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Investigating Immersive Augmented Reality as a Rehabilitation Tool for Parkinson disease

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Graduate Program in Neuroscience
A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science
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Investigating Immersive Augmented Reality as a Rehabilitation Tool for Parkinson disease

(Thesis format: Monograph)

by

Danielle Bell Boucher

Graduate Program in Neuroscience

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

The School of Graduate and Postdoctoral Studies
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Abstract

Physical rehabilitation programs are often prescribed in an effort to maintain range of motion, and to adapt strategies for managing the debilitating symptoms of Parkinson disease (PD) in everyday life. An emerging trend to overcome the limitations of traditional rehabilitation is the use of virtual reality technologies. The goal of the present study was to determine the feasibility of augmented reality technology (IAR) in a rehabilitative setting. Three IAR environments were designed and a corresponding task was completed in each one. Not surprisingly, the control group generally performed better than the PD group on the tasks. All participants typically performed better in the real-world than the IAR environment. Additionally both the PD and control groups' performances improved with repeated visits. The system was well-tolerated and important lessons are highlighted about future implementation of this rehabilitation approach (e.g., the need for a familiarization period to the system).

Keywords

Virtual reality, immersive augmented reality, physical rehabilitation, Parkinson disease

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Chapter 1

1 Introduction

Parkinson disease (PD) is the second most common neurodegenerative disorder (after Alzheimer's disease) and predominantly affects older people over 60 years of age. The cardinal diagnostic manifestations of the disease accepted by the UK Brain Bank Criteria are four major motor symptoms: resting tremor, rigidity, bradykinesia and postural instability along with asymmetry and response to Levodopa therapy (Hughes, Daniel, Kilford, & Lees, 1992). These motor symptoms are thought to be due in part to the degeneration of pigmented dopaminergic neurons in the ventrolateral portion of the substantia nigra pars compacta within the midbrain. Nonmotor symptoms such as depression, apathy, anxiety, hallucinations and psychosis may emerge at different stages of disease and exhibit complex relationships with motor symptoms. The major cause of disability in PD is impaired mobility (Wood, Bilclugh, Bowron & Walker, 2002), or the ability to move safely in a variety of environments in order to accomplish functional tasks (Patla & Shumway-Cook, 1998).

This thesis will present ideas about the use of immersive augmented reality (IAR) in a rehabilitation setting for people living with PD. In this chapter, an overview of PD will be presented in order to provide a context for those not familiar with aspects the disease relevant for the ensuing discussion throughout the thesis.

1.1 Physical, Cognitive, and Quality of Life Symptoms in Parkinson disease

People living with PD have several prominent symptoms that are possible therapeutic targets for exercise and physical rehabilitation programs. These include physical symptoms (including balance and gait issues as well as the cardinal motor symptoms), cognitive impairment, and quality of life issues.

1.1.1 Physical Symptoms

PD is a relatively common neurodegenerative disease where dopamine-producing neurons in the substantia nigra are progressively lost resulting in a neurotransmitter imbalance (Greenfield & Bosanquet, 1953). This occurs largely unnoticed by the individual until approximately 80% of neurons have died at which point physical symptoms become evident such as motor skill, cognitive and autonomic dysfunction (Hughes, Daniel, Blankson, & Lees, 1992). Locomotor abilities including gait are prominently affected even in early stage disease. Step length is reduced and becomes asymmetrical, walking speed diminishes, and gait initiation becomes effortful and difficult (Morris, 2006; Jankovic, Nutt & Sudarsky, 2001). Resting tremor, rigidity, and in late disease postural instability and falling are also common physical symptoms of PD.

These physical impairments are associated with decreased mobility. Mobility will be defined here as the ability to move freely within and between various environments in order to actively participate in the community. Safety becomes compromised while completing ADLs such as walking and turning around the home or community, transferring from lying to sitting or sitting to standing, and more complex tasks such as house chores or preparing a meal (Stack, Ashburn, & Jupp, 2006). The ability to perform complex functional tasks is compromised while the ability to perform simple movements is preserved. Simple movements are controlled by frontal, cerebellar, and brain stem regions as opposed to the coordination and timing operations controlled by the basal ganglia (Shibasaki, 2012; Seitz & Roland, 1992); and these regions are not directly affected in early stages of PD. Additionally, muscle tone and strength are preserved suggesting that the difficulty in completing tasks is not purely biomechanical and that there is likely a large role of higher order processing that may be impaired. These activity limitations restrict participation in societal roles related to work, family, civic life and leisure (Morris, 2005).

1.1.2 Cognitive Symptoms

Although PD is typically classified as a motor disorder, cognitive changes occur at all stages of disease (Bassett, 2005; Stocchi & Brusa, 2000). Longitudinal studies have identified cognitive deficits in many areas but particularly in language, visuospatial functioning, long-term memory, and executive functioning, they are greater in PD than would be expected in a typically aging population (Locasico, Corkin, & Growdon, 2003). There is ongoing debate about the number of people with PD who will advance from mild cognitive impairment to dementia, however a review of prevalence studies suggests that 29% of patients are diagnosed with PD-related dementia (Rajput, 1992).

The frontal lobes are thought to underlie many executive processes and therefore these types of impairments in PD are attributed to frontal dysfunction. However unlike frontal lobe injury patients who are unable to adapt responses to environmental change, the issues in PD are characterized by difficulty in “filtering” or ignoring unnecessary and irrelevant environmental stimuli (Menza & Dobkin, 2006). During divided attention tasks PD patients have difficulty ignoring distractors and appropriately allocating resources (Richard, 2005).

Even in early disease, a subtle decline in cognitive ability can have a substantial impact on daily functioning and quality of life. Younger patients who engage in cognitively challenging activities or employment are more at risk for drastic life changes. However smaller scale memory lapses can result in serious safety threats (e.g. forgetting to turn off the stove or lock the door). Another area of concern is how cognitive impairment may affect fitness to drive a vehicle (Devos, Vandenberghe, Nieuwboer, et al, 2007; Stolwyk, Charlton, Triggs, et al, 2006). Patients often perceive the ability to drive a major determinant of their independence.

A growing body of research is investigating how cognitive disturbances are also implicated in gait changes (Hausdorff, Yogev, Springer, Simon, & Giladi, 2005; Marqui, Moore, Howieson, et al., 2002; Verghese, Lipton, Hall, Kuslansky, Katz, & Buschke, 2002; Hausdorff, Schweiger, Herman, Yogev-Seligmann, & Giladi, 2008). Declines in attention, psychomotor processing, problem solving, and awareness of self and

surroundings have the biggest impact on postural control, gait and falls (Alexander & Hausdorff, 2008). These are common deficits experienced by people with PD, raising concern about their ability to maintain safe ambulation across disease.

Evidently, cognitive issues can have a large impact on mobility. This is in part due to the attentional demands required to safely navigate the community by motor vehicle or other means, and partly due to the cognitive consequences on gait patterns resulting in increased fall risk.

1.1.3 Quality of Life

Motor and cognitive changes are strongly associated with instability, falls, and fear of future falls. These symptoms often lead to self-imposed restrictions of daily activities, which contribute to reduced mobility, result in a further loss of independence and deprive patients of social contacts, leading to isolation, depression, and overall reduced quality of life (Rahman, Griffin, Quinn, & Jahanshahi, 2008; Forsaa, Larsen, Wentzel-Larsen, Herlofson, & Alves, 2008). Some factors that contribute to a lower quality of life are the rate of disease progression, motor fluctuations and dyskinesias (Marras, Lang, Krahn, Tomlinson & Naglie, 2004).

Other challenges encountered by people living with PD include fatigue (Herlofesen & Larsen, 2003), changing social roles and identity, and changes in existing relationships (Habermann, 1996). Experiences with affective disorders, such as depression or anxiety, psychosis, sleep disorders, and lack of independence can also seriously influence quality of life. (Schrag, Jahanshahi, & Quinn, 2000; Symister & Friend, 2003).

Interestingly, a study conducted in Israel reported that people living with PD felt symptoms other than the cardinal motor signs had the greatest effect on their quality of life. Over half of the 39 patients without PD perceived their difficulty with mental changes, activity loss, psychosocial difficulties such as anxiety and depression, and nonspecific symptoms such as constipation and insomnia, and major motor symptoms were much less frequently reported (Abudi, Bar-Tal, Ziv, & Fish, 1997).

1.2 Pharmacological Treatment of Parkinson disease

Current treatment of PD is symptomatic and does not significantly modify disease progression. The gold standard for treatment of PD is L-dihydroxyphenylalanine (Levodopa), (Yahr, Duvoisin, Schear, Barrett & Hoehn, 1969) combined with a peripheral decarboxylase inhibitor to inhibit peripheral bioconversion of Levodopa to dopamine, thereby reducing dopaminergic side-effects and improving availability of Levodopa to the brain (Lees, Katzenschlager, Head, & Ben-Shlomo, 2001; Macphee & Stewart, 2012). More recent advancements in medical symptomatic treatment have focused on Levodopa treatments that do not require such bioconversion and target the dopamine receptors directly, namely dopamine agonists. Enzyme blockers that reduce the breakdown of dopamine include monoamine oxidase (MAO) B inhibitors and catechol-O-methyltransferase inhibitors (COMT) inhibitors.

Agonists act directly on postsynaptic dopamine receptors. Dopamine agonists may be prescribed as monotherapy in early disease to delay motor complications from Levodopa therapy (Rascol, Brooks, Korczyn, DeDeyn, Clarke, & Lang, 2000; Parkinson Study Group, 2000; Rinne & PKDS009 Collaborative Study Group, 1999). Additionally, agonists may prolong on time, reduce off time and also delay time to dyskinesia in patients already taking Levodopa compared to increasing the Levodopa dose alone (Watts, Lyons, Pahwa, Sethi, Stearn, Hauser, et al., 2010). This is known as the Levodopa sparing effect.

In the basal ganglia, dopamine is predominantly metabolized by MAO-B and COMT. MAO-B inhibitors such as Rasagiline may also be used as monotherapy in early disease (Parkinson Study Group, 2002) and also as an adjunct to Levodopa in order to decrease off-time between doses (Parkinson Study Group, 2005; Rascol, Brooks, Melamed, Oertel, Poewe, Stocchi, et al., 2005).

The addition of decarboxylase inhibitors to the levodopa dose shifts peripheral dopamine metabolism more to COMT. Peripheral and central COMT inhibitors reduce levodopa metabolism by this alternative pathway, allowing more to reach the brain thereby

decreasing motor fluctuations, wearing off, and increasing the amount of daily on-time (Nutt, Woodward, Beckner, Stone, Berggren, Carter, et al., 1994).

Anticholinergic drugs are the oldest drug-class to be used in PD management and are typically used to treat tremor. Finally, amantadine may also be used in combination with levodopa to treat dyskinesias. Amantadine has been shown to be a weak, non-competitive NMDA receptor antagonist, however its precise mechanism of action is not well known.

There are evidently many pharmacological treatment options available for PD that should theoretically provide great motor function improvement. Although dramatic motor improvement is obtained, after a number of years of levodopa treatment, side effects such as motor fluctuations and dyskinesias become prominent and disabling. This brief review of drug therapy in PD management is intended to provide an understanding that pharmacotherapy in PD is extremely complicated and yet does not provide 100% alleviation of symptoms. Furthermore, it provides validation for investigating alternative symptom management strategies to be combined with drug options. It is theoretically possible that the combination of non-pharmacological and pharmacological strategies would together allow better control of motor symptoms and enhance the ability to perform activities of daily living. This could lead to maintenance of lower medication dosage thereby reducing the side effects discussed above.

1.3 Summary of Introduction

Pharmacological interventions are in place to effectively treat many motor symptoms of PD. However as the disease progresses, it becomes more difficult to balance drug therapy benefits with side effects. Motor symptoms of PD cause debilitating decreases in mobility, and physical rehabilitation including physical and occupational therapies as well as alternative approaches may improve mobility functioning. It is possible that if implemented early, these alternative approaches could target specific components of disability that are important to the performance of activities of daily living. In addition, these interventions could also reduce the need for pharmacotherapy thereby reducing the drug dependent side effects.

Current physical and occupational therapy treatment approaches have limited customizability, scalability, and/or functional relevance. Investigations into alternative methods of physical rehabilitation are required that provide a motor-cognitive challenge scalable across all stages of disease. Furthermore, physical rehabilitation does not address the cognitive deficits inherent in PD progression. Rehabilitation must focus on more than just the physical disability of PD and rather address the interaction between motor and cognitive deficits together.

This introduction has served to present the basic facts about Parkinson disease motor dysfunction, the complications and complexities of pharmacological management, how physical rehabilitation options may assist in symptom management, and finally the limitations of existing rehabilitation approaches. This information is vital to the reader in order to appreciate the discussion that follows about the potential for immersive augmented reality in rehabilitation for PD.

The second chapter will discuss related work and lead to the rationale of this project. Reasoning for including PD as the target population is provided as well as rationale for why IAR may be suitable for rehabilitation as it relates to immersiveness and performance.

The third chapter describes the method employed in this study with respect to the hardware, software, and tasks used.

The fourth chapter describes the result of the software programming, and performance of the participants on all tasks.

The fifth chapter presents a discussion about the viability of an IAR system in a rehabilitation setting. A compilation of final conclusions, limitations of the study, future directions are discussed.

Chapter 2

2 Background

The aim of this chapter is to describe PD from the perspective of how rehabilitation may aid in the management of particular symptoms including the physical and cognitive symptoms, and overall quality of life will first be discussed. This will be followed by a discussion of the current pharmacological treatments to demonstrate the limited options and to begin to present the complexities of managing this disease. Rehabilitative interventions such as physical therapy and their role in PD treatment will be positioned to provide some rationale about the inclusion of physical rehabilitation in the treatment regime. Finally the limitations of traditional physiotherapy specifically in the PD population will be highlighted and more recent work that has been done using alternative methods of delivery including virtual reality will also be presented. The objective is to identify the rehabilitation needs unique to the PD population and hence why a non-standard rehabilitation paradigm may be beneficial. Such a framework then justifies the rationale for investigating novel rehabilitation techniques for PD such as IAR.

2.1 Physical Rehabilitation Options in Parkinson disease Management

Parkinson disease is the hallmark of neurodegenerative mobility dysfunction. Typical motor deficits include bradykinesia, rigidity, tremor and akinesia. In addition, postural instability and compromised balance are serious and common symptoms among patients (Benatru et al 2008). However PD is not purely a motor disease. Mild cognitive impairment is a well-recognized feature of early PD, and will often progress to dementia by late-stage disease. Cognitive function has been shown to be an important predictor of quality of life (Karlsen et al 1998; Schrag et al 2000) and therefore has been subjected to much investigation.

Despite optimal pharmacological treatment, motor functions continue to deteriorate leading to impaired mobility (defined as the ability to navigate and function in a variety of environments), self-care, and participation, all of which contribute to limitations of daily living (Ransmayr, 2011). Rehabilitative therapy interventions can be employed at any stage as an adjunct to levodopa therapy to help manage some of the motor symptoms and improve quality of life.

2.1.1 Physical Therapy

The most widely used form of allied health care for PD is physical therapy (Nijkraake, Bloehm, Keus, & Mulleners, 2006). The goal of physical therapy is to address specific physical issues including gait dysfunction, diminished control of physical capacity (i.e. strength and endurance), postural instability, and poor balance (Keus, Bloehm, Verbaan, et al., 2004). Together, treatment of these limitations may improve overall mobility including social and activity participation as well as activities of daily living. There have been some investigations into gait training with treadmills to improve gait parameters in PD. Findings suggest that treadmill training can reduce gait variability (Frankel-Toledo, Giladi, Perets, et al., 2005) as well as improve walking speed and stride (Pohl, Rockstroh, Ruckriem, et al., 2003). However there has been insufficient evaluation of transferability of these improvements to activities of daily living and reports vary with regards to the duration of sustained improvement (Mehrholtz, Friis, Kugler, et al., 2010 for review).

Other physical therapy strategies include balance training and high intensity resistance training. One study noted improved balance function four weeks after the intervention (Hirsch, Toole, Maitland, & Rider, 2003). Muscle stretching, reinforced patterns of movement, and active muscle contraction have also been implemented to facilitate proprioceptive neuromuscular function (Chandler & Plant, 1999; Comella, Stebbins, Brown-Toms, & Goetz, 1994). Overall, there has been inadequate reporting of sustained, measurable outcome benefits after receiving physical therapy.

A limitation of traditional physical therapy treatments is that they are largely not task-specific or goal-oriented, making the transfer of skill or physical improvement difficult to perceive. This may diminish the functional relevance of traditional physical therapy approaches and requires novel techniques that provide individualized functional relevance within the rehabilitation approach.

2.1.2 Occupational Therapy

Occupational therapy involves therapeutic use of everyday functional activities for enhancing participation (Rao, 2010). Occupational therapy focuses on training motor skills such as balance, mobility, transfers and object manipulation and methods may overlap with those of physical therapy (Gutman, Mortera, Hinojasa, & Kramer, 2007).

Occupational therapy approaches include task-related training where functional tasks are practiced. Studies report improvement in performance of activities of daily living, however do not address improvement beyond therapy (Rao, 2010). A pilot study (Clarke, Furnston, Morgan, Patel, Sackley, Walker, et al., 2009) implementing at-home occupational therapy techniques including task-specific practice, reducing complexity/demands of a task, and/or altering the environment with the addition of aids and adaptations. The authors stated their intervention was well tolerated by PD patients and that there was an improvement in quality of life scores (Parkinson Disease Quality of life Questionnaire-39) and also on activities of daily living scale (Nottingham Extended Activities of Daily Living scale).

A second approach in occupational therapy is the addition of auditory or visual cues to functional training. This approach assumes that external cueing would circumvent the impairment in production of internal cues. However, reports are mixed about the longevity of benefit of such cueing techniques beyond the duration of the therapeutic intervention. Marchese and colleagues (2000) were able to measure significant and lasting changes in the activities of daily living (ADL) and motor subsection scores of the Unified Parkinson Disease Rating Scale six weeks

following a six week rehabilitation program with external sensory cues (Marchese, Diverio, Zucchi, Lentino, & Abbruzzese, 2000). However, a much larger single-blind randomised crossover trial with 153 participants saw no carryover effects in functional or quality of life domains after a 3-week home cueing program (Nieuboer, Kwakkel, Rochester, Jones, Weggen, Willems, et al., 2007).

Despite reports from patients on the benefits of occupational therapy, there is inadequate literature to support any substantial benefit, and more randomized controlled trials are required to understand its applicability to PD.

2.1.3 Strength Training

A study by Dibble and colleagues (2006) investigated the effect of high-intensity resistance training on muscle hypertrophy and functional gains in a sample of 19 people with Parkinson disease. Ten participants received eccentric training (production of muscle force while the muscle is lengthening) and nine participants received “standard care” exercises three times per week over twelve weeks. All participants completed the standard care exercises including stretching, treadmill walking, cycling on a stationary bicycle, and weight lifting; while only the eccentric training group had additional training on an eccentric ergometer. The progression of eccentric work was gauged by ratings of perceived exertion (RPEs).

Outcome measures included muscle cross-sectional area determined by magnetic resonance imaging (MRI) of the quadriceps muscles, knee extension strength, and three functional mobility measures (6-minute walk test, stair ascent and stair descent time). Comparisons between the two treatment groups were made to determine any benefit of the eccentric training.

The eccentric training group demonstrated significantly greater gains in muscle volume of the quadriceps femoris muscle, but there were no significant differences in muscle strength. The eccentric group experienced greater improvements in the stair descent ($p = 0.007$) and 6-minute walking ($p = 0.013$) tasks than the standard-care group, but not in the stair ascent measure ($p=0.06$). These results suggest that

eccentric training may lead to muscle hypertrophy and strength gains that translate to functional improvements as well.

Although these peripheral gains were seen with eccentric training, this study addressed only the peripheral musculoskeletal system and neglected the cognitive-motor interaction prominently involved in motor control.

A second study by Hass and colleagues (2012) investigated the effect of progressive resistance training on gait initiation in people with PD. Participants' gait initiation was biomechanically evaluated with force-plates prior to and after a ten week progressive resistance training program. A non-contact control group was also involved. The training program involved exercises such as seated leg-press, knee extension, knee flexion, calf raises, and theraband ankle exercises. Weighted exercises were performed at 70% of maximal knee-extension and knee-flexion one repetition strength, with the load progressively increasing over the course of the training program. The authors were interested in documenting changes in centre of pressure pattern changes and the initial stride (first two-steps) length and velocity before and after the progressive resistance training.

There was a significant difference in the posterior displacement of the centre of pressure (the primary mechanism for generating forward motion for gait initiation) in the resistance-training group, and not in the control group. The authors claim that this program may improve anticipatory postural adjustments with respect to posterior movement of the centre of pressure. There was also a significant effect of the training program on initial stride velocity where the training group had a significant increase and the control group did not change, but there was no effect on stride length. This was interpreted as further support that improved strength may be associated with postural control during gait initiation in people with PD. Additionally the training group had significant increases in muscular strength for both knee extension and knee flexion exercises, however they do not address whether this is a result of increased central drive or improved peripheral muscular efficiency (Hass, Buckley, Pitsikoulis, & Barthelemy, 2012).

Although there was some change in the anticipatory postural adjustment patterns of the training group, it is difficult to extrapolate the benefits of strength training alone. Furthermore, there was no follow-up study to determine if strength gains or the improved gait initiation patterns were maintained.

Strength training may be beneficial for obtaining peripheral strength gains, however further benefits are difficult to rationalize and quantify. In order to achieve sustainable, transferable disease management, strength training should be incorporated with functional task training. Isolated strength training benefits may be lost quickly if the skills learned are not applicable to daily life.

2.1.4 Aerobic Training

Aerobic training can be part of an exercise program for people with PD to address symptoms of weakness and fatigue. A study by Bergen and colleagues (2002) investigated the effect of a sixteen-week aerobic training program on aerobic capacity (peak VO_2) and movement initiation as a proxy for neuromuscular coordination. Four participants with PD completed the training program, and 4 other participants with PD who did not have an exercise intervention completed pre- and post-testing. This consisted of peak VO_2 testing on a cycle ergometer, and a series of movement initiation responses to visual and proprioceptive cues. The exercise program involved three sessions per week of cycling and treadmill walking at a target heart rate (60-70%) for sixteen weeks and was followed by peak VO_2 and movement initiation post-testing.

The treatment group had a significant increase in peak VO_2 and a significant decrease in movement initiation time while the PD control group showed no change on either measure. Interestingly, there was a greater improvement in movement initiation time for “choice conditions” (21% versus 8% for non-choice) where the participants were able to choose a response and process information about the execution plan prior to making the movement. The authors propose that aerobic

exercise may have improved the decision making process by enabling the PD participants to select the appropriate neuromuscular response more efficiently.

While the Bergen study (2002) was mainly concerned with the physical benefits of aerobic exercise, a series of case studies by Tabak, Aquije, and Fisher (2013) investigated improvement in executive function. One participant with PD dementia and one participant with mild cognitive impairment (MCI) completed an 8-week program of aerobic exercise training 3-times per week on a stationary bicycle. Executive function evaluation pre- and post-intervention included the Montreal Cognitive Assessment (MoCA), the Parkinson Disease Cognitive Rating Scale (PDCRS), as well as a dual task involving serial subtractions while walking. Gait speed and walking were also measured with the 10-meter walk test and the Functional Gait Assessment, respectively.

MoCA scores for both participants improved dramatically (17/30 pre to 24/30 post, and 22/30 pre to 27/30 post), and PDCRS scores improved (55/134 pre to 70/134 post, and 81/143 pre to 94/143 post). Gait speed decreased for one participant (0.96 m/s to 0.92 m/s) and increased for the other (0.73 m/s to 0.82 m/s). Functional gait assessment scores improved for both participants (13/30 to 23/30, and 25/30 to 26/30). The authors also noted improvements in quality of life after the exercise intervention. Although these are only two case studies, it is interesting to note the dramatic improvement in executive function.

These two studies investigated very different outcomes of aerobic exercise in PD. Many performance improvements specific to the particular tests administered were reported, however there were no functionally relevant tasks included in either study. Aerobic exercise may be a suitable adjunct to physical rehabilitation however functionally relevant gains in movement performance are difficult to demonstrate with this training method.

2.1.5 Gait Training

Gait disturbances are common in PD and greatly increase the risk of falling which results in a loss of independence and a decrease in quality of life. Physical interventions specifically designed to address the common gait symptoms associated with PD have been investigated. A particularly popular approach has been treadmill training.

Herman et al. (2007) designed a six-week intensive treadmill training program to determine its effect on gait rhythmicity and functional mobility in PD. Nine participants with PD were assessed before, immediately after, and 4 to 5 weeks after the training program. Assessment included the motor portion of the Unified Parkinson Disease Rating Scale (UPDRS), the Short Physical Performance Battery (SPPB), and gait analysis (walking speed, average stride length, and stride-to-stride variability via pressure-sensitive insoles). The training involved four 30-minute sessions per week, with the treadmill speed progressively increasing each week according to each participant's speed.

UPDRS and SPPB scores significantly improved, while gait speed and stride length significantly increased. UPDRS, SPPB scores, gait speed and stride length remained significantly improved at the 4 to 5 weeks post-training testing compared to baseline values.

Another study by Protas and colleagues (2005) implemented an eight-week treadmill gait and step training program involving 3 one-hour sessions per week. Gait training consisted of walking on a treadmill at a speed greater than over ground walking speed while walking in 4 directions and while supported in a harness for safety. Step training consisted of suddenly turning the treadmill on and off while the subject stood in the safety harness facing either forwards, backwards, or sideways. Nine participants with PD completed the training protocol and another nine participants with PD did not. Pre- and post-testing included an evaluation of gait parameters using an instrumented walkway, recording of time required to step onto

and back down from an 8.8 cm step for 5 consecutive steps, and report of falls in the two weeks prior to and two weeks after gait training.

The training group demonstrated significant improvements in gait speed while the non-training group did not. Furthermore, the training group reported significantly less falls after gait training while the non-training group did not change.

Although these studies show promising results that treadmill training may improve gait parameters and mobility, these improvements were limited to walking in a straight line, without the features of everyday environments typically encountered by community-dwelling adults. These would include tripping hazards, sudden changes in direction, attentional distractors, among others. Gait rehabilitation should be done via realistic tasks that incorporate the unpredictable features of the “real-world”.

2.2 Rehabilitation with Virtual Systems

The flexibility and level of control offered by virtual systems has made it an attractive option for delivering rehabilitation programming to people with PD. However it is still in the early stages of investigation as a true rehabilitation tool. Some gaming technology, such as the Wii, has been investigated for rehabilitative purposes, while other studies have implemented custom programming and hardware.

2.2.1 Nintendo Wii™

A series of two studies by the same group (Pompeu, dos Santos Mendes, da Silva, Lobo, de Paula Oliveira, Zomignani, et al., 2012; dos Santo Mendes, Pompeu, Lobo, da Silva, de Paula Oliveira, Zomignani, et al., 2012) investigated using the Nintendo Wii™ for cognitive motor training. The first study by this group (Pompeu et al., 2012) investigated the effect of Wii-based training on activities of daily living. The Wii Fit program was implemented with the rationale that these games might

promote balance training, and cognitive-motor integration practice. All 32 participants completed 14 one-hour sessions twice per week over seven weeks.

The first thirty minutes consisted of global exercises (stretching, strengthening, axial mobility), the control group (n = 16) then completed balance exercise therapy and the Wii Fit group (n = 16) completed 10 Wii Fit games, specially selected for incorporating motor and cognitive tasks.

The Wii Fit group demonstrated improvement in performance of the games over the seven-week training period, demonstrating their ability to learn. Both the control and Wii Fit groups demonstrated a significant improvement in the UPDRS section II (activities of daily living) and Berg balance scores. This improvement in scores remained for sixty days after training. There was no apparent benefit of the Wii Fit program over conventional balance training, however the virtual program was just as effective. The authors also suggested a cognitive improvement induced by the increase in physical activity achieved by the balance training.

The second study (dos Santos Mendes et al., 2012) involved a similar Wii Fit training protocol, however specifically addressed learning, retention and transfer of performance of participants with PD (n = 16) compared to healthy controls (n = 11). The training program consisted of twice-weekly training sessions over fourteen weeks. Each session included global mobility exercises as well as training on ten Wii Fit games. Performance of the games was scored after each week to monitor performance improvement and again at 60 days post-training to determine retention. The functional reach test was the main outcome measure to demonstrate transfer effects and was performed at baseline, one week after training and sixty days after training.

Not surprisingly, the authors concluded that, overall, the PD group demonstrated reduced learning and retention compared to the healthy control group for the Wii Fit games. For the transfer of learning effects to the functional reach test, both the one-week and sixty-day post-training assessments were significantly improved

compared to baseline values which suggests the PD group was able to transfer a motor ability from the Wii training to an untrained task.

Although both of these Wii studies demonstrated some performance improvement, there are limitations inherent to Wii programming that make it difficult to apply to a task-specific rehabilitation program. Both of these protocols were limited to a defined set of Wii Fit games that may not directly apply to realistic everyday settings or ADLs. Additionally, the games are not scalable, or modifiable, to each individual's needs or progress.

2.2.2 Virtual Reality

There have been two recent studies that incorporate virtual reality technologies in a rehabilitative setting to directly address some of the most debilitating symptoms in PD.

The first study by Mirelman and colleagues (2011) incorporated virtual obstacles with treadmill training. Twenty participants with PD completed 18 sessions over six weeks of progressive and intensive treadmill training. Outcome measures included gait speed with and without a dual task, and while navigating around obstacles. These measures were tested at baseline, upon completion of training, and 4 weeks post-training to determine retention effects.

Participants were required to walk on a treadmill while viewing a virtual environment simulated on a screen presented in front of them. The virtual system simulated an outdoor environment with obstacles of varying size and frequency that were to be avoided. The virtual environment was specifically designed for this protocol and imposed an attentional cognitive load as well as processing of visual stimuli while participants were walking. With every level that was cleared, the difficulty of the virtual environment (i.e., frequency, size of obstacles) was increased.

After training, gait speed, stride length, and stride time had significantly increased and remained elevated at the four-week follow-up session, both with and without a

dual-task. Gait speed while navigating obstacles also improved after training and was again maintained at the follow-up assessment. It appears that this training program had a beneficial impact on the participant's walking ability and gait patterns.

However, this protocol confines participants to straight-walking, a gait pattern that is relatively uncommon in "real-life" environments. Furthermore the virtual system was not portable and the environment was not immersive which again limits the implementation of more realistic ADLs.

A randomized controlled trial by Yen and colleagues (2011) aimed to determine the effects of VR-augmented balance training on postural control and how this compares to conventional balance (CB) training as well as an untrained control group (n = 12 in each group). Posturography tests with single- and dual-task conditions were performed at baseline, after training, and after a follow-up period of four weeks. The VR and CB groups received balance training for six weeks. The VR training hardware included a dynamic "balance board", an LCD screen, and a personal computer. Two games were simulated to allow participants to practice weight shifting in different directions. Both indoor and outdoor environments were simulated. The CB training program consisted of exercises involving static stance, dynamic weight shifting, and external perturbations.

After training, both the VR and CB groups had significantly improved stance stability, while the control group experienced no change. The authors explained that the training groups were able to more effectively use sensory information for postural control compared to the control group after training. However, there was no difference between the VR and CB groups with respect to reducing attentional demand for postural stability.

This virtual system allowed for more interaction between a "real-world" object (i.e., the dynamic balance board) while viewing a virtual scene. However the virtual scene was delivered only via an LCD screen, and may not have been immersive

enough to simulate realistic environments. Additionally, by confining the participants to one position on the balance board, they are prevented from practicing realistic ADLs. This raises questions as to the utility of practicing static balance and postural control if it may not be directly applicable in everyday life.

2.2.3 Virtual Reality for Cognitive Training

A study by Sinforiani and colleagues (2004) included twenty PD participants with mild cognitive impairment (MMSE score 25.1 ± 2.5) who underwent twelve one-hour sessions of “cognitive rehabilitation” over six weeks. The cognitive training program consisted of an Italian computer program (Tonetta, 1995) designed to stimulate attention, abstract reasoning, and visuo-spatial abilities at different levels of complexity. Neuropsychological tests were administered pre- and post-training as well as a six month follow-up to determine lasting effects of the training. Participants had significantly improved performance on Babcock’s story, phonological word fluency, and Raven’s matrices. Performance at the six-month follow-up was not significantly different than the post-testing scores. The authors suggested that the improvement in performance was a result of reinforced cognitive strategies, particularly enhanced frontal function, which is impaired in PD.

The practical benefit of cognitive training alone may be limited. However the study by Sinforiani and colleagues demonstrates that cognitive ability in PD may be improved with practice. Therefore people living with PD are ideal candidates for a rehabilitative program that includes a cognitive training component as well.

2.3 Limitations of Current Rehabilitation Approaches

Rehabilitation techniques are an important option to help maintain mobility in addition to pharmacological treatment. Rehabilitation training is predominantly catered to recoverable symptoms (e.g. gait parameters, balance control) via gait training, cueing, or with the addition of assistive devices.

Physical therapy practices are rigid in that they are not specifically applicable to the PD population. Typical approaches do not address how constraints on mobility specific to PD such as rigidity, bradykinesia, freezing, poor sensory integration, inflexible motor program selection, and impaired cognitive processing, can limit mobility. There have been some efforts to identify these shortcomings of typical physical therapy practice and to implement exercise training specific to PD (King & Horak, 2009). However, even these programs are rigid and do not include an easily scalable program that would be effective for all stages of disease. There have been some loose guidelines presented for physical therapy outcomes (Keus, Munneke, Nijkrakem Kwakkel, & Bloehm, 2009). However they are not founded in functionally relevant tasks or skills that would be directly applicable to activities of daily living. Furthermore, physical therapy does not address the motor-cognitive issues in PD, as it is more focused on the motor symptoms of disease.

Occupational therapy is oriented to more task-driven and context-dependent strategies (i.e. cueing and assistive devices to aid in frequently encountered environments). However, there is often little flexibility for individualized programming in this field. Every patient has unique environments they encounter on a daily basis, for example their particular pharmacy, grocery store, street crossing or home. It is impossible to cater one physical space or a particular treatment regimen to every patient. Services do exist for occupational therapists to go to the patient's home, however these are financially unfeasible for many families. As a result, people with PD are limited to the standardized rehabilitation programs, often in fixed locations, to learn isolated strategies that may or may not be incorporable into their everyday "real" life.

2.4 Rationale for Present Study

People living with Parkinson disease are ideal candidates for rehabilitation. Many of the classical symptoms associated with PD are prime targets for rehabilitation programs.

While people living with PD clearly have a physical impairment, by implementing specific techniques such as those described in this chapter, performance can be improved from baseline. This may suggest that the overall motor system is not destroyed and there is room for improvement in daily functioning.

People living with PD commonly have cognitive impairments. This requires an integrative approach to rehabilitation including both motor and cognitive exercise within a single treatment program. It is also important to know that participants with PD who have cognitive impairments have been shown to benefit from cognitive training and are thus amenable to rehabilitation (Sinforiani, et al., 2004).

There is literature to show that exercise is a reliable factor for predicting quality of life in people living with PD. Falling and fear of falling are highly correlated with quality of life (Brozova, Stochl, Roth, & Ruzicka, 2009). If new strategies can be learned within a physical rehabilitation program that may be applied to everyday life tasks, there is potential to increase confidence of completing activities without falling.

The symptoms of PD outlined in the introductory chapter described various motor disabilities, cognitive impairments, and decreased quality of life. There is sufficient evidence that each of these areas may be improved with increased exercise and by learning new motor strategies that may be applied to everyday life. For these reasons, the PD population is an ideal “test subject” for obtaining benefit from any rehabilitative program.

2.4.1 Criteria for Successful Rehabilitation in PD

In order to implement a successful rehabilitation program for people living with PD, it must be designed with the ability to address the major areas of concern simultaneously. A rehabilitation technique must be designed that allows context-dependent functional training of everyday tasks that strongly considers the typical cognitive deficits in PD. There is a strong interaction between the cognitive and motor systems that together create the unique symptoms encountered by people living with PD in everyday tasks.

By implementing these types of programs in the community, participants may be exposed to a social and supportive setting while learning strategies to improve movement ability and therefore increase mobility. As described above, these skills would also contribute to overall quality of life.

2.4.2 Augmented Reality for Rehabilitation in PD

Immersive augmented reality (IAR) is a type of virtual reality and may be an optimal tool for meeting these rehabilitative criteria for people living with PD. This type of platform would provide a flexible and scalable means of implementing realistic, functionally relevant tasks. Most importantly, by making use of virtual features, the major areas of concern (motor, cognitive, quality of life) in the PD population may be addressed simultaneously.

IAR technology is able to simulate realistically hazardous environments that are expensive to physically recreate for training purposes within a rehabilitative context. There have been several types of programs created to simulate fully immersive virtual environments for video games and military training that include highly sophisticated and expensive equipment. The goal of the current rehabilitation program was to design a functional system that provides some level of immersion (i.e. a sense of “being there”), is interactive, user-friendly, and most of all affordable, so it may be implemented in the community within a manageable cost.

Other groups have attempted to implement virtual systems in the PD population with the same objective. Studies have focused on aspects of reaching, problem-solving and navigation using non-ambulatory, desktop-based systems (Albani, Pignatti, Bertella, Priano, Semenza, Molinari et al., 2002; Messier, Adamovich, Jack, Hening, Sage & Poizner, 2007). Mirelman et al. (2011) used immersive virtual environments to provide visual context and cognitive/motor challenges in a VR gait-training program. However, the trajectory of ambulation was restricted to treadmill walking (Mirelman, Maidan, Herman, Deutsch, Giladi, & Hausdorff, 2011). The limitations to using a treadmill or

desktop system are obvious; participants must be able to ambulate and practice movement strategies in realistic situations in order to have some transferability to activities of daily living.

The system must also be wireless to allow full ambulation in an open space, to ensure the user is not confined to a desktop or a treadmill, but is able to ambulate freely along an unspecified path and in any direction.

A final area of concern would be the level of presence created by the program. Immersiveness contributes to presence and is a physical feature of the VR system, defined by the amount of display, to all sensory modalities, that is delivered to the user. Presence is defined as the sense of being there in the virtual environment, signaled by people acting and responding realistically to virtual situations and events (Slater et al., 2009). Presence may be thought of as a subjective reaction to the system. It is imperative that a system appears to be realistic to the user if any rehabilitative benefit is to be achieved from the program. A fundamental requirement within a virtual reality system is the maintenance of the sensorimotor loop: the continued, predictable correlation between proprioception of motoric movements and sensory data and the motoric output by the user. A head-turn must result in a concomitant and predictable change in the visual field; a movement of the body must result in the expected correlated sensory and sensed physical changes that have been learned over a lifetime (Slater et al, 2009).

People living with PD have sensory processing and integration deficits. For this reason, it is important to understand how users with PD perceive the artificial sensory information and how this may be different than controls' perception. The reported level of presence experienced by the user is necessary information to determine if the system is able to simulate realistic scenarios, and therefore amenable to rehabilitative tasks and goals for PD.

In summary, there are three areas to be addressed in relation to the use of VR systems in physical rehabilitation for people living with PD: 1) the effect of the virtual environment may result in differences in motor task performance compared to "real world" situations; 2) it is unknown whether performance may improve across visits; and 3) if this change in

performance over time might be different for people with PD compared to controls. This information would also provide insight about a period of accommodation that may occur when participants are introduced to the IAR system.

Chapter 3

3 Method

The experimental protocol was approved by the Health Sciences Research Ethics Board at Western University. The method will be described in several sections: participants, system development, tasks in the immersive augmented reality (IAR) environment, and presence questionnaire.

3.1 Participants

Participants with PD were recruited from a movement disorders clinic at the London Health Sciences Centre in London, Ontario. Healthy controls were recruited from the community or were spouses of the participants with PD. Inclusion and exclusion criteria are in Appendix A.

In order to describe the PD sample included in this thesis in the context of being ideal for rehabilitation, several measures were collected. Each scale was included to specifically measure and describe the presence of a particular symptom or deficit in the sample.

To describe motor impairments, a motor profile was generated for each PD participant. The motor profile consisted of several scores that, when considered together, were able to provide a well-rounded description of the disease and motor status both for each participant individually and for the PD group as a whole. The disease duration was obtained from the onset of the earliest clinical sign in the patient chart and was recorded in years. The Hoehn & Yahr stage was extracted from the most recent clinic note (within a maximum of six months of the study date). The Hoehn and Yahr staging system ranges from 1-5 and is commonly used for describing the progression of disease for a particular patient. The Levodopa equivalent dose (LED) was also calculated according to Tomlinson et. al (2010) as a further proxy for disease severity. A select number of items

from the Unified Parkinson Disease Rating Scale were also scored to add to the participant motor profiles.

Participants completed a number of scales. More complete descriptions and copies of each scale are in appendices B to F. The University of Toronto's Community Balance and Mobility (CB&M) test was administered to all participants. The CB&M was designed to evaluate balance and mobility through relatively difficult and dynamic tasks in patients who, although ambulatory, have balance impairments which reduce their full engagement in community living (Howe, et. al, 2006). There is a maximum score of 96 for the CB&M. Age of all participants in years was also collected.

A cognitive screening test, the Montreal Cognitive Assessment (MoCA) was administered to measure cognitive ability. The MoCA assesses different cognitive domains: attention and concentration, executive functions, memory, language, visuoconstructional skills, conceptual thinking, calculations, and orientation. There is a maximum possible score of 30 and a score of 26 or higher is considered normal. A shortened version of the Parkinson Disease Questionnaire, the PDQ-8, is considered to be a reliable, valid, responsive, acceptable and feasible as the tool for assessment of quality of life in PD patients. The PDQ-8 score is a percentage of 32 points scored across the eight items. The Activities-specific Balance Confidence (ABC) scale is a sixteen-item scale frequently used for assessing balance confidence in the elderly while performing functional activities. Balance confidence and fear of falling is highly correlated with QOL (Adkin, Frank, & Jog, 2003). The ABC score is calculated as an average percentage for all items.

Scales that were administered to both groups were analyzed using an independent T-test.

3.2 Immersive Augmented Reality System Development

The IAR system was developed in three stages: construction of the physical space in which the virtual environments would be implemented, assembly of the necessary hardware components for simulating the environment to the user, and design of the software to configure the environments.

3.2.1 Physical Space

All IAR scenes were applied within the same physical space: an empty room of dimensions 6.68 m × 4.92 m. The room was lined with heavy white vinyl curtains to which 110 fiducial markers were installed. Fiducial markers are points of reference that a computer vision system uses to measure the position of the camera with respect to each marker, (i.e., they provide information to the system as to where the user is standing and therefore what image should be projected to the user). An image of the room with the markers installed is in appendix G.

3.2.2 Hardware

The hardware consisted of three components: a head-mounted display (HMD), a camera system, and a laptop. The Vuzix iWear® 920VR™ visor (Vuzix Corporation: Rochester, New York) was the HMD used for this system and projected the IAR environments to the user. It was mounted with the Vuzix iWear® CamAR™ (Vuzix Corporation: Rochester, New York) to capture information from the fiducial markers about the users position. The visor was connected to a light-weight laptop, the ASUS® UX31 (ASUSTeK Computer Inc., Taipei, Taiwan) weighing 3.08 lbs, stored in a small backpack worn by the participant. The camera fixed to the visor transmitted the information from the fiducial markers to the IAR software (running in the backpack), which in turn projected the simulated scene back to the visor to be viewed by the participant. Images of all equipment are in appendix H. There were some real-world objects that were specifically coded into the software to allow the participants to interact with solid objects while experiencing the IAR environments. Some examples are cereal boxes, a watering can, and grocery bins. These were included in order to simulate natural interactions between the users and the objects while immersed in a virtual environment.

3.2.3 Software

The IAR scenes were designed using Open Graphics Library (OpenGL) (Silicon Graphics, 2012), an open access software program. Three scenes were developed to pilot the design of functionally relevant scenes. A scene was created of three locations

commonly encountered by community-dwelling adults: a living room scene inside a home, a grocery store scene in the community, and a street crossing scene in an outdoor environment. The house in which the living room scene was situated as well as the outdoor setting of the street crossing were completely artificial in their rendering. However, the grocery store scene was uniquely rendered by integrating digital images of a real grocery store into the program. Images of each scene are in Appendix I. For specific programming procedure, please refer to Ayala Garcia (2012).

After participants completed the IAR protocol (described below), they were asked to complete a presence questionnaire (Witmer & Singer, 1999; Appendix J). The presence questionnaire was designed to evaluate presence in virtual environments. The questionnaire consists of 33 questions rated from 1 to 7 on a Likert scale. The scores from each question are summed to obtain the participant's score with a maximum score of 231 points with a higher score implying a higher perceived presence. The full presence questionnaire as well as a description of the reliability and validity of this measure is in Appendix J.

3.3 Immersive Augmented Reality and Real World Protocol

The protocol consisted of three weekly visits to the testing centre. At the first visit, several baseline assessments were conducted (described above). A task specifically designed for each of the three scenes was performed in the IAR environment followed by an analogous task in the same physical space, but in the real-world (RW) (i.e., without the visor). In the IAR environment, the patient saw the entire scene rendered, while in the RW environment, the patient saw the whole room as is without any scene rendering.

In the living room scene, participants were required to stand still in front of a long table with two rows of potted flowers. Participants were handed a watering can (visible through the visor) and asked to reach forward to “water” the plant furthest away from them on the left and then on the right. Three trials were completed in each direction. This was analogous to the Reach Test (Newton, 2001) that was performed in the RW. The maximum anterior limit of the arm was recorded as the dependent variable for this task.

In the cereal aisle of the grocery store, participants had to put cereal boxes into five baskets placed on the ground throughout the room and numbered 1 through 5. Participants were given a random number sequence of the numbers 1 to 5 to remember. This sequence represented the order the cereal boxes were to be filled. Three trials of this task were completed, followed by three tasks in the RW. The dependent variables were time to complete the trial and accuracy of the baskets filled.

Finally at the street crossing scene, participants were asked to walk a specified distance at a “regular, comfortable pace”. This was completed in the IAR environment as a street crossing task and in the RW as a simple walking task. The street sign always displayed the “white man” walking symbol. The dependent variable was the time in seconds required to walk the specified distance. The IAR and RW task were completed at each weekly visit.

Data Analysis

Multivariate analysis of variance (MANOVA) models were used for each task. Group (PD or control), environment (IAR or RW), and week (1, 2, or 3) were independent variables and included all dependent variables listed above.

Chapter 4

4 Results

A low-cost, fully ambulatory IAR system was implemented in both a PD and control group of older adults. Three virtual scenes were designed and implemented. Results will be presented with respect to the participant data, tolerability of the system, the IAR protocol, and finally the presence questionnaire.

4.1 Participants

Twenty-two people with PD (15 male, mean age = 67.1 ± 6.1 years, mean disease duration = 6.2 ± 3.3 years) and 11 controls (6 male, mean age = 64.1 ± 5.6 years) completed the scales protocol.

The average disease duration for the PD group was 6.18 years (SD ± 3.30 years). The average Hoehn & Yahr Stage for the PD group was 2.36 ± 0.49 . The mean levodopa equivalent dose was 401.4 ± 276.3 mg/day. Disease duration, Hoehn & Yahr score, and LED data were not collected in the control group, and are therefore presented as means with standard deviation values for the PD group only. The control group scored significantly higher on the CB&M than the PD group (Control mean = 72.18 ± 14.82 , PD mean = 57.73 ± 16.62 , $p = 0.02$). Motor profiles of the participants with PD are in Table 1, and scores for select UPDRS items are listed in Table 4.1.

Table 4.1 Motor profiles of participants with PD.

| Participant | Disease Duration* | PDQ-8** | CBM[‡] | H&Y stage | LED[€] |
|--------------------|--------------------------|----------------|------------------------|----------------------|------------------------|
| VR-01 | 2 | 3.125 | 61 | 2 | 400 |
| VR-02 | 8 | 3.125 | 59 | 2 | 700 |

| | | | | | |
|-------|----|---------|----|---|------|
| VR-03 | 7 | 12.5 | 76 | 2 | 600 |
| VR-04 | 4 | 31.25 | 27 | 2 | 600 |
| VR-05 | 5 | 12.5 | 65 | 2 | 0 |
| VR-06 | 2 | 21.875 | 64 | 3 | 400 |
| VR-07 | 4 | 31.25 | 19 | 3 | 100 |
| VR-08 | 11 | 18.75 | 71 | 2 | 1250 |
| VR-09 | 5 | 21.875 | 71 | 2 | 300 |
| VR-10 | 5 | 6.25 | 57 | 2 | 300 |
| VR-11 | 10 | 18.75 | 47 | 3 | 400 |
| VR-12 | 2 | 21.875 | 45 | 2 | 600 |
| VR-13 | 10 | 15.625 | 45 | 3 | 0 |
| VR-14 | 10 | 9.375 | 35 | 2 | 400 |
| VR-15 | 10 | 18.75 | 47 | 3 | 600 |
| VR-16 | 6 | 17.1875 | 75 | 2 | 380 |
| VR-17 | 1 | 28.125 | 51 | 2 | 0 |
| VR-18 | 9 | 28.125 | 64 | 2 | 300 |
| VR-19 | 10 | 18.75 | 67 | 3 | 400 |
| VR-20 | 3 | 31.25 | 74 | 3 | 300 |
| VR-21 | 9 | 6.25 | 84 | 2 | 500 |

| | | | | | |
|-------|------|------|------|------|-------|
| VR-22 | 3 | 6.25 | 66 | 3 | 300 |
| Mean | 6.18 | 17.4 | 57.7 | 2.36 | 401.4 |
| SD | 3.30 | 9.18 | 16.6 | 0.49 | 276.3 |

*Disease duration is number of years from onset of symptoms (not diagnosis).

**Parkinson Disease Questionnaire-8 (PDQ-8) is a percentage of the maximum score of 32 points for the 8 items.

‡Community Balance and Mobility (CBM) is scored out of 96.

€LED is levodopa equivalent dose in mg per day.

Table 4.2. Select UPDRS item scores

| Participant | #18 | #20 | #22 | #23 | #24 | #25 | #26 | #29 | #30 | Total |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| VR-01 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| VR-02 | 0 | 2 | 4 | 2 | 1 | 2 | 0 | 0 | 0 | 11 |
| VR-03 | 1 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 5 |
| VR-04 | - | 4 | - | - | - | - | - | - | - | - |
| VR-05 | 1 | 5 | 0 | 2 | 0 | 0 | 2 | 1 | 0 | 11 |
| VR-06 | 1 | 0 | 7 | 3 | 2 | 2 | 0 | 2 | 2 | 19 |
| VR-07 | 0 | 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 15 |
| VR-08 | 1 | 4 | 4 | 3 | 3 | 1 | 1 | 1 | 2 | 20 |

| | | | | | | | | | | |
|-------|---|-----|-----|---|---|-----|---|---|---|------|
| VR-09 | 0 | 0 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 6 |
| VR-10 | 1 | 1 | 2.5 | 2 | 0 | 0 | 2 | 1 | 1 | 10.5 |
| VR-11 | 1 | 3.5 | 3 | 4 | 2 | 0 | 0 | 0 | 0 | 13.5 |
| VR-12 | 0 | 2 | 4 | 3 | 1 | 4.5 | 0 | 0 | 0 | 14.5 |
| VR-13 | 0 | 2.5 | 5 | 3 | 3 | 0 | 1 | 0 | 0 | 14.5 |
| VR-14 | 0 | 6 | 2 | 2 | 0 | 2 | 1 | 1 | 0 | 14 |
| VR-15 | 1 | 2 | 4 | 2 | 2 | 2 | 2 | 0 | 0 | 15 |
| VR-16 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| VR-17 | 0 | 3 | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 7 |
| VR-18 | 1 | 0 | 9 | 4 | 2 | 2 | 0 | 0 | 1 | 19 |
| VR-19 | 0 | 0 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 6 |
| VR-20 | 0 | 2 | 9 | 1 | 2 | 2 | 0 | 1 | 0 | 17 |
| VR-21 | 1 | 0 | 5 | 3 | 2 | 4 | 0 | 0 | 0 | 15 |
| VR-22 | 0 | 8 | 0 | 2 | 1 | 0 | 0 | 1 | 1 | 3 |
| Mean | | | | | | | | | | 11.5 |
| SD | | | | | | | | | | 5.67 |

The mean score on the MoCA for the control group was 26.0 ± 2.37 and 25.2 ± 4.02 for the PD group. These scores were not significantly different.

The average score of the PDQ-8 was 17.4 ± 9.18 out of a maximum of 100%. The mean score on the ABC for the control group was 92.4 ± 8.23 and for the PD group was 83.8 ± 11.0 out of a maximum score of 100%. A comparison of scores for all scales is in Table 4.3.

Table 4.3. Scores of demographic scales for the PD and control groups.

| Measure | PD (Mean \pm SD) | Control (Mean \pm SD) |
|-------------------------------|--------------------|-------------------------|
| Age (years) | 67.1 ± 6.10 | 64.1 ± 5.61 |
| Activities Balance Confidence | $83.8 \pm 11.0^*$ | $92.4 \pm 8.23^*$ |
| Montreal Cognitive Assessment | 25.2 ± 4.02 | 26.0 ± 2.37 |
| Community Balance & Mobility | $57.7 \pm 16.6^*$ | $72.2 \pm 14.8^*$ |

* $p < 0.05$

4.2 Tolerability of the System

The system was well tolerated by both the PD and control groups, with no reports of disorientation or nausea. All participants were able to complete the full protocol other than two who wore either bi-or tri-focal prescription lenses. These participants had orientation issues in one scene only and experienced vertical tracking issues as the scene was projected through the various prescriptions of the lenses. Minor complaints with the comfort of the HMD used were reported (e.g., pinching sensation or pressure on the nose, sliding off the nose) in $< 25\%$ of participants. There were no complaints of discomfort relative to the positioning or weight of the backpack and computer. On item 25 of the Presence Questionnaire (Witman & Singer, 1999), participants were asked to rate from 1 to 7 how distracting the control mechanism (i.e., the HMD, backpack, laptop) was with 1 being not distracting and 7 being very distracting. The mean response was $2.9/7 (\pm 1.7)$.

As implementation of this system continued, there were some patient characteristics that became exclusion criteria as they prevented an effective experience of the IAR environments. These included cognitive impairment, postural issues (specifically, a “stooped” posture), and excess movement issues such as tremor or dyskinesias.

4.3 IAR Protocol

Three scenes were developed: a living room, a cereal aisle, and a street crossing, in which specific tasks were completed.

4.3.1 Living Room Scene

Results from the reach task in the IAR and RW environment are shown in figure 4.1. A 2x2x3 multivariate analysis of variance was applied to the reach task data with group (PD or control), environment (IAR or RW), and visit number (one, two, or three) as independent variables and anterior reach limit as the dependent variable. Box’s M test of equality of covariance was not violated, however the p value was low ($p = 0.006$), therefore Pillai’s Trace F value will be reported where applicable as it is considered to be more conservative. Mauchley’s test of sphericity was violated for the visit effect and therefore the Greenhouse-Geisser values will be reported here where applicable.

There was a significant effect of group ($F(1, 31) = 4.980$, $p = 0.033$, $\eta^2_p = 0.138$) on the range of motion limits in both the plant watering and reach tasks such that control participants had a greater anterior reach limit (87.33 ± 12.21 cm for PD and 93.71 ± 11.96 cm for the control group). No other movement limits measured in the functional reach test were compared as only forward reaching was performed in the IAR condition.

There was a significant effect of environment condition (Pillai’s $F(1, 31) = 98.519$, $p < 0.001$, $\eta^2_p = 0.761$) such that participants reached further in the RW condition (82.87 ± 11.90 cm in the IAR environment and 96.04 ± 9.11 cm in the RW environment). There was also a univariate effect of visit number (Greenhouse-Geisser $F(1.689, 52.360) = 3.603$, $p = 0.041$, $\eta^2_p = 0.104$) such that a longer reach was achieved with successive visits (87.23 ± 14.42 cm for visit 1, 90.07 ± 11.67 cm for visit 2, and 91.07 ± 10.89 cm

for visit 3). A polynomial contrast was statistically significant for a linear effect of visit number and a least-significant difference (LSD) post-hoc test revealed there was a statistically significant difference between visit one and visit three (mean difference = 3.45 ± 1.47 cm, $p = 0.025$).

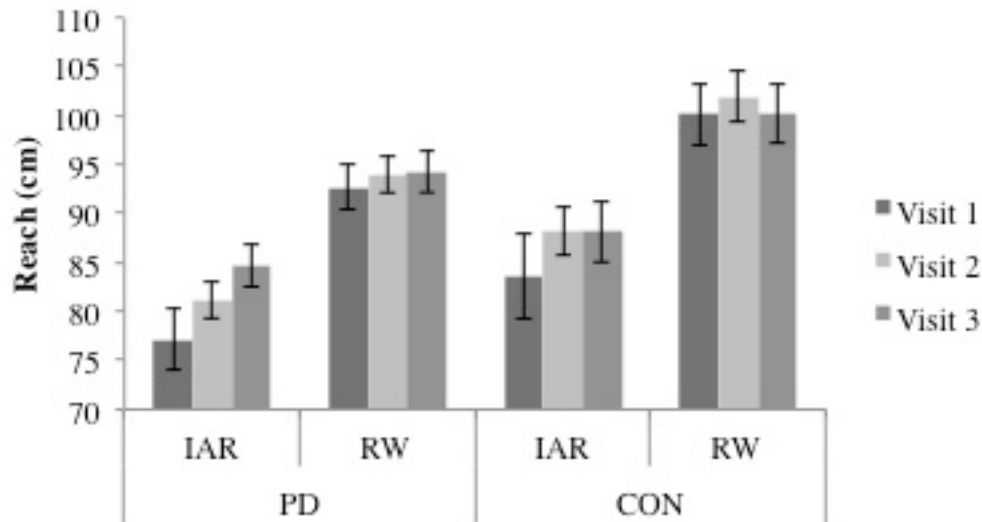


Figure 4.3.1. Results from reach task. In the immersive augmented reality (IAR) environment, participants were asked to keep both feet on the ground and “water” the plant furthest from them by bending at the waist. There was a significant effect of group (Parkinson disease (PD) compared to controls) ($F(1, 31) = 4.980$, $p = 0.033$, $\eta^2_p = 0.138$), environment condition (real world (RW) versus IAR environment) (Pillai’s $F(1, 31) = 98.519$, $p < .001$, $\eta^2_p = 0.761$), and visit number (Greenhouse-Geisser $F(1.689, 52.360) = 3.603$, $p = 0.041$, $\eta^2_p = 0.104$). Error bars represent standard error.

4.3.2 Cereal Aisle Scene

Data from the grocery store task are presented in figure 4.2. A $2 \times 2 \times 3$ multivariate analysis of variance was applied to the grocery store scene task with group (PD or control), environment (IAR or RW), and visit number (one, two, or three) as independent variables and time to complete the task and accuracy of baskets filled as the dependent variables. There was a within subjects multivariate effect of condition (Pillai’s Trace $F(2, 28) = 19.323$, $p < 0.05$, $\eta^2 = 0.58$), of visit (Pillai’s Trace $F(4, 116) = 3.371$, $p < 0.05$, $\eta^2 =$

0.208), and a within subjects multivariate condition x visit interaction (Pillai's Trace $F(4, 116) = 4.487, p < 0.002, \eta^2 = 0.265$).

There was no significant multivariate effect of group. However, there was a significant univariate effect of group on time ($F(1,29) = 5.543, p = 0.026, \eta^2_p = 0.160$), but not accuracy for this task.

There was a univariate effect of condition on time (Greenhouse-Geisser $F(1, 29) = 31.356, p < 0.05, \eta^2_p = 0.520$) and accuracy (Greenhouse-Geisser $F(1, 29) = 6.919, p = 0.014, \eta^2_p = 0.193$). There was a univariate condition*group interaction effect on accuracy of basket filling order (Greenhouse-Geisser $F(1, 29) = 4.308, p = 0.047, \eta^2_p = 0.129$). There was a univariate condition*visit interaction effect on time (Greenhouse-Geisser $F(1.272, 36.889) = 8.562, p = 0.003, \eta^2_p = 0.228$) and accuracy (Greenhouse-Geisser $F(1.535, 44.528) = 4.250, p = 0.029, \eta^2_p = .0128$), where both polynomial contrasts were statistically significant for a linear effect.

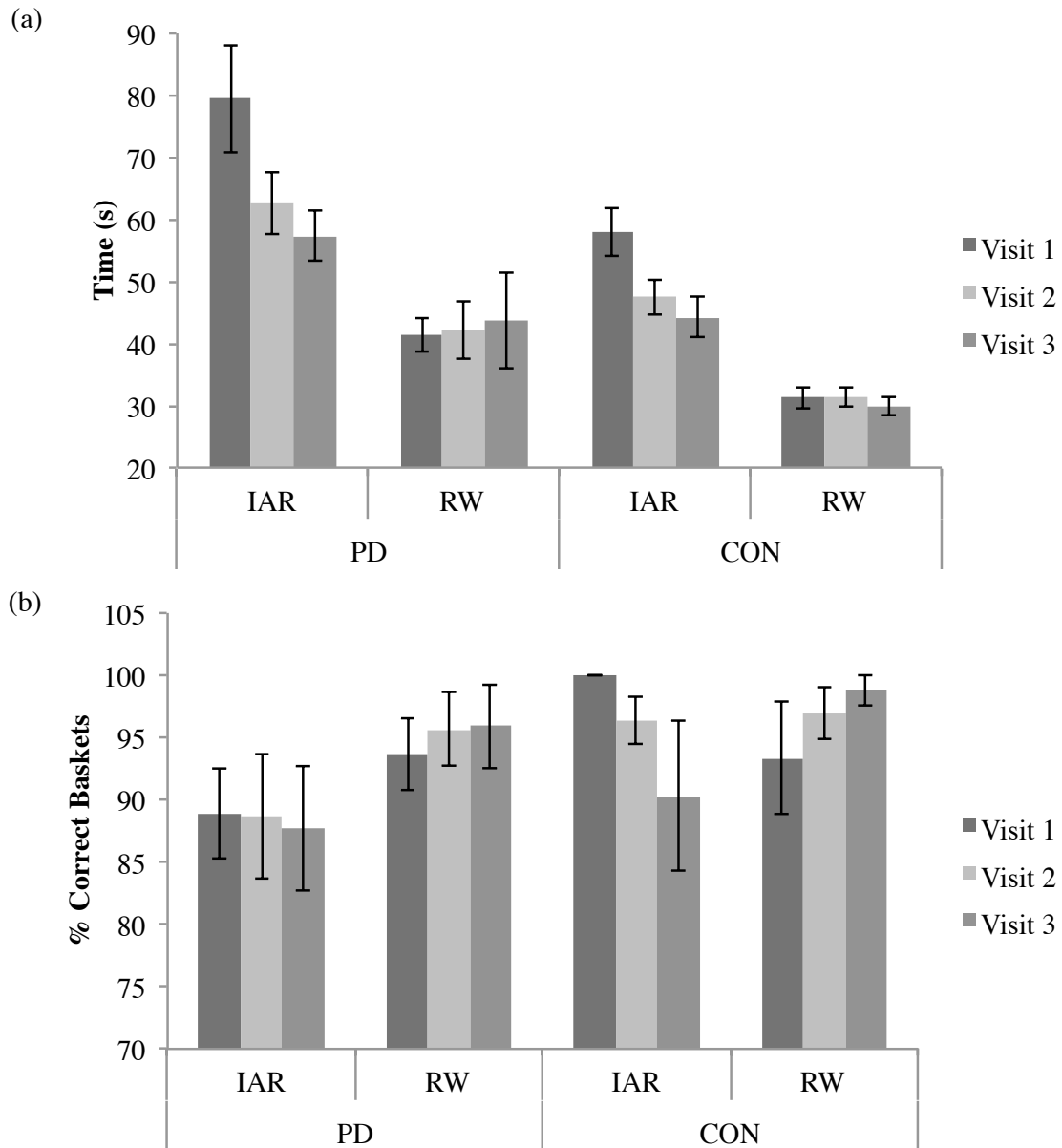


Figure 4.3.2. Results from cereal aisle task. Time to complete the trial in seconds (a) and accuracy of filling the baskets (b). Participants were given a sequence of the digits 1 through 5 that they were required to remember. They were instructed to place a cereal box into 5 bins around the room in the same order they were given at the beginning of each trial. There was a multivariate effect of condition (Pillai's $F(2, 28) = 19.323$, $p < 0.05$, $\eta^2 = 0.58$), of visit (Pillai's Trace $F(4, 116) = 3.371$, $p < 0.05$, $\eta^2 = 0.208$), and a within subjects multivariate condition x visit interaction (Pillai's Trace $F(4, 116) = 4.487$, $p < 0.002$, $\eta^2 = 0.265$). Error bars represent one standard error.

4.3.3 Street Crossing Scene

Data from the street-crossing scene are presented in figure 4.3.3. A 2x2x3 multivariate analysis of variance was applied to the grocery store scene task with group (PD or control), environment (IAR or RW), and visit number (one, two, or three) as independent variables and time to cross the street at the participant's "normal, comfortable pace" was the dependent measure. Box's M test of covariance equality was not violated however the p value was low; therefore Pillai's trace F is reported where applicable. There was a multivariate main effect of condition (Pillai's $F(1, 31) = 18.389, p < 0.05, \eta^2_p = 0.372$) and visit (Pillai's $F(2, 30) = 3.995, p = 0.029, \eta^2_p = 0.210$); however there was a multivariate condition*visit interaction effect ($F(2, 30) = 0.020, \eta^2_p = 0.229$).

There was a between-subjects main effect of group ($F(1, 31) = 6.311, p = 0.017, \eta^2_p = 0.169$), such that the control group completed the task faster.

Mauchly's test of sphericity was significant, indicating the sphericity assumption was violated. Therefore the Greenhouse-Geisser F values will be reported for the within-subjects effects where applicable. There was also a within-subjects effect of condition (Greenhouse-Geisser $F(1, 31) = 18.389, p < 0.05, \eta^2_p = 0.372$) and visit (Greenhouse-Geisser $F(1.201, 37.229) = 6.371, p = 0.012, \eta^2_p = 0.170$) as well as a condition*visit interaction (Greenhouse-Geisser $F(1.367, 42.383) = 6.996, p = 0.012, \eta^2_p = 0.184$). Tests of within-subjects polynomial contrasts for the visit and condition*visit interaction were statistically significant for both linear and quadratic effects.

To parse the condition*visit interaction Bonferroni-adjusted pairwise T-tests were applied. These pairwise tests revealed a significant difference between visit 1 & 2 ($T = 3.081, p = 0.013$) and visit 1 & 3 ($T = 2.655, p = 0.037$) in the IAR environment only.

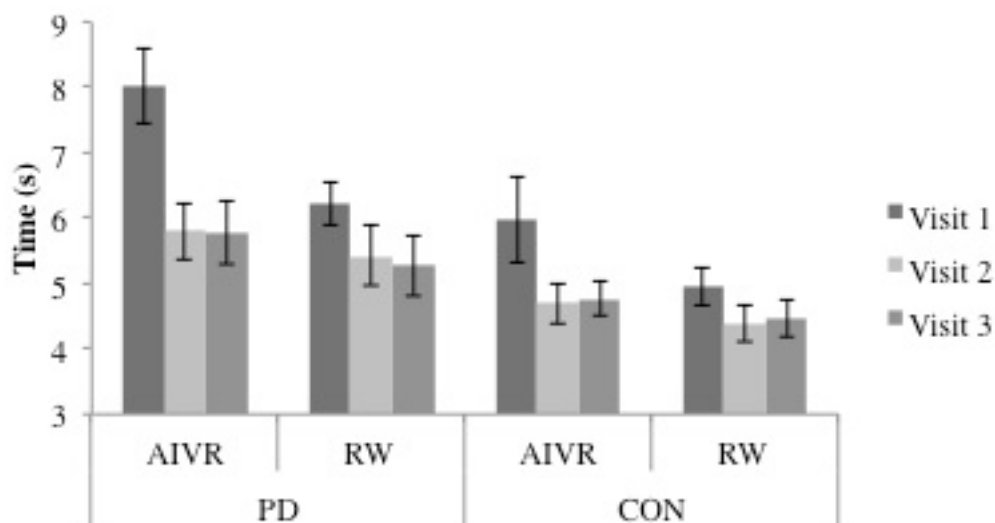


Figure 4.3.3. Data from street walking task. Participants were asked to walk at their “regular, comfortable pace”. Time to complete the task was recorded. There was a between-subjects main effect of group ($F(1, 31) = 6.311, p = 0.017, \eta^2_p = 0.169$), such that the control group completed the task faster. There was a main effect of condition (Pillai’s $F(1, 31) = 18.389, p < 0.05, \eta^2_p = 0.372$) and visit (Pillai’s $F(2, 30) = 3.995, p = 0.029, \eta^2_p = 0.210$); however there was a multivariate condition*visit interaction effect ($F(2, 30) = 0.020, \eta^2_p = 0.229$).

4.4 Presence Questionnaire

Results from the Presence Questionnaire are in Figure 4.4. A 2x3 repeated measures analysis of variance was applied to the presence questionnaire scores. There was a significant main effect of group (Pillai’s $F(1, 31) = 5.683, p = .023, \eta^2_p = 0.198$) such that the control group had a statistically higher score (171.85 ± 11.49) than the PD group (156.73 ± 21.52). The maximum score for this questionnaire is 231 (33 questions each with a score of 1 to 7 points). A higher score indicates a higher level of presence.

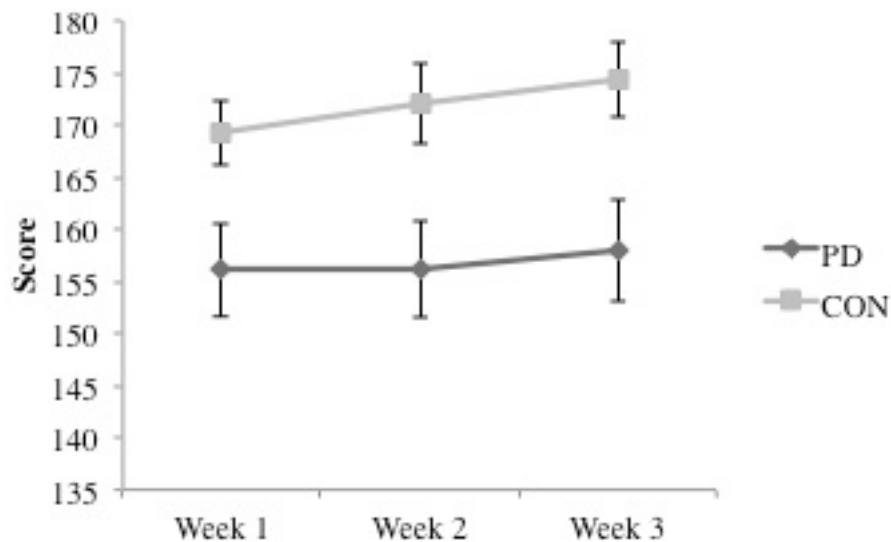


Figure 4.4.1. Presence questionnaire scores. There is a significant effect of group (Pillai's $F(1, 31) = 5.683$, $p = .023$, $\eta^2p = 0.198$), but not visit number. No interaction effects.

Chapter 5

5 Discussion

A pilot immersive augmented reality (IAR) software program was developed using open access software to successfully simulate three distinct scenes. Performances in the IAR condition were compared to the performance of analogous tasks in the RW condition in an attempt to understand if and how the IAR simulation might affect or alter movement in both PD and control participants.

The results will be discussed under three main headings: the implementation of the immersive augmented reality (IAR) system, the IAR tasks, and the presence questionnaire results.

5.1 Implementation of IAR System

Three scenes were successfully developed and implemented in a single hazard-free real-world open space. The ability to flexibly apply different virtual environments is a key benefit to applying this technology in a rehabilitative setting. Three environments commonly encountered by community dwelling adults are living rooms in the home, street crossings, and grocery stores in the community. Although these were generic scenes, there is potential to customize each of these environments to the specific homes, streets, and stores of any individual participant. Evidently, a virtual reality-based system is highly flexible and customizable.

A series of tasks were successfully implemented and completed in a safe environment. Although the user perceived various environments with numerous obstacles and objects nearby, the physical space was actually clear of any tripping or falling hazards. For this reason, a virtual environment may actually be considered as more safe than practicing rehabilitative techniques in real world settings as they may also present real world dangers.

With the ability to simulate real world scenes, movement strategies specific and functionally relevant to the user may be learned and practiced. Rather than completing simple exercises in a rehabilitation clinic, a participant could perceive they are actually going grocery shopping and practice movement and cognitive strategies to facilitate this task in the real world.

5.2 IAR Tasks

5.2.1 Living Room

In the simulated living room, a plant-watering task was designed to mimic an established measure of balance and range of motion, the Reach Test (Newton, 2001). As would have been predicted, the control group had a greater limit of motion than the PD group as shown in figure 4.1. This is most likely due to the typical symptoms of PD such as rigidity or bradykinesia and is not surprising. The lower CB&M scores relative to the control group reflect the physical balance deficits and the ABC scores reflect the decreased balance confidence of this PD group. Therefore, the PD participants may have experienced a greater sense of imbalance and reduced stability resulting in the shorter reach scores. It is well-known that people living with PD have serious balance and stability issues (Mak, et al, 2009) but with specific instruction and practice, effective strategies can be adopted to manage these symptoms and reduce the risk of falling (Mirelman et al., 2011). Therefore it is a suitable target for rehabilitative intervention.

There was a significant effect of environment such that both the PD and control groups reached further in the RW condition. This indicates that both groups perform differently depending on the environmental condition. A limited range of motion in the IAR environment may be expected, since it was an unfamiliar experience and setting. There was also a main effect of visit indicating that performance changed across the three visits such that all participants reached further in subsequent visits. This confirms that in this task participants have a capacity for improving performance with successive visits, which may indicate both increasing comfort and balance confidence in the virtual environment. This suggests a familiarization period or a number of familiarization exposures to an IAR

system may be valuable to improve comfort (and performance) within this type of environment.

The data shows an environment*visit interaction that approaches significance. Although not significant, it is interesting to briefly consider this effect. This interaction suggests that the change in performance across visits may have been different in the RW and IAR conditions. Although the watering task is very simple, the added challenge provided by the VR system makes it more difficult and allows for an improvement in performance across time whereas the RW reach test results in a maximal performance from the first visit. In terms of a rehabilitation setting, even for such a simple task, this added challenge may actually be beneficial.

5.2.2 Cereal Aisle Scene

In the cereal aisle scene, a simple verbal working memory task was combined with free walking to challenge participants' dual-tasking abilities. Several published studies report working memory deficits (Siegart, et al., 2008) and dual-tasking difficulties (Wild, et al., 2012) in PD samples.

There was a significant difference between the PD and control groups for the multivariate effect in this task. This should not be surprising. The test for between-subjects revealed a main effect of group on time to complete the trial only, and not on the accuracy scores for the order in which the baskets were filled. The effect of group on time to complete the trial is an expected finding because of the classical PD symptoms exhibited by the PD group including slowness of gait. Our previous work (not published, under review) has shown that PD will allocate substantial attentional resources to a secondary cognitive task, possibly at the expense of ensuring safe and stable gait patterns. The increased attention to the working memory task may also explain why there was no significant difference between the PD and control groups in accurately filling the baskets in the instructed order. An alternative explanation would be the simplicity of the 5-item numerical working memory task. The sample in this study was cognitively intact; therefore remembering a series of numbers from 1-5 may have not presented enough of a challenge.

There was a significant multivariate effect of environment*condition, however there was also an environment*visit interaction. Therefore the effect of environment condition will not be further discussed outside of the interaction with visit number. This interaction is indicative of differing motor performance in the virtual environment compared to the RW environment, depending on the visit number and vice versa.

The univariate effect of the environment condition*visit interaction was significant for both the time and accuracy dependent variables. This suggests that participants were able to improve both the time required to complete the task and their accuracy in the IAR environment over their three visits. This reinforces the point earlier stated that virtual reality systems present an initial challenge that allow room for learning strategies to improve performance with practice.

There was also a univariate environment*group interaction effect on accuracy of the order the baskets were filled. This suggests that the PD group is more affected by the IAR environment than the control group for accuracy. Although there was not a main effect of group on accuracy of this task, it is not surprising that the IAR environment would have a greater effect on the PD group. People with PD have difficulty focusing on the most relevant sensory information in a given environment (Lee, Cowan, Vogel, Rolan, Valle-Inclan & Hackley, 2010). With the addition of a virtual system, this may have “overloaded” the sensory information and somewhat distracted the patients from the working memory task, resulting in an effect on the ability of the PD group to accurately fill the grocery baskets.

5.2.3 Street Crossing Scene

A street crossing scene was developed in order to create a realistic scenario where tasks may be implemented to address some of the issues involved with completing daily tasks (Richard, et al., 2004). Participants were asked to walk at their “normal, comfortable pace”.

There was a main effect for all three independent variables: group, visit number, and environment condition in this task. The effect of group is again expected as it has been

reported numerous times that people with PD walk at a lower velocity than age-matched controls (Frankel-Toledo, et al., 2005).

There was also a condition*visit interaction, therefore the environment condition and visit number effects will only be discussed in the context of their interaction and not as separate effects. This interaction effect was shown to be composed of the significant difference between visits 1 & 2 and 1 & 3 in the IAR environment. This is again supportive of IAR in a rehabilitative setting as it presents a sensorimotor challenge that also affords improvement with practice.

5.3 Presence Questionnaire

A presence questionnaire (appendix J) was administered to measure the subjective experience of the virtual environment with respect to the level of presence experienced by the participants. Presence has been shown to influence the effectiveness of a virtual reality system. For this reason, it was imperative to collect some measure of the subjective experience of the participants. Interestingly, the control group scored significantly higher than the PD group. According to Witman & Singer (1998), “immersion depends on perceiving oneself as a part of the VE stimulus flow”, where stimulus flow includes all available sensory information and events that influence and are influenced by the user’s actions. It is well-known that people with PD have sensory integration issues (Lewis & Byblow, 2002) so by the given definition, it may be reasonable to conclude that the PD group experienced less presence due to their decreased ability to perceive all stimuli presented in an appropriate way. Similarly, people with PD are unable to appropriately filter incoming sensory information and tend to pay more attention to functionally irrelevant sensory information, which results in an inaccurate perception of their surrounding environment. The discrepancy in the presence Q scores between the two participant groups may reflect this deficit. The environments presented in the virtual scenes were detailed to appear as realistic as possible and therefore were full of sensory cues. Additional sensory information was provided from the virtual reality system components (i.e., the weight and feel of the backpack and goggles). An inability to “filter out” non-relevant sensory information contributes to the

sensory integration issues in PD. While the control group may have been able to effectively “ignore” the distraction of the equipment, this additional sensory input may have prevented the PD participants from experiencing the same presence level as the control group.

The next step to improve the presence scores in general (i.e., for all participants) would be to increase the rate of visual update, improve the viewing angle and make the display more realistic in color and sound. This would help the virtual environment appear even more realistic and coincide more closely with the user’s rapid head movements. New programming using the latest full-surround visor technology is underway in order to create even more realistic scenes. New visors are also to be implemented that prevent any peripheral view of the real world which will also greatly improve presence. The rate at which such new technology is becoming available is high, making it difficult to implement and then report the most recent technologies before a new advancement becomes available.

A solution to the reduced presence scores of the PD group may be to limit the amount of sensory information available within their visual field. A benefit of systematically constructing the virtual scenes is that every detail is meticulously controlled. Versions of a scene with simplified sensory input may facilitate a higher level of presence by allowing participants to accurately perceive the environment, allowing them to believe that they are part of the virtual scene.

5.4 Overall Conclusions, Limitations and Future Directions

5.4.1 Conclusions

Virtual reality technology has the potential to be adaptable to any individual’s particular needs while minimizing hazards typically present in daily environments. As this thesis has explained, IAR may be useful for the needs of physical rehabilitation. It is flexible, customizable, safe, and can be created at an affordable cost.

A novel and affordable IAR system was designed and implemented in a sample of people living with PD and healthy older adults. Simple tasks were successfully implemented and simple quantitative measures of performance were collected.

Participants' performance often improved with repeated exposure to the system. This was interpreted as familiarization to the IAR system and to the tasks that continued across several visits. Therefore it is important to include a sufficient period for acclimatization to a virtual system prior to measuring performance gains.

The IAR approach allows control over: the level of sensory stimuli provided by the environment, attentional demands, and cognitive load, which can be varied to challenge the participant. Together, this will challenge the cognitive-motor interface that is compromised in PD.

The virtual environment can be constructed with increasing levels of complexity and sensory inputs in order to retrain how the patient responds to various manipulations. When implemented within a rehabilitation environment, this is an ideal tool for sequential learning. Functional tasks in simulated everyday environments can be developed with varying levels of difficulty. This is precisely how a virtual rehabilitation program can be tailored to the abilities of each individual patient. For example, strategically increasing or limiting extraneous details, and decreasing or emphasizing critical sensory information can challenge and "train" the system to be more efficient with incoming stimuli. By learning new strategies to manage the symptoms of PD in order to complete ADLs, quality of life and independence may be maintained.

This pilot testing of an IAR system has confirmed the viability of this type of system for scientific investigation of clinical populations and has demonstrated potential within the rehabilitation world. Indeed, this approach can be seen as an enhanced and practical version of occupational and physical therapy intervention.

5.4.2 Limitations

The results presented throughout this thesis suggest that IAR has great potential for successful implementation in rehabilitation settings. However, the technology implemented in this first round of testing requires some modification to improve the level of presence experienced by the user. As stated by Witmer and Singer (1999), “presence is an indispensable contributor to the effectiveness of a virtual system.” The graphical programming for this project must be upgraded for future use. A less than optimal level of presence may have contributed to any learning effects that were observed (i.e., the effect of visit number).

All tasks were first completed in the IAR environment and subsequently completed in the real world. This was initially done to avoid learning in the real world tasks that may carry over to the IAR performance in order to identify the effect of the system on performance. However, this may have affected the results as performance in the real world may be partially due to a learning effect from first completing the task in the IAR environment. Future studies of a similar nature should randomize and alternate the order of environments in which the tasks are completed.

The control group in this study was half the size of the PD sample. This may have skewed some results. Future studies should aim for a larger and equal size of groups.

5.4.3 Future Directions

The purpose of this study was to confirm the tolerability and viability of this technology for rehabilitation purposes in a clinical population. For this reason, deliberately simple tasks were implemented that do not necessarily have direct functional relevance to real world activities of daily living. Future studies will implement more complex and realistic tasks.

This study was designed to quantify the change in performance over a series of three weekly visits. For this reason, the same protocol with the same tasks was completed at each visit. Future studies will include both more frequent training sessions and over a

longer duration (e.g., 6 to 12 weeks). Additionally, the program will adhere to more rehabilitative “training” methods and will quantify translational benefit from the program to daily tasks. For example, participants will complete a number of simple everyday tasks, such as going grocery shopping or preparing a meal, and will then complete a training program within the IAR environment designed to facilitate these everyday tasks. To measure translational benefit, the same tasks performed prior to the training will be completed and any gain in performance may be quantified.

As previously mentioned, there is room for improvement with respect to the programming as well as the technological aspects of this system. New visor technology has already been purchased and the next stage of programming is underway. These advancements are promising and will improve the experience of presence and the overall delivery of the virtual environment. Together, this will substantially improve the effectiveness, applicability and viability of the IAR system as a rehabilitation tool.

Presence is a critical component to the effectiveness of a virtual reality program. For this reason, future work should investigate novel techniques for increasing the level of presence experienced by PD. For example, strategically limiting extraneous details, or emphasizing critical sensory information to challenge and “train” the system to be more efficient with incoming stimuli. The sensory deficits inherent to this population require a flexible and dynamic approach to the software development process.

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Appendices

Appendix A: Inclusion/Exclusion Criteria

Inclusion criteria were: 1) diagnosis of idiopathic PD Hoehn & Yahr stage 2-3 to limit disease severity thereby reducing confounding factors of dementia or motor involvement impacting testing; 2) stable PD management (have been a clinic patient for 12 months prior to enrollment) with no change in medication during the study; 3) minimum grade 10 education to reduce education variance as a factor on test performance; 4) between the ages of 40 and 80 years old to reduce any confounding aging effects; 5) no significant wearing off or fluctuations between medication doses as cognitive fluctuations can be a component of wearing off; 6) no other neurological disease to prevent any confounding results as a result of a co-morbidity, specifically stroke, seizure disorder, brain tumor, head injury, spinal cord injury or severe peripheral neuropathy; 7) no other injuries or illness that may impair motor function such as recent fractures, dislocations, artificial limbs, recent surgical procedures or any injury or illness requiring a brace or walking aid; 8) no other psychiatric illness that may affect motor or cognitive performance.

Exclusion criteria were: 1) freezing of gait or other severe gait symptoms as this could present an unnecessary risk in an unfamiliar environment; 2) on- or off-state dyskinesia because the current technology of the visor causes a timelag that is amplified with dyskinesic movements; 3) a Montreal Cognitive Assessment score less than 20 since cognitive performance will be measured and substantial cognitive decline may skew the results; and 4) any neuro-ophthamological condition or pathology that may affect performance, specifically convergence deficiencies and oculomotor abnormalities as determined by a neuro-ophthamologist.

Appendix B: The Activities-Specific Balance Confidence Scale

The Activities-specific Balance Confidence (ABC) scale was created by Powell & Myers (1995) and has been validated for assessing balance confidence while performing a variety of functional activities in the elderly. This paper-based scale takes approximately ten minutes to complete. Participants are asked, “For each of the following, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady by choosing one of the percentage points on the scale from 0% (no confidence) to 100% (complete confidence).” If the participant does not do a particular activity, they are asked to imagine how confident they would be if they had to do the activity. Examples include walking around the house or walking on icy sidewalks. The sum of the ratings for all tasks (possible range from 0-1600) is divided by 16 to obtain the ABC score. Patients with a score below 75.6 are at risk for falls (Landers MR, Backlund A, Davenport J, Fortune J, Schuerman S, Altenburger P. Postural instability in idiopathic Parkinson’s disease: discriminating fallers from nonfallers based on standardized clinical measures. *J Neurol Phys Ther.* 2008;32:56-61). The ABC has a test-retest reliability $r = 0.92$ ($p < .001$) in community dwelling elders (Powell & Myers, 1995) and internal consistency of 0.85 (95% CI, .68-.93) in community dwelling adults with stroke (Botner & Miller, 2005). No reliability scores have been reported specifically in a PD sample. The ABC has acceptable construct validity as scores have been significantly correlated with many other measures. ABC scores have shown weak correlations with older age ($r = -.23$), longer Timed-Up-and-Go time ($r = -.39$), greater activity restriction ($r = -.43$), higher Geriatric Depression Scale score ($r = -.38$), more falls in the previous year ($r = -.20$), a greater number of chronic illnesses ($r = -.32$), and moderate correlations with lower Berg Balance Test score ($r = .57$), slower gait speed ($r = .51$), assistive device use ($r = .51$), ($p < .001$ for all values) (Talley, Wyman & Gross, 2008).

The ABC also has reported concurrent validity with moderate positive, linear correlation between the ABC total score and the Berg Balance Test score using Spearman’s correlation coefficient, $r = 0.36$, $p < 0.001$; and moderate, positive linear correlation between the ABC total score and gait speed, $r = 0.48$, $p < 0.001$ (Botner & Miller, 1995). Finally there is also indication for discriminative/predictive validity: A score $< 67\%$

identifies fallers from non- fallers, with 84% sensitivity and 87% specificity in older people living in the community (Lajoie & Gallagher, 2004).

The ABC was administered to both the PD and control groups at the initial visit, prior to any experimental tasks.

The Activities-specific Balance Confidence (ABC) Scale*

Instructions to Participants:

For each of the following, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady from choosing one of the percentage points on the scale form 0% to 100%. If you do not currently do the activity in question, try and imagine how confident you would be if you had to do the activity. If you normally use a walking aid to do the activity or hold onto someone, rate your confidence as it you were using these supports. If you have any questions about answering any of these items, please ask the administrator.

The Activities-specific Balance Confidence (ABC) Scale*

For each of the following activities, please indicate your level of self- confidence by choosing a corresponding number from the following rating scale:

0% 10 20 30 40 50 60 70 80 90 100% no confidence completely confident

“How confident are you that you will not lose your balance or become unsteady when you...

1. ...walk around the house? ____%
2. ...walk up or down stairs? ____%
3. ...bend over and pick up a slipper from the front of a closet floor ____%
4. ...reach for a small can off a shelf at eye level? ____%
5. ...stand on your tiptoes and reach for something above your head? ____%
6. ...stand on a chair and reach for something? ____%
7. ...sweep the floor? ____%

8. ...walk outside the house to a car parked in the driveway? ____%
 9. ...get into or out of a car? ____%
 10. ...walk across a parking lot to the mall? ____%
 11. ...walk up or down a ramp? ____%
 12. ...walk in a crowded mall where people rapidly walk past you? ____%
 13. ...are bumped into by people as you walk through the mall? ____%
 14. ... step onto or off an escalator while you are holding onto a railing? ____%
 15. ... step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%
 16. ...walk outside on icy sidewalks? ____%
-

*Powell, LE & Myers AM. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol Med Sci* 1995; 50(1): M28-34

Appendix C: Parkinson Disease Questionnaire-8

The paper-based 8-item Parkinson Disease Questionnaire (PDQ-8) is a shortened version of the original 39-item quality of life questionnaire, both developed by Peto, Jenkinson & Fitzpatrick (1998) to obtain information about self-perceived health in PD. The PDQ-39 was designed to obtain a score for 8 dimensions (e.g., mobility, activities of daily living, emotional well-being, etc.) through a number of questions. The item most highly correlated with each dimension score was used to construct the PDQ-8. This scale is completed by the participants and the items ask the participant to consider how often in the last month they have experienced certain events (e.g. had difficulty getting around in public?) and to indicate the frequency of each event by selecting one of 5 options (likert Scale): never/occasionally/sometimes/ often/always or cannot do at all which are each scored 0-4 respectively. The score for the PDQ-8 is a percentage of the thirty-two point maximum (i.e., the sum of scores for all questions is divided by 32 and multiplied by one hundred).

The PDQ-39 is accepted to be a valid and reliable tool (Jenkinson, 1998). The PDQ-39 and PDQ-8 scores are highly correlated ($r = 0.96$, $p < 0.001$, $n = 459$). In the initial validation study of this scale, the mean PDQ-8 index score was 47.25 (SD = 20.96, min = 0, max = 100, $n = 543$; 95% CI = 45.5-49.0). The 25th, 50th and 75th percentile scores were calculated which were 31.25, 50.00 and 62.50 ($n=543$), respectively. The data was divided by clinician Hoehn and Yahr staging and produced the following benchmarks: stage 1 mean = 17.74 (SD = 16.27), stage II mean = 33.14 (SD = 18.80), stage III mean = 37.05 (SD = 22.05), Stage IV, V mean = 47.86 (SD = 16.17).

The authors claim construct validity is high as the original items were generated from exploratory in-depth interviews with patients. Cronbach's alpha statistic for internal reliability in Canada was found to be 0.83 (Jenkinson & Fitzpatrick, 2007).

The PDQ is designed specifically for people with PD, and was included in the study protocol as a proxy for disease severity from the patient's point of view. The PDQ-8 index score was included to comprise part of the motor profile score of each participant. For these reasons it was administered to the PD group only, and not the control group.

PDQ 8 – Parkinson's Disease Quality of Life Questionnaire

DUE TO HAVING PARKINSON'S DISEASE, how often have you experienced the following, during the last month?

Due to having Parkinson's disease,
how often during the last month
have you....

Please tick one box for each question

Never Occasionally Sometimes Often Always

or cannot do at all

| | | | | | |
|---|--|--|--|--|--|
| 1. Had difficulty getting around in public? | | | | | |
| 2. Had difficulty dressing yourself? | | | | | |

| | | | | | |
|--|--|--|--|--|--|
| 3. Felt depressed? | | | | | |
| 4. Had problems with your close personal relationships? | | | | | |
| 5. Had problems with your concentration, i.e. when reading or watching tv? | | | | | |
| 6. Felt unable to communicate with people properly? | | | | | |
| 7. Had painful muscle cramps or spasm? | | | | | |
| 8. Felt embarrassed in public due to having Parkinson's disease? | | | | | |

Appendix D: Montreal Cognitive Assessment

Cognitive impairment on neuropsychologic testing is evident in over 20% of Parkinson's disease (PD) patients at the time of diagnosis (Foltynie, 2004; Muslimovi et al., 2005), and over 80% of PD patients will develop dementia over an 8 year period (Maxieux et al., 1998). Some cognitive tests such as the Mini-Mental State Examination (MMSE) (Folstein et al., 1975) are insensitive to the cognitive impairments in PD (Marinus et al 2003) and the length of neuropsychologic batteries is inconvenient for research purposes (Biggins et al., 1992). Specifically, the executive and visuospatial function domains are known to be affected in early PD (Muslimovic et al., 2005; Mahieux et al., 1998), therefore it was imperative to include such a screen prior to enrolling participants in this virtual reality paradigm.

The Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) was developed as a screening tool for mild cognitive impairment. The MoCA is a short cognitive screening tool that resembles the widely used MMSE, but is more sensitive than the MMSE in identifying mild cognitive impairment in the general population. The MoCA takes about 10 minutes to administer in the general population, therefore was advantageous and convenient to include in the study protocol. The MoCA tests several cognitive domains: executive and visuo-spatial functioning, memory, language, and attention. Some examples of items are the alternating trail making test to assess visual attention and task switching, cube copying and clock drawing test to assess visuoconstructional ability, identifying line drawings of animals test naming ability, forward and backward digit span tests to assess attentional ability, and naming as many words beginning with a particular letter within 60 seconds to assess verbal fluency. There are eleven items in total that are completed, with increased scoring weight to the items most discriminant of mild cognitive impairment. To obtain a score, the total of all items is summed for a maximum score of 30. A final score of 26 or above considered normal.

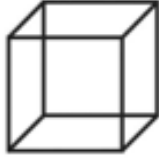
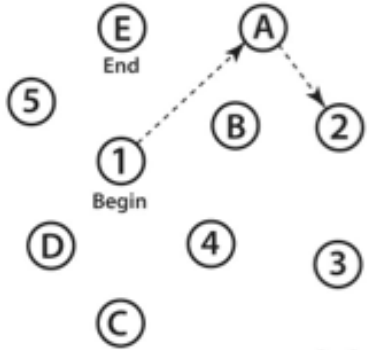

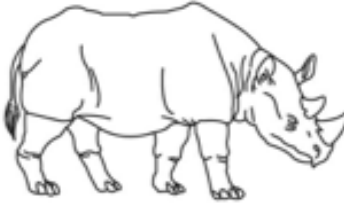
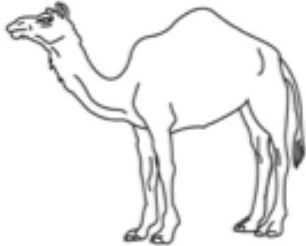
Gill et al. (2008) conducted a validation study of the MoCA specifically in the PD population. The average administration time for the MoCA was 8.1 6 2.1 min. The test-retest intraclass correlation coefficient was 0.79 (95% CI: 0.36–1.2). Inter-rater reliability

testing revealed a mean change in MoCA scores between examiners of 0.6 and the intraclass correlation coefficient between examiners was 0.81 (95% CI: 0.41–1.2). The correlation coefficient between the MoCA and a neuropsychological battery was 0.72 ($p < .0001$), indicating high construct validity. The scores were divided according to Hoehn & Yahr stages I-V: for Stages I–II the average score was 23.3 ± 4.1 , for Stage III the average score was 21.2 ± 4.8 , and for Stages IV–V, the average score was 19.9 ± 4.3 . These results confirm the MoCA is reliable and valid in the PD population. A copy of the MoCA is below.

MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME :
Education :
Sex :

Date of birth :
DATE :

| | | | | | | | | | | | | | | | | | | | | | | |
|---|------|---|---|---|------------|--|---------|-------------------------------|-------|-----------|--|--|--|--|--|-----------|--|--|--|--|--|-----------|
| VISUOSPATIAL / EXECUTIVE | |  | Copy cube | Draw CLOCK (Ten past eleven) (3 points) | POINTS | | | | | | | | | | | | | | | | | |
|  | | [] | [] | [] Contour [] Numbers [] Hands | ___/5 | | | | | | | | | | | | | | | | | |
| NAMING | |  | [] |  | [] |  | [] | ___/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. | <table border="1" style="width:100%; border-collapse: collapse;"> <tr> <td></td> <td style="text-align: center;">FACE</td> <td style="text-align: center;">VELVET</td> <td style="text-align: center;">CHURCH</td> <td style="text-align: center;">DAISY</td> <td style="text-align: center;">RED</td> </tr> <tr> <td style="text-align: center;">1st trial</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td style="text-align: center;">2nd trial</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table> | | FACE | VELVET | CHURCH | DAISY | RED | 1st trial | | | | | | 2nd trial | | | | | | No points |
| | FACE | VELVET | CHURCH | DAISY | RED | | | | | | | | | | | | | | | | | |
| 1st trial | | | | | | | | | | | | | | | | | | | | | | |
| 2nd trial | | | | | | | | | | | | | | | | | | | | | | |
| 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 | | | | | | | | | | | | | | | | |
| ATTENTION | | Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors [] FBACMNAAJKLBAFAKDEAAA JAMOF AAB | | | | ___/1 | | | | | | | | | | | | | | | | |
| ATTENTION | | 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 | | | | | | | | | | | | | | | | |
| LANGUAGE | | Fluency / Name maximum number of words in one minute that begin with the letter F [] ____ (N ≥ 11 words) | | | | ___/1 | | | | | | | | | | | | | | | | |
| ABSTRACTION | | Similarity between e.g. banana - orange = fruit [] train - bicycle [] watch - ruler | | | | ___/2 | | | | | | | | | | | | | | | | |
| DELAYED RECALL | | Has to recall words WITH NO CUE | FACE [] | VELVET [] | CHURCH [] | DAISY [] | RED [] | Points for UNCUED recall only | ___/5 | | | | | | | | | | | | | |
| Optional | | Category cue Multiple choice cue | | | | | | | | | | | | | | | | | | | | |
| ORIENTATION | | [] Date [] Month [] Year [] Day [] Place [] City | | | | ___/6 | | | | | | | | | | | | | | | | |
| © Z.Nasreddine MD www.mocatest.org Normal ≥ 26 / 30 | | TOTAL | | ___/30 | | | | | | | | | | | | | | | | | | |
| Administered by: _____ | | Add 1 point if ≤ 12 yr edu | | | | | | | | | | | | | | | | | | | | |

Appendix E: Community Balance and Mobility Scale

The Community Balance and Mobility (CB&M) scale was developed at the University of Toronto to evaluate balance and mobility in patients who are ambulatory and functioning at a high level, yet who have persistent balance problems. Due to the nature of this protocol, the sample included was fully ambulatory and without excessive risk of falling. For this reason typical tests of balance such as the Berg Balance test might not have been sensitive enough to identify the true balance limits of the participants or to distinguish between these high-functioning patients and the control group. The items of the CB&M encompass challenging balance and mobility tasks and are therefore useful in a fully ambulatory sample.

There are 13 various tasks within the CB&M and six are performed on the left and right side, resulting in a total of 19 tasks. Some examples are tandem walking, unilateral stance, descending stairs, crouch and walk, hopping forward, and lateral foot “scooting”. Each task is scored from 0-5 with detailed grading instructions. One item (descending stairs) has an additional point awarded to those who can complete the task carrying a laundry basket. Therefore, the highest possible score of the CB&M is 96.

The CB&M was initially created for use in patients with traumatic brain injury as balance is a persistent symptom long after the initial injury even after patients have regained many other functions. There have not been validation studies done for this test specifically in PD, however it has been extensively validated by Howe et al (2005) in brain injury patients. In the original validation study, content validity was ensured by including items only identified by practicing physical therapists as functionally relevant to measuring balance ability. Furthermore, the CB&M scores were correlated with global balance ratings (a 5-point questionnaire about self-perceived balance) completed by both the physical therapists at $r = 0.62$ ($p < 0.001$) the patients at $r = 0.39$ ($p = 0.023$).

The CB&M was found to have acceptable construct validity by correlated the CB&M scores with other measures of balance ability here was a significant correlation with self-paced and maximal gait velocity at $r = 0.53$ ($p < 0.001$) and $r = 0.64$ ($p < 0.001$), respectively.

Intraclass correlation coefficient (ICC) for intra-rater reliability was 0.977 (95% CI: 0.957-0.986), for inter-rater reliability was 0.977 (95% CI: 0.972-0.988), for immediate test-retest reliability was 0.975 (95% CI: 0.810-0.991), and for test-retest reliability 5 days apart was 0.898 (95% CI: 0.624-0.953).

Internal consistency was evaluated within both validity and reliability with a Cronbach's alpha of 0.96 and 0.95, respectively, suggesting that the items correlate highly and reflect the same construct.

The positive results support the CB&M as a useful clinical outcome measure to evaluate balance in the higher functioning, ambulatory patient. The authors also state that "clinical feedback and preliminary evidence indicates that the scale is also appropriate for clients with diagnoses other than traumatic brain injury" further indicating that this scale was appropriate for the IAR protocol. A copy of the CB&M is below.

COMMUNITY BALANCE & MOBILITY SCALE

(CB&M) SCORE SHEET

Participant #: _____

Full CB&M guidelines must be reviewed to ensure accurate administration and scoring. To score 5, actions must appear coordinated and controlled without excessive equilibrium reactions.

| CB&M Tasks | Notes | Score |
|--|-----------------------|-------|
| 1. UNILATERAL STANCE 0 unable to sustain 1 2.00 to 4.49 sec. 2 4.50 to 9.99 sec. 3 10.00 to 19.99 sec. 4 > 20.00 secs. 5 45.00 sec., steady and coordinated | "Look straight ahead" | Left |

| | | |
|---|---|--------------------------------|
| | <p>Test is over if stance foot moves from start position or raised foot touches ground.</p> | Right |
| <p>2. TANDEM WALKING</p> <p>0 Unable 1 1 step 2 2 to 3 consecutive steps (heel-toe distance < 3") 3 > 3 consecutive steps (heel-toe distance < 3") 4 > 3 consecutive steps(in good alignment = heel-toe contact and feet straight) 5 7 consecutive steps</p> | <p>"Look ahead down the track, not at your feet."</p> | |
| <p>3. 180° TANDEM PIVOT</p> <p>0 unable to sustain tandem stance 1 sustains tandem stance but unable to unweight heels or initiate pivot 2 initiates pivot but unable to complete 180° turn 3 completes 180° turn but discontinuous pivot (e.g. pauses on toes) 4 completes 180° turn in a continuous motion but can't sustain reversed position 5 completes 180° turn in a continuous motion and sustains reversed position</p> | <p>Test is over if touches heels down or steps out of position.</p> | |
| <p>4. LATERAL FOOT SCOOTING</p> <p>0 unable 1 1 lateral pivot 2 2 lateral pivots 3 > 3 pivots but < 40 cm 4 40 cm in any fashion and/or unable to control final position 5 40 cm continuous, rhythmical motion with controlled stop.</p> | <p>Test is over if patient hops or opposite foot touches down.</p> | <p>Left</p> <hr/> <p>Right</p> |

| | | |
|---|--|-------|
| <p>5. HOPPING FORWARD</p> <p>0 Unable 1 1 to 2 hops, uncontrolled 2 2 hops, controlled but unable to complete 1 metre 3 1 metre in 2 hops but unable to sustain landing (touches down) 4 1 metre in 2 hops but difficulty controlling landing (hops or pivots) 5 1 metre in 2 hops, coordinated with stable landing</p> | <p>Test is over if opposite foot touches down.</p> | Left |
| <p>6. CROUCH AND WALK</p> <p>0 unable to crouch 1 able to descend only 2 descends and rises but hesitates, unable to maintain forward momentum 3 crouches and walks in continuous motion, time < 8.00 sec. protective step 4 crouches and walks in continuous motion, time < 8.00 sec. excess equilibrium reaction 5 crouches and walks in continuous motion, time < 4.00 sec.</p> | | Right |

1 CB&M Scale

Toronto Rehab / U of T

| | | |
|--|--|--|
| <p>7. LATERAL DODGING</p> <p>0 unable to perform 1 cross-over in both directions without support 1 1 cross-over in both directions in any fashion 2 1 or more cycles, but does not contact line every step 3 2 cycles, contacts line every step 4 2 cycles, contacts line every step 12.00 to 15.00 sec. 5 2 cycles, contacts line every step < 12.00 sec. coordinated direction change</p> | <p>“Do this as fast as you can yet at a speed that you feel safe.”</p> | |
|--|--|--|

| | | |
|---|--|-------|
| <p>8. WALKING & LOOKING</p> <p>0 unable to walk and look e.g. stops 1 performs but loses visual fixation at or before 4 metre mark 2 performs but loses visual fixation after 4 metre mark 3 performs and maintains visual fixation between 2-6 metre mark but protective step 4 performs and maintains visual fixation between 2-6 metre mark but veers 5 performs, straight path, steady and coordinated < 7.00 sec.</p> | <p>“Walk at your usual pace.”</p> | Left |
| | | Right |
| <p>9. RUNNING WITH CONTROLLED STOP</p> <p>0 unable to run 1 runs, time > 5.00 sec. 2 runs, time > 3.00 but < 5.00 sec., unable to control stop 3 runs, time > 3.00 but < 5.00 sec., with controlled stop, both feet on line 4 runs, time < 3.00 sec., unable to control stop 5 runs, time < 3.00 sec., with controlled stop, both feet on line, coordinated 6 and rhythmical</p> | <p>“Run as fast as you can.” Hold position on finish line.</p> | |
| <p>10. FORWARD TO BACKWARD WALKING</p> <p>0 unable 1 performs but must stop to regain balance 2 performs with reduced speed, time > 11.00 sec. or requires 4 or more steps 3 to turn 4 performs in < 11.00 sec. and/or veers during backward walking 5 performs in < 9.00 sec. and/or uses protective step during or just after turn 6 performs in < 7.00 sec., maintains straight path</p> | <p>“Walk as quickly as you can yet at a speed that you feel safe.”</p> | |
| <p>11. WALK, LOOK AND CARRY</p> <p>(Score same as #8 Walking and Looking)</p> | <p>“Walk at your usual pace.”</p> | Left |
| | | Right |
| <p>12. DESCENDING STAIRS</p> <p>0 0 unable to step down 1 step, or requires railing or assistance</p> | | |

| | | |
|---|---|--------------------------------|
| <p>1 able to step down 1 step with/without cane (no railing) 2 able to step down 3 steps with/without cane, any pattern (no railing) 3 3 steps reciprocal or full flight in step-to pattern (no cane, no railing) 4 full flight reciprocal, awkward (no cane, no railing) 5 full flight reciprocal, rhythmical and coordinated (no cane, no railing) +1 bonus for carrying basket</p> | | |
| <p>13. STEP-UPS X 1 STEP</p> <p>0 unable to step up, requires assistance or railing 1 steps up, requires assistance or railing to descend 2 steps up and down (1 cycle) (not looking at feet) 3 completes 5 cycles (not looking at feet) 4 completes 5 cycles in > 6.00 but < 10.00 sec. (not looking at feet) 5 completes 5 cycles in < 6.00 sec., rhythmical (not looking at feet)</p> | <p>“Do this as quickly as you can. Try not to look at your feet.”</p> | <p>Left</p> <hr/> <p>Right</p> |
| <p style="text-align: right;">TOTAL SCORE:</p> | | |

Appendix F: Unified Parkinson Disease Rating Scale Items

The Unified Parkinson Disease Rating Scale is a commonly used tool to assess people living with Parkinson disease. It is divided into several sections: I. Mentation, behavior and mood, II. Activities of daily living, III. Motor examination, IV. Complications of therapy, V. Modified Hoehn and Yahr Staging, and VI. Schwab and England activities of daily living scale. The third section (motor examination) is commonly reported to provide an idea of the motor function status of people with PD.

The following items were reported as part of the participants' "motor profile":

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.

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.

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.

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.

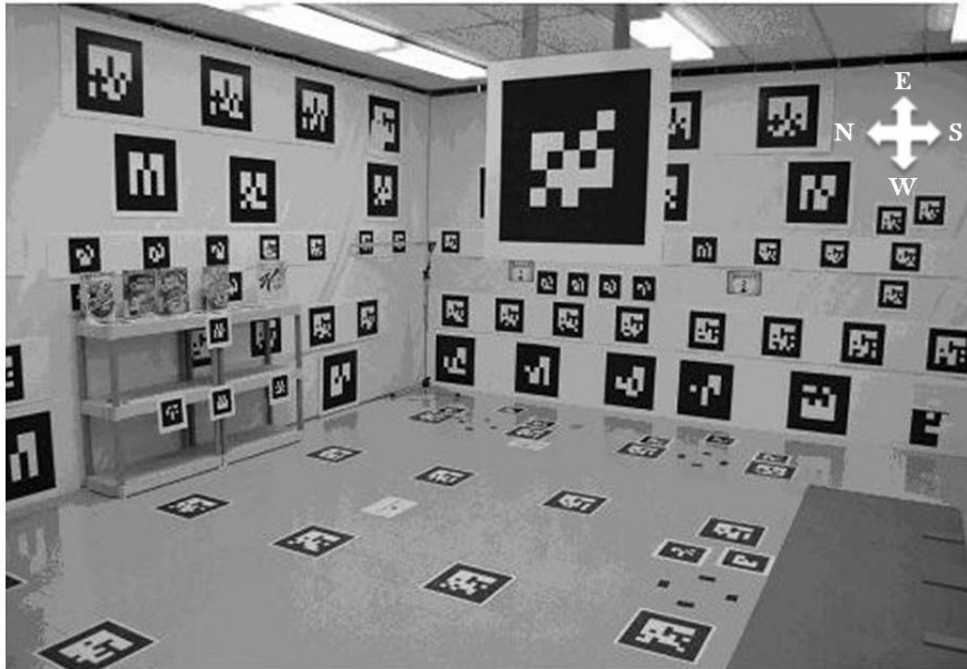
1 = Retropulsion, but recovers unaided.

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.

Appendix G: Physical Space



Fiducial marker setup. A total of 110 black and white fiducial markers made of corrugated plastic were mounted on the walls and floor. The markers used were unique black and white patterns printed on corrugated plastic squares. The chosen patterns exhibited high contrast to facilitate detection by the camera system. There were five different sizes of markers (45 cm^2 , 30 cm^2 , 20 cm^2 , 15 cm^2 and 10 cm^2); the largest ones enabled the camera to track positions from longer distances while the smallest markers allowed the user to interact with objects from shorter distances.

Appendix H: Hardware



Hardware: The head mounted display, camera, and light-weight laptop.



Participant wearing all hardware (laptop in backpack).

Appendix I: Immersive Augmented Reality Scenes



Living room scene.



Living room scene. Participant could see their hand holding a watering can to “water” flowers.



Cereal aisle scene.



Cereal aisle scene.



Street crossing scene.

Appendix J: Presence Questionnaire

Presence Questionnaire

Please place an "X" in the appropriate box of the scale in accordance with the question content and descriptive labels.

1. How much were you able to control events?

| | | | |
|-------------|--|--------------------|--------------|
| | | | |
| NOT ABLE | | MODERATELY ABLE | VERY ABLE |

2. How responsive was the environment to actions that you initiated (or performed)?

| | | | |
|-------------------|--|--------------------------|--------------------|
| | | | |
| NOT RESPONSIVE | | MODERATELY RESPONSIVE | VERY RESPONSIVE |

3. How natural did you interactions with the environment seem?

| | | | |
|----------------|--|-----------------------|-----------------|
| | | | |
| NOT NATURAL | | MODERATELY NATURAL | VERY NATURAL |

4. How completely were all of your senses engaged?

| | | | |
|----------------|--|-----------------------|-----------------|
| | | | |
| NOT ENGAGED | | MODERATELY ENGAGED | VERY ENGAGED |

5. How much did the visual aspects of the environment involve you?

| | | | |
|-----------------|--|------------------------|------------------|
| | | | |
| NOT INVOLVED | | MODERATELY INVOLVED | VERY INVOLVED |

7. How natural was the mechanism which controlled movement through the environment?

| | | | |
|----------------|--|-----------------------|-----------------|
| | | | |
| NOT NATURAL | | MODERATELY NATURAL | VERY NATURAL |

8. How aware were you of events occurring in the real world around you?

| | | | |
|--------------|--|---------------------|---------------|
| | | | |
| NOT AWARE | | MODERATELY AWARE | VERY AWARE |

9. How aware were you of your display and control devices?

| | | | | | | |
|--------------|--|--|---------------------|--|--|---------------|
| | | | | | | |
| NOT AWARE | | | MODERATELY AWARE | | | VERY AWARE |

10. How compelling was your sense of objects moving through space?

| | | | | | | |
|-------------------|--|--|--------------------------|--|--|--------------------|
| | | | | | | |
| NOT COMPELLING | | | MODERATELY COMPELLING | | | VERY COMPELLING |

11. How inconsistent or disconnected was the information coming from your various senses?

| | | | | | | |
|---------------------|--|--|----------------------------|--|--|----------------------|
| | | | | | | |
| NOT INCONSISTENT | | | MODERATELY INCONSISTENT | | | VERY INCONSISTENT |

12. How much did your experiences in the virtual environment seem consistent with your real-world experiences?

| | | | | | | |
|-------------------|--|--|--------------------------|--|--|--------------------|
| | | | | | | |
| NOT CONSISTENT | | | MODERATELY CONSISTENT | | | VERY CONSISTENT |

13. Were you able to anticipate what would happen next in response to the actions that you performed?

| | | | | | | |
|-------------|--|--|--------------------|--|--|--------------|
| | | | | | | |
| NOT ABLE | | | MODERATELY ABLE | | | VERY ABLE |

14. How completely were you able to actively survey or search the environment using vision?

| | | | | | | |
|-------------|--|--|--------------------|--|--|--------------|
| | | | | | | |
| NOT ABLE | | | MODERATELY ABLE | | | VERY ABLE |

15. How well could you identify sounds?

| | | | | | | |
|-------------|--|--|--------------------|--|--|--------------|
| | | | | | | |
| NOT WELL | | | MODERATELY WELL | | | VERY WELL |

16. How well could you localize sounds?

| | | | | | | |
|-------------|--|--|--------------------|--|--|--------------|
| | | | | | | |
| NOT ABLE | | | MODERATELY ABLE | | | VERY ABLE |

17. How much did external auditory stimuli experienced affect your feeling of involvement within the virtual environment?

| | | | | | | |
|---------------|--|--|------------------------|--|--|------------------|
| | | | | | | |
| NOT AFFECT | | | MODERATELY AFFECTED | | | VERY AFFECTED |

18. How well could you actively survey or search the virtual environment using touch?

| | | | | | | |
|-------------|--|--|--------------------|--|--|--------------|
| | | | | | | |
| NOT WELL | | | MODERATELY WELL | | | VERY WELL |

19. How compelling was your sense of moving around inside the virtual environment?

| | | | | | | |
|-------------------|--|--|--------------------------|--|--|--------------------|
| | | | | | | |
| NOT COMPELLING | | | MODERATELY COMPELLING | | | VERY COMPELLING |

20. How closely were you able to examine objects within the virtual environment?

| | | | | | | |
|----------------|--|--|-----------------------|--|--|-----------------|
| | | | | | | |
| NOT CLOSELY | | | MODERATELY CLOSELY | | | VERY CLOSELY |

21. How well could you examine objects from multiple viewpoints?

| | | | | | | |
|-------------|--|--|--------------------|--|--|--------------|
| | | | | | | |
| NOT WELL | | | MODERATELY WELL | | | VERY WELL |

22. How well could you move or manipulate objects in the virtual environment?

| | | | | | | |
|-------------|--|--|--------------------|--|--|--------------|
| | | | | | | |
| NOT WELL | | | MODERATELY WELL | | | VERY WELL |

23. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?

| | | | | | | |
|-----------------|--|--|------------------------|--|--|------------------|
| | | | | | | |
| NOT CONFUSED | | | MODERATELY CONFUSED | | | VERY CONFUSED |

24. How involved were you in the virtual environment experience?

| | | | | | | |
|-----------------|--|--|------------------------|--|--|------------------|
| | | | | | | |
| NOT INVOLVED | | | MODERATELY INVOLVED | | | VERY INVOLVED |

25. How distracting was the control mechanism?

| | | | | | | |
|--------------------|--|--|---------------------------|--|--|---------------------|
| | | | | | | |
| NOT DISTRACTING | | | MODERATELY DISTRACTING | | | VERY DISTRACTING |

26. How much delay did you experience between your actions and expected outcomes?

| | | | | | | |
|-------------|--|--|-------------------|--|--|-------------------|
| | | | | | | |
| NO DELAY | | | MODERATE DELAY | | | A LOT OF DELAY |

27. How quickly did you adjust to the virtual environment experience?

| | | | | | | |
|----------------|--|--|-----------------------|--|--|-----------------|
| | | | | | | |
| NOT QUICKLY | | | MODERATELY QUICKLY | | | VERY QUICKLY |

28. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

| | | | | | | |
|-------------------|--|--|--------------------------|--|--|--------------------|
| | | | | | | |
| NOT PROFICIENT | | | MODERATELY PROFICIENT | | | VERY PROFICIENT |

29. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

| | | | | | | |
|--------------------|--|--|---------------------------|--|--|---------------------|
| | | | | | | |
| NOT DISTRACTING | | | MODERATELY DISTRACTING | | | VERY DISTRACTING |

30. How much did the control devices interfere with the performance of assigned tasks or with other activities?

| | | | | | | |
|--------------|--|--|--------------|--|--|--------------|
| | | | | | | |
| NO | | | MODERATE | | | A LOT OF |
| INTERFERENCE | | | INTERFERENCE | | | INTERFERENCE |

31. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

| | | | | | | |
|------|--|--|----------|--|--|----------|
| | | | | | | |
| NOT | | | MODERATE | | | A LOT OF |
| WELL | | | WELL | | | WELL |

32. Did you learn new techniques that enabled you to improve your performance?

| | | | | | | |
|----|--|--|---------|--|--|-----|
| | | | | | | |
| NO | | | NEUTRAL | | | YES |

33. Were you involved in the experimental task to the extent that you lost track of time?

| | | | | | | |
|----|--|--|---------|--|--|-----|
| | | | | | | |
| NO | | | NEUTRAL | | | YES |

34. How natural did the interaction with real world objects feel when immersed within the virtual environment

| | | | | | | |
|---------|--|--|------------|--|--|---------|
| | | | | | | |
| NOT | | | MODERATELY | | | VERY |
| NATURAL | | | NATURAL | | | NATURAL |

35. How would you rate level experience with video games in general?

| | | | | | | |
|-------------|--|--|-------------|--|--|-------------|
| | | | | | | |
| NOT | | | MODERATELY | | | VERY |
| EXPERIENCED | | | EXPERIENCED | | | EXPERIENCED |

36. How comfortable do you feel playing video games?

| | | | | | | |
|-------------|--|--|-------------|--|--|-------------|
| | | | | | | |
| NOT | | | MODERATELY | | | VERY |
| COMFORTABLE | | | COMFORTABLE | | | COMFORTABLE |

37. How much experience have you had playing casual video games on your phone or mobile device?

| | | | | | | |
|-------------|--|--|-------------|--|--|-------------|
| | | | | | | |
| NOT | | | MODERATELY | | | VERY |
| EXPERIENCED | | | EXPERIENCED | | | EXPERIENCED |

38. How much experience have you had playing video games on a computer?

| | | | | | | |
|-------------|--|--|-------------|--|--|-------------|
| | | | | | | |
| NOT | | | MODERATELY | | | VERY |
| EXPERIENCED | | | EXPERIENCED | | | EXPERIENCED |

39. How experienced are you with video games that are controlled from a first person view?

| | | | | | | |
|-------------|--|--|-------------|--|--|-------------|
| | | | | | | |
| NOT | | | MODERATELY | | | VERY |
| EXPERIENCED | | | EXPERIENCED | | | EXPERIENCED |

40. How much experience have you had playing video games that were controlled from a third person view?

| | | | | | | |
|-------------|--|--|-------------|--|--|-------------|
| | | | | | | |
| NOT | | | MODERATELY | | | VERY |
| EXPERIENCED | | | EXPERIENCED | | | EXPERIENCED |

41. How much experience have you had playing video games on a console (e.g. Xbox, Playstation, etc.)?

| | | | | | | |
|-------------|--|--|-------------|--|--|-------------|
| | | | | | | |
| NOT | | | MODERATELY | | | VERY |
| EXPERIENCED | | | EXPERIENCED | | | EXPERIENCED |

Curriculum Vitae

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Publications:

F. Rahimi, A. South, **D. Bell-Boucher**, P. Bapat, Y. Mohammad, L. Zhu, M. Vyas, M. Jog, M. Jog Characterization of gait freezing in Parkinson's disease using a novel foot-sensor based methodology in laboratory and in patients' homes Movement Disorders, Vol. 27, Suppl. 1, 2012

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