of coordination. The following definitions describe the types of symmetry calculated in this study.

- *Trunk Symmetry* was defined as the ratio of trunk excursion to the right, compared to trunk excursion on the left. It was derived by dividing the average excursion of the trunk to the right by the average excursion of the trunk to the left. A value of 1 = perfect symmetry, a value > 1 indicated that the trunk moved more to the right, a value < 1 indicated that the trunk moved more to the left.
- *Hip Intralimb Symmetry* was defined as the ratio of excursion of the 'hip up' to the 'hip down' motion of each hip. It was derived by dividing the excursion of the 'up' motion of the hip by the 'down' motion of the hip. A value of 1 = perfect symmetry, a value > 1 indicated that the up motion was greater than the down motion and a value <1 indicated that the down motion was greater than the up motion.
- *Hip Interlimb Symmetry* was defined as the ratio of total excursion of the right hip compared to total excursion of the left hip. It was derived by dividing the excursion of the right hip by the excursion of the left hip. A value of 1 = perfect symmetry, a value > 1 indicated that the right hip excursion was greater than the left hip excursion and a value <1

indicated that the left hip excursion was greater than the right hip excursion.

- *Trunk to Hip Symmetry* was defined as the ratio of total trunk excursion to total right hip excursion and total trunk excursion to total left hip excursion. It was derived by dividing the excursion of the trunk by the excursion of the right hip, and by dividing the excursion of the trunk by the excursion of the left hip. A value of 1 = perfect symmetry, a value > 1 indicated that trunk excursion was greater than that of the hip, a value < 1 indicated that trunk excursion was less than that of the hip.

a. *Trunk Variability* was defined as the lack of consistency of trunk excursion. It was derived by dividing the standard deviation of the average trunk excursion by the mean of the average trunk excursion (i.e. the coefficient of variation (CV) of trunk excursion). A larger value indicated greater variability of movement. A smaller value indicated less variability of movement.

b. *Hip Variability* was defined as the lack of consistency of hip excursion. It was derived by dividing the standard deviation of right hip excursion by the mean of right hip excursion (i.e. the coefficient of variation (CV) of trunk excursion). A similar procedure was performed for the left hip. A larger value indicated greater variability of movement. A smaller value indicated less variability of movement.

Statistical analysis

Separate 2x3 RMANOVAs were conducted to assess for significant differences and interaction effects of group (2 levels) and condition (3 levels), during stationary cycling (SPSS Inc. Chicago, IL; v22). When the sphericity assumption was violated, the Greenhouse Geyser adjustment was used. When a significant main effect was found, post hoc comparisons with a Bonferroni adjustment were used to determine the exact location of the differences. Normality was tested using the Shapiro-Wilk test.

When differences in kinematics; excursion, symmetry, and variability, were found, Pearson product moment correlation coefficients were used to discern if these changes were due to an increase in pedaling rate or due to the influence of the VE. When a moderate or strong correlation was found between pedaling rate and kinematics, it was determined that the changes in kinematics were due to an increase in pedaling rate. Where no correlation between pedaling rate and kinematics were found, the changes in kinematics were attributed to the influence of the VE. Strength of the correlations were based on the following scale: 0-.25= little or no relationship, .25-.5= fair relationship, .5-.75= moderate to good relationship, < .75= good to excellent relationship (Portney & Watkins, 2009). Only correlations of .50 or above were considered in the interpretation of these results. All test were conducted using a significance level of α=0.05. SPSS v22 was used for all analyses.

Results

Participants with PD were average age 71.3 (7.5) years with an average MoCA score of 26.8 (2.2), average UPDRS score of 31.8(16.5) and in stage II or III on the Hoehn and Yahr scale. Healthy older adults were average age 66.0 (7.1) years, with an average MoCA score of 28.0 (1.1). A one-way ANOVA revealed no significant differences between groups.

Part 1. Pedaling Rate

A significant difference was found for RPM within subjects ($F= 52.782$, df2, $p<0.000$). No between group or interaction effects were found. In people with PD, a significant difference was found between baseline and the feedback condition ($t= -5.130$, df3, $p<0.007$) and between 20% faster and the feedback condition ($t= -14.771$, df3, $p<0.001$). In healthy adults significant differences were found between baseline and the 20% faster condition ($t= -5.149$, df3, $p<0.007$) baseline to the feedback condition ($t= -8.412$, df3, $p<0.002$), and 20% to the feedback condition ($t= -6.611$, df3, $p<0.004$) (Table 1).

Insert Table 1

Part 2. Trunk:

Trunk Excursions Right, Left, and Total

There were no within condition differences, between group differences or interaction effects found in Trunk Excursion right, left, or total (Tables 2a and 2b).

Insert Tables 2a and 2b

Symmetry of Trunk Excursion

Within group differences were found for trunk symmetry of total excursion (F=4.907, df2, p<0.028). No between group differences or interactions were found. People with PD had greater symmetry of trunk excursion in the feedback condition compared to baseline (t=8.118, df3, p<0.002) (Table 3). .

Insert Table 3

Trunk Variability

No within condition differences, between group differences or interaction effects were found for Trunk Variability *right, left,* or *total* (Tables 4a and 4b).

Insert Tables 4a and 4b

Part 3. Hip

Hip Excursion

For excursion in the right hip, significant within condition differences were found (F=5.542, df 2, p<0.021). No between group differences or interaction effects were found. No within condition differences, between group differences or interaction effects were found for total excursion in the left hip. In people with PD, less excursion of the right hip was found in the 20% faster condition compared to the baseline condition ($t= 4.417$ df3, $p<0.011$). Greater hip excursion on the right was found in the feedback condition compared to cycling 20% faster ($t= -4.362$ df3, $p<0.011$). There were no significant differences in hip excursion for healthy adults (Table 5).

Insert Table 5

Hip Intralimb Symmetry Right

Within condition differences were found for symmetry of hip excursion right ($F=7.638$, df2, $p<0.007$). No between group differences or interaction effects were found. Post hoc comparisons did not support within condition effects for intralimb symmetry of the right hip, but a trend toward significance was found for the following conditions: People with PD pedaled less symmetrically from baseline to the feedback condition ($t= -2.942$, df3, $p<0.030$). Healthy adults also pedaled less symmetrically in the feedback condition compared to 20% faster ($t= -2.982$, df3, $p<0.029$) but more symmetrically in the 20% faster condition compared to Baseline ($t= -2.794$, df3, $p<0.034$) (Table 6).

Insert Table 6

Hip Intralimb Symmetry Left

No within or between group differences or interaction effects were found for hip intralimb symmetry left (Table 7).

Insert Table 7

Interlimb Symmetry

There were no within condition differences, between group differences or interaction effects for interlimb Symmetry of the hips (Table 8).

Insert Table 8

Hip Variability

There were no within condition differences, between group differences, or interaction effects for variability of the right hip or left hip (Table 9).

Insert Table 9

Correlations

Part 1. Trunk

Trunk Excursion

Max Excursion Right

In healthy adults, there were no moderate or strong correlations for *Max Excursion Right* in any of the conditions. In persons with PD, RPM and *Max Excursion Right* at 20% faster showed a moderate negative correlation, $r = -.72$, $p<0.14$. In the feedback condition, RPM and *Max Excursion Right* showed a moderate negative correlation in persons with PD, $r=-.60$, $p<0.20$ (Table 10).

Max Excursion Left

In healthy adults, RPM and *Max Excursion Left* at baseline showed a moderate negative correlation, r= -.57, p<0.22. In persons with PD, RPM and *Max Excursion Right* in the feedback condition also showed a moderate negative correlation, r=-.87, p<0.07 (Table 10).

Insert Table 10

Max Excursion Total

In healthy adults, RPM and *Max Excursion Total* at baseline showed a moderate negative correlation, r= -.71, p<0.14. In persons with PD, RPM and *Max Excursion Total* at 20% faster showed a moderate negative correlation, r= -.73, p<0.14. RPM and *Max Excursion Total* in the feedback condition, in persons with PD, also showed a moderate negative correlation, r=-.78, p<0.11 (Table 11).

Insert Table 11

Trunk Symmetry

Trunk Symmetry of Average Excursion

In healthy adults, there were no significant or moderate correlations for *Trunk Symmetry of Average Excursion*. In persons with PD, RPM and *Trunk Symmetry of Average Excursion* at 20% faster showed a moderate positive correlation, r= .89, p<0.06 (Table 12).

Insert Table 12

Trunk Variability

Trunk Variability Right

In healthy adults, there were no significant or moderate correlations for *Trunk Variability Right*. In persons with PD, RPM and *Trunk Variability Right* at baseline showed a moderate positive correlation, r= .68, p<0.16. RPM and *Trunk Variability Right* at 20% faster showed a moderate negative correlation in persons with PD, r= -.67, p<0.16 (Table 13).

Trunk Variability Left

In healthy adults, RPM and *Trunk Variability Left* in the feedback condition showed a moderate negative correlation, r= -.56, p<0.22. In persons with PD, there were no significant or moderate correlations for *Trunk Variability Left* (Table 13).

Insert Table 13

Trunk Variability Total

In healthy adults, RPM and *Trunk Variability Total* at 20% faster showed a strong positive correlation, r= .91, p<0.05. In persons with PD, RPM and *Trunk Variability Right* at 20% faster showed a moderate negative correlation, r= -.69, p<0.16 (Table 14).

Insert Table 14

Part 2. Hip

Hip Excursion

Average Excursion Total Right

In healthy adults, RPM and *Average Excursion Total Right* at baseline showed a moderate positive correlation, r= .59, p<0.20. RPM and *Average Excursion Total Right* at 20% faster showed a strong positive correlation, r= .91, p<0.04. In the feedback condition, RPM and *Average Excursion Total Right* showed a strong positive correlation in healthy adults, r= .93, p<0.03 (Table 15).

In persons with PD, RPM and *Average Excursion Total Right* at baseline showed a strong positive correlation, r= .88, p<0.06. RPM and *Average Excursion Total Right* at 20% faster showed a strong positive correlation, r= .84, p<0.08. In the feedback condition, RPM and *Average Excursion Total Right* showed a strong positive correlation in persons with PD, r= .95, p<0.03.

Average Excursion Total Left

In healthy adults, RPM and *Average Excursion Total Left* at baseline showed a strong positive correlation, r= .99, p<0.01. RPM and *Average Excursion Total Left* at 20% faster showed a strong positive correlation, r= .97, p<0.01. RPM and *Average*

Excursion Total Left in the feedback condition showed a strong positive correlation, r= .99, p<0.01.

In persons with PD, RPM and *Average Excursion Total Left* at 20% faster showed a strong positive correlation, r= .87, p<0.07. RPM and *Average Excursion Total Left* in the feedback condition showed a moderate positive correlation, r= .75, p<0.13 (Table 15).

Insert Table 15

Hip Symmetry

Symmetry Average Excursion Right Hip

In healthy adults, there were no significant or moderate correlations for *Symmetry Average Excursion Right*. In persons with PD, RPM and *Symmetry Average Excursion Right* at 20% faster showed a strong negative correlation, r= -.83, p<0.08. RPM and *Symmetry Average Excursion Right* in the feedback condition showed a strong positive correlation in persons with PD, r= .91, p<0.05 (Table 16).

Symmetry Average Excursion Left Hip

In healthy adults, RPM and *Symmetry Average Excursion Left* at baseline showed a strong positive correlation, r= .80, p<0.01. In persons with PD, RPM and *Symmetry Average Excursion Left* at 20% faster showed a strong negative correlation, r= -.91, p<0.05 (Table 16).

Insert Table 16

Hip Variability

Hip Variability Total Right

In healthy adults, RPM and *Hip Variability Total Right* in the feedback condition showed a moderate negative correlation, r= -.61, p<0.20. In persons with PD, RPM and *Hip Variability Total Right* at baseline showed a moderate positive correlation, r= .60, p<0.20. RPM and *Hip Variability Total Right* at 20% faster showed a strong negative correlation, r= -.99, p<0.01. In persons with PD, RPM and *Hip Variability Total Right* in the feedback condition showed a strong negative correlation, r= - .89, p<0.06 (Table 17).

Hip Variability Total Left

In healthy adults, RPM and *Hip Variability Total Left* at baseline showed a moderate negative correlation, r= -.55, p<0.22. RPM and *Hip Variability Total Left* in the feedback condition showed a moderate negative correlation, r= -.61, p<0.19.
In persons with PD, RPM) and *Hip Variability Total Left* at 20% faster showed a moderate positive correlation, r= .52, p<0.24 (Table 17).

Insert Table 17

Discussion

This exploratory study examined if health condition (PD) and exposure to a VE altered hip and trunk kinematics during stationary cycling. Changes in excursion and symmetry were found with an increase in pedaling rate. Because participants experienced changes in kinematics as well as an increase in pedaling rate, we sought to dissociate the contribution from the VE and the change in RPM. Below we discuss findings where pedaling rate can be differentiated from the influence of the VE.

Excursion:

No significant difference in trunk excursion for either group in the baseline or the VE conditions. This lack of change in trunk excursion may be expected given the known axial rigidity in people with PD (Peterson & Horak, 2016), coupled with the constrained nature of the upper body during cycling. One may also speculate that the low demands of the task did not require extraordinary demands on the trunk. However, people with PD increased their hip excursion in the feedback condition. A strong relationship between pedaling rate and hip excursion in the feedback condition was also found, which confirms the findings of ANOVA; hip excursion increased as pedaling rate increased. Therefore, we conclude that in people with PD, the change in hip kinematics was due to an increase in pedaling rate rather than to the influence of the VE.

Symmetry

The asymmetrical nature of motor symptoms in PD (Jankovic, 2008) coupled with rigidity and bradykinesia may affect coordination of movements. In people with PD, a significant increase in trunk symmetry between baseline and the feedback condition was found. However, correlations show no relationship between pedaling rate and changes in kinematics. Therefore, changes in trunk symmetry may be attributed to the VE and not the increase in pedaling rate. We speculate that the increase in trunk symmetry was due to visually fixating on the VE resulting in more symmetric movement. In contrast, trunk symmetry was not found in the baseline condition for people with PD where there was no VE on which to fixate their gaze.

A significant difference was found in hip symmetry for the feedback condition. Both groups pedaled less symmetrically in the feedback condition compared to baseline. A strong relationship between pedaling rate and the feedback condition for hip symmetry for people with PD was also found, confirming the results of the ANOVA. Thus, the changes in kinematics may be attributed to an increase in pedaling rate rather than from the influence of the VE in this population. A study by Abe et al. investigated the rotational velocity of pedaling in people with PD while cycling on a constant velocity ergometer. Abnormal patterns, such as unnatural phase differences, and cessation of pedaling with re-initiation; a stop-and-start type pedaling pattern, were found (Abe, Asai, Matsuo, Nomura, Sato, Inoue,…& Sakoda, 2003). The stop and start pattern was observed in our participants as well, particularly in the feedback condition where they were trying to find the correct rate of cycling that would make the markers change color.

Healthy adults showed weak correlations between pedaling rate and hip symmetry despite significant increases in pedaling rate between baseline and the feedback condition. The lack of relationship between increased pedaling rate and changes in kinematics points to the influence of the VE as the cause of the change in hip symmetry. Symmetry in pedaling power, but not kinematics, has been investigated in healthy adults (Smak, Neptune, & Hull, 1999). The relationship between increased pedaling rate and symmetry of lower extremity power during pedaling was investigated. Eleven male competitive cyclists pedaled a conventional racing bicycle at a constant workload but different pedaling rates ranging from 60 to 120 RPM. Results show an increase in symmetry of power of the lower extremities with an increase in pedaling rate (Smak et al., 1999). Relating symmetry of power to symmetry of kinematics, we would expect our healthy participants to show increased symmetry with increased pedaling rate, but this was not the case. This further supports our interpretation that in this instance, the change in kinematics was most likely due to the VE.

In summary, both healthy older adults and people with PD increased their pedaling rate but their kinematic patterns differed. In the trunk, healthy older adults showed no correlation for excursion, symmetry or variability with increased pedaling rate in any of the conditions. However, people with PD showed a relationship between kinematics and increased pedaling rate in the 20% faster and FB conditions. A positive correlation with trunk symmetry in the 20% condition indicates that the increase in trunk symmetry was achieved at the expense of trunk excursion and variability, which showed negative correlations. People with PD also showed a negative correlation in trunk excursion in the FB condition with the increase in pedaling rate.

Although healthy controls showed no changes in kinematic changes in the trunk with increased pedaling rate, they did show changes in the hip. With an increase in pedaling rate, a positive correlation with hip excursion in the 20% faster and FB conditions, and a negative correlation in variability in the FB condition were found. Similar to healthy older adults, in people with PD in both the 20% faster and the FB conditions showed a positive correlation in hip excursion. However, the findings for symmetry and variability differed. While healthy older adults showed no correlation in symmetry in any of the conditions for either hip, and a negative correlation in variability in both hips in the FB condition, the response in people with PD differed. In the 20% condition, a negative relationship with symmetry was found in both hips. In the FB condition, a positive relationship was found with symmetry in the right hip, but no correlation in the left hip. In addition, the association between variability and increased pedaling rate in the 20% condition showed opposite responses in each hip; a negative relationship in the right hip and a positive relationship in left hip which suggests that one limb may be compensating for the other. The feedback condition showed a negative relationship in the right hip and no relationship in the left hip. Although these observations are for a small sample size, the findings suggest that people with PD did not adopt the same kinematic strategies for increasing pedaling rate as healthy older adults.

Limitations

Several limitations exist in this study that may have affected the results. First, this study is part of a larger study and therefore, prior trials may have affected the outcome of subsequent trials. Second, a small sample size, although indicative of the larger trial, may not have been large enough to see significant changes in kinematics. Third, seat height was standardized for all participants. In people with PD, the height of the seat may have been higher than their self-selected seat height and resulted in changes in kinematics not specific to the VE or changes in pedaling rate.

In addition, markers were placed on the skin and clothing and may have moved during data capture. This is a common problem in kinematic studies as it can affect the resultant joint angles and excursions. Placing as many markers directly on the skin will help decrease this error. Lastly, direct measurement of pelvic motion through the use of a triad of markers on the sacrum and posterior superior iliac spines as is more commonly done, may have resulted in more accurate representation of pelvic motion.

Other considerations include how posture in people with PD may affect kinematics. A typical standing posture for a person with PD includes a forward flexed posture with increased hip, knee, and trunk flexion (Jankovic, 2008), and is often accompanied by axial rigidity (Peterson & Horak, 2016), which results in limited trunk rotation. A decreased ability to rotate the trunk may affect the translation of forces from the trunk, through the pelvis and hips, to the lower extremities during cycling.

The use of handedness and footedness of each participant, as well as taking into account the side more affected in participants with PD, may have influenced interpretation of the results. In large studies, more than half of the people with PD show an evident right versus left difference on the UPDRS, which does not change, even as the disease becomes bilateral (Djaldetti, et al., 2006). In this study, the participants did not show a propensity toward one side more affected than the other. Of the 4 subjects with PD in the analysis, two subjects had both sides affected equally, one had the right side more affected than the left and one had the left side more affected than the right according to UPDRS scores.

The propensity toward one side more affected in motor output in people with PD raises the possibility that asymmetry in their cycling patterns may be found. Indeed, we did find asymmetry in the right hip as pedaling rate increased in the feedback condition in participants with PD in this study but not at slower pedaling rates. Asymmetry in kinematics during cycling has not been reported elsewhere in people with PD, but asymmetry of power has (Penko, Hirsch, Voelcker-Rehage, Martin, Blackburn, & Alberts, 2014). Penko et al., in 2014, tested twenty five people with PD aged 44-72 years as they rode a stationary bicycle at three different workloads; 20W, 60W and max performance. A significant difference in symmetry was found between all three stages. The dominant leg (as determined by kicking) produced more force than the non-dominant leg. However, as participants fatigued, the non-dominant leg contributed more power (Penko et al., 2014).

Asymmetry of power during cycling has also been found in healthy young men (Smak, et al., 1999). Eleven young male competitive cyclists cycled at a fixed workload at 5 different pedaling rates ranging from 60 to 120 rpms. Results show that asymmetry of pedaling became less pronounced with an increase in pedaling rate. At lower pedaling rates, the dominant leg contributed more average power than the non-dominant leg, but when pedaling rate increased, changes in pedaling asymmetry became unrelated to limb dominance (Smak, et al., 1999). With a larger number of participants, handedness, footedness, and/or side more affected may have contributed to a more complete interpretation of the results in the current study.

The role of gender may also influence the findings. Of the four participants in this study, two were male, and two female. It is reasonable to assume that cycling kinematics, particularly of the pelvis or hip may be influenced by differences in anthropometrics between males and females. However, the literature on cycling includes either males and females (Allen, Canning, Sherrington, & Fung, 2009; Brown, Kautz, & Dairaghi, 1996; Gregor, Perell, Rushatakankovit, Miyamoto, Muffoletto, & Gregor, 2002; Sauer, Weisshaar, Ploeg, & Thelen, 2007), or only one gender (Brown, et al., 1996; Ericson,1986; Gregor et al, 2002; Allen et al., 2009). When both males and females were included in a study, the results were reported in aggregate.

Current evidence regarding gender differences in hip motion during cycling were not found. However, Gregor et al. in an early review stated that substantial hip motion during cycling can occur, particularly in the vertical plane, of up to 3cm, and in the anterior-posterior direction up to 1-2 cm (Gregor, Broker, & Ryan, 1991). Other sources in this review believe the pelvis is fixed, and only moves approximately 1cm, and that any hip motion is due to incorrect seat height or improper placement of markers (Gregor, et al., 1991). Gender differences were not taken into account in this review.

More recently, a study by Sauer et al. in 2007 investigated the influence of anthropometric differences of the pelvis between males and females to determine if these differences influenced pelvic motion during cycling. Pelvic motion during cycling is natural and may facilitate the transfer of energy from the upper to lower body (Sauer, et al., 2007). Twelve experienced healthy male and 14 experienced female cyclists rode a stationary bicycle at 3 power outputs with their hands in 2 positions, 'tops', and 'drops'. Pelvic kinematics were captured with results showing the largest angular excursion of the pelvis in a non-sagittal plane and included internal rotation of approximately 3 degrees, and lateral rolling of approximately 2 degrees. This movement caused the hip on the downstroke to translate anterior and inferiorly. Differences between male and female pelvic motion were only found when hand position changed- females showed greater anterior pelvic tilt when hands were in the drops position compared to males. But this difference could not be explained by differences in anthropometrics using ischial tuberosity width, or differences in hamstring flexibility. The authors did not report any differences in hip motion between males and females. In light of this information, there is not enough evidence to conclude that there would be a gender difference in hip kinematics in the present study.

Conclusions

Several factors affect cycling performance and include environmental, biomechanical, and physiological factors such as muscle length, joint angles, type of muscle contraction, muscle recruitment pattern, and pedaling rate (Too, 1990). In this exploratory study we investigated kinematic changes in the trunk and hip in people with PD and healthy older adults while riding a stationary bicycle in a cycling VE. Results show that trunk and hip kinematics changed with increased pedaling rate and that in the presence of a cycling VE, these changes may be due to the influence of the VE and not due solely to an increase in pedaling rate. However, we cannot truly separate these influences as this was a preliminary exploration in an attempt to dissociate the effects of pedaling rate and the influence of the VE on trunk and hip kinematics.

If clinicians are aware of the influence stationary cycling has on trunk motion, and the relationship of the motion between trunk and the hip, the bicycle becomes more than just a tool used for warm up or fitness, especially for their patients with PD. A better understanding of trunk kinematics during stationary cycling could improve our use of this modality for rehabilitation and may provide insight into gait dysfunction. Future research should investigate the influence of auditory cues on pedaling rate and kinematics of the trunk and hip in people with PD and the effects of freezing of gait on kinematics.

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Tables

Table 1. Pedaling Rate (rpm) (mean /SD)

	Pedaling Rate		
	Baseline	20% faster	Feedback
HC	67.7 (6.4)	84.7 (11.5)	103.11 (14.1)
PD	58.0 (21.4)	71.0 (10.3)	90.2 (12.5)*

*within condition significance (p<0.02)
Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Table 2a. Trunk Excursions Right and Left (degrees) (mean /SD)

	Excursion Right			Excursion Left		
	Baseline	20% faster	Feedback	Baseline	20% faster	Feedback
HC	1.0 (0.6)	1.0 (.06)	0.9 (0.4)	-0.7 (0.3)	-0.9 (0.2)	-1.0 (0.3)
PD	1.8 (1.0)	0.9 (0.4)	0.9 (0.5)	-0.6 (0.2)	-1.4 (1.0)	-1.0 (0.2)

*within condition significance (p<0.02)
Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 2b. Trunk Excursion Total (degrees) (mean /SD)

	Excursion Total		
	Baseline	20% faster	Feedback
HC	1.7 (0.6)	1.8 (0.4)	1.9 (0.3)
PD	2.4 (1.2)	2.2 (0.9)	1.4 (0.7)

*within condition significance (p<0.02)
Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 3. Trunk Symmetry of Excursion (degrees) (mean/SD)

	Trunk Symmetry of Excursion		
	Baseline	20% faster	Feedback
HC	1.8 (1.2)	1.3 (1.0)	1.1 (0.7)
PD	2.8 (0.6)	1.2 (1.2)	0.9 (0.5)*

*within condition significance (p<0.02)
Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 4a. Trunk Variability Right and Left (mean/SD)

	Variability Right			Variability Left		
	Baseline	20% faster	Feedback	Baseline	20% faster	Feedback
HC	0.7 (0.2)	0.7 (0.0)	0.8 (0.1)	0.7 (0.1)	0.7 (0.1)	0.7 (0.0)
PD	0.6 (0.1)	0.7 (0.2)	0.8 (0.2)	0.8 (0.1)	0.6 (0.1)	0.6 (0.1)

*within condition significance (p<0.02)
Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 4b. Trunk Variability Total (mean/SD)

	Variability Total		
	Baseline	20% faster	Feedback
HC	1.4 (0.1)	1.4 (0.1)	1.4 (0.1)
PD	1.4 (0.1)	1.4 (0.2)	1.3 (0.2)

*within condition significance (p<0.02)
Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 5. Hip Excursion (degrees) (mean/SD)

	Excursion Right			Excursion Left		
	Baseline	20% faster	Feedback	Baseline	20% faster	Feedback
HC	6.7 (2.6)	6.5 (3.2)	7.5 (3.1)	8.5 (2.6)	8.2 (3.0)	9.2 (3.8)
PD	8.7 (0.8)	8.1(1.0)*	9.0 (1.7)*	10.4 (1.7)	10.3 (1.6)	11.8 (2.1)

*within condition significance (p<0.02)
Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 6. Hip Intralimb Symmetry Right (degrees) (mean/SD)

	Intralimb Symmetry Right		
	Baseline	20% faster	Feedback
HC	1.6 (0.8)	1.5 (0.6)	2.5 (0.4)
PD	1.0 (0.2)	1.5 (0.7)	1.8 (0.4)

*within condition significance (p<0.02)
Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 7. Hip Intralimb Symmetry Left (degrees)(mean/SD)

	Intralimb Symmetry Left		
	Baseline	20% faster	Feedback
HC	0.6 (0.2)	0.7 (0.3)	0.9 (0.2)
PD	0.6 (0.2)	0.8 (0.3)	0.8 (0.1)

*within condition significance (p<0.02)

Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 8. *Hip Interlimb* Symmetry (degrees) (mean/SD)

	Interlimb Symmetry		
	Baseline	20% faster	Feedback
HC	0.8 (0.2)	0.8 (0.2)	0.8 (0.1)
PD	0.9 (0.1)	0.8 (0.1)	0.8 (0.1)

*within condition significance (p<0.02)

Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 9. Hip Variability Right and Left (mean/SD)

	Variability Right			Variability Left		
	Baseline	20% faster	Feedback	Baseline	20% faster	Feedback
HC	0.1 (0.0)	1.0 (0.1)	1.1 (0.1)	0.9 (0.0)	1.0 (0.1)	0.9 (0.1)
PD	0.8 (0.2)	0.9 (0.0)	1.0 (0.1)	1.0 (0.1)	0.9 (0.1)	0.9 (0.1)

*within condition significance (p<0.02)

Key: HC, Healthy age-matched controls, PD, Parkinson's disease

Table 10. Pearson's r for RPM and Trunk Excursion

	Trunk to Hip Excursion Right			Trunk to Hip Excursion Left		
	RPM to Baseline	RPM to 20% faster	RPM to Feedback	RPM to Baseline	RPM to 20% faster	RPM to Feedback
HC	- .26	-.15	.40	-.65	-.40	-.08
PD	- .02	.65	-.39	.29	-.67	-.85

*= significant at the .05 level

Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Table 11. Pearson's r for RPM and Total Trunk Excursion

	Total Trunk Excursion		
	RPM to Baseline	RPM to 20% faster	RPM to Feedback
HC	-.65	-.42	.44
PD	.04	-.49	.46

*= significant at the .05 level

Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Table 12. Pearson's r for RPM and Symmetry of Trunk Excursion

	Total Trunk Symmetry		
	RPM to Baseline	RPM to 20% faster	RPM to Feedback
HC	-.01	-.10	.49
PD	-.54	.89	-.07

*= significant at the .05 level

Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Table 13. Pearson's r for RPM and Trunk Variability

	Trunk Variability Right			Trunk Variability Left		
	RPM to Baseline	RPM to 20% faster	RPM to Feedback	RPM to Baseline	RPM to 20% faster	RPM to Feedback
HC	-.26	.47	- .11	.42	.50	-.56
PD	.68	-.67	-.17	.29	-.09	.24

*= significant at the .05 level

Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Table 14. Pearson's r for RPM and Total Trunk Variability

	Total Trunk Variability		
	RPM to Baseline	RPM to 20% faster	RPM to Feedback
HC	-.06	.91*	-.47
PD	.05	-.69	.39

*= significant at the .05 level

Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Table 15. Pearson's r for RPM and Hip Excursion

	Excursion Right			Excursion Left		
	RPM to Baseline	RPM to 20% faster	RPM to Feedback	RPM to Baseline	RPM to 20% faster	RPM to Feedback
HC	.59	.91*	.93*	.99*	.97*	.99*
PD	.88	.84	.95*	.33	.87	.75

*= significant at the .05 level

Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Table 16. Pearson's r for RPM and Hip Intralimb Symmetry Right and Left

	Hip Intralimb Symmetry Right			Hip Intralimb Symmetry Left		
	RPM to Baseline	RPM to 20% faster	RPM to Feedback	RPM to Baseline	RPM to 20% faster	RPM to Feedback
HC	-.48	.07	.20	.80	.03	.11
PD	-.11	-.83	-.91*	-.13	-.91*	-.40

*= significant at the .05 level

Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Table 17. Pearson's r for RPM and Hip Variability

	Hip Variability Right			Hip Variability Left		
	RPM to Baseline	RPM to 20% faster	RPM to Feedback	RPM to Baseline	RPM to 20% faster	RPM to Feedback
HC	-.33	-.05	-.61	-.57	-.46	-.61
PD	.60	-.99*	-.89	.35	.52	-.13

*= significant at the .05 level

Key: HC, Healthy age-matched controls, PD, Parkinson's disease, RPM, revolutions per minute

Figure Titles and Legends

1. Fig 1. Schematic of representation of trunk angles, posterior view
   T10= reflective marker on thoracic vertebrae 10, LGRT=left greater trochanter, LRGRT= right greater trochanter
   Key: Angle 1, Trunk lean to the left; Angle 2, Trunk lean to the right

2. Fig 2. Schematic of representation of hip angles, posterior view
   T10= reflective marker on thoracic vertebrae 10, LGRT=left greater trochanter, LRGRT= right greater trochanter
   Key: Angle 3, Hip motion UP; Angle 4, Hip Motion DOWN

Figures

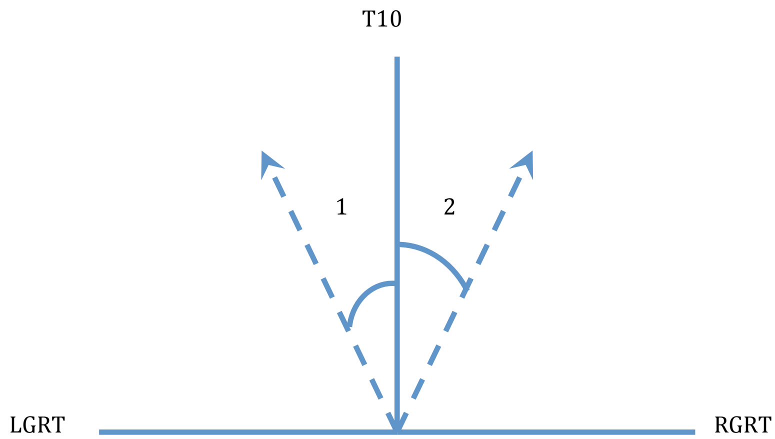

Fig 1.

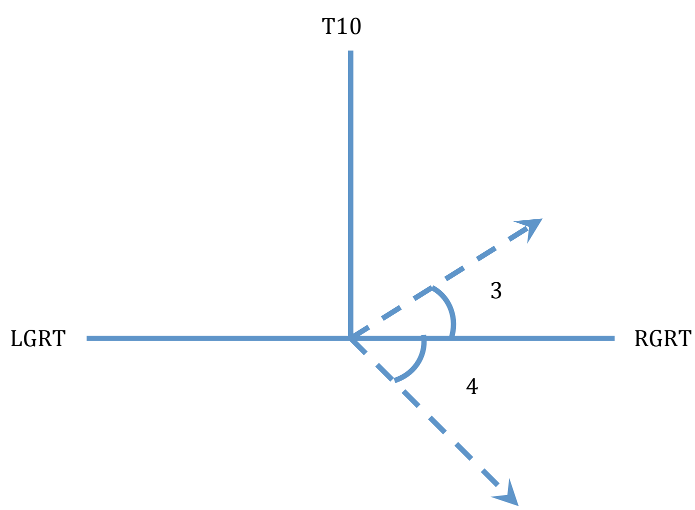

Fig. 2

Chapter 7: General Discussion

Exercise is essential in people with PD and healthy older adults to maintain optimal health and function. It has been shown to improve cognitive and motor function, (Kraft, 2012; Seidler et al., 2010;Van Wegen, Hirsch, Juiskamp, & Kwakkel, 2014) and to have neuroplastic (Hotting & Roder, 2013) and neuroprotective effects, which in PD may help to decelerate the disease process (Van Wegen et al., 2014). Symptoms of postural instability, rigidity, and bradykinesia in people with PD however, create barriers to exercise. In older adults, barriers also exist and include strength and balance deficits, pain, and poor overall health. Therefore, there is a need for safe and motivating forms of exercise for these populations.

Stationary cycling is commonly found in rehabilitation, fitness, and home settings, and presents a viable alternative to walking in people with balance deficits. Stationary cycling may be used not only to improve cardiovascular health, but high intensity cycling has been shown to mitigate symptoms of PD such as tremor, rigidity, and bradykinesia (Ridgel, Peacock, Fickes, & Kim, 2012; Ridgel, Phillips, Walter, Discenzo, & Loparo, 2015; Ridgel, Vitek, & Alberts, 2009). Cycling may also be used to address axial and limb rigidity, asymmetry of symptoms, and variability of movement, commonly found in people with PD.

Virtual environments have been used in rehabilitation and fitness settings to improve gait and function, and may be adapted for use with other exercise equipment such as a stationary bicycle. Virtual environments can easily incorporate compensatory and motor learning strategies such as cueing and feedback, known to work in the real world to improve gait, functional activities, and execution of ADL's (Van Wegen et al., 2014). However, cueing and FB embedded in a cycling VE has not been studied. Further, a specific knowledge of cycling biomechanics in persons with PD is lacking. To optimize the use of a cycling VE for rehabilitation and fitness in older and patient populations, a thorough understanding of the influence of cueing and feedback embedded in a cycling VE on temporal and spatial parameters of cycling is needed.

Dissertation Outcomes

The goal of this dissertation was to investigate the influence of cueing, feedback, and directing attention in a cycling VE on temporal and spatial parameters in people with PD and healthy age matched adults.

In study 1, we sought to determine if people with PD and aged matched healthy adults responded to auditory and visual cueing embedded in a cycling VE as a method to increase exercise intensity. Outcomes of this study revealed that both groups increased their pedaling rate with auditory and visual cues. However, people with PD required attention directed to the VC in order to obtain an increase in cycling intensity proportional to cue rate. This was interpreted as the VC may not have been salient enough for people with PD and they needed attention directed in order to fully respond. Additionally, based on previous studies in the walking literature where inconsistent results were found when auditory and visual cues were presented simultaneously, together with known limited cognitive resources in people with PD, there was a concern that the combination of VCs with the ACs would reduce the rate of pedaling. However, the combination was neither additive nor interfering. These results serve as preliminary evidence that embedding auditory and visual cues to alter cycling speed in a VE may be used as method to increase exercise intensity that may promote fitness.

In study 2, we investigated whether persons with PD and healthy age-matched adults modulated pedaling rate as a result of augmented external feedback and directing attention in a cycling VE. People with PD and healthy older adults increased their cycling behavior in response to bandwidth speed feedback. Simultaneous auditory and visual cue presentation also increased pedaling rate, and directing attention toward one or the other cue, although not significant, increased the magnitude of the effect. These results suggest that incorporating feedback and directing attention into a virtual reality-based rehabilitation program may also be used as a strategy to increase exercise intensity.

In study 3, we examined the spatial changes of the trunk and hip in people with PD and healthy age-matched adults while in a cycling VE to determine the contribution of pedaling rate and influence of the VE. While both groups increased pedaling rate in all conditions in the prior studies, the visual cue and feedback conditions, compared to baseline, were chosen to examine spatial changes because the magnitude of the effect of the visual cues and feedback was greater than any other manipulation. Results show changes in trunk and hip excursion and/or symmetry in both groups in the VE conditions. These changes were interpreted as due either to the influence of the VE or an increase in pedaling rate. However, one cannot completely separate the influence of pedaling rate and the VE in this study. The results however, suggest that cycling in a VE can modify trunk and hip kinematics and may be used as a strategy to change kinematics.

Limitations and Considerations

Limitations across the experiments involve the design of the VE and the study design. First, limitations regarding the VE exist. Projection size and elements embedded in a VE can affect motor behavior (Powell & Stevens, 2013) by influencing the degree of immersion and subsequently, the ability to appropriately respond to the environment. Such factors, as they pertain to this study, include the use of a monoscopic rather than a stereoscopic projection, and a relatively small screen size and small horizontal field of view. A stereoscopic projection has been found to increase self-motion perception and depth estimation compared to a monoscopic projection (Powell & Stevens, 2013). A small horizontal field of view does not incorporate objects in the periphery (Powell & Stevens, 2013).

One might also speculate that participants would respond differently if the horizontal field of view of the environment were larger or was projected using a head mounted display (HMD). A wide field of view incorporates objects in the periphery, which improves perception of self-motion and sense of immersion (Powell & Stevens, 2013). The human visual system has a horizontal field of view of approximately 180 degrees (Xiao & Benko, 2016) while the horizontal field of view of the flat screen projection in this study was 80 degrees, the low end of an ideal projection of 80 to 120 degrees (Powell and Stevens, 2013). Current head mounted displays have a horizontal field of view of around 90 degrees, with some as small as 40 degrees (Xiao & Benko, 2016), but a unlike a flat screen projection, a HMD, is considered a fully immersive environment. Therefore, use of a HMD in this study may have resulted in a stronger response of participants to the environment.

There may also have been an overlap in the influence of peripheral optic flow and decreasing the spatial frequency between the central road markers. Peripheral optic flow provides velocity cues that influence a rider's sense of immersion and self-speed estimation (Powell, 2013). In this study, the rate of optic flow was matched to the pedaling rate of the rider; as pedaling rate increased, the rate of presentation of the environment increased. This in turn increased the peripheral optic flow and therefore the potential to influence the users' behavior. Decreasing the spatial frequency between objects in a VE influences a user's response by improving the perception of moving faster through the environment (Banton et al, 2005; Holden, 2005). The spatial frequency between the central road markers in this study was decreased by 20%, compared to a real-world distance apart. Two trials with the decreased spatial frequency were used, one with no instruction to look specifically at the markers, and one with instructions to 'Try to decrease the gray space between the markers', thereby instructing them to focus on the markers. The expectation was that the increased optic flow from the decrease in spatial frequency of the markers would result in a faster pedaling rate, separate from the influence of the peripheral optic flow. However, it is not possible to fully parse out the influence of the peripheral optic flow from the influence of the central road markers.

Another consideration is the use of vertical rather than horizontal lines for the visual cues, which may have influenced the response of participants. Horizontal lines have been shown to normalize stride length in persons with PD (Morris, Iansek, Matyas, & Summers, 1996), however, the choice of vertical lines as a visual cue in this study was an effort to make the environment more environmentally valid. Perhaps horizontal lines would have presented a more salient cue and the need to direct a user's attention would be diminished.

In terms of study design, an order effect also cannot be ruled out. Each trial in a block was presented in the same order in the auditory, visual and feedback conditions, this was done purposefully to determine the effect of adding visual flow and cues on the participant. However, the early trials may have affected the outcome of later trials. Randomization of the blocks may have helped avoid this effect.

To ensure validity, the same instructions, specific for each trial, were provided to every participant. During debriefing, however, many participants (7 with PD and 6 healthy controls) acknowledged that they were confused on the instructions in the visual cue trial, 'Try to decrease the gray space between the markers'. This was shown in their response in which a stop/start, or fast/slow/fast type of pattern was adopted. More clearly worded instructions may have helped to avoid this confusion and ensure that participants were responding to the instructions appropriately.

In addition, in the feedback condition, participants were seen over and underestimating their pedaling rate in an attempt to determine the rate that would make the markers change color. We suspect the one-minute trial length was not long enough to allow participants to stabilize their pedaling rate to the bandwidth feedback.

One may also speculate that disease severity may have played a part in overestimation in the feedback condition. However, this relationship was not found in this study. The participants who overestimated their pedaling rate the greatest amount in the feedback condition were in stage II on the Hoehn and Yahr scale (Hoehn & Yahr, 1967), compared to those in stage III. However, this study included a narrow range of Hoehn and Yahr stages; only stages II or III. A sample of participants with a wider range of disease stage, for example, stages I through IV, may have shown a relationship between severity of disease and overestimation.

In terms of seat height, a standardized seat height based on each participants' leg length,was used. However, the position of the seat may have been too high for people with PD and therefore may have influenced pedaling kinematics over and above the influence of the VE or the increase in pedaling rate.

Other considerations include the role of gender in the study. Parkinson's disease is more prevalent in the male population (Haaxma Bloem, Borm, Oyen, Leenders, Eshuis, Booij, Dluzen & Hortsink, 2007). Participants in this study reflected the higher incidence in males. However, gender differences were not taken into account in this study as it was not expected that males and females would process or interpret visual or auditory information differently from one another. Therefore, results were interpreted in aggregate.

Another consideration is that of a possible dual task paradigm. This study was designed with an external focus of attention in mind; participants were instructed to attend to the cues or to the feedback in the environment, with the expectation that pedaling rate would increase. However, this study design may also be thought of as a dual task paradigm. Participants were instructed to attend to a specific cue or concentrate on reaching a goal, as in the feedback condition, while performing the simultaneous task of pedaling.

An external focus of attention is the act of focusing on the intended movement effect as opposed to an internal focus, which is a focus on body movements themselves (Wulf 2013). An external focus of attention has been found to impact immediate performance as well as learning (Wulf 2013). The instructions in the visual cue trial; 'Try to decrease the gray space between the markers', the feedback trial; 'Pedal at a rate that will make the marker turn color and keep that change in color throughout the entire trial', and the directed attention trials, 'Match your pedaling rate to the metronome' or, 'Look at the white lines', in this experiment were worded specifically with an external focus on the markers, rather than focusing on the movement of their legs as they pedaled. The latter would be an internal focus of attention.

Attentional focus instructions however, can create a dual task situation (Wulf 2013). Dual tasking is the simultaneous performance of cognitive or motor tasks (Kelly, Eusterbrock, & Shumway-Cook, 2012). While dual tasking, the ability to divide attentional resources properly is necessary to perform both tasks effectively

(LaCour, Bernard-Demanze, & Dumitrescu, 2008), therefore requiring cognitive abilities and resources to perform more than one activity at the same time (Nieuwhof, Bloem, Reelick, Aarts, Maidan, Mirelman,…Helmich, 2017). Impaired dual tasking has been found both in healthy older adults (LaCour, et al., 2008) and in people with PD (Nieuwhof, et al., 2017). In this study, the attentional instructions together with the physical task of pedaling may have created a dual task situation.

Generalizations

Cueing and feedback are commonly seen in rehabilitation interventions in healthy and patient populations. Virtual environments for gait modulation have been successful by incorporating cueing and feedback into their environments. Results found in this dissertation show an ability to respond to cueing and feedback in a cycling VE in healthy and people with PD. Perhaps other patient populations would also respond to cueing, feedback and directing attention in a cycling VE.

Future Research:

Ideas for future research that stem from the current study include:

1. The use of VEs yoked to exercise equipment as a tool for fitness promotion. Design of a training study that utilizes a cycling VE embedded with cueing and feedback to improve cardiovascular conditioning.

2. Design of a training study that utilizes a cycling VE embedded with cueing and feedback to assess carryover to improved gait, function and a reduction of PD symptoms.
3. To determine the true effect of the VE on kinematics, conduct a study in a cycling VE, but with a constant pedaling rate.
4. Investigate the effect of auditory cues on kinematics of the trunk and hip in people with PD and healthy adults. In this study, the visual cue trials were used to examine changes in kinematics. Auditory cues may prove more conspicuous than visual cues thereby providing a more prominent mechanism with which to attend.
5. Examination of knee and ankle kinematics in people with PD and healthy adults during cycling in a VE to better understand the kinematic changes that occur not only in the trunk and hip, but in the entire lower extremity to enable rehabilitation professionals to design cycling interventions that more closely target problem areas such as asymmetry of motor symptoms in people with PD.
6. This current study used RPMs to determine exercise intensity. A future study might investigate Rate of Perceived Exertion of these participants as an alternate method to determine exercise intensity.
7. Compare the response of participants using a head mounted display to the flat display used in this experiment.

Summary:

Results of this preliminary work speak to the efficacy of embedding motor learning and compensatory techniques in a cycling VE to increase pedaling rate as a strategy to increase exercise intensity and modify trunk and hip kinematics in people with PD and healthy older adults. First, we showed that external auditory and visual cueing in a cycling VE increased pedaling rate, but in the visual cue condition, people with PD required attention directed to the visual cue to achieve this increased rate. Second, the presence of bandwidth feedback and simultaneous presentation of cues also increased pedaling rate in both groups and, in the presence of simultaneous cues, directing attention to either the auditory or visual cue increased the strength of the effect. Of clinical importance is the need to explicitly direct the attention of people with PD to a salient cue in order to modify a response. This shows that VEs are not static, but rather support interaction between the clinician, patient, and the VE. Finally, axial rigidity and asymmetry of motor symptoms in persons with PD result in restricted movement, which can negatively affect everyday activities. The modulation of trunk and hip kinematics found in this study can be attributed to both the influence of the VE and an increase in pedaling rate indicating that a cycling VE may be a strategy to address rigidity.

These results add to the body of knowledge about the use of VEs in rehabilitation. By embedding cueing and feedback in a cycling VE, together with directing a user's attention for a desired motor response, shows an advance over prior studies. Implementation of long term programs for promoting safe, motivating, and engaging exercise in persons with PD and older adults may benefit from the integration of a VE. These findings create options for clinicians to optimize treatment programs for their patients with PD.

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Appendix A: Preliminary Results

Influence of cueing, feedback and directed attention on cycling in a virtual environment: Preliminary Findings in Healthy Adults and Persons with Parkinson's Disease

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***Abstract*— Evidence based virtual environments that incorporate motor learning and compensatory strategies such as feedback and cueing may change motor behavior while also being engaging and motivating. Although virtual environments have been used for exercise promotion in healthy people and persons with stroke, its use for fitness in persons with PD has not been investigated. Further a specific understanding of embedding cueing and feedback in a virtual environment is absent. METHOD: We tested two groups of participants, older adults (n=4) and people with Parkinson's disease (n=4) as they cycled on a stationary bicycle while interacting with a virtual environment. Participants cycled under 4 conditions; auditory cueing, visual cueing, feedback, and directed attention. Data between groups were analyzed using a 2 X 2 factorial RMANOVA and within groups using a RMANOVA with post-hoc t-tests corrected for multiple comparisons. RESULTS: There were no between group differences, however, within groups healthy older adults increased their cycling speed in the auditory cueing (F 21.59, p=0.000) and directed attention conditions (F 6.04, p=0.030). For people with PD pedaling rate increased in the auditory cueing (F 4.78, p=0.029, visual cueing (F 26.48, p<0.000), feedback (F 18.77, p<0.000), and directed attention conditions (F 27.65, p<0.000). These data serve as preliminary validation of embedding cues, feedback to alter cycling speed in a VE. Further, the role of directing attention to the cues enhances cycling performance.**

Keywords—Virtual environments; virtual reality; VE; VR; motor learning, cueing, feedback, directed attention, bicycling

II. INTRODUCTION

Improvements in medical and preventive care have resulted in a growing number of people age 65 and older. With normal aging, deterioration in the central and peripheral nervous systems leads to slower execution of movement, decreased balance, and impaired coordination, resulting in changes in motor performance and skill acquisition [1]. These impairments can set off a chain of events leading to a sequela of inactivity, resulting in further deterioration in mobility and function. This decline can be remediated in a variety of ways, including exercise.

With age, increased susceptibility to chronic diseases such as Parkinson's disease (PD) compound and accelerate this process. Parkinson's disease is a progressive neurological disorder primarily affecting people 60 years of age and older [2]. Medical management of the disease includes both pharmacological and non-pharmacological treatment. However, limitations in medical interventions motivate the need for adjunct and/or alternative management of the disease [3]. Exercise has arisen as a viable method to manage the sequelae of PD [4-5]

Stationary cycling is a viable form of exercise that is commonly used in rehabilitation for a variety of patient populations, including persons with PD, to increase range of motion and improve cardiovascular fitness [6]. However, there are barriers to exercise in the older adult and people with PD [7-8] that affect motivation to participate in a regular exercise program [9]. Therefore, there is a need to find safe and engaging exercise programs for healthy older adults and people wit PD to improve and maintain fitness.

Virtual environments (VE) and video games have been successful in improving mobility and physical activity in healthy people and persons with PD [10-15] and may provide a structure to optimize motor learning and fitness in a rehabilitation setting. Virtual environments are an ideal medium to incorporate motor learning and compensation techniques such as feedback and cueing [16]. They have been used extensively in the walking literature [12,17] with the possibility for use with other standard exercise equipment such as the stationary bicycle. However, there is limited evidence to support the efficacy of external cueing and feedback embedded in a virtual cycling environment for fitness and activity promotion in healthy older adults or persons with PD.

Therefore, the purpose of this study was to determine if cueing, feedback, and directed attention embedded in a virtual environment can change motor behavior in the short run, with the eventual long term goal of promoting fitness in healthy older adults and people with PD. Specifically we sought to validate that cues and feedback embedded in the VE would alter cycling speed. We hypothesized that pedalling rate would increase for both healthy adults and people with PD with auditory and visual cueing as well as feedback. A non-directional change was hypothesized for the directed attention condition. We anticipated that healthy adults would execute all the cycling tasks faster than individuals with PD.

III. Methods

A. Virtual Cycle set up

An upright stationary bicycle (Cybex model #750C) was used in this study. A Wahoo revolutions per minute (rpm) cadence sensor was attached to the crank of the bike pedal which measured the pedal rpm and transferred the data via bluetooth to an Apple Mac OS X computer. A custom Xcode algorithm captured the rpm and heart rate (HR) (from a Bluetooth Polar HR7 HR monitor) which is saved as a .CSV file.

An Epson (Model 485Wi) short throw projector was used to project the environment onto a flat wall, resulting in an equivalent size of a 94-inch screen (43 X 83 inches) with a horizontal field of view of 80 degrees.

B. Unity Game Design

The free version of Unity version 4.3 was used in the design of the virtual environment. The scenery consisting of a road, mountains, trees and sky was designed using the default terrain editor. The goal of the design process was to create an open straight road surrounded by mountains with ample field of view and variability in the scenery. The models and avatars used during the design were purchased or downloaded from the Unity asset store. Rendering was done using the built in renderer for terrain and Skybox for the clouds and sky. The input manager was used to accept keyboard controls for pausing, quitting, and manual override functions for control of avatar.

Scripts within Unity were written in C++ to customize and have control over the VE during the trial. The rpm, along with HR data were collected and recorded independent of Unity using a Wahoo SDK and saved as a .CSV file. This file is used to read the pedal rpm data from the Wahoo sensor to control the speed of the rider. The linear distance covered by the bike/minute in the VE is calculated as (2Π * radius of wheel) * rpm. Other important scripts used include those to control the status of data collection, timer and control of feedback marker.

The virtual environment utilizes the RPM data from the .CSV output file to control the speed of the avatar in the VE. The VE consists of an avatar riding a bicycle in first person view on a straight road surrounded by grass, trees, plants, shrubs, and mountains (Figure 1). A pair of Logitech desktop speakers connected to an iphone metronome application were used for trials with audio cueing.

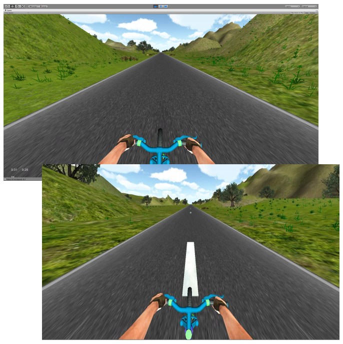

Figure 1. Screenshot of the VE without (L) and with (R) road markers.

C. Participants

For this preliminary aspect of the study, 8 participants, 4 older adults (range 58-68 years), and 4 people with PD (range 59-79 years old, Hoehn &Yahr stages II and III) voluntarily participated. Participants were included if they met the following criteria:

Inclusion- Healthy older participants between 50 and 85 years, able to ride a stationary upright bicycle and provide informed consent.

Exclusion- Significant cognitive deficits as defined by the Montreal Cognitive Assessment (MoCA) < 24 [18]; severe hearing or visual deficit including color blindness, history of stroke, traumatic brain injury or neurological disorder other than PD; unstable medical condition including musculoskeletal disorders such as severe arthritis, knee surgery, hip surgery; any other condition that the investigators determine would impair the ability to ride a stationary bicycle; any other medical or musculoskeletal contraindications to exercise.

Specific Criteria for participants with PD:

Inclusion-Parkinson's Disease diagnosed by a neurologist and Hoehn & Yahr stage II-III [19].

Exclusion: Incapacitating tremors or dyskinesias that would limit ability to ride a stationary bicycle.

Institutional approval was obtained from Rutgers University and New York Institute of Technology. All subjects were consented.

D. Protocol

Subjects attended two testing sessions. The first session included consent and baseline measures collected to define the cohort: age, gender, weight, height, trunk and lower extremity range of motion. Additional measures for persons with PD included: disease duration, Hoehn and Yahr stage, and the motor subsection (part III) of the Unified Parkinson's Disease Rating Scale [20].

The second session consisted of the bicycling protocol. The bicycle was placed in the center of the room and the virtual environment front-projected onto a flat wall approximately 5 feet in front of the participant. Participants were seated on the bicycle with the seat height adjusted between 100% and 110% of the length from the greater trochanter to the floor (measured without shoes) [21]. After a 5-minute warm-up, participants performed 14 trials (1 minute each) of cycling divided into 3 blocks, Auditory (4 trials), Visual + Feedback (6 trials) and Directed Attention (5 trials), to address four conditions: auditory cueing (AC), visual cueing (VC), feedback (FB) and directed attention (DA).

Auditory cueing was in the form of a metronome set at a rate 20% higher than the baseline, pedaling rate of the subject. The 20% metronome rate was based on the walking literature and trials on 3 healthy and 3 people with PD to determine a physiological upper limit of pedaling speed. Visual cueing was in the form of central road markers in the VE, scaled to represent a real road. The speed of the markers was presented at a real-world distance apart (approximately 10') and at a 20% faster rate, which was operationalized as a decreased spacing between the markers.,

Augmented feedback was presented visually. When the participant cycled at a predetermined rate, feedback was generated in the form of the white central road markers changing to purple.

In the directed attention condition, both auditory and visual cues were presented simultaneously. Participants were instructed to direct their attention either to the AC or VC.

E. Data Analysis

Means and standard deviations were calculated for dependent variables. Hypotheses were tested with either a one-tailed or two-tailed significance based on the evidence to support directionality. Separate factorial RMANOVAs were conducted to determine between and within group differences for each condition. For each cue condition (auditory, visual, feedback, and directed attention). Follow-up post hoc analysis were performed using paired t- tests. For all analysis, an alpha level was set at 0.05 and corrected for multiple pre-planned post-hoc comparisons. IBM SPSS (Version 22) was used for all analyses.

IV. Results

A. *Auditory Condition*

There were no significant between group differences in RPMs. There were significant within group differences for persons with PD ($F=6.27$, $p=0.017$) for baseline to AC ($t=-4.15$, $SE= 2.46$, $p=0.009$), and baseline to AC+VE ($t=-3.93$, $SE= 2.37$, $p=0.011$) (Figure 2). There were no significant within group differences for older adults (Figure 3).

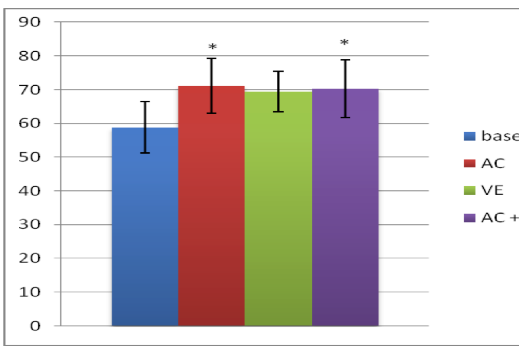

Figure 2. Mean RPM for Auditory Condition: Persons with PD

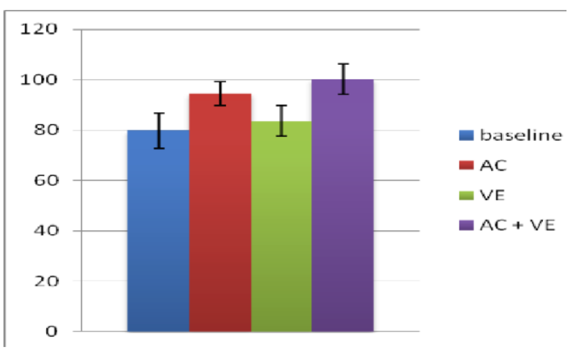

Figure 3. Mean RPM for Auditory Condition: Older Adults

The percent change in RPMs from baseline to each of the auditory conditions is reported for both for persons with PD and older adults in Table 1.

TABLE 1. AUDITORY CONDITION: PERCENT CHANGE OF RPMS

Condition	Change (%)	
	PD	*Older Adults*
Baseline to AC	21*	19
Baseline to VE	18	5
Baseline to AC + VE	20*	26

*p=/<.02

B. *Visual Condition*

There were significant between group ($F=6.25$, $p=0.030$) and within group ($F=29.46$, $p<0.000$) differences in RPMs for both persons with PD and older adults for the following trials: Persons with PD showed a significant difference in RPMs from baseline to VE +VC 20% with instruction to VC ($t=-5.80$, $SE =5.61$, $p=0.002$) (Figure 4). Older adults: baseline to VE +VC 20% ($t=-4.07$, $SE= 1.41$, $p=0.010$), baseline to VE +VC 20% with instruction to VC ($t=-8.79$, $SE=3.16$, $p<0.000$), and VE +VC 20% to VE +VC 20% with instruction to VC ($t=-5.34$, $SE=4.12$, $p=0.003$) (Figure 4).

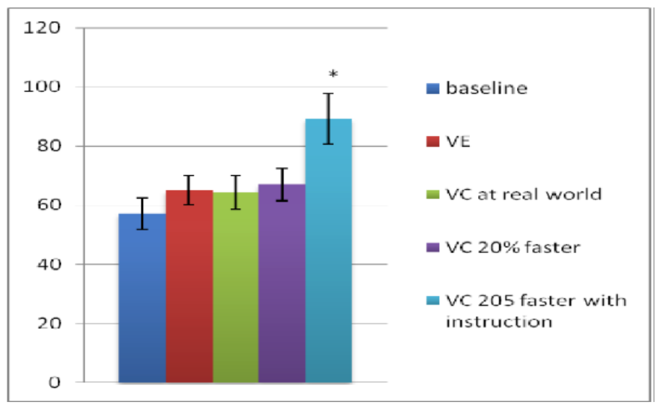

Figure 4. Mean RPM for Visual Condition: Persons with PD

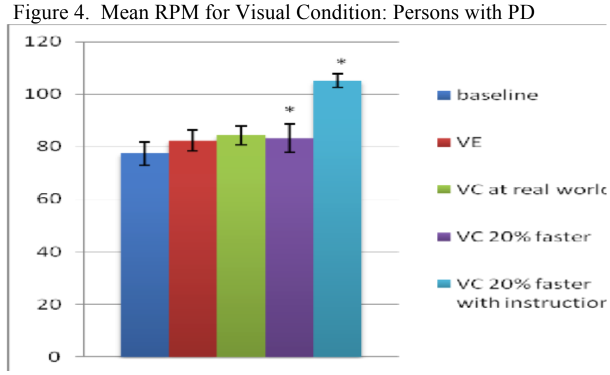

Figure 5. Mean RPM for Visual Condition: Older Adults

The percent change in RPMs from baseline to each of the Visual conditions is reported for both for persons with PD and older adults in Table 2.

TABLE 2. VISUAL CONDITION: PERCENT CHANGE RPMS

	Change (%)

	PD	Older Adults
Baseline to VE	14	6
Baseline to VE plus VC real world	13	9
Baseline to VE +VC 20%	17	7*
Baseline to VE +VC 20% with instruction to VC	56*	36*

*p=/<.01

C. Feedback

There were significant between group (F=6.25, p=0.031) and within group (F=45.51, p<0.000) differences in RPMs for both persons with PD and older adults for the following trials: Persons with PD: baseline to FB (t=-4.28, SE=8.34, p=.008), and VE to FB (t=-3.62, SE=7.54, p=0.015) (Figure 5). Older adults showed a significant difference in pedaling rate in the same trials as persons with PD: baseline to FB (t=-6.57, SE=6.03, p=0.001), and VE to FB (t=-8.30, SE=4.18, p<0.000) (Figure 6).

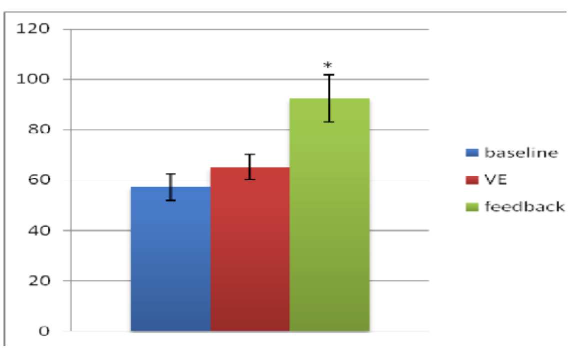

Figure 6. Mean RPM for Feedback Condition: Persons with PD

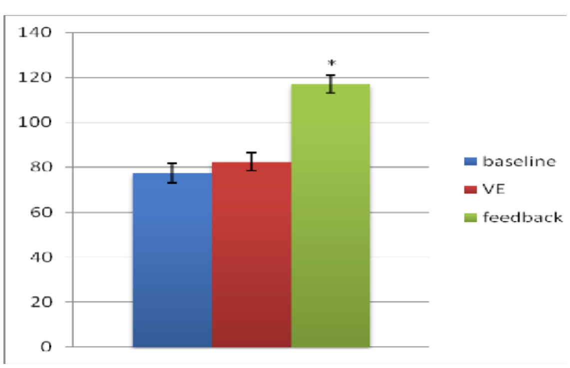

Figure 7. Mean RPM for Feedback Condition: Older Adults

The percent change in RPMs from baseline for each of the Feedback conditions is reported for both for healthy adults and people with PD in Table 3.

TABLE 3. FEEDBACK CONDITION: PERCENT CHANGE RPMS

	Change (%)	
	PD	Older Adults
Baseline to VE	14	6
VE to FB	42*	42*
Baseline to FB	62*	51*

*p=/<.02

D. Directed Attention

There were no significant differences between groups. Significant within group difference were found for both persons with PD and older adults (F=9.63, p<0.000). A significant difference in RPMs was found in persons with PD between baseline to DA + AC (t=-3.27, SE=2.58, p=0.011) and baseline to DA + VC (t=-3.58, SE= 3.66, p=.008) (Figure 7).Older adults showed a significant difference in RPMs for baseline to DA + VC no directed attention (t= -6.96, SE=2.09, p=0.001), and baseline to DA+VC with attention directed to VC (t=-2.83, SE= 5.74,p=0.019) (Figure 8).

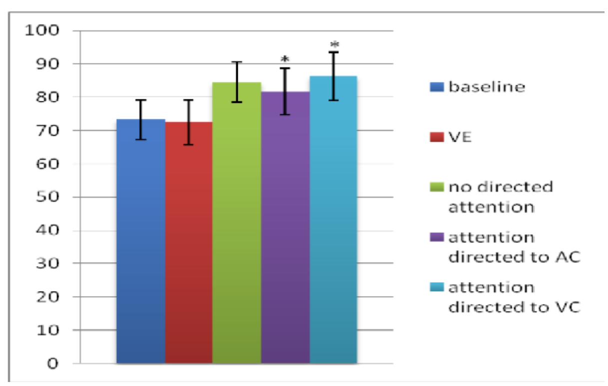

Figure 8. Mean RPM for Directed Attention Condition: Persons with PD

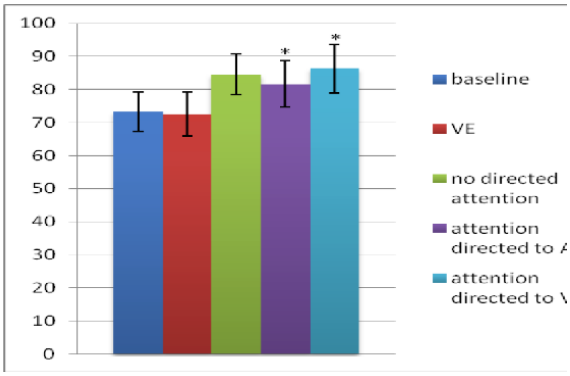

Figure 9. Mean RPM for Directed Attention Condition: Older Adults

The percent change in RPMs from baseline to each of the Directed Attention conditions is reported for both persons with PD and older adults in Table 4.

TABLE 4. DIRECTED ATTENTION CONDITION: PERCENT CHANGE RPMS

	Change (%)	
	PD	***Older Adults***
Baseline to no DA	15	14
Baseline to DA to AC	12*	17
Baseline to DA to VC	18*	19

*p=/<.02 (2-tailed)

IV. DISCUSSION

The purpose of this study was to determine if persons with PD and age matched older adults modulated their pedaling rate in a virtual environment in response to cueing, feedback and directed attention. There were significant between group differences for the visual and feedback conditions. Older adults cycled at a faster RPM than persons with PD in conditions that did not have auditory cueing. People with PD modulated their pedaling rate in all conditions, while older adults modulated their cycling speed in all conditions except auditory. The findings will be discussed by condition.

A. Auditory Condition

Pedaling rate increased (18-21%) compared to baseline in all trials indicating that persons with PD responded equally to AC and VE separately, as well as the AC combined with the VE. A significant increase in RPM however, was only found for AC and AC+ VE. This is in line with our hypothesis that people with PD can respond to AC's [22-23] and shows that the addition of a VE does not interfere with AC, but it was not additive, which is in contrast with the older adults. RPM increased (while not significantly) for older adults with the addition of AC ranging from 19% with AC to 26% with AC+VE. This finding agrees with our hypothesis and aligns with the literature that healthy people can match their walking speed to an auditory cue [24-26. In contrast to the walking literature, however, we did not see an interference between the VE and the AC for either older adults and persons with PD [26].

B. Visual Condition

Both persons with PD and older adults had their greatest increases in RPM when they were explicitly instructed to attend to the visual cues (56% and 36% increase in RPMs respectively) compared to the other visual cue conditions, which were implicit. This finding suggests that the stimuli in the VE alone may not be salient enough to produce a response. The use of explicit instructions to augment motor performance is well demonstrated in the PD literature [27-28. This has implications for adding explicit messages into the VE.

C. Feedback Condition

Both persons with PD and older adults increased their pedaling rate when the VE provided feedback on their pedaling rate. These increases were substantial (62% and 51% respectively) and much greater than the 20% increase (+/- 3RPMs) from baseline bandwidth of the feedback. Participants were observed both over and underestimating the speed (with a bias towards over estimation). Likely, the one-minute trial was too short for participants to perform within the bandwidth. The findings for individuals with PD are consistent with the literature shows that people with PD can change their motor behavior in the presence of external feedback [29-30.

D. Directed Attention

Participants in both groups increased their pedaling rate when presented with the auditory and visual cues simultaneously (15% for PD and 14% for older adults) when attention was directed to the auditory cues (12% for PD and 17 % for older adults) and to the visual cues (18% for PD and 19% for older adults). The finding for healthy adults is consistent with our hypothesis of non-preference. It appears that when auditory and visual conditions are coupled, it is not necessary to explicitly direct the rider's attention to a stimulus. For older adults, the auditory finding is consistent with the literature regarding the ability of the motor system to synchronize with an auditory cue [24-26]. This was the case regardless of the condition as all three conditions had auditory cueing. It should be noted however, that the increase in pedaling rate (12% for PD and 17% for older adults) was lower than the metronome rate of 20% increase cueing frequency, but approached the cueing frequency when attention was directed to the visual. We had hypothesized that persons with PD would respond more strongly to visual cues [14, 31-33]. Our preliminary results support the hypothesis that participants with PD had greater increases in pedaling rate when their attention was not directed, or directed to visual cues rather than auditory cues.

Coupling visual cues with auditory cues, or explicitly instructing participants to look at the visual cues increased the pedaling rate of the riders. These findings suggest that the delivery of the visual cues alone did not suffice to change the cycling behavior in healthy adults. This may be in part explained by the delivery of the VE. Front projecting on a wall and creating a semi-immersive environment may be too weak a stimulus. In addition, the size of the projection (43 X 83 inches) with a horizontal field of view of 80 degrees is relatively narrow. This, coupled with a monoscopic projection, may have contributed to a decreased sense of immersion, diminished accuracy in perception of self-motion, and lack of speed cues, which may have contributed to non-significant results. Alternatively the lack of significance may be due to the small sample size, in addition, it cannot be ruled out that there was no difference. A larger sample is needed to verify this.

In addition, walking studies typically utilize visual cues in the form of lines oriented perpendicular to the walking progression [14, 23, 32-33]. In this cycling simulation the lines are oriented in parallel to the cycling progression. This decision was made to make the environment ecologically valid. However, an alternate marking with perpendicular road side markers may be a more salient visual stimulus in the correct orientation presented in the peripheral visual field.

The use of feedback and directed attention consistently produced an increase in pedaling rate These findings support the use of feedback in modulating performance, but also highlights the opportunity for VEs to explicitly direct user's attention for a desired behavioral response. This strategy is consistent with an external focus attention that has been shown to improve performance in both older adults and persons with PD [29,330].

These findings, while clearly preliminary begin to validate that a virtual cycling environment can modulate pedaling rate by embedding cueing, feedback and directing attention both for persons with PD and older adults. These modulations could be applied to increase cycling speeds as a strategy to increase exercise intensity during training studies.

ACKNOWLEDGMENT

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Appendix B: Forms

1. 1 Screening form

1.2 Data Collection Form

1.3 Montreal Cognitive Assessment

1.4 Hoehn and Yahr Scale

1.5 Borg Scale

1.6 Unified Parkinson's Disease Related Scale (UPDRS)

Influence of cueing, feedback and directed attention on cycling in a virtual environment: healthy older adults and people with Parkinson's disease

Screening Form

Name: ______________________________ Subject ID: _________ Date: _________

Contact Information: Home Phone:__________________ Cell: _________________

Email:______________________

Inclusion Criteria:

Age: (50 to 85 years inclusive) ____ DOB: ________

Able to ride a stationary bicycle? Yes/No Experienced Cyclist: Yes/No

Prior exposure to VE's? Yes/No How often? _________________________________

Dx of Parkinson's Disease? Yes/No Duration of Disease: ____________

On PD Medications? Yes/No

List PD Meds:

____

Ability to understand study? Yes/No

Exclusion Criteria:

History of severe cardiovascular disease, stroke, or other neurological conditions other than Parkinson's disease? Yes/No

Musculoskeletal disorders such as severe arthritis, knee surgery, hip surgery that would impair ability to ride a bike? Yes/No

Any other condition that the investigators determine would impair the ability to ride a stationary bicycle? Yes/No

Any other medical or musculoskeletal contraindications to exercise? Yes/No

Comments:

Meets Criteria? Yes/No

Date and time of testing: __________________

Influence of cueing, feedback and directed attention on cycling in a Virtual Environment: healthy older adults and people with Parkinson's disease
Auditory Block First

Test Date: _____________Subject ID:____________ Examiner Initials: ___________

Nexus Data Folder:___________Time since last dose of PD meds: __________

Baseline Measures:

Height: ________Weight: ________HR: ________ BP:________

MoCA score: _______ UPDRS Motor Subscore: _____

Hoehn and Yahr Level: I II III IV

Greater Trochanter Height (gr.troch to floor-cm): Right ____Left ____
Seat Height (+10%):_____

LE Range of Motion:

Joint Motion (degrees)	Right	Left	Comments
Knee Ext (supine)			
HS length (SLR)			
Dorsiflexion (supine-KE)			
Dorsiflexion (prone-KF to 90)			
Hip Extension (prone)			

Gross LE ROM Assessment Findings: ____

Instructions for Cycling Protocol:
You will be asked to cycle for fourteen 1-minute trials. You will rest on the bike between each trial for as long as you need. If you need to get off the bike to rest, you may do that also. We will give you specific instructions for each trial and may ask you questions after you completed a trial. After each trial we will show this scale (show Borg Scale) *and ask you to rate your perceived level of exertion. Six means no exertion at all, and 20 means you are working at your maximal level of exertion. You'll be asked to choose the number that best describes your level of exertion. Do you have any questions?*

Cycling Trials:

Trial name	Parameter	Comments
1. Warm up (2 min) 2. Fast (20 seconds) 3. Baseline (2 min) (no VE, no auditory cues)	1. **Warm up:** Instructions to Participant: *Look ahead of you. Start pedaling until you reach a comfortable speed. Continue pedaling until you are asked to stop.* (2 minutes) 2. **Fast Pace:** Instructions to Participant: *Ride at the fastest speed you can for 20 seconds then return to a comfortable speed.* (To establish subjects' fast speed capacity) 3. **Baseline:** Instructions to Participant: *Now ride at a comfortable speed for approximately 2 minutes. Keep looking ahead of you.*	
Upper threshold rpms: ___ Baseline RPM: ____ RPM + 20%: ____	Baseline HR: Baseline RPE: *From range of 6 to 20, with 6 being "no exertion at all" and 20 being "maximal exertion" how hard were you exerting yourself?* Comments:	
REST:		
Auditory Block		
AB1. AC only (60 sec) (No VE)	Instructions to subject: *Look ahead of you* *Match your cycling speed to the metronome beat* *Continue to pedal until you are asked to stop. When I say 'start' you can begin.*	
Motus Trial #:	Metronome rate (20% above baseline): _____ HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and 20 being "maximal exertion" how hard were you exerting yourself?* Comments:	
REST: VAS: ***On a scale of 1(not difficult)-5(very difficult), how difficult was it to keep pace with the metronome in this trial?***		
AB2. VE only, no AC (60 sec)	Instructions to subject: *Look ahead of you at the road.* *Continue to pedal until you are asked to stop* *When I say 'start' you can begin.*	
Motus Trial #:	HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and 20 being "maximal exertion" how hard were you exerting yourself?* Comments:	
REST:		

AB3. AC + VE (60 sec)	Instructions to subject: *Look ahead of you at the road.* *Match your cycling speed to the metronome* *Continue to pedal until you are asked to stop. When I say 'start' you can begin.*

Motus Trial #:	Metronome rate (20% above baseline): _____ HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and 20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST: VAS: ***On a scale of 1(not difficult)-5(very difficult), how difficult was it to keep pace with the metronome in this trial?***	

Visual Block

VB1. No VE (baseline for Visual block) (60 sec)	Instructions to subject: *Look ahead of you* *Ride at a comfortable pace, one that you can keep up for a while* *Continue to pedal until you are asked to stop. When I say 'start' you can begin.*
Motus Trial #:	**New baseline rpm: ____** HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and 20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST:	

VB2. VE no VC (60 sec)	Instructions to subject: *Look ahead of you at the road.* *Continue to pedal until you are asked to stop. When I say 'start' you can begin.*
Motus Trial #:	HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST	
VB3.VE + VC (real world) (60 sec)	*Look ahead of you at the road.* *Continue to pedal until you are asked to stop* *When I say 'start' you can begin.*
 Motus Trial #:	HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST	
VB4.VE + VC (20% markers) (60 sec)	*Look ahead of you at the road.* *Continue to pedal until you are asked to stop* *When I say 'start' you can begin.*
 Motus Trial #:	HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:

REST:	

VB5.VE + VC (20% markers) (60 sec)	*Look ahead of you at the road.* *Try to decrease the gray space between the markers.* *Continue to pedal until you are asked to stop* *When I say 'start' you can begin.*
Motus Trial #:	HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST: **VAS:** ***On a scale of 1(not difficult)-5(very difficult), how difficult was it to*** *decrease the gray space between the markers.*	

VB6. VE + VC (20%) with Visual FB (60 sec)	*Look ahead of you at the road.* *Your goal in this trial is to cycle at a rate that will make the marker turn from white to purple and to keep the change in color throughout the entire trial.* *Continue to pedal until you are asked to stop* *When I say 'start' you can begin.*
Motus Trial #:	HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST: VAS: ***On a scale of 1(not difficult)-5(very difficult), how difficult was it to make the markers turn purple?***	

Directed Attention Block

Counterbalance of trials DA 4 and DA5: Circle one: Attention to AC first or VC first

DA1. Blank screen, No AC (baseline for DA block) (60 sec)	Instructions to subject: *Look ahead of you* *Ride at a comfortable pace, one that you can keep up for a while* *Continue to pedal until you are asked to stop. When I say 'start' you can begin.*
Motus Trial #:	New baseline rpm: ____ Metronome rate (20% above baseline): _____ HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST	
DA2. VE no VC	Instructions to subject: *Look ahead of you at the road.* *Start pedaling and continue to pedal until you are asked to stop*

(60 sec)	*When I say 'start' you can begin.*
Motus Trial #:	HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST	
DA3. AC + VC No directed attention (AC 20% above new baseline speed) (60 sec)	Instructions to subject: *Look ahead of you* *Start pedaling and continue to pedal until you are asked to stop* *Continue to pedal until you are asked to stop. When I say 'start' you can begin.*
Motus Trial #:	Metronome rate (20% above baseline): _____ HR: RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST	

Circle one: Attention to AC first or VC first

DA4. AC + VC Attention directed to AC (AC 20% above new baseline speed) (60 sec)	Instructions to subject: *Look ahead of you at the road.* *Match your cycling speed to the metronome* *Continue to pedal until you are asked to stop* *When I say 'start' you can begin.*
Motus Trial #:	Metronome rate (20% above baseline- same as DA3): _____ HR: Baseline RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?* Comments:
REST: VAS: ***on a scale of 1(not difficult)-5(very difficult), how difficult was it to keep pace with the metronome in this trial?***	
DA5. AC + VC. Attention directed to VC (VC 20% above new baseline rpm) (60 sec)	Instructions to subject: *Look ahead of you at the road.* *Look at the road markers* *Continue to pedal until you are asked to stop* *When I say 'start' you can begin.*
Motus Trial #:	Metronome rate (20% above baseline- same as DA3): ____ HR: Baseline RPE: *From range of 6 to 20, with 6 being "no exertion at all" and* *20 being "maximal exertion" how hard were you exerting yourself?*

	Comments:
REST: VAS: ***On a scale of 1(not difficult)-5(very difficult), how difficult was it to pay attention to the lines?***	

HR: ________ BP:________

Debriefing:

1. **What did you look at in the scene on the screen?**

2. **Did you like when asked to pace to metronome?**

3. **What did you think when asked to 'decrease the gray space between the markers'?**

4. **What did you think about the trial when the markers changed color?**

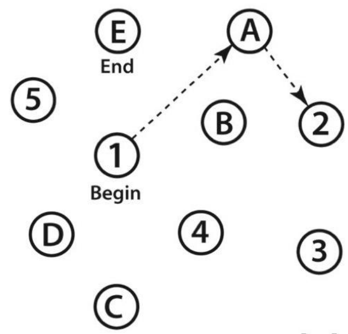
5. **Any other comments/suggestions?**

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

MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

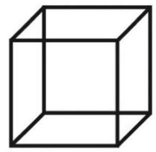
	POINTS

VISUOSPATIAL / EXECUTIVE



[ ]

Copy cube



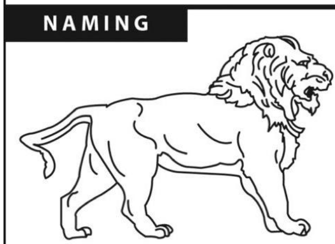
[ ]

Draw CLOCK (Ten past eleven)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

___/5

NAMING



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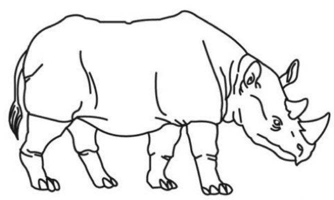

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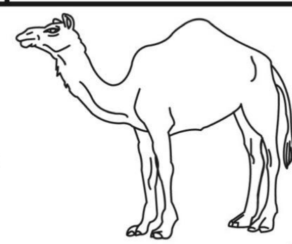

[ ]

___/3

MEMORY

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

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION

Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 2 1 8 5 4

Subject has to repeat them in the backward order [ ] 7 4 2

___/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

___/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

___/3

LANGUAGE

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

___/2

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

___/1

ABSTRACTION

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

___/2

DELAYED RECALL

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

___/5

ORIENTATION

[ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

___/6

www.mocatest.org

Normal ≥ 26 / 30

TOTAL ___/30

Add 1 point if ≤ 12 yr edu

Administered by: ______________________________

Hoehn and Yahr Scale
1: Only unilateral involvement, usually with minimal or no functional disability
2: Bilateral or midline involvement without impairment of balance
3: Bilateral disease: mild to moderate disability with impaired postural reflexes; physically independent
4: Severely disabling disease; still able to walk or stand unassisted
5: Confinement to bed or wheelchair unless aided

(Hoehn and Yahr, 1967)

Borg Rating of Perceived Exertion

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Unified Parkinson's Disease Related Scale (UPDRS)

III. MOTOR EXAMINATION

18. Speech

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

19. Facial Expression

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

20. Tremor at rest (head, upper and lower extremities)

0 = Absent.
1 = Slight and infrequently present.
2 = Mild in amplitude and persistent. Or moderate in amplitude, but only intermittently present.
3 = Moderate in amplitude and present most of the time.
4 = Marked in amplitude and present most of the time.

21. Action or Postural Tremor of hands

0 = Absent.
1 = Slight; present with action.
2 = Moderate in amplitude, present with action.
3 = Moderate in amplitude with posture holding as well as action.
4 = Marked in amplitude; interferes with feeding.

22. Rigidity (Judged on passive movement of major joints with patient relaxed in sitting position. Cogwheeling to be ignored.)

0 = Absent.
1 = Slight or detectable only when activated by mirror or other movements.
2 = Mild to moderate.
3 = Marked, but full range of motion easily achieved.
4 = Severe, range of motion achieved with difficulty.

23. Finger Taps (Patient taps thumb with index finger in rapid succession.)

0 = Normal.
1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

24. Hand Movements (Patient opens and closes hands in rapid succession.)

0 = Normal.
1 = Mild slowing and/or reduction in amplitude.
2 = Moderately impaired. Definite and early fatiguing. May have occasional arrests in movement.
3 = Severely impaired. Frequent hesitation in initiating movements or arrests in ongoing movement.
4 = Can barely perform the task.

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

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

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

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

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

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

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

Alternatively, some reduced amplitude.
3 = Moderate slowness, poverty or small amplitude of movement.
4 = Marked slowness, poverty or small amplitude of movemen