Virtual Reality as a Clinical Modality For Retraining Balance and Mobility.

Daniel McEwen

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Daniel W.D. McEwen

PhD Rehabilitation Sciences Candidate

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Abstract

Physical rehabilitation of individuals who are experiencing a disabling illness or have survived a traumatic injury (i.e. stroke) must seek to train the body's structures and functions to reduce disability (activity limitations, participation restrictions) (Stucki, 2005). Figure 1 represents a modified version of the International Classification of Functioning (ICF), Disability and Health (World Health Organization, 2002). This figure illustrates how, for example, a stroke impacts the body structures and functions (e.g. muscle recruitment) which influences the ability to complete activities (e.g. gait) ultimately restricting participation in all areas of life (e.g. employment).

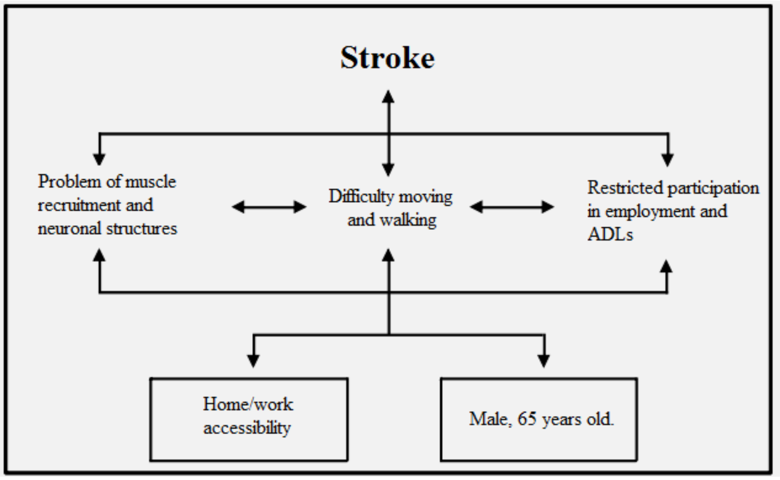

Figure 1: Illustration of functioning associated with neurological injury.

The ICF model presents a framework for clinical practice and rehabilitation research studies. Although it has been shown to be strongly correlated (Schmid, Van Puymbroeck, et al., 2013) the concept of function cannot always be directly correlated with the concept of quality of life (Stucki, 2005) as the individual may not perceive, for example, impaired balance and mobility as detrimental to their quality of life. However, reduced function does put an individual

at further risk of complications including falls and injuries from compensatory mechanisms and therefore must be addressed.

The focus of this thesis is the study of the potential benefits of an exercise modality (virtual reality) to encourage restoration of the body's structures and functions for individuals post-stroke. As the individuals engage in physical rehabilitation through exercise, there may be improvements on the individual's abilities as seen through measurements of the control of posture and walking.

The thesis comprises four studies, two of which have been published in peer reviewed journals. The progression of studies attempts to characterize outcomes following the use of virtual reality training in clinical populations (dementia and stroke) to address impairments to the body structures and functions (e.g. mobility) as measured by both clinical measures of activity and laboratory based measures of balance and to elucidate a possible mechanism (focus of attention) that makes training in a virtual environment effective.

List of Abbreviations

ADL: Activity of Daily Living

ANOVA: Analysis of Variance

AP: Anteroposterior

ASA: Acetylsalicylic Acid

BBS: Berg Balance Scale

BOS: Base of Support

CoM: Centre of Mass

CoP: Centre of Pressure

IREX: Interactive Rehabilitation Exercise

ML: Mediolateral

MoCA: Montreal Cognitive Assessment

OSSm: Ottawa Sitting Scale (modified)

PWD: Persons with Dementia

SD: Standard Deviation

TMWT: Two-Minute Walk Test

TUG: Timed Up and Go

UE: Upper Extremity

VE: Virtual Environment

VR: Virtual Reality

Contents

Chapter 1: General Introduction & Review of Literature

Stroke

Introduction

Stroke is a leading cause of long-term disability in adults in North America costing the Canadian economy $3.6 billion a year in physician services, hospital costs, lost wages, and decreased productivity (Public Health Agency of Canada, 2009). Quick and efficient stroke rehabilitation is essential to minimize the burden of stroke for survivors, their family/caregivers and the health care system (Brady, McGahan, & Skidmore, 2005).

Depending on which blood vessels are ruptured (hemorrhagic) or are occluded (ischemic), the corresponding brain structures will lose their connectivity and may result in impaired intellectual faculties (Patel, Coshall, Rudd, & Wolfe, 2002), loss of control of autonomic processes (Xiong et al., 2012) and reduced ability to transmit signals to the periphery for motor control (Burke et al., 2014). The focus of this doctoral thesis will remain in the physical component of motor control.

Following occlusion, there is a core ischemic area accompanied by a region known as the ischemic penumbra. The core ischemic area is where neurons have sustained necrosis due to a complete lack of oxygen and glucose (Gouix et al., 2014). The surrounding region is known as the ischemic penumbra representing structures that have reduced blood flow due to the occlusion but without collapse of cerebral blood volume (Fisher, Ginsberg, 2004) due to networks of collateral arteries. The ischemic penumbra was first defined by Astrup et al. (1981) as 'hypoperfused brain tissue which has capacity to recover if perfusion is improved'. Therefore, early recanalization of the occluded vessel can restore perfusion in the penumbra and possibly even in the ischemic core to prevent permanent damage (Molina et al., 2004).

Hemorrhagic strokes can present in two locations in the brain. An intracerebral hemorrhage occurs when a weakened blood vessel within the brain bursts allowing blood to leak inside the brain. In contrast, a subarachnoid hemorrhage occurs when a blood vessel outside the brain ruptures causing the subarachnoid space (area under the skull surrounding the brain) to fill with blood. Tissue damage is caused through compression of brain structures from an expanding hematoma (Adeoye & Broderick, 2010). Further damage is caused by the toxic effect of blood on tissue and vasculature and the subsequent inflammation (Wang, 2010). Epidemiological studies (Feigin, Lawes, Bennett, & Anderson, 2003) find that hemorrhagic strokes accounts for 8-18% of cases however, hemorrhagic strokes are associated with a lower survival rate (Broderick et al., 2007).

There is potential for recovery/ improvement for individuals following a stroke as the brain has a remarkable capacity for restoring function. Varying degrees of spontaneous recovery occur in the weeks to months following injury (Cramer, 2008). Spontaneous recovery results from changes to the structure of axons and synapses, angiogenesis (new vessel formation) and increased activation of neural stem cells (Andres et al., 2011).

Stroke Rehabilitation

Once the individual becomes medically stable, the rehabilitation process becomes the primary focus. If the patient meets specific functional criteria for the region they are in (OHA, 2013), they may be transferred to inpatient rehabilitation services. Others may be referred to outpatient services or community resources.

Inpatient rehabilitation facilities are usually staffed with an interdisciplinary team that may include physiatrists, nurses, physiotherapists, occupational therapists, speech and language pathologists, psychologists, pharmacists, dieticians, social workers and recreational therapists (Lindsay et al., 2008). Patients stay for extended periods of time and undergo intensive rehabilitation programs in hopes of restoring neuronal connections in the affected tissue which will allow for restoration of functional abilities.

Spontaneous gains can be accentuated with “motor activities on an intensive basis, in a behavioral context designed to re-engage and strengthen the neuromodulatory systems… with the goal of increasing the fidelity, reliability, and power of cortical representations” (Mahncke, Bronstone, & Merzenich, 2006). The ability of the brain to undergo changes following an injury is termed neuroplasticity. It has been described in other individuals with acute CNS injury including traumatic brain injury (Levin, 2003) and spinal cord injury (Behrman, Bowden, & Nair, 2006). Neuroplasticity can be defined as the ability of the nervous system to respond to intrinsic or extrinsic stimuli by reorganizing its structure, function and connections (Cramer, 2008). Berlucchi (2011) reports that the re-organization of the nervous system includes “development and maturation, adaption to novel environments, specific and unspecific kinds of learning, and compensatory adjustments in response to functional losses from brain damage.” Neuroplasticity following brain damage (stroke) is what makes neuro-rehabilitation advantageous as it provides a mechanistic rationale (Nudo, 2013) for understanding therapeutic interventions. These restorative therapies (Brown, Deriso, & Tansey, 2012) allow for activity-dependent rewiring and synapse strengthening (Murphy & Corbett, 2009) to reach the ultimate goal of improving quality of life.

As Berlucchi (2011) stated earlier, one component to maximize neuroplasticity during stroke recovery is adaption to novel environments. It is therefore important to challenge the patient with novel tasks that encourage motor relearning. Research from basic science (Biernaskie & Corbett, 2001) has shown that an enriched environment paired with daily reach training is advantageous over housing environments. Following focal ischemia, rats were housed in enrichment cages which had several different objects for exploration (i.e., tubes, shelves, ladders, and rope). These objects were changed twice weekly to provide continuous novel stimuli. The enriched housing rats took part in reach training (5 days/week) during which they were encouraged to reach for treats using the affected forelimb. Both functional reach and foot placement during skilled walking tasks were shown to be significantly higher for the enriched group while the standard housing group remained significantly impaired on both tasks. Meta-analysis data indicate that enriched environments do provide significant improvements in sensorimotor function in animal models (Janssen et al., 2010).

Enriched rehabilitation environments have also been shown to be enjoyable and effective on inpatient stroke rehabilitation wards for both patients (White, Bartley, Janssen, Jordan, & Spratt, 2015) and rehabilitation care team (White et al., 2014). With the increased participation in engaging activities outside of therapy time including music, crafts, social interaction and virtual environments (Nintendo Wii™), the patients reported benefits of "(1) increased motor, cognitive and sensory stimulation, (2) increased social interaction, (3) alleviation of degree of boredom and (4) increased feelings of personal control" (White et al., 2015).

Current systems analysis (Linkewich, Metcalfe, & Hall, 2016) from the Ontario Stroke Network (OSN) using the National Rehabilitation Reporting System (NRS) indicates that rehabilitation intensities received on inpatient stroke rehabilitation wards fall drastically lower than the best practice recommendation of three hours of therapy per-patient-day (De Wit et al., 2007; Wang et al., 2013). Patients received an average of 68 (median=61) minutes of rehabilitation intensities per day with only 2% meeting the target of 3 hours/day (Linkewich et al., 2016). Within therapy sessions, patients have been observed to spend less than two-thirds of their physiotherapy sessions engaged in physical activity (Connell, McMahon, Simpson, Watkins, & Eng, 2014; Kaur, English, & Hillier, 2012). Granted, time needs to be spent educating the patient (Rindflesch, 2009) with, for example; proper bracing, use of assistive devices and safe ADL self-care. However, the current constraints (i.e. inadequate staffing) of the inpatient rehabilitation settings may prevent patients from reaching the number of physical repetitions of a motor task necessary for cortical changes and functional improvements (Richards, Stewart, Woodbury, Senesac, & Cauraugh, 2008). Opportunities for exercise and activity outside of scheduled therapy time may help to address this gap.

Conclusion

A stroke is a debilitating cerebrovascular event that has drastic effects on multiple domains of an individual's functioning resulting in reduced participation in daily activities which may ultimately affect their quality of life. Recovery from stroke begins with spontaneous changes (Andres et al., 2011) in neuroanatomy as some rewiring of the affected region begins to occur. This neuroplasticity is harnessed in stroke rehabilitation during which the patient is encouraged to engage in repetitive practice with help from clinicians. The current health care system does not facilitate adequate opportunities for movement to reach optimal functioning post-stroke (Hall et al., 2016). Alternative modalities that can be implemented outside of therapy time may provide a complimentary adjunct to conventional rehabilitation.

Balance

Introduction

Throughout the day, individuals are required to control their posture as they engage in activities of daily living. The tasks may require reaching, leaning or stepping from the posture they are in. Postural control therefore has been defined as “the ability to control the body’s position in space for the dual purpose of stability and orientation.” (Shumway-Cook & Wollacott, 2011). Thus, postural control may occur in multiple positions including standing and seated.

Balance can be considered an extension of postural control as it describes the dynamic control of the body’s position to prevent an unexpected loss of posture. As Winter (1995) describes, balance is related to the inertial forces acting on the body and the inertial characteristics of body segments. Balance can be exercised in a dynamic fashion as the individual voluntarily moves their centre of mass (CoM) around within their base of support (BoS) or as a quasi-static fashion as the individual attempts to stabilize and limit the movements of the CoM. This movement or control is predominantly done as a subconscious/automatic task that facilitates the achievement of a primary motor task (i.e. combing hair) (Wulf, McNevin, & Shea, 2001).

However, changes to the body’s systems (visual, somatosensory, musculoskeletal) for example, post-stroke, that are required to successfully achieve balance may impair an individual’s ability to maintain postural control, subsequently negatively impacting activities of daily living. Balance should then be treated as a primary motor task requiring attention and effort that can be trained and improved upon.

Falls

A major component of stroke rehabilitation is retraining balance. Falls become a primary medical risk after acute stroke (Holloway, Tuttle, Baird, & Skelton, 2007) and remains a health concern throughout the post-stroke lifespan (Weerdesteyn, de Niet, van Duijnhoven, & Geurts, 2008). A fall can be considered *"an event which results in a person coming to rest unintentionally on the ground or lower level, not as a result of a major intrinsic event (such as a stroke) or overwhelming hazard"* (Tinetti, Speechley, & Ginter, 1988). Although the fall incidence rates among individuals post-stroke vary significantly between studies (Teasell, McRae, Foley, & Bhardwaj, 2002; Suzuki et al., 2007), it is apparent that the rates are much higher than the general population and therefore a cause for concern for rehabilitation specialists. Rehabilitation interventions have been shown to be effective for reducing stroke-related impairments subsequently reducing the risk of falls (Verheyden et al., 2013) as seen through clinical and laboratory measures of balance and mobility.

A high percentage of falls result in physical injuries (Schmid et al., 2013) including lacerations, bruising and potentially broken bones. Individuals post-stroke are further at risk for increased complications following a fall due to osteopathic changes (Eng, Pang, & Ashe, 2008) due to a reduced bone marrow density from lower physical activity. Approximately 37 hip fractures have been reported per 1,000 stroke person-years; 84% of which would have resulted from a fall (Ramnemark, Nyberg, Borssén, Olsson, & Gustafson, 1998). Minor injuries (cuts and bruises) have been found to occur in about 20% of falls (Stein, Viramontes, & Kerrigan, 1995). During the year 2000 in the USA, around 10,300 fatal and 2.6 million non-fatal but medically-treated fall-related injuries occurred in individuals over 65 years (with and without stroke) resulting in direct medical costs of 200 million dollars for fatal and 19 billion dollars for non-fatal injuries (Stevens, Corso, Finkelstein, & Miller, 2006). The economic burden of falls is substantial. Falls and fractures are serious medical problems that have high personal, social and economic impacts for both patients and their caregivers (Belgen, Beninato, Sullivan, & Narielwalla, 2006).

Stroke-related impairments (e.g. muscle weakness, reduced attention, reduced peripheral feedback) put individuals post-stroke at greater risk of falls as compared to their healthy age-matched comparisons (Jørgensen, Engstad, & Jacobsen, 2002; Simpson, Miller, & Eng, 2011). Decreased postural stability reduces an individual's ability to safely engage in activities of daily living (ADLs)(Ashburn, Hyndman, Pickering, Yardley, & Harris, 2008), navigate the community and respond to unexpected perturbations (Mansfield et al., 2015). In addition, Hyndman, Ashburn, & Stack (2002) found that repeat fallers had reduced upper extremity (UE) function limiting their ability to use the UE to assist in preventing any attempts to stop the fall by grasping a nearby object for stability (Maki & McIlroy, 2006).

Research has shown that post-stroke falls occur most often shortly after discharge from the hospital or a rehabilitation facility (Mackintosh, Hill, Dodd, Goldie, & Culham, 2005). Although there is a wide range of incidence rates of post-discharge falls, (Lim, Jung, Kim, & Paik, 2012; Verheyden et al., 2013) research finds roughly 55% (Ashburn et al., 2008) to 73% (Sackley et al., 2008) of community dwelling individuals post-stroke fall within the first year post-stroke. This staggering finding suggests that upon return to their home, individuals post-stroke have difficulty maintaining balance while attending to the complex challenges in their living environment.

In addition to physical domain of falls post-stroke, the fear of falling is found to be significantly associated with poor physical functional ability (Andersson, Kamwendo, & Appelros, 2008). This fear of falling results in a negative downward spiral of disuse which leads to instability which cycles back to increase a fear of falling (Cumming, Salkeld, Thomas, & Szonyi, 2000). In a systematic review, Scheffer et al. (2008) identified multiple consequences from a fear of falling for community based seniors including future falls, declines in physical activity, depression, lower quality of life (QoL) and changes in psychological and social functioning. Interventions (Zijlstra et al., 2007) including fall-related multifactorial programs, tai chi and physical exercise programs, have been shown to have a positive influence in reducing the fear of falling for individuals. Further investigation into successful interventions for postural control post-stroke is necessary in hopes to reduce the incidence of falls and the fear of falling.

Clinical Assessments (Available in Appendix B)

As an individual engages in a rehabilitation intervention to improve balance impairments, clinicians use a myriad of assessment tools to track progression in balance abilities. The primary purposes of clinical balance assessments are twofold in that they identify whether or not a balance problem exists as well as possibly determining any underlying causes of the balance problem (Mancini & Horak, 2010) by isolating potential sensorimotor mechanisms. Multiple clinical tests have metric adequacy including high validity and reliability. This lends to easy adoption and utilization in clinical practice. Reliability can be described as the extent to which a tool provides consistent results when repeated measurements are performed. Validity is described as the extent to which an assessment tool actually measures what it claims to measure.

A well accepted clinical assessment tool that is currently used in stroke rehabilitation is the Berg Balance Scale (BBS) (Berg, Wood-Dauphinee, Williams, & Maki, 1992; Mao, Hsueh, Tang, Sheu, & Hsieh, 2002). The BBS is a 14-item validated standardized test with a maximum score of 56. It measures static, dynamic, adaptive and anticipatory components of balance. It was developed for balance assessments for older adults. Although there is debate on it the predictive value of the BBS (Baetens, De Kegel, Calders, Vanderstraeten, & Cambier, 2011) others have shown a strong prediction value of falls in individuals post-stroke (Maeda, Urabe, Murakami, Itotani, & Kato, 2015). In a study (Simpson et al., 2011) including individuals post-stroke that were discharged to the home environment it was found there is a sharp increase in fall risk when the BBS score was below 44.

The Timed Up and Go (Podsiadlo & Richardson, 1991) is a test of functional mobility requiring a participant to rise from a chair, walk 3 m, turn, and return to sit back in the chair. The participant walks through the test once to familiarize themselves with the objective. Since it is a timed test, a faster time indicates better functional performance. A score of 13.5 seconds or more has been shown to indicate a high risk of falls in community dwelling older adults (Barry, Galvin, Keogh, Horgan, & Fahey, 2014) and 14 seconds or more for older sub-acute stroke patients (Andersson, Kamwendo, Seiger, & Appelros, 2006).

Functional endurance is often measured with time-limit walk test, for example, the Six-Minute Walk Test (Butland, Pang, Gross, Woodcock, & Geddes, 1982), to document the maximum distance an individual can safely walk in the allotted time. Originally created for patients with cardiovascular or pulmonary problems, walk tests have become widely used in stroke rehabilitation. Depending on the functional level of the individual and the available clinical time, the time may be modified (e.g. 2-Minute Walk Test (TMWT)) to test mobility over cardiovascular endurance (Bohannon, Wang, & Gershon, 2015). The 2, 6 and 12-minute walk tests have acceptable inter/intra rater reliability and are found to be highly correlated to each other whilst being used for individuals sub-acute stroke (Kosak & Smith, 2004).

Centre of Pressure

In addition to clinical balance and mobility tests, assessments of postural stability are also done with platforms that measure the point of application (weighted average position) of the ground reaction forces labelled as the centre of pressure (CoP). According to Winter, D. (1995) the centre of pressure (CoP) is best defined as:

"…the point location of the vertical ground reaction force vector. It represents a weighted average of all the pressures over the surface of the area in contact with the ground… If one foot is on the ground the net CoP lies within that foot. If both feet are in contact with the ground the net CoP lies somewhere between the two feet, depending on the relative weight taken by each foot. Thus when both feet are in contact with the floor, there are separate CoPs under each foot. When one force platform is used only the net CoP is available. Two force platforms are required to quantify the CoP changes within each foot."

Body sway is expressed through various calculations of CoP movements including velocity (cm/s), 95% ellipse sway area (cm^2) and range (cm). The CoP movements are continuous as the individual attempts to maintain balance as the CoM moves. This is clearly identified in the inverted pendulum model (Winter, Patla, Prince, Ishac, & Gielo-Perczak, 1998) that relates the controlled variable (CoM) with the controlling variable (CoP). Depending on the postural strategy used, the movement of the CoP would be relational to the movement of the CoM in both the sagittal (anterior/posterior direction, A/P) (Figure 2) and frontal (medial/lateral direction, M/L) planes.

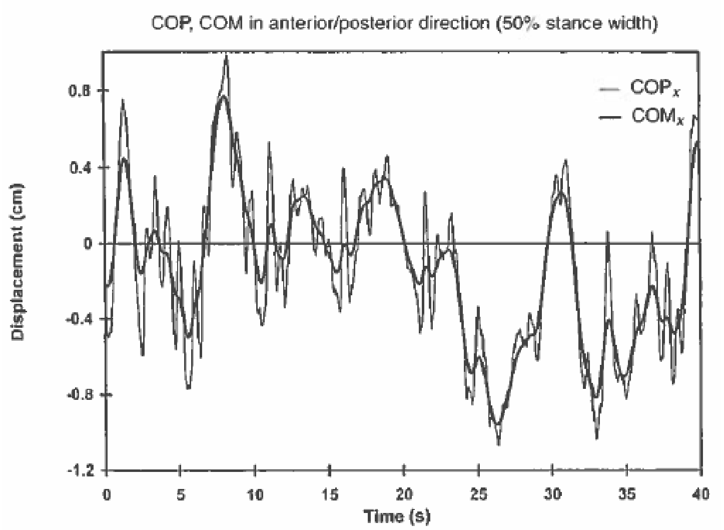

Figure 2: Illustration of how the CoP responds to movements of the COM during a 40s static posture trial.(Winter et al., 1998)

As the CoP continuously regulates the postural sway, the CoP can be tracked to provide information on the individual’s ability to limit sway (quasi-static posture) (Mansfield, Danells, Inness, Mochizuki, & McIlroy, 2011) or control sway during dynamical reaching tasks (Chern et al., 2010). In both tasks, individuals post-stroke have been shown to be less able to maintain control of their posture represented by greater postural sway as well as being less able to shift their CoP towards their affected side (Kamphuis, de Kam, Geurts, & Weerdesteyn, 2013).

Quantitative results indicate that individuals post-stroke have greater postural sway during quiet stance (de Haart, Geurts, Huidekoper, Fasotti, & van Limbeek, 2004), with higher percent of total body weight under the non-paretic lower limb (Laufer, Sivan, Schwarzmann, & Sprecher, 2003). Also, individuals post-stroke have delayed and reduced responses to external perturbations (Ikai, Kamikubo, Takehara, Nishi, & Miyano, 2003). All of which limit the individual’s ability to maintain the CoP within the base of support to prevent falls.

Centre of pressure variables have been shown to be responsive to rehabilitation. For example, in a cohort study (de Haart et al., 2004), balance in the ML direction showed a reduction of static velocity of 33% over a 12-week inpatient rehabilitation process. Another study (De Nunzio et al., 2014) found a significant reduction in CoP index of asymmetry, a valid measure of paretic limb loading. Laboratory based quantification of postural stability delivers more sensitive measures that provide information of how the patient controls their balance during tasks over simply task completion.

Conclusion

Individuals post-stroke often have impairments to their body's structures that impair the ability to maintain balance (standing/seated) required for postural control. Controlling a posture is required to safely engage in activities of daily living. If the impairments increase the attentional demands required for postural stability (reduced automaticity), the individual may not have the ability to prevent a fall through maintaining balance (keeping the CoM within the BoS) or responding efficiently to a perturbation (Patel & Bhatt, 2015), which has shown to be highly probable post-stroke, primarily post-discharge (Simpson et al., 2011). Monitoring of balance abilities can be done through clinical and laboratory measures. These methods have been shown to be highly valid and reliable as well as sensitive to detect changes during rehabilitation programs. Balance should therefore be treated as a motor task that requires intensive training post-stroke to limit the probability of falls and to return the individual's ability to automatically control balance to allow a greater amount of attentional focus to be dedicated to an alternative primary motor task.

Virtual Reality

Introduction

Virtual reality (VR) is defined as the “use of interactive simulations created with computer hardware and software to present users with the opportunity to engage in environments that appear and feel similar to real-world objects and events” (Sveistrup, 2004; Weiss, Sveistrup, Rand, & Kizony, 2009). Using this widely accepted definition, numerous platform designs have been described as VR ranging from desktop computer/TV systems (Glegg, Tatla, & Holsti, 2014) to more expensive, more immersive technology such as head mounted displays (Simone, Schultheis, Rebimbas, & Millis, 2006; Kim, Chung, Nakamura, Palmisano, & Khuu, 2015) which engulf the entire field of vision while adapting the virtual image to the orientation of the participant’s head. A key characteristic of all VR applications that differentiate them from other media is interaction (Sveistrup, 2004). Virtual environments (VE) allow a user to interact with the VE as well as virtual objects or people within that environment.

Multiple platforms have been used to deliver interventions. Some platforms require peripherals (controllers) including the Nintendo Wii™ (Deutsch et al., 2012; Dos Santos et al., 2015) and the PlayStation’s EyeToy™ (Yavuzer, Senel, Atay, & Stam, 2008) while others rely on motion capture of the participant to create an avatar representation including Motek’s CAREN™ (Computer Assisted Rehabilitation Environment) system (Subramanian, Lourenço, Chilingaryan, Sveistrup, & Levin, 2013), X-box Kinect™ camera systems (Webster & Celik, 2014), RehabMaster (J.-H. Shin, Ryu, & Jang, 2014) or real time video display of the individual as with Gesturetek’s IREX™ (Interactive Rehabilitation Exercise) system (Glegg et al., 2014). Each platform provides a unique set of activities, tasks or games targeted at a specific rehabilitation goal. A recent review (Lohse, Hilderman, Cheung, Tatla, & Van Der Loos, 2014) found no significant difference in effectiveness between the platforms and suggested larger RCTs for further investigation of the clinical utility of each platform.

A key feature of VR is the ability to interact with the environment or objects presented within it. The mode of interaction may differ between systems. Certain systems create a representation of the user's hand or full body, through either an avatar/cartoon or with a moving object (for example as a ball in a maze) which responds to movement of the participant's corresponding body/body part. Other systems project the participant's image directly into the software. Throughout this thesis, the IREX VR platform will be used. This software takes a video image through a webcam and uses colour-subtraction software to remove a monochrome (green) background from the image to immerse the individual into the VE. This video-capture platform has many advantages (Weiss, Rand, Katz, & Kizony, 2004) over other platforms including: a mirror image view which facilitates feedback about the body's posture and quality of movement, a red glove option to force use of the paretic hand to interact with virtual images, a high control over levels of difficulty and performance outcomes and the lack of extra devices (i.e. handheld controller) used to interact with the VE.

VR provides a controlled setting which allows the participant to attempt and perfect movements or tasks that may otherwise put them at risk in a real-world setting or may only be physically possible in a VE (i.e. juggling, catching with slower gaming parameters). For example, medical students are able to practice neurosurgical laparoscopic protocols (Nagendran, Gurusamy, Aggarwal, Loizidou, & Davidson, 2013), pilots are able to execute maneuvers in virtual aircrafts (Lele, 2013) and individuals post-stroke are able to attempt to cross the street

(Navarro, Lloréns, Noé, Ferri, & Alcañiz, 2013). The rich stimulus (i.e. auditory, visual, tactile) provided by the VR system can draw people in to the point at which they feel the scenario is ‘real’ (Walshe, Lewis, O’Sullivan, & Kim, 2005). VEs therefore have been shown to have high ecological validity (Rizzo, Schultheis, Kerns, & Mateer, 2004) as the skills learned in a VE translate directly to success in real-world applications (Gourlay, Lun, Lee, & Tay, 2000; Rose et al., 2000).

Some VEs provide an opportunity to engage in a game like scenario that may or may not have real-world applications. For example, the Gesturetek IREX software includes a game titled Airbourne in which the player is parachuting and must lean side to side to stay in the middle of the screen and bend and stretch to avoid birds flying in from the sides. This game is not set-up to provide realistic practice for real-world application and thus, does not make individuals post-stroke ready for their first jump from an airplane. However, the motor skill that is being practiced during these VR games is rather balance and reaching abilities that can transfer to real world application.

VR as a Clinical Modality

VR has been used to engage individuals for recreational purposes (Frostling-Henningsson, 2009) and vocational training (Francis et al., 2012). In recent years, it is becoming adopted as a clinical modality used for rehabilitation of a wide spectrum of patients including those with pain (Malloy & Milling, 2010), post-traumatic stress disorder (Gonçalves, Pedrozo, Coutinho, Figueira, & Ventura, 2012), Parkinson’s Disease (Mirelman, Maidan, & Deutsch, 2013), traumatic brain injury (Pietrzak, Pullman, & McGuire, 2014), cerebral palsy (Mitchell, Ziviani, Oftedal, & Boyd, 2012; Brien & Sveistrup, 2011) and stroke (McEwen, Taillon-Hobson, Bilodeau, Sveistrup, & Finestone, 2014; Laver, George, Thomas, Deutsch, & Crotty, 2015). A systematic review found consistent evidence that VR: '…is a promising new rehabilitation approach for [stroke recovery]…However, at present, the studies are too few and too small to draw conclusions." (e.g. Laver et al., 2015).

A major strength of VR interventions for motor rehabilitation is the ability to provide enjoyable, motivating environments to interact with in a unique way. As such, some VR interventions have been found to be more enjoyable than conventional rehabilitation methods (Housman, Scott, & Reinkensmeyer, 2009; Bryanton et al., 2006). Qualitative feedback from participants after VR participation found that some participants would welcome VR training at an early stage of inpatient stroke rehabilitation as the conventional therapies offered were not challenging nor engaging (Lewis, Woods, Rosie, & McPherson, 2011). However, not all participants find VR engagement an enjoyable experience as the games can be viewed as "hard work", too fatiguing either cognitively or physically (Joo et al., 2010) or discouraging due to low scores (Lewis et al., 2011). Maintaining an adequate challenge level becomes vital to the success of a VR intervention to ensure high levels of effort and engagement. VR platforms address this through providing progressive levels in which the challenges can be adapted to meet the patient's abilities while providing progressive difficulty through increasing task complexity or the degrees of freedom necessary to interact with the virtual environment.

Ensuring proper task difficulty during VR training may prove difficult with populations that have altered cognitive abilities for example, for individuals with dementia, or as secondary complication following neurological trauma. To successfully participate in a virtual task, comprehension of multiple aspects is vital. These include understanding the method of interaction of the VR environment, understanding the instructions for the task and sustained attention to carry out the task for the duration of the activity.

VR interventions allow the participant to become immersed in a stimulus-rich environment with novel experiences in visual, auditory and even tactile senses. This enriched environment provides the participant the opportunity to engage in interactions with the VE to encourage problem solving and accomplish new skills. Animal research in stroke (Biernaskie & Corbett, 2001) has shown that training in an enriched environment results in better performance in functional tasks than training in basic environments

VR in Stroke Rehabilitation

In recent years, the use of VR interventions for stroke rehabilitation have increased in frequency (Laver et al., 2015). Research and clinical usage is predominately focused on upper-extremity exercises (Oujamaa, Relave, Froger, Mottet, & Pelissier, 2009) but has also been used to treat neglect (Pedroli, Serino, Cipresso, Pallavicini, & Riva, 2015), gait (Deutsch & Mirelman, 2007; Rodrigues-Baroni, Nascimento, Ada, & Teixeira-Salmela, 2014) and standing balance (Li, Han, Sheng, & Ma, 2015) (McEwen et al., 2014). Rehabilitation for individuals post-stroke has been shown to be advantageous at all time points of recovery and therefore inclusion of patients at inpatient/outpatient, sub-acute and chronic stages has been optimal to assess the benefits of VR training.

Upper Extremity Training

Virtual reality has applicability in numerous components of stroke rehabilitation. Due to the nature of interaction with the VR platforms as well as safety concerns from physical limitations of the patients, VR has most readily been studied for upper extremity function with positive outcomes. Certain platforms utilize a force-used type of interaction algorithms that can limit use to one arm/hand for participation. Platforms like the Nintendo Wii™ utilize a hand-held remote to interact with the VE while other platforms like the IREX utilize a body tracking software. Participation is only possible through use of the pre-specified extremity, which would be the paretic arm post-stroke. Using only the paretic arm during VR exposure can facilitate repetitive movement which may lead to increased range of motion, provided the parameters are set to an appropriate level for that patient.

Thus, VR has been shown to make improvements for individuals post-stroke in upper extremity function. Improvements have been seen through clinical assessments including the Wolf Motor Function test with Nintendo Wii™ training (Saposnik et al., 2010), improvements in Brunnstrom stages using the Playstation EyeToy™ (Yavuzer et al., 2008) as well as improvements in kinematics (movement time/velocity) with the Hand Dance Pro™ platform (Combs et al., 2012). However, a systematic review of VR for upper limb rehabilitation finds "there is insufficient high quality evidence to reach generalizable conclusions about risks or benefits on activities of daily living or upper limb function/movement" (Thomson, Pollock, Bugge, & Brady, 2014). This is due to the wide variety of outcome measures, training dosages and small sample sizes.

Balance and Mobility

Interactions with the virtual environment can be extended from a forced-use of an upper extremity to full-body participation. Seated or standing VR training can facilitate improvements of balance and mobility through repetitive reaching, leaning and stepping to accomplish the goals of the VE. Some VR platforms are integrated with robotics (Mirelman, Bonato, & Deutsch,

2009) or treadmills (Yang et al., 2011) to further encourage proper movement patterns or greater movement distances. Systematic reviews (Corbetta, Imeri, & Gatti, 2015; Laver et al., 2015) and meta-analyses on balance (Li et al., 2015) and gait (Rodrigues-Baroni et al., 2014) consistently find improvements on clinical measures of balance and mobility.

However, prior to 2011 (the commencement of study #2), studies that focused on VR as a clinical modality for balance and mobility for individuals post-stroke remained at a chronic stage post-stroke ranging from a few months (Walker et al., 2010) to 6 years (Yang, Tsai, Chuang, Sung, & Wang, 2008) post-stroke. Methodologies were either case study (Deutsch, Latonio, Burdea, & Boian, 2001), feasibility (Fung, Richards, Malouin, McFadyen, & Lamontagne, 2006), small (n=7/group)(Yang et al., 2011) between-group comparisons or smaller sample RCTs (n=5/group) (You, Jang, Kim, Hallett, et al., 2005). Studies have ranged in outcome measures including clinical measures (Flynn, Palma, & Bender, 2007), kinematic and kinetic parameters (Mirelman, Patritti, Bonato, & Deutsch, 2010) and cortical activation parameters (You, Jang, Kim, Hallett, et al., 2005). The VR platforms used also range from independently developed platforms (Betker, Szturm, Moussavi, & Nett, 2006) to commercially available platforms (Kim, Jang, Kim, Jung, & You, 2009).

The following table provides a comprehensive list of articles that focus on the use of virtual reality for retraining balance and mobility for individuals post-stroke. Level of evidence was rated using the same system as Weiss et al. (2009) (adapted from (Butler & Darrah, 2001) and (Crosbie, Lennon, Basford, & McDonough, 2007)). Time post-stroke was considered chronic when the mean was greater than 6 months post-stroke. Literature search strategies are available in appendix A.

Authors & Year	Method	Outcome Measures	Time Post-Stroke	Equipment	Rating
Deutsch, Latonio, Burdea, & Boian, 2001	Case Study (n=1)	**Clinical measures:** (Manual Muscle Test, stair walking), **Joint kinetics**: (Rutgers Ankle System: force generation, endurance, coordination, ROM) and **Game parameters:** (accuracy)	Chronic (9 months)	Rutgers Ankle System & An Airplane Simulation.	V
Deutsch, J., Paserchia, C., Becchione, C., Mirelman, A., Lewis, J., Boian, R. et al., 2004	Double Baseline Pre-Post (n=6)	**Clinical measure:** (6-minute walk test) and **Gait parameters:** (GAITRite: gait speed, elevation speed, gait endurance)	Chronic (9 months to 8 years)	Rutgers Ankle Rehabilitation System (RARS)	II
Jaffe, D., Brown, D., Pierson, Carey, C., Buckley, E., Lew, H., 2004	Pre-Post Between groups (n=10/group)	**Clinical measures:** (Performance-Oriented Assessment of Mobility, Physical Performance Test, 6-minute Walk Test) and **Gait parameters:** (Stride Analyzer gait analysis system: velocity, cadence and stride length)	Chronic (mean= 3.8 ± 2.2 years)	Virtual Research V6 HMD on a treadmill	II
You, S., Jang, S., Kim, Y., Halett, M., Ahn, S., Kwon, Y. et al., 2005	RCT (n=5/group)	**Clinical measures:** (Functional Ambulation Category, Modified Motor Assessment Scale) and **Neurological scans:** (1.5T MR scanner - Vision; Siemens: Functional MRI (Laterality Index))	Chronic (Exp: 18.20 ± 2.27 SE, Con: 19.40 ± 4.27SE)	IREX VR System	I
Betker, A., Szturm, T., Moussavi, Z., Nett, C., 2006	Case Study (n=1)	**Posturography:** (Force Sensitive Applications (FSA) pressure mapping system: CoP Range, CoP Path Length) and number of falls.	Unclear	Independent CoP-Controlled	V
Fung, J., Richards, C., Malouin, F., McFadyen, B., Lamontagne, A., 2006	Feasibility (n=2)	**Gait parameters:** (Treadmill speed: Gait Speed)	Sub-acute (2 & 4.5 months post-stroke)	CAREN System, SoftImage XSI Software	IV

Flynn, S., Palma, P., Bender, A., 2007	Case Study (n=1)	**Clinical measures:** (Fugl-Meyer Assessment, Upper Extremity Functional Index, Beck Depression Inventory, BBS, Dynamic Gait Index, Mini-Mental State Exam, TUG, 6-Minute Walk Test, Motor Activity Log, Modified Ashworth Scale, Functional Reach Test)	Chronic (17 Months)	Sony Playstation 2 Eye Toy	V
Dunning, K., Levine, P., Schmitt, L., Israel, S., Fulk, G., 2008	Case Study (n=1)	**Clinical measures:** (Emory Functional Ambulation Profile, Fugl-Meyer Scale Lower Extremity portion), **Gait parameters:** (Eagle; Motion Analysis Corp.: walking speed, step length, cadence, cycle time, stance time, swing time, step length asymmetry ratio, stance support time asymmetry ratio)	Chronic (9 months)	The sEMG TIM VR rehabilitation device	V
Yang, Y., Tsai, M., Chuang, T., Sung, W., Wang, R., 2008	RCT (n= 11 Exp 9 Con)	**Clinical measures:** (walking ability questionnaire and activities specific balance confidence (ABC)) and **Gait parameters:** (Chronograph: 10m walking speed, 400m community walking time)	Chronic (Exp: 5.93 ± 4.17 years, Con: 6.10 ± 10.32 years)	Independent Treadmill Community Walking VE	I
Kim, J., Jang, S., Kim, C., Jung, J., You, J., 2009	RCT (n=12/group)	**Clinical measures:** (BBS, 10MWT, Modified Motor Assessment Scale), **Posturography** (Balance Performance Monitor: mean balance, sway area, and maximal sway velocity) and **Gait parameters:** (GAITRite: cadence, velocity, step time, stance time, swing time, single/double support time, and step/ stride length)	Chronic (Exp: 25.91 ± 9.96 months, Con: 24.25 ± 8.87 months)	IREX VR System	I
Mirelman, A., Bonato, P., Deutsch, J., 2009	Single Blind RCT (n=9/group)	**Clinical measures:** (6-Minute Walk Test, Lower Extremity Fugl-Meyer and BBS)and **Gait parameters:** (Patient Activity Monitor: number of steps per day, average daily distance walked, speed, cadence, walking strides, maximum walking speed, longest consecutive locomotion period in minutes, and the longest consecutive distance traveled)	Chronic (Exp: 37.7 ± 25 months, Con: 58.2 ± 26.3 months)	Rutgers Ankle Rehabilitation System (RARS)	I

Mirelman, A., Patritti, B., Bonato, P., Deutsch, J., 2010	RCT (n=9/group)	**Gait parameters:** (Eight-camera Vicon motion capture system: bilateral spatiotemporal parameters, and kinematics and kinetics of the ankle, knee and hip joints during the stance and swing phases of gait)	Chronic (>2 years)	Rutgers Ankle Rehabilitation System (RARS)	I
Shin, W., Lee, D., Lee, S., 2010	RCT (n=16/group)	**Clinical measures:** (6-minute Walk Test, 10MWT)	Chronic (Exp: 69.19 ± 36.42 months, Con: 71.5 ± 33.87 months)	Sony Playstation 2 (Eyetoy)	I
Walker, M., Ringleb, S., Maihafer, G., Walker R., Crouch, J., Van Lunen, B., Morrison, S., 2010	Pre-Post (n=6)	**Clinical measures:** (Functional Gait Assessment, BBS, Overground Gait Speed)	Sub-acute (mean= 18.67 ± 14.91)	Biodex GaitTrainer: 2 treadmill with custom TV VR system using OpenScene Graph, the 3D character animation library Cal3D, the character animation toolkit ReplicantBody, and 3D modelling program Autodesk's 3D Studio Max.	IV
Bergmann, J., Krewer, C., Muller, F., Koenig, A., Riener, R., 2011	Case Study (n=1)	Weighted Interaction Torques (WIT) Between Robot and Patient	Sub-acute (1 month)	Driven Gait Orthosis (DGO) Lokomat (Howcoma, Switzerland) with a flatscreen forest walking task.	V
Fung, J. & Perez, C., 2011	Between Group Comparison (n=9 patients, 9 healthy controls)	**Gait parameters:** (6-camera Vicon MX motion analysis system: gait variability measured by the percentage coefficient of variation in the stride duration (% CV), step width and gait speed)	Chronic (≥1 year)	Computer Assisted Rehabilitation Environment (CAREN-3)	II
Gil-Gomez, J., Llorens, R., Alcaniz, M., Colomer, C., 2011	RCT (n=9 Exp 8 Con)	**Clinical measurements:** (BBS, Brunel Balance Assessment, Anterior Reach Test, Timed Stair Test, Stepping Test, 1 Minute Walking Test, 10MWT, TUG, 30 second sit-to-stand Test)	N/A (ABI participants, not all post-stroke).	eBaViR system: PC, a 42" LCD screen and a Wii Balance Board with interactive independent 2D and 3D applications (Simon, Balloon Breaker and Air Hockey)	I

Yang, S., Hwang, W., Tsai, Y., Liu, F., Hsiesh, L., Chern, J., 2011	Between Group Comparison (n=7/group)	**Posturography:** (FootScan: maximum AP/ML CoP displacement, CoP excursion, CoP sway area, and bilateral limb-loading symmetrical index (SI) and **Gait parameters:** (Tekscan in-sole: stance time of the paretic limb, number of steps of the paretic limb, and contact area of the paretic foot)	Chronic (Exp: 17.0 ± 8.6 months, Con: 16.3 ± 10.4 months)	Treadmill (HRC-8500, Vision Fitness) and Commercial Software (3D Web, Superscape)	II
Cikajlo, I., Rudolf, M., Goljar, N., Burger, H., Matajcic, Z., 2012	Pre-Post (n=6) with a historical control group (n=22)	**Clinical measures:** (BBS, TUG, 10MWT and standing on the unaffected and affected extremity) and **Game parameters:** (track time, number of collisions)	Sub-Acute (Exp: 4.33 ± 2.42 months, Con: 3.2 ± 2.0 months)	Personalized VE (V-Realm builder, Integrated data systems, Inc., USA) with Balance Trainer (Medica Medizin, Germany).	III
Cho, K., Lee, K., Song, C., 2012	RCT (n=11/group)	**Clinical measures:** (TUG and BBS) and **Posturography:** (Good Balance Force Platform System: sway velocity with eyes open & eyes closed)	Chronic (Exp: 12.54 ± 2.58 months, Con: 12.63 ± 2.54 months)	Nintendo Wii (Wii Fit Balance Board)	I
Jung, J., Yu, J., Kang, H. J, 2012	RCT (n=11 Exp/ 10 Con)	**Clinical measures:** (TUG, Activities-Specific Balance Confidence (ABC) scale)	Chronic (Exp: 12.6 ± 3.3 months, Con: 15.4 ± 4.7 months)	VR treadmill training with a head-mounted device (HMD) simulating a park stroll.	I
Kang, H., Kim, Y., Chung, Y., Hwang, S., 2012	RCT (n=10/group) (3 groups)	**Clinical measures:** (TUG, Functional Reach Test, 10MWT, 6-Minute Walk Test)	Chronic (VR: 14.1 ± 4.4 months, Treadmill: 13.5 ± 4.0 months, Con: 15.1 ± 7.4 months)	Head-mounted device (MSP-209, Kowon Technology, Korea) with a programme which reproduces a street walking optic flow VE.	I
Kim, Kang, Park, & Jung, 2012	RCT (n=10 Exp/ 7 Con)	**Clinical measures:** (Postural Assessment Scale, Modified Motor Assessment Scale, FIM)	Chronic (Exp: 12.6 ± 7.12 months, Con: 12.85 ± 6.06 months)	Nintendo Wii (Wii Sports)	I

Kim, I., & Lee, B., 2012	RCT (n= 9 augmented reality with FES (AG-FES), 10 FES, 9 just treadmill (Con)).	**Clinical measures:** (BBS, TUG) and M**uscle measurements:** (strength, tone)	Chronic (VR-FES: 9.74 ± 4.19 months, FES: 9.19 ± 2.74 months, CON: 10.39 ± 3.09 months).	Treadmill training with a head-mounted display (HMD) (i-visor, fx601) showing a recording of typical gait pattern on one side and the subjects' actual movement is shown on the other side.	I
Barcala, L., Grecco, L., Colella, F., Lucareli, P., Salgado, A., Oliveira, C., 2013	RCT (n=10/group)	**Posturography:** (Medicapteurs pressure plate, Fusyo model: peak plantar pressures, AP/ML oscillations) and **Clinical measures:** (BBS, TUG, FIM)	Chronic (Exp: 12.3 ± 7.1 months, Con: 15.2 ± 6.6 months)	Nintendo Wii (Wii Fit)	I
Cho, K. & Lee, W., 2013	Pilot RCT (n=7/group)	**Clinical measures:** (BBS, TUG) and **Gait parameters:** (GAITRite: velocity, cadence, step length, stride length, single limb support %).	Chronic (Exp: 288.28 ± 69.20 days, Con: 312.42 ± 83.68 days)	VR treadmill training using a real-world video recording displayed on a screen, depicting a sunny 400-m track, a rainy 400-m track, a 400-m track with obstacles, daytime walks in a community, nighttime walks in a community, and walking on trails.	I
Fritz, S., Peters, D., Merlo, A., Donley, J., 2013	RCT (n=15 Exp /13 Con)	**Clinical measures:** (Fugl-Meyer Assessment, BBS, Dynamic Gait Index, 6-minute walk test, 3-meter walk test, Stroke Impact Scale, TUG)	Chronic (Exp: 2.5 ± 2.6 years, Con: 3.6 ± 3.2 years)	Nintendo Wii (Wii Fit, Wii Sports) and Sony Playstation (Eyetoy Play 2 and Kinetic)	I
Krpic, A., Savanovic, A., Cikajlo, I., 2013	RCT (n= 6 VR, 11 Con, 9 Balance Trainer (BT) device.	**Clinical measures:** (BBS, TUG, 10MWT)	Sub-Acute (VR: 2-10 months, Con: 1-10 months, BT: 3-8 months).	Balance Trainer with VE feedback displayed on a screen in front of participants which was created with Panda3D engine for Ubuntu operating system.	I
Park., Y., Lee, C., Lee, B., 2013	RCT (n=8/group)	**Gait parameters:** (GAITRite: velocity, cadence, step length, stride length, functional ambulation profile (score)) and **Clinical measure:** 10MWT	Chronic (Exp: 11.63 ± 4.44 years, Con: 11.25 ± 4.53 years)	VR-based postural control feedback program with a HMD	I

Rajaratnam, B., Kaien, J., Lee Jialin, K., SweeSin, K., FenRu, S., Enting, L., et al., 2013	RCT (n= 10 Exp 9 Con)	**Clinical measures:** (Functional Reach Test, TUG, BBS, Modified Barthel Index) and **Posturography**: (Wii Fit Board: CoP Sway)	Sub-acute (Exp: 15.2 ± 6.3 days, Con: 14.7 ± 7.5 days)	Nintendo Wii (Wii Fit) and Microsoft Kinect game console system.	I
Singh, D., Nordin, N., Aziz, N., Lim, B., Soh L., 2013	RCT (n=15 Exp 13 con)	**Clinical measures:** (TUG, Thirty-second Sit to Stand, Timed 10MWT, Six-Minute Walk Test, Barthel Index) and **Posturography:** (Probalance Board: Overall Balance Score).	Chronic (Exp: 40.5 ± 41.8 months, Con: 34.9 ± 23.6 months)	Nintendo Wii (Wii Fit Plus with Balance Board) and Microsoft Xbox 360 Kinect.	I
Bower, K., Clark, R., McGinley, J., Martin, C., Miller, K, 2014	Phase II, Single-Blind RCT (n= 17 Exp 13 Con)	**Feasibility:** (recruitment, retention, enjoyment and efficacy) and **Clinical measures:** (step test, functional reach test, TUG, Short Falls Efficacy Scale, Upper-Limb Motor Assessment Scale and Stroke Rehabilitation Assessment of Movement score) and **Posturography:** (Wii Balance Board: Overall, AP & ML sway velocity (eyes open & closed) and ML weight shifting)	Sub-acute (mean=24.8 ± 18.1 days)	Nintendo Wii Balance Board (Wii-Fit Plus)	I
Cho, K. & Lee, W., 2014	RCT (n=15/group)	**Posturography:** (Good Balance System: AP/ML sway velocity, postural sway velocity moment), **Clinical measures:** (BBS, TUG) and **Gait parameters: (**GAITRite: gait speed, cadence, single limb support period, double limb support period, step length and stride length)	Chronic (Exp: 414.46 ± 150.38 days, Con: 460.33 ± 186.78 days)	VR treadmill training using a real-world video recording displayed on a screen, depicting a sunny 400-m track, a rainy 400-m track, a 400-m track with obstacles, daytime walks in a community, nighttime walks in a community, and walking on trails.	I

Hung, J., Chou, C., Hsieh, Y., Wu, W., Yu, M., Chen, P., Chang, H., Ding, S., 2014	RCT (n=13 Exp 15 Con)	**Posturography:** (Tetrax Interactive Balance System: stability index, percent body weight on affected limb) and **Clinical measures:** (TUG, forward reach test, falls efficacy scale and Physical Activity Enjoyment Scale)	Chronic (Exp: 21 ± 11.26 months, Con: 15.93 ± 8.02 months)	Nintendo Wii (Wii Fit)	I
McEwen, D., Taillon-Hobson, A., Bilodeau, M., Sveistrup, H., Finestone, H., 2014	RCT (n=30 Exp 29 Con)	**Clinical measures:** (TUG, Two-Minute Walk Test, Chedoke McMaster Stroke Assessment Leg Domain)	Sub-Acute (Exp: 30.1 ± 18.9 days, Con: 39.6 ± 17.8 days)	IREX VR System	I
Morone, G., Tramontano, M., Iosa, M., Shofany, J., Iemma, A., Musicco, M., et. al., 2014	RCT (n=25/group)	**Clinical measures:** (BBS, 10MWT, Functional Ambulatory Category and Barthel Index)	Sub-acute (Exp: 61.00 ± 36.47 days, Con: 41.65 ± 36.89 days)	Nintendo Wii (Wii Fit)	I
Song, Y., Chun, M., Kim, W., Lee, S., Yi, J., Park, D., 2014	RCT (n=10/group)	**Posturography**: (Tetrax instrument: stability index, weight distribution index) and **Clinical measures:** (BBS, Falling Index)	Sub-acute (Exp: 12.7 ± 3.2 days, Con: 12.8 ± 3.4 days)	IREX VR System	I
Subramaniam, S., Wan-Ying Hui-Chan, C., Bhatt, T., 2014	Pre-Post (n=8)	**Dynamic Posturography:** (EquiTest balance platform: limits of stability test in single task and dual task conditions - reaction time, movement velocity, max excursion, directional control) and **Clinical measures:** (BBS, TUG) and **Gaming scores.**	Chronic (mean=3.94 ± 6.1)	Nintendo Wii (Wii Fit)	IV

Lee, H., Kim, Y., Lee, S., 2014	RCT (n=12/group)	**Posturography:** (Wii Balance Board: path length and velocity).	Chronic (>6months)	Nintendo Wii (Wii Fit Plus)	I
Ciou, S., Hwang, Y., Chen, C., Chen, S., Chou, S., Chen, Y., 2015	Pre-Post (n=2)	**Clinical measures:** (TUG, Motor Assessment Scale) and **Posturography**: (Independent CoP Capture Device: CoP distribution (eyes open/eyes closed))	Chronic (6 & 11 months)	Developed using Microsoft .NET Framework with XNA Game Studio. The patients had to move their CoP to match a moving target.	IV
da Silva Ribeiro, N., Ferraz, D., Pedreira, E., Pinheiro, I., da Silva Pinto, A., Neto, M. et al, 2015	RCT (n=15/group)	**Clinical measures:** (SF-36, Fugl-Meyer scales)	Chronic (Exp: 42.1 ± 26.9 months, Con: 60.4 ± 44.1 months)	Nintendo Wii	I
Garcia et al., 2015	Pilot RCT (n=5/group)	**Clinical measures:** (BBS, Dynamic Gait Index, Functional Reach, TUG)	Chronic (>6months)	Nintendo Wii (Wii Fit)	I
Kim, H., Choi, W., Lee, K., Song, C., 2015	RCT (n=20/group)	**Gait parameters:** (GAITRite: Gait speed, cadence, step time, stride time, step length, stride length)	Chronic (>6months)	Virtual dual-task treadmill training with a first person scene in which a cart is pushed in a major supermarket and displayed on a 100 inch screen placed in front of the participants.	I

Kim, N., Park, Y., Lee, B., 2015	RCT (n=10 Exp 7 Con).	**Posturography:** (Wii Balance Board: path length and average postural sway speed).	Chronic (>6months)	Community-based VR treadmill training program displayed on a screen that adjusts to participants' speed in accordance with the optic flow.	I
Lee, I., Kim, Y., Lee, D., 2015	RCT (n=10/group)	**Clinical measures:** (BBS, TUG)	Chronic (>6 months)	VR program used the city walking, hot air balloon, and bubble activities available in BioRescue.	I
Llorens, R., Gil-Gomez, J., Alcaniz, M., Colomer, C., Noe, E., 2015	RCT (n=10/group)	**Clinical measures:** (BBS, Tinetti Performance-Oriented Mobility Assessment, Brunel Balance Assessment and 10MWT)	Chronic (>1 year)	VR based stepping exercise	I
Llorens, R., Noe, E., Colomer, C., Alcaniz, M., 2015	RCT (n=15/group)	**Clinical measures:** (BBS, Performance-Oriented Mobility Assessment balance subscale, Performance-Oriented Mobility Assessment gait subscale, Brunel Balance Assessment)	Chronic (Exp: 316.73 ± 49.81 days, Con: 334.13 ± 60.79 days)	VR game using a television, a conventional computer, and a Microsoft Kinect.	I
Song, G., Park, E., 2015	RCT (n=20/group)	**Posturography:** (AP1153 BioRescue: weight bearing, AP limit of stability, posterior range LOS) and **Clinical measures**: (TUG, 10MWT) and **Psychological measures:** (Beck Depression Index, Relationship Change Scale)	Chronic (Exp: 14.75 ± 6.06 months, Con: 14.30 ± 3.40 months)	Microsoft X-Box Kinect	I
Yatar, G., Yildirim, S., 2015	RCT (n=15/group)	**Posturography:** (Wii Balance Board: weight distribution), **Clinical measures:** (BBS, TUG, Dynamic Gait Index, Functional Reach Test, Activities-specific Balance Confidence)	Chronic (Exp: 3.70 ± 4.42 years, Con: 4.23 ± 4.86 years)	Nintendo Wii (Wii Fit)	I
Yom, C., Cho, H., Lee, B., 2015	RCT (n=11/group)	**Clinical measures:** (TUG, muscle tone (Modified Ashworth Scale, Tardieu Scale)), **Gait parameters:** (GAITRite: velocity, cadence, step length, stride length, stance time percentage, swing time percentage, double limb support percentage.)	Chronic (Exp: 11.14 months, Con: 11.63 months)	Virtual reality-based ankle exercise (VRAE) program.	I

Hung, J., Yu, M., Chang, K., Lee, H., Hsieh, Y., Chen, P., 2016	Feasibility RCT (n= 14 Exp 13 Con)	**Feasibility:** (adherence, safety, and satisfaction), **Clinical measures:** (TUG, Forward Reach Test, physiologic profile assessment) and P**osturography:** (Tetrax System: total weight bearing per limb)	Chronic (Exp: 17.50 (Q1:10.67; Q3: 21.93), Con: 18.60 (Q1:10.47; Q3:32.53) months)	Tetrax biofeedback exercise system (11 different games challenging balance) displayed on a screen in front of the participants.	I
Park, S., Yang, D., Uhm, Y., Heo, J., Kim, J., 2016	RCT (n=15/group (VR slow eccentric training "Group 1" and VR fast eccentric training "Group 2")	**Posturography** (BioRescue: Limits of stability) and **Surface Electromyography (EMG)** system (muscle activation).	Sub-acute (Group 1: 5.4 ± 1.4 months, Group 2: 5.3 ± 1.2 months)	Eccentron system comprised of a screen used to narrate the VR and to provide feedback and an ergometer with a force plate.	I
Yin, C., Hsueh, Y., Yeh, C., Lo, H., Lan, Y., 2016	2 group convenience sample (n=6 Exp 3 Con)	**Force measurements:** (average force output, difference force per limb)	Chronic (Exp: 15 ± 10.6, Con: 13.3 ± 4.16)	VR-Cycling Training System (VRCTS) with a cycling device with sensors, cycling graph user interface control and data record system (Cycling CR System) and a VR rehabilitation system (Virtools 4.0) showing a roadway with left and right turns.	II

Conclusion

Although VR has been shown to be a safe and enjoyable clinical activity during inpatient stroke rehabilitation (Celinder & Peoples, 2012), rigorous larger sample RCTs have not provided support for its use as a clinical modality for balance and gait specifically during inpatient rehabilitation. A high percentage of VR clinical interventions for stroke rehabilitation have been delivered in an outpatient setting, with very few recruiting patients in inpatient rehabilitation settings. Those that have used inpatient participants have either been small sample size pilot studies (You, Jang, Kim, Hallett, et al., 2005; Saposnik et al., 2010), or focused on upper extremity rehabilitation (Yavuzer et al., 2008).

Focus of Attention

Introduction

Within the field motor learning, maximizing effectiveness and efficiency (Cavanagh & Kram, 1985; Wulf & Lewthwaite, 2010) of motor performance has been a key interest for coaches, clinicians (Bar-Haim et al., 2010) and researchers. If effectiveness and efficiency are maximized throughout the learning process, the performer will develop skill within that task. Guthrie (1952) describes skill as “the ability to bring about some end result with maximum certainty and minimum outlay of energy, or of time and energy.” (p. 136). This definition implies that a skilled performer will display a higher degree of reliability in outcomes (effectiveness) obtained through a higher quality of movement patterns (efficiency)(Sparrow & Irizarry-Lopez, 1987). This is apparent in athletics as skilled professionals have greater success in their respective sport than a novice as they display more efficient movements to accomplish their goals (Chatfield, Krasnow, Herman, & Blessing, 2007) with greater effectiveness.

Facilitating an optimal motor learning process becomes a goal of any coach or therapist to allow their athlete/patient to achieve both effective and efficient motor performance. One method to facilitate this is the manipulation and control of what the learner is focused on during practice/performance. Evidence has been building in favour of adopting an external focus on the movement effect (e.g. on an object) over an internal focus on the body’s movements (Wulf, 2013). For example, during a golf swing, the player may focus on the movements of their arms and body throughout the swing (internally focused) or they may externally focus on the movement of the club through space to make contact with the ball. This has been effective for motor performance in athletes (Ille, Selin, Do, & Thon, 2013) and healthy individuals (Polskaia, Richer, Dionne, & Lajoie, 2014). The applicability to motor performance for individuals post-stroke is still in question, while the effects during standing balance tasks has yet to be examined.

Constrained Action Hypothesis

Wulf, McNevin, & Shea (2001) titled the contrast of two focus of attention types as the constrained action hypothesis. They differentiate the two attentional types in that "when performers utilize an internal focus of attention (focus on their movements) they may actually constrain or interfere with automatic control processes that would normally regulate the movement, whereas an external focus of attention (focus on the movement effect) allows the motor system to more naturally self-organize." If the motor system trains and organizes in an optimal way, learning, movement effectiveness and efficiency will be maximized. In contrast, consciously intervening in the motor system learning process through an internal focus of attention, may result in freezing or constraining the degrees of freedom (Vereijken, Emmerik, Whiting, & Newell, 1992) of the joints involved, resulting in reduced performance and subsequently, reduced motor learning.

In participants without neurological disorders, encouraging an external focus of attention during training has been shown to be more effective for motor performance and motor learning. This has been supported in basketball free throws (Zachry, Wulf, Mercer, & Bezodis, 2005), standing long-jump (Porter, Anton, & Wu, 2012), sprint starts (Ille et al., 2013) as well as clinical studies of balance training including older adults (Chiviacowsky, Wulf, & Wally, 2010).

In clinical populations, external focus of attention has also been shown to induce less postural sway during perturbations in patients with Parkinson's disease (Landers, Wulf, Wallmann, & Guadagnoli, 2005), shorter movement time and greater peak velocity during functional reaching tasks with participants post-stroke (Durham et al., 2014) and greater control of posture during a dynamic balance task (Biodex Stability System) when used during re-training after an ankle sprain (Rotem-Lehrer & Laufer, 2007). As Wulf (2001) summarizes, ‘the external focus advantage has been found so consistently’.

Using an external focus of attention has produced mixed outcomes for movements in individuals post-stroke. Upper extremity reaching was found to have shorter movement time and greater velocity (Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002) as well as increased percentage time to peak deceleration (Durham et al., 2014) with feedback inducing an external focus of attention. Relating to balance, individuals post-stroke have been shown to improve the immediate maximum lateral body weight shift while in a sitting posture (Mückel & Mehrholz, 2014). Individuals post-stroke were instructed to shift their body weight as much as possible towards a) the green circle (placed 20cms lateral from the participant) (external focus task) or, b) your healthy side (internal focus). Results indicate that the individuals in an external focus task had greater weight shifting than the control group (approximately two-fold).

A recent study (Kal et al., 2015) provides contrary outcomes indicating that an internal focus of attention enhances movement automaticity. The motor task consisted of a single leg stepping task while seated. Participants were asked to alternately flex and extend their leg at a self-selected pace for 60s. Movement automaticity (or fluency) of the movement was measured from the minimal jerk model (Flash & Hogan, 1985) as the rate of change of acceleration of the movement. Therefore the more fluent a movement is, the less jerky it is indicating more automatic motor control. However, an external focus of attention did not result in more automated movements but rather reduced movement fluency in the paretic limb and hindered dual-task performance (fluency task and a verbal auditory reaction time response) for chronic individuals post-stroke. The authors provide support for these outcomes by indicating individuals in a chronic stage post-stroke may have a “pronounced inclination to consciously control their movements in daily life.” (Kal et al., 2015).

The literature is split on whether an external focus of attention is advantageous for individuals post-stroke. While upper extremity protocols indicate a clear benefit of an external focus of attention, lower extremity and balance articles provide conflicting outcomes. Additionally, eliciting an external focus of attention during postural training during inpatient stroke rehabilitation has not been studied to date. Ensuring clear instructional cues that eliminate confounding variables is necessary to evaluate any difference between focus of attention types. It may be possible to reduce a post-stroke individual’s inclination to control motor movements through externally focused balance training which may in turn produce greater functional improvements as seen through clinical outcome measures.

Virtual Reality as an External Focus Task

A VR interface provides opportunities to become more than just an observer, but rather an actor in an environment that may require attention, concentration and interaction with virtual objects and/or virtual people. As such, it is inherent that the virtual reality system facilitates an external focus of attention during gameplay. Remaining focused on the virtual task may encourage an automatic movement during a postural lean, reach or step. As the individual trains in this externally focused environment, they could achieve greater improvements on balance measurements.

For example, significant differences were observed for younger and older adults between functional lateral reach performances performed in the real environment as compared to the same reaches in a virtual environment (Lott, Bisson, Lajoie, McComas, & Sveistrup, 2003). Both groups reached significantly further for virtual objects that were presented in the VE as compared to when real objects were presented to either side of the individual. It was proposed that embedding the task within the VE resulted in "shifting attention away from the potential loss of balance, whereas focusing attention on balance, such as in the real environment, may have resulted in increased fear of destabilization and underestimation of true ability" (Lott et al., 2003).

Conclusion

Although it is suggested that using an external focus of attention is beneficial for motor performance and motor learning (Wulf, 2013), contradictory results indicate that an external focus of attention may not be advantageous for individuals post-stroke during reaching and seated tasks and have not been tested during standing postural tasks. Virtual reality naturally engages an individual to become immersed into the environment and thus, ensures an external focus of attention as the individual moves to the body to participate in the virtual task. Further research is needed on the effect of an external focus of attention during standing postural tasks for individuals post-stroke and how this compares to similar movements done in a virtual environment.

Aim of Dissertation

Effective stroke rehabilitation requires higher intensity training during inpatient stroke rehabilitation to maximize clinical gains. A staggering percentage of individuals post-stroke suffer a fall following discharge from an inpatient stroke unit. Virtual reality provides a nice adjunct to conventional stroke rehabilitation as it can engage patients in a fun and motivating exercise program that can encourage implicit balance motor skill training. As the patient is immersed and engaged in the VE, their attention will remain on the environment and not on their body's movements. The external focus of attention may be advantageous for training balance post-stroke.

The following series of studies attempt to assess clinical and laboratory improvements on balance and mobility from training in a VE and assess the role of focus of attention during postural tasks post-stroke.

Study #1: Case Study.

The first study was a single-subject design used to identify changes in balance and functioning during, immediately following and at one month after a daily, 2-week long, virtual reality (VR) training program. The purpose of this study was to provide initial evidence (case study) of the feasibility of implementing and the effect of an intensive VR training program on balance and mobility in a veteran with dementia.

The participant was a 78 year old veteran who met the criteria for vascular dementia. It was hypothesized that due to the standing balance training, improvements on clinical measures would be seen. It was also hypothesized that the participant would tolerate the increased physical activity without any adverse events.

The full article published in the Journal of Rehabilitation Research and Development can be found in Chapter 2. Information letter, consent form & ethics approval are available in Appendix C.

Study #2: VRRASS Randomized Control Trial.

The second project of my thesis was a blinded parallel group randomized control trial (RCT) with balanced (1:1) randomization considering two factors (age and pre-intervention Berg Balance Scale [BBS] score) and was conducted on the inpatient stroke rehabilitation unit at the Elisabeth Bruyère Hospital. We sought to determine whether VR exercise, as an adjunct treatment, is beneficial for rehabilitation by improving standing balance and functional mobility in those who are able to stand independently for >1 minute.

Clinical outcome measures of balance, mobility and function were assessed prior to, immediately and 1-month following VR training. Training consisted of daily sessions (~1 hour in length) of various games that elicited repeated lateral weight shifting, reaching and stepping (e.g., soccer goaltending, snowboarding). The treatment group (n=30) received standard stroke rehabilitation therapy plus a program of VR exercises that challenged balance (e.g., soccer goaltending, snowboarding) performed while standing. The control group (n=29) received standard stroke rehabilitation therapy plus the same exposure to identical VR environments but whose games did not challenge balance (performed in sitting).

It was hypothesized that due to the concurrent physical therapies, all participants would have improvements on clinical measures of balance and mobility from pre to post training. We further hypothesized that an intensive inpatient VR-based exercise program designed to challenge dynamic stability in standing would result in greater improvements in objective measures of dynamic stability than a similar period of exposure to VR performed while sitting and thus not a challenge to dynamic stability.

The full article was published in the Stroke Journal and can be found in Chapter 3. Information letter, consent form & ethics approval are available in Appendix D. Trial registry in the Australian, New Zealand Clinical Trials Registry is available in Appendix E.

Manuscript #3: Flow, Presence and Immersion.

The third manuscript is a review of the existing literature on the definition and application of three terms used in virtual reality research including flow, presence and immersion. In the context of virtual environments (VE), the terms have been used interchangeably which does not facilitate clear understanding or quantification of a user's experience and interaction in a virtual environment. It is vital to understand the underlying and overlapping concepts of each term prior to use in description of an experience in a VE. Therefore, a review of terms and concepts as well as quantification methods of both qualitative and quantitative methodologies is presented to help guide future research in the field of VE.

The full article is pending submission to a peer reviewed journal and can be found in Chapter 4.

Study #4: Focus of Attention Study.

The fourth study reports on the laboratory based documentation of postural variables during three dynamic postural tasks. Three groups (n=10 per group) consisting of young adults, older adults and individuals post-stroke were recruited.

Participants performed 4 tasks while standing on two AMTI force platforms. Participants first completed 2 1-minute trials of static posture during which they were instructed to remain as still as possible. Participants then completed 3 1-minute trials of 3 different dynamic tasks. The tasks consisted of an internal focus, external focus and a VR task and were counterbalanced.

The instructions were as follows:

Internal focus: *With your hands by your side, I want you to focus on* ***leaning your body*** *from side to side as far as you can. When you get to the furthest point, please pause for a moment then return to the middle and pause again for a moment before leaning the other direction. Go at a pace that you feel safe and comfortable with.*

External focus*: With your hands by your side, I want you to focus on* ***moving this line*** *from side to side as far as you can. When you get to the furthest point, please pause for a moment then return to the middle and pause again for a moment before leaning the other direction. Go at a pace that you feel safe and comfortable with.*

VR Task: *With your hands by your side, I want you to save as many soccer balls as you can by leaning your body to stop them from going into the net. Always return to the middle after a save.*

It is important to note that the instructions for the internal/external tasks differ in very few words. This is recommended for instructions for tasks as to avoid confounds with other variables (Wulf, 2013). The line referred to in the external focus task consisted of a rotated live display of Fz (weight) trace under the right foot. The trace was displayed on the same TV that was used to display the VE. The line was placed in the middle of the screen and was set up to allow the participants to move the line from side to side as it scrolled up the screen (see Figure 4).

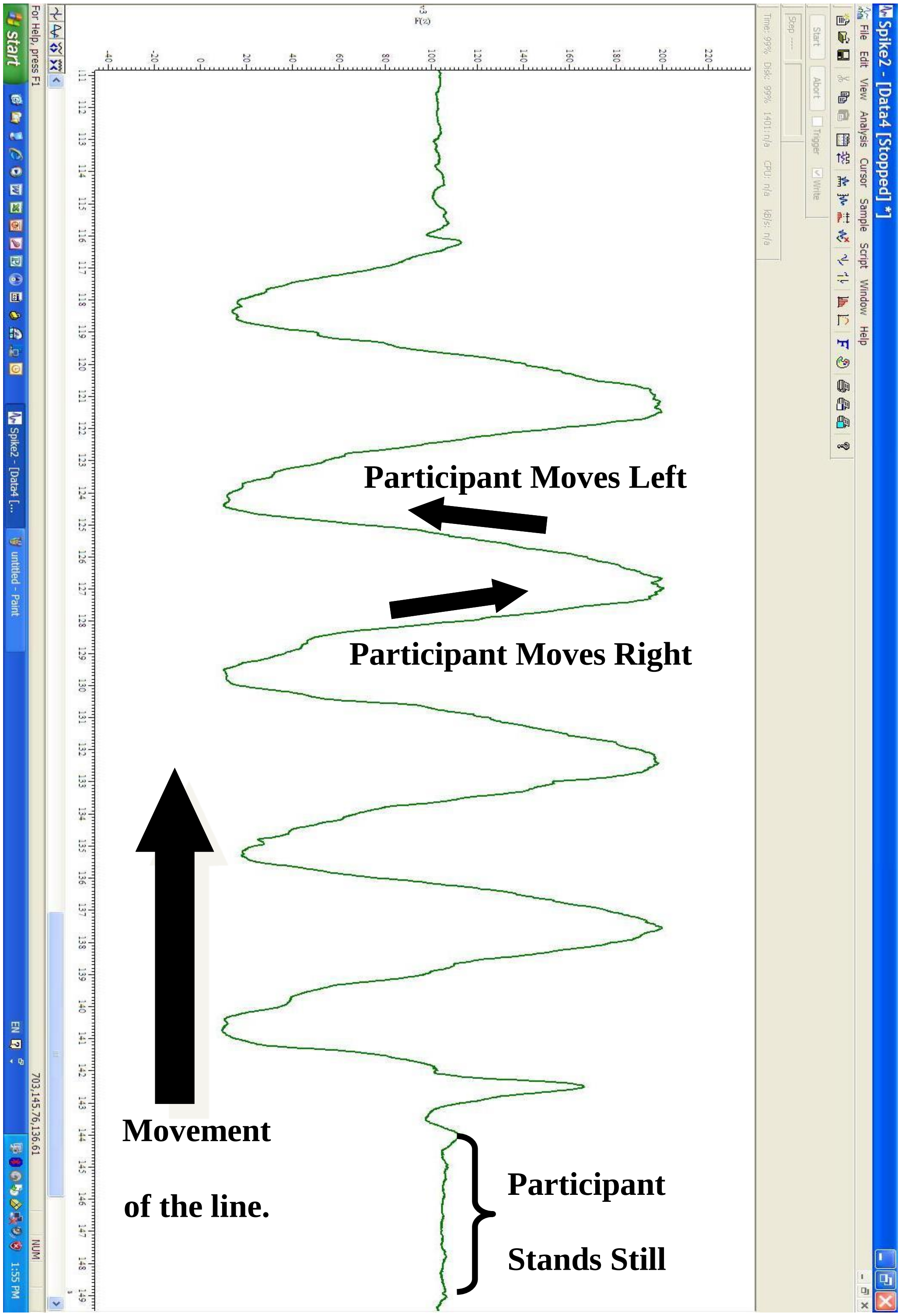

Figure 4: Example of the external focus of attention task. As the line moved up the screen, it followed the participant from side to side. The line represents the weight under the right foot. Increased weight on the right foot displays as a movement of the line to the right. Conversely, as the participant moved to the left (i.e. reducing weight on the right foot), the line moved to the left. This trace was displayed on the same TV screen as the VR task.

It was hypothesized that participants would have larger postural movements (greater CoP range) with an external/VR focus of attention than when they are internally focused. This effect would be more pronounced for the post-stroke population. It was also hypothesized that an external/VR focus of attention would encourage greater use and higher movement (range/area) of the CoP under the paretic limb.

The full article has been submitted to the Archives of Physical Medicine and Rehabilitation journal and can be found in Chapter 5. Information letter, consent form & ethics approval are available in Appendix F.

Chapter 2: Two-week virtual reality training for dementia: a single case feasibility study.

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Article Title:

Two-week virtual reality training for dementia: a single case feasibility study.

Short Title:

Virtual reality training for dementia.

Authors

Daniel McEwen, MSc [1,2], Anne Taillon-Hobson, PT[1], Martin Bilodeau, PhD[1,2,3], Heidi Sveistrup, PhD[2,3], Hillel Finestone, MD[1,3,4,5*]

1 Bruyère Research Institute, Ottawa, Ontario

2 School of Rehabilitation Sciences, University of Ottawa, Ottawa, Ontario

3 School of Human Kinetics, University of Ottawa, Ottawa, Ontario

4 Faculty of Medicine, University of Ottawa, Ottawa, Ontario

5 Department of Physical Medicine and Rehabilitation, Elisabeth Bruyère Hospital.

Corresponding Author(*):

Hillel Finestone, MDCM, FRCPC
Bruyère Research Institute.
43 Bruyère St.
Ottawa Ontario, Canada, K1N 5C8
Tel: 613-562-6094
Fax: 613-562-6312
hfinestone@bruyere.org

Abstract

People with dementia (PWD) are known to have difficulty with participation and focus during physical activity. Virtual reality (VR) offers a unique medium for motor learning but has only been previously used for cognitive assessment for PWD. Our study had two objectives: 1) investigate the feasibility and safety of an exercise-based VR training program in PWD, and 2) investigate its effects on balance and mobility. The intervention consisted of daily (5 days/week, one hour each) VR training sessions for two weeks for a single research participant. Clinical balance and mobility measures were assessed 1 week prior to, during, 1 week following and one month after the intervention. Post-intervention interviews provided qualitative feedback from the participant and his caregivers. Results indicate that VR training is feasible, safe and enjoyable for PWD. However, balance and mobility measures were unaffected. VR training is well tolerated in a single research participant with dementia and is an engaging medium for participation in exercise.

Key Words: Dementia, Virtual Reality, Exercise, Balance, Walking, Games, Training, Single-subject Design, Rehabilitation, Intervention.

Abbreviations: PWD (Persons with Dementia), VR (Virtual reality), MoCA (Montreal Cognitive Assessment), ASA (acetylsalicylic acid), IREX (Interactive Rehabilitation Exercise), TUG (Timed Up and Go), BBS (Berg Balance Scale), OSSm (Ottawa Sitting Scale (modified)), TMWT (Two-Minute Walk Test), SD (Standard Deviation).

Introduction

Dementia is a growing health care concern. The 2012 World Health Organization report on dementia estimated a worldwide prevalence of persons with dementia (PWD) at 35.6 million. This number is expected to double by 2030 and more than triple by 2050. Exercise has been shown to be physically and cognitively beneficial for numerous populations including those with dementia. A recent systematic review [2] on physical activity for persons with dementia (PWD), reported randomized controlled trials that assessed a wide range of exercise interventions including aerobics, stretching and strengthening. Selected outcomes of these trials included improved walking speed [3], improved strength and flexibility [4] and improved performance on the “Timed Up and Go” test [5].

Virtual reality (VR) training has been shown to be an effective, motivating and safe training tool when used alone or as an adjunct to conventional rehabilitation. Several studies have found objective improvements in clinical balance and mobility outcome measures in a variety of populations [6-9]. VR study protocols involve the adjustment of VR training parameters in order to meet the changing needs and rehabilitation goals of each individual patient. Task difficulty should reflect the skill level of the performer [10] in order to maximize performance outcome. Therefore, close monitoring of task difficulty while a patient is engaged in a stimulating environment will help to ensure an appropriate level of challenge while maintaining engagement, motivation and enjoyment. VR training is particularly well suited to allow such a versatile and engaging environment [11].

VR technology has been used with PWD for cognitive assessments [12] and cognitive training [13]. Multiple studies found that the use of virtual environments is feasible with PWD without problems of cyber-sickness or disorientation (e.g. [14]). Individuals with dementia are known to experience balance and mobility issues [15] and since previous studies have reported improvements in balance and mobility in other populations following an intensive VR training program, similar results could be expected in the PWD population. Because patients with dementia can experience difficulty with exercise program adherence [16], the engaging and motivating nature of VR training may help alleviate this problem. The purpose of this study was to provide initial evidence (case study) of the effect of an intensive VR training program on balance and mobility in veteran with dementia.

The study was conducted on an outpatient basis over an 8-week period. Because it was unknown whether this methodology and protocol would be feasible for an outpatient client with PWD and their caregivers, this case study had two objectives; 1) to explore the feasibility and safety of an intensive, outpatient-based, VR training exercise program for a veteran with dementia and 2) to assess the effects of VR training on balance and mobility in this individual.

<u>Methods</u>

Participant

Mr. YZ was a 78 year old, right handed veteran who met the criteria for vascular dementia. His score on the Montreal Cognitive Assessment (MoCA) [17], a well-accepted screening test of cognition, was 12/30 (less than 26 is abnormal, 12 is extremely low). At the time of the study, Mr. YZ was taking daily doses of acetylsalicylic acid (ASA) (81mg) in addition to Aricept via a patch. Bilateral sub-cortical microvascular disease was noted on brain imaging. Two years prior to his entry into this study, he presented with a right cortical ischemic stroke affecting his right occipital lobe. He had no known stroke risk factors.

Physical examination revealed a left visual field deficit. Mr. YZ ambulated independently, with occasional hand-held guidance for cueing. He intermittently complained of right tibiofemoral joint pain. However, no palpable warmth, erythema or limited range of motion was noted on assessment. He demonstrated full range of motion and strength within normal limits for his age in both upper extremities. His scores for arm, leg and posture subscales of the Chedoke-McMaster Stroke Assessment, a reliable and valid measure used to assess physical impairment and disability in clients with stroke and other neurological impairment [18], was used as a standard measure of his functional status were 6, 5 and 5, respectively. Each dimension is measured on a 7-point scale ranging from 1 (total assistance) to 7 (safely independent). His scores indicate he requires supervision.

Research Design

A single-subject design was used to identify changes in balance and functioning during, immediately following and at one month after a daily, 2-week long, VR training program (Table 1). The participant's power of attorney provided written informed consent in accordance with the research ethics board at the Bruyère Research Institute. Mr. YZ was accompanied at all sessions by one of his permanent caregivers.

Intervention

The VR intervention was delivered using the Interactive Rehabilitation Exercise software (IREX™; Gesturetek, Toronto, Ont.), which involves the use of green screen technology. Mr. YZ stood in front of a 50" television located 10 feet away which displayed his image with the use of a camera, immersed in five different virtual environments in which he interacted with virtual objects (Appendix 1). The applications were chosen to train his standing balance and were administered in the same order each day. Each session lasted approximately one hour with an average of 25 minutes of VR exercise time. The remaining time was spent resting and explaining how to play the upcoming game.

Due to the progressive nature of training programs, a baseline soccer game with a consistent difficulty level allowed for assessment of improvements with interacting with the VR system. Mr. YZ thus completed 1 minute of a standardized soccer application at the beginning of each training session. The scores on this baseline game provided an overall skill evaluation. On the soccer goaltending application, balls saved on the right side and the left side were counted to determine the impact of Mr. YZ's visual field deficit on his performance and to assess any related performance changes as the training progressed.

In order to ensure safety from falls or stumbles, Mr. YZ wore a physiotherapy belt and was monitored during all sessions by a registered kinesiologist. The VR applications were selected in order to elicit specific movements that would challenge balance including reaching beyond arm's length, weight-shifting and lateral stepping. Rest was given as needed to prevent fatigue and to retain focus.

Feasibility

To the best of our knowledge, this is the first implementation of a VR exercise training protocol with a PWD. Therefore, factors that facilitated or hindered feasibility were identified through interviews with caregivers following each session and at the end of the intervention trial. Positive events during training as well as intervention-related adverse events were also documented.

Open ended interview questions prepared by the research team were used to obtain feedback from the family and care providers regarding the safety and usefulness of the intervention as well as their perception of Mr. YZ's enjoyment during the VR sessions. The exit interview was conducted by a third party who was uninvolved with the research project. Responses were recorded and transcribed for extraction of major themes.

Clinical Outcome Measures

Four clinical outcome measures, Timed Up and Go (TUG) [19], Berg Balance Scale (BBS) [20], a modified version of the Ottawa Sitting Scale (OSSm) [22] and the Two-Minute Walk Test (TMWT) [23], were used to measure functional balance and motor performance.

The BBS is a 14-item validated standardized test with a maximum score of 56. It measures static, dynamic, adaptive and anticipatory components of balance [21]. Community dwelling elderly people and individuals with dementia have been reported to score 54 ±3 [24] and 47.5 ±16.9 [25], respectively. The Timed Up and Go is a validated test of functional movement requiring rising from a chair, walking 3 m, negotiating a turn, and returning to sit back in the chair. It is reliable for use with people with dementia with scores ranging from 17.1 to 24.7 seconds [26, 27]. A score of 13.5 seconds or more has been shown to indicate a high risk of falls in community dwelling older adults [28]. Functional endurance measured with the Two-Minute Walk Test documented the maximum distance Mr. YZ could safely walk in two minutes. The mean distance recorded for individuals with dementia in respite care is 32.2 ± 15.7m [29] and for retirement home dwelling older adults is 150.4 ±23.1m [30]. A modified version of the Ottawa Sitting Scale, with 6 tasks graded on a scale of 1-4 for a maximum score of 24 was used as an indicator of static and dynamic sitting balance.

All measures were recorded on Monday, Wednesday and Friday during the week prior to and the week following the VR training sessions as well as once at one-month follow-up (see Table 1). Also, each day immediately before completing the VR training session, Mr. YZ performed the BBS and the TMWT. All clinical outcome measures were administered by the same experienced registered physiotherapist.

Insert Table 1 approx. here.

Analysis

When appropriate, means and standard deviations (SDs) as well as individual scores are reported and describe performance in outcome measures. Statistical analysis using the 2-SD band method [31] was performed for both the BBS and the TMWT. Results are considered to be statistically significant if two consecutive data points are outside the 2-SD band. If the values at follow-up remained outside the 2-SD band, significance was considered to be maintained.

Results

Qualitative Results

Mr. YZ attended all VR training sessions and was always a cooperative participant. He was able to complete the entire game set in each session provided he had sufficient rest between the applications. He did not experience any negative effects of the VR such as cybersickness, dizziness nor loss of balance or falls. Mr. YZ intermittently understood the information provided about the nature of VR, the equipment set-up and his role in playing the VR applications. He followed instructions within the limits of his concentration abilities throughout the exercise sessions.

Difficulties encountered with implementing VR training with Mr. YZ arose from his memory deficits and his difficulty concentrating on the tasks at hand. He frequently did not remember what applications he had completed in earlier sessions, and thus daily instructions were required and there was no opportunity to progress task complexity. Mr. YZ would often stop in the middle of an application because he was distracted. He was not always actively engaged and thus could not always provide a full effort during the training. His visual field deficit was manifested by a frequent inability to attend to activities occurring on his left side.

During a post-intervention interview with his caregivers, family members reported Mr. YZ had greater concentration when performing activities at home such as dressing in the morning with less time required on training days. Family members noted relatively higher levels of physical activity and this gave them confidence to encourage Mr. YZ to perform other physical activities at home. More energy and interest in doing physical activities throughout the day, for example, walking the dog was also commented upon. The family also reported Mr. YZ was more engaged in the VR games than during his home exercises.

Quantitative Results

Clinical Outcome Measures

No changes were found in the clinical measures of balance and mobility for the BBS, TMWT or OSSm.

BBS scores (Figure 1a) fluctuated from an average of 50.0 SD 1.0 (Pre-VR) to 48.6 SD 2.3 (Post-VR) and 50.0 (no SD due to only 1 measure) (1-month follow-up).

Insert Figure 1 approx. here.

The average distances (m) covered in the TMWT (Figure 1b) were 115.1 SD 14.5 m (Pre-VR), 122.9 SD 10.5 m (Intervention Phase), 99.6 SD 18.3 m (Post-VR) and 135.5 m (1 month follow-up). There were no significant differences between the pre, post and one-month follow-up measurements.

There was a marked decline in both the BBS and TMWT scores on the first post-VR session (session 14). Session 14 was done on a Monday morning. The participant had been busy with family outings over the weekend and was complaining about right knee pain at the start of session 14. This may have decreased his gait speed and weight-bearing ability, lowering his scores on the BBS and the Two-Minute Walk Test distance on this particular day.

Visual analysis of the TUG (Figure 2) indicated a significant change between the post intervention and the one-month follow-up assessments. At the pre and post intervention, scores were respectively 26.3 seconds and 28.7 seconds while at one-month follow-up, the mean time improved to 14.3 seconds. The OSSm scores (Figure 2) did not change during the study.

Insert Figure 2 approx. here.

Performance Outcome Measures

Data from the baseline soccer application played at the beginning of every session, shows that MR. YZ was able to learn and improve on the VR applications (Figure 3). Comparing the first 5 to the last 5 sessions, there was an increased number of saves on his left side, the side with the visual field deficit. There was no change in the number of saves on his right side.

Insert Figure 3 approx. here.

Discussion

This study investigated the feasibility, safety and effectiveness of an intensive 10-session VR intervention program for an individual with dementia. Our results suggest that VR is a feasible and safe activity for PWD. Significant objective improvements in the clinical measures of balance and mobility were not found but post-intervention interviews with the participant and his caregiver revealed that the intervention was an enjoyable experience, which seemed to have a motivating effect on his participation in activities at home.

VR training was shown to be feasible as Mr. YZ attended every session, participated in the full training session without any adverse events (falls, dizziness, cybersickness etc.). However, Mr. YZ demonstrated frequent limitations in concentration and occasionally forgot how to play the games. These factors made it difficult to confidently progress the level of difficulty of the games in order to ensure an adequate effort level allowing for measurable performance improvements. Ideally, any future modifications to the games of the IREX or any other VR system should allow for adjustments of game parameters to meet the attention requirements of a client with dementia or other cognitive/attentional impairments.

This study was conducted on an "outpatient" basis, but not within an outpatient physiotherapy setting. From a health professional human resource perspective, the frequency of appointments required by this type of an intensive VR exercise training program could be a challenge. Due to the frequency of the appointments (daily) over a relatively short period of time (2 weeks), suitable staffing support should be considered when planning future VR intervention programs with a larger sample size.

Although this two week intensive VR training program was shown to be feasible, it was not effective in improving clinical balance and mobility for Mr. YZ. Compared to healthy individuals of similar age, Mr. YZ's clinical measures were impaired at baseline and thus there was potential for improvements with intervention. Although the TUG did show significant improvement between post and 1 month, there was no improvement between the pre-post time points, suggesting the improvement may not be directly due to the intervention. The lack of intervention dependent improvements (pre-post comparisons) in the clinical measures likely reflects a confounding effect of the cognitive impairment on motor function. For example, Mr. YZ often did not use the full range of his arm movements or challenge his base of support by leaning or stepping despite repeated encouragement and demonstrations. He also appeared to forget how to play the games in between sessions and attempts to achieve "just right" challenge [10] proved difficult. The one-month improvement in the TUG may be an indirect effect of the VR intervention. Specifically, the care providers indicated that witnessing Mr. YZ's performance in the VR environment facilitated their encouragement for activity at home. Mr. YZ did, however, improve his task performance in the virtual soccer application. The decrease in the number of goals, particularly the left side, indicates that he was able to learn the game as indicated by a decreased need for instructions. The participant had left visual field deficits. We speculate that game participation increased scanning ability to the left, leading to a decrease in the number of goals on the left (Figure 3)

Conclusion

VR exercise using the IREX system was found to be an enjoyable, safe and feasible intervention for a single research participant with dementia. Physical benefits from training were reported from family members including increased reports of energy and more involvement in ADLs at home. However, objective clinical measures of balance and mobility failed to demonstrate significant improvements following this short intervention. The VR technology was able to encourage activity in our study participant (despite his low cognition) and he was able to succeed at the VR games. These observations suggest that virtual reality game play provides an opportunity to increase leisure activity and challenge cognitive skills; aspects that should be explored in greater detail. Finally, although we failed to see any improvements on physical outcome measures, future studies are required to assess whether intervention programs with longer exposure and at higher intensity are feasible with PWD and whether they would result in measurable improvement on game scores (e.g. soccer) as well as balance and mobility outcomes.

Table 1: Illustration of the timing of outcome assessments. BBS (Berg Balance Scale: a score /56; lower scores indicates lower function), TUG (Timed Up & Go: lower score indicating better mobility), TMWT (Two-Minute Walk Test: maximum distance walked in 2 minutes; higher scores indicate higher function), OSSm (modified Ottawa Sitting Scale: a score /24; lower score indicates lower function.).

Outcome Measures

Pre-Intervention	**Intervention Phase**	**Post-Intervention**	**One Month Follow-up**
Three sessions in one week	5 times per week for 2 weeks	Three sessions in one week	One session
- BBS - TUG - TMWT - OSSm	- BBS - TMWT	- BBS - TUG - TMWT - OSSm	- BBS - TUG - TMWT - OSSm

Appendix 1

Description of the IREX virtual reality games as performed by Mr. YZ. (Adapted from [7]).

IREX Applications	**Task Description**
Soccer	The participant is a goaltender and must stop the soccer balls from entering the net with any part of his/her body. *Settings:* The number of soccer balls was kept at 2 and the 'travel time', or time from appearing on the screen to when it would enter the net was kept at 2 seconds with a full & even distribution to encourage movements. *Scores:* Saves & goals.
Snowboarding	The participant is snowboarding down a hill and must go over as many jumps as possible while avoiding other objects (rocks, trees, snowmen). *Settings:* The travel time was kept at 4 seconds. *Scores:* Jumps & slams (objects hit).
Birds & Balls	The participant is in a field-setting with a variety of colourful balls floating by. They must reach and touch the virtual object gently with the red glove to produce a bird. If the movement is too quick or sporadic, the ball pops and no points are awarded. *Settings:* Red gloves limit use to the hands. *Scores:* 50 points for each bird.
Formula Racer	The participant is in a formula-1 racecar and must navigate through the track while avoiding other racecars as well as the sides of the track. *Settings:* body-tracking to work balance. *Scores:* Time on track & time off track.
Juggler	The participant is in a circus environment with balls floating down from the top. The objective is to keep the balls in the air for as many consecutive hits as possible. *Settings:* The red glove was used to limit interactions with virtual objects to the hands. The number of balls was kept at 1 with a fall rate of 4 seconds with a full & even distribution to ensure maximal movement opportunities. *Scores:* Most consecutive hits & misses.

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Figures:

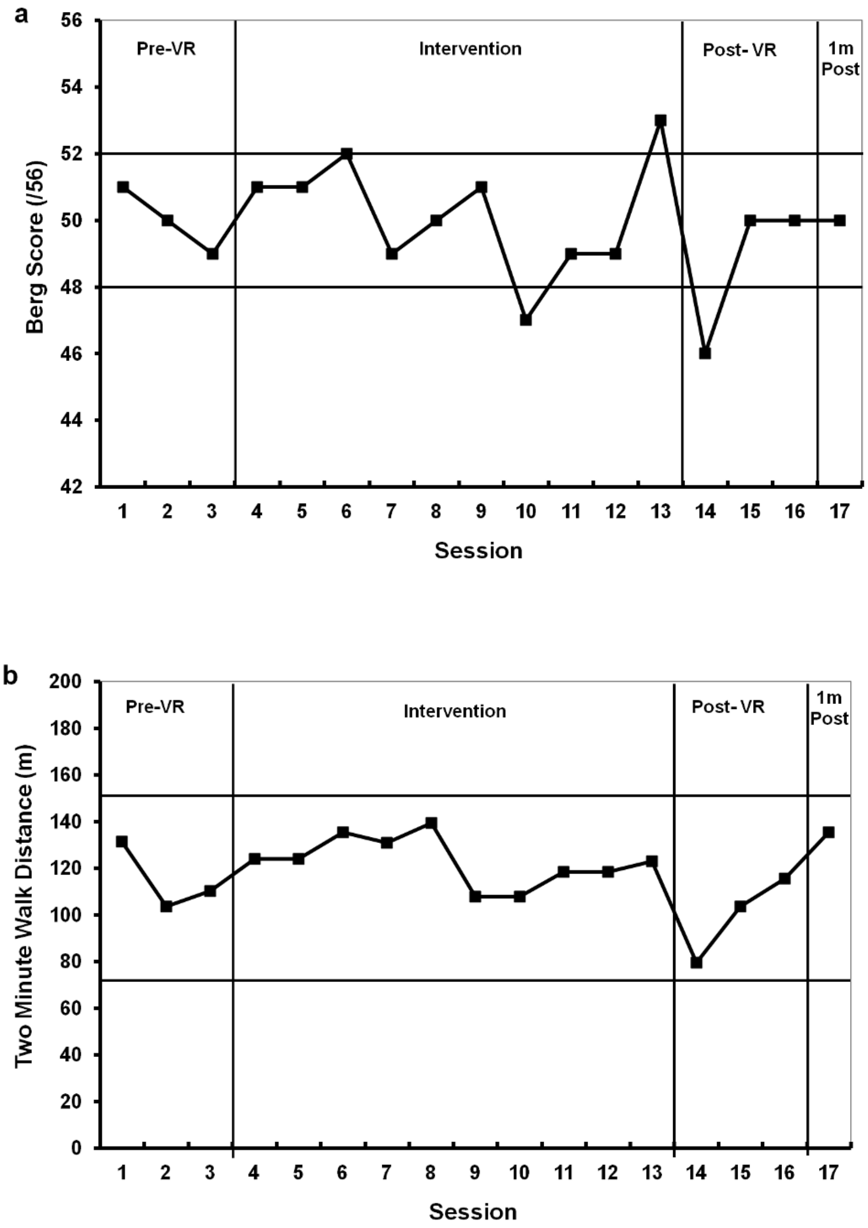

Figure 1: Visual representation of a) the Berg Balance Scale and b) the Two Minute Walk Test (m). The solid horizontal lines indicate +/- 2 standard deviations from the mean of the Pre-VR scores. Berg Balance Scale: a score /56; lower scores indicates lower function. Normative value for age matched controls is 53/56[32]. Two-Minute Walk Test: maximum distance walked in 2 minutes; higher scores indicate higher function. Normative value for age matched controls (70-79 years) is 191.5m[33].

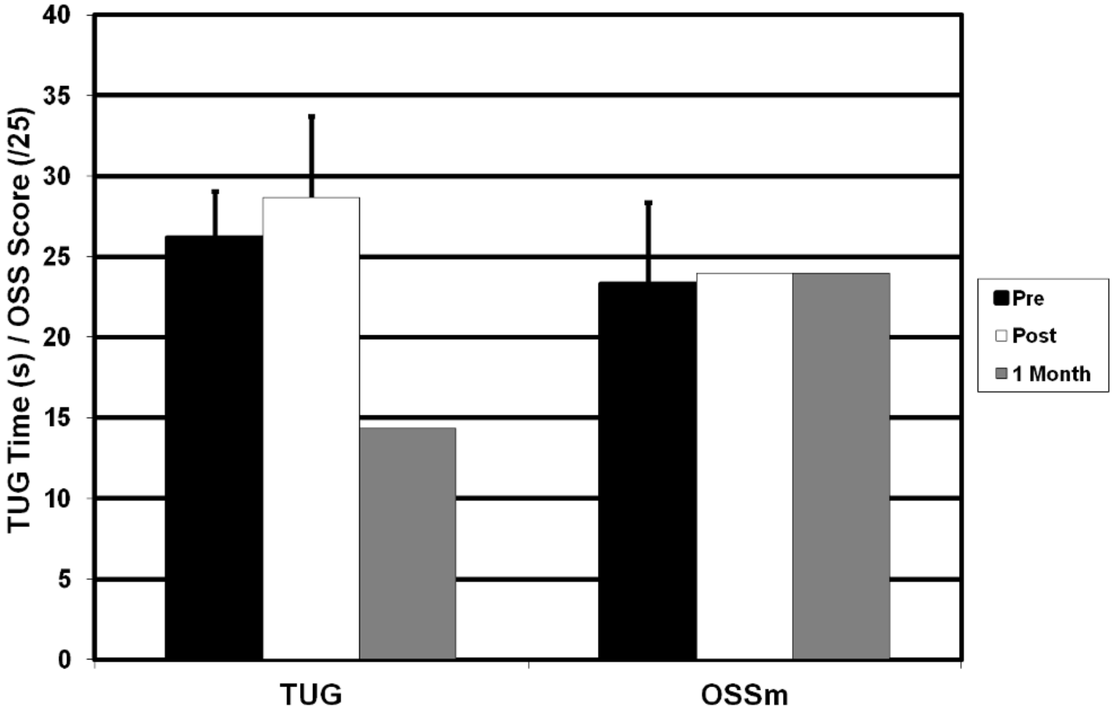

Figure 2: Mean scores for clinical measures completed at pre-test, post-test and 1 month follow-up only. Bars represent standard deviation. The absence of a standard deviation bar in the Post-test OSSm is due to the same score at all three post-test sessions while the 1 month follow-up measures for the OSSm and TUG are from a single test session. No normative values available for the OSSm. Normative value for healthy age matched controls on the TUG is 8.39(±1.36) seconds[34].

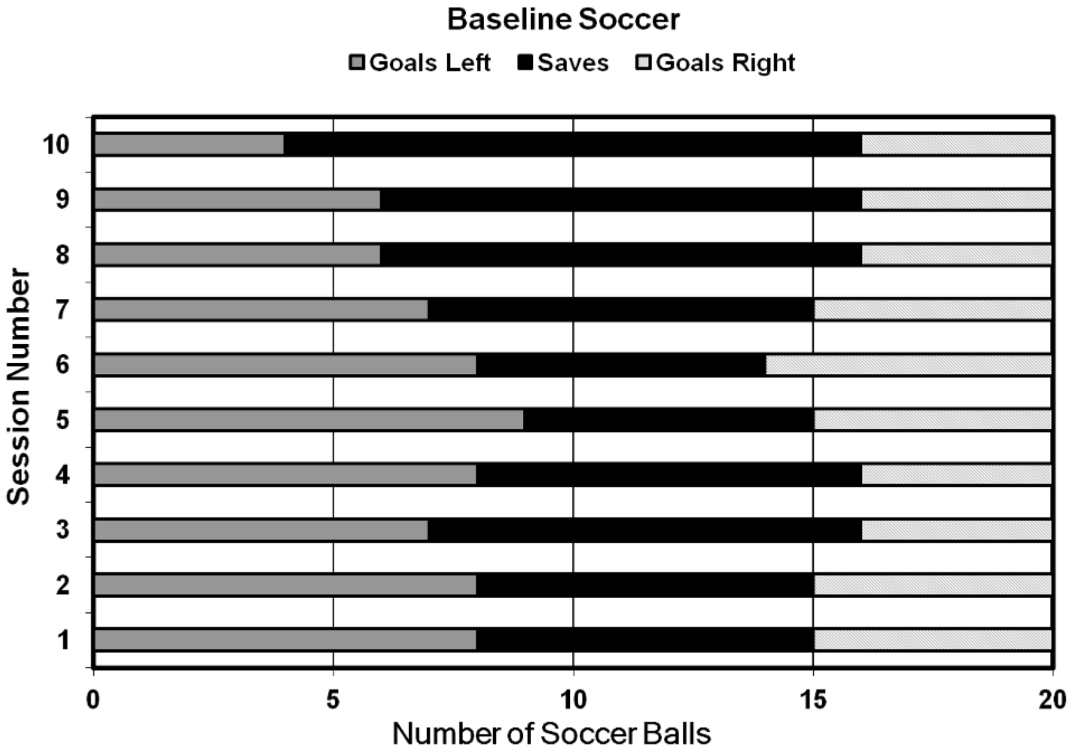

Figure 3: Scores in the soccer baseline set. The same 60 second application with 20 total soccer balls was used prior to every VR training session.

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The authors have declared that no competing interests exist. GestureTek Inc was not involved in the study design; collection, analysis, and interpretation of data; writing of the report; or decision to submit the report for publication.

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Additional Contributions:
Sincere thanks goes to our participant and his caregivers for their hard work and dedication throughout the entirety of the study.

Institutional Review: The Bruyère Research Institute Ethics Committee approved this study. Our participant’s power of attorney signed an informed consent form.

Participant Follow-Up: There has been ongoing follow-up with the participant and his family of the study results.

Chapter 3 Virtual Reality Exercise Improves Mobility After Stroke: An Inpatient Randomized Controlled Trial

Appears in Stroke. 2014;45:1853-1855

Article Title:

Virtual reality exercise improves mobility after stroke: an in-patient, randomized control trial.

Authors

Daniel McEwen[1, 2], Anne Taillon-Hobson[1], Martin Bilodeau[1, 2, 3], Heidi Sveistrup[2, 3], Hillel Finestone[1, 3, 4, 5*]
1 Bruyère Research Institute, Ottawa, Ontario
2 School of Rehabilitation Sciences, University of Ottawa, Ottawa, Ontario
3 School of Human Kinetics, University of Ottawa, Ottawa, Ontario
4 Faculty of Medicine, University of Ottawa, Ottawa, Ontario
5 Department of Physical Medicine and Rehabilitation, Elisabeth Bruyère Hospital.

Corresponding Author (*):

Hillel Finestone, MDCM, FRCPC
Bruyère Research Institute.
43 Bruyère St.
Ottawa Ontario, Canada, K1N 5C8
Tel: 613-562-6094
Fax: 613-562-6312
hfinestone@bruyere.org

Cover Title:

Virtual Reality Rehabilitation After Stroke Study

Key Words:

Virtual Reality, Rehabilitation, Balance, Gait, Intervention

Number of words:

1967

Abstract:

Background and Purpose: Exercise using virtual reality (VR) has improved balance in adults with traumatic brain injury and community dwelling older adults. Rigorous randomized studies regarding its efficacy, safety and applicability, with individuals following stroke, are lacking. The purpose of this study was to determine whether an adjunct VR therapy, improves balance, mobility and gait in stroke rehabilitation inpatients.

Methods: A blinded randomized controlled trial studying 59 stroke survivors on inpatient stroke rehabilitation unit was performed. The treatment group (n=30) received standard stroke rehabilitation therapy plus a program of VR exercises that challenged balance (e.g., soccer goaltending, snowboarding) performed while standing. The control group (n=29) received standard stroke rehabilitation therapy plus the same exposure to identical VR environments but whose games did not challenge balance (performed in sitting). VR training consisted of 10-12, 30-min daily sessions, over a three week period. Objective outcome measures of balance and mobility were assessed before, immediately after and 1 month following training.

Results: Confidence intervals and effect sizes favoured the treatment group on the Timed Up and Go and the Two Minute Walk Test, with both groups meeting minimal clinical important differences after training. More individuals in the treatment than in the control group showed reduced impairment in the lower extremity as measured by the Chedoke McMaster Leg domain (p=0.04) immediately after training.

Conclusion: This VR exercise intervention for inpatient stroke rehabilitation improved mobility related outcomes. Future studies could include non-ambulatory participants as well as the implementation strategies for the clinical use of VR.

Clinical Trial Registration-URL: http://www.ANZCTR.org.au/ACTRN12613000710729.aspx

Introduction

Following a stroke, patients are often left with disabling motor impairments that disrupt balance and mobility, leading to reduced function and quality of life[1]. Virtual reality (VR) exercise programs use computer-simulated interactive environments to promote movement and have been shown to improve clinical measures of functional mobility in adolescents with cerebral palsy[2], traumatic brain injury survivors[3] and community living older adults[4.] Rigorous studies, including inpatient populations, are lacking to confirm the benefits of VR for post-stroke rehabilitation.[5]

The main objective of this randomized controlled trial (RCT) was to examine the effect of VR exercise, as a supplement to a conventional in-patient stroke rehabilitation program, on outcome measures of balance, mobility and motor impairment. We hypothesized that an intensive in-patient virtual reality-based exercise program designed to challenge dynamic stability in standing would result in greater improvements in objective measures of dynamic stability than a similar period of exposure to VR performed in sitting and thus did not challenge dynamic stability.

A secondary objective included determining whether improvements persisted one month after discharge from the inpatient rehabilitation setting. We hypothesized that both groups would maintain gains in dynamic stability, with the treatment group retaining a higher level of improvement compared to the control group.

Methods

The study was a blinded, parallel-group randomized control trial with balanced (1:1) randomization considering two factors (age and pre-intervention Berg Balance Scale [BBS] score) and was conducted on the inpatient stroke rehabilitation unit at the Élisabeth Bruyère Hospital between May 2011 and March 2013. Participants signed informed consent forms approved by the Research Ethics Board of Bruyère Continuing Care.

Patients were included in the present study if they 1) were aged 18 or over, 2) could stand unaided for 1 minute at the time of enrolment, and 3) could provide informed consent. Patients were excluded if they presented with 1) severe cognitive impairments (unable to follow instructions), 2) an unstable medical condition, 3) vestibular deficits, vertigo, and/or 4) seizure activity in the previous 6 months.

Of the 330 patients admitted to the stroke rehabilitation unit, seventy-four participants were enrolled and outcome measures were assessed on fifty-nine (30 treatment; 29 control) immediately after the final training session (POST) and on fifty-two (28 treatment; 24 control) one-month following the cessation of training (1 MO) (see flow chart at http/:astrokejournal.com). The first thirty participants were randomly assigned through coin-toss method to the control or treatment group, with subsequent participants being allocated using age and BBS scores to minimize group differences. Participants in the treatment group interacted with the VR games (e.g., soccer goaltending, snowboarding) in a standing position thereby challenging their balance and weight shifting. In contrast, individuals in the control group were seated, and played games which did not require any weight shifting within their base of support. Participants in both groups completed 10 to 12 sessions of 20 minutes of interactive virtual reality exercise using the Interactive Rehabilitation Exercise software (IREX™; Gesturetek, Toronto, Ont.; for detailed description of individual games see online supplement at http/:strokejournal.com)[6] in addition to their regular in-patient rehabilitation therapy sessions.

Exposure time to VR exercise was similar in both groups (treatment group= 176.6 minutes ± 27.8 SD, control=179.1 minutes ± 14.6 SD, p=0.584)**.** Both the team member performing the assessments/evaluations (RA) and the participants were blinded to group allocation.

Clinical assessments of balance and mobility were completed three times: prior to the VR training (PRE), at POST and 1 MO after the final training session. The primary outcome measure was the Timed Up and Go test (TUG). Secondary outcome measures included the Two Minute Walk test (TMWT) and the Chedoke McMaster Stroke Assessment Scale Leg domain (CM-L).

To test our hypothesis, the differences in improvements between groups are reported with 95% confidence intervals and effect sizes for the TUG and the TMWT. Since scores on the CM-L ranged from 5-7, the data were transformed to a count data set where a participant's score either improved (+1) remained the same (0) or decreased (-1) from PRE to POST. The Fisher Exact test for count data was used to determine between group differences in improvements on the CM-Leg.

Results

Demographic data for the two groups at PRE are presented in table 1.

Insert table 1 approximately here.

Confidence intervals and the effect sizes for the TUG and the TMWT are shown in figure 1.

Insert figure 1 approximately here.

Both groups met MCID values at POST for the TUG[7] and the TMWT[7] (Table 2).

Insert table 2 approximately here.

More individuals in the treatment than the control group showed improvements on the CM-L at POST (p=0.04) and 1MO (p=0.02).

Discussion

This study is the first RCT demonstrating the positive effects on balance and mobility outcomes of a standing VR training program supplementing an in-patient stroke rehabilitation program. As expected from prior work on stroke rehabilitation[7], the participants in both groups improved and reached the MCIDs for the TUG and the TMWT. However, there was a greater improvement in the treatment group with the addition of the standing VR intervention that the authors believe is clinically meaningful. Such difference in improvements between groups was not significant for the TUG and the TMWT. This is likely because the study was underpowered. Post-hoc power analysis suggests 20 additional subjects per group would be needed to achieve statistical significance. The improvement between PRE and 1MO was relatively similar between both groups indicating that the control group continued to make gains on balance and mobility outcome measures reaching similar performance levels as the treatment group. We did not control or document activity levels (e.g. further physiotherapy or other exercise programs) of participants between POST and 1-MO, and therefore we are unable to explain the difference in recovery rate following POST.

We have shown that VR balance and mobility exercise is a positive addition to inpatient stroke rehabilitation. The VR training sessions did not lead to any falls, seizures, shortness of breath or fainting. Our future studies will include non-ambulatory inpatient participants, as well as explore administrative/scheduling challenges encountered when incorporating a VR-based modality in an active inpatient rehabilitation environment.

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Disclosures: None

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		TMWT (ft)	CMSA-Leg	TUG (s)
MCID		62	N/A	-4.8
Control	Pre	279.1 (86.4)	5.9 (0.3)	22.5 (8.9)
	Post	349.6 (103.5)	6.0 (0.3)	16.8 (5.2)
	Post-Pre	70.5*	0.1	-5.7*
Treatment	Pre	327.3 (146.2)	5.9 (0.5)	21.4 (9.6)
	Post	438.5 (153.6)	6.3 (0.5)	13.6 (6.0)
	Post – Pre	111.2*	0.4	-7.8*

Table 1: Group averages (SD) are shown for both groups. Numbers with a (*) represent changes that meet MCID (Minimal Clinical Important Difference) for that measure.

Characteristic		Treatment Group (n=30)	Control Group (n=29)	Overall (n=59)
Mean Age ± SD		62.2 ± 14.1	66.0 ± 15.8	64.1 ± 15.0
Sex	Male	16	16	32
	Female	14	13	27
Side of Stroke	Left	12	9	21
	Right	15	16	31
	Bilateral	3	4	7
Type of Stroke	Ischemic	23	25	48
	Hemmorhagic	7	4	11
Location of Stroke	Cortical	21	19	40
	Subcortical	12*	20*	32
Mean no. of days between stroke and start of VR training ± SD		30.1 ± 18.9	39.6±17.8	34.8±18.8
Mean Total FIM score on admission ± SD		88.4 ± 13.5	81.2±16.5	84.8±15.4

Table 2: Demographics and stroke characteristics. Independent sample t-tests and chi-square tests were used to compare groups. Groups were similar on all characteristics excluding the number of sub-cortical strokes (*chi-square, p=0.023).

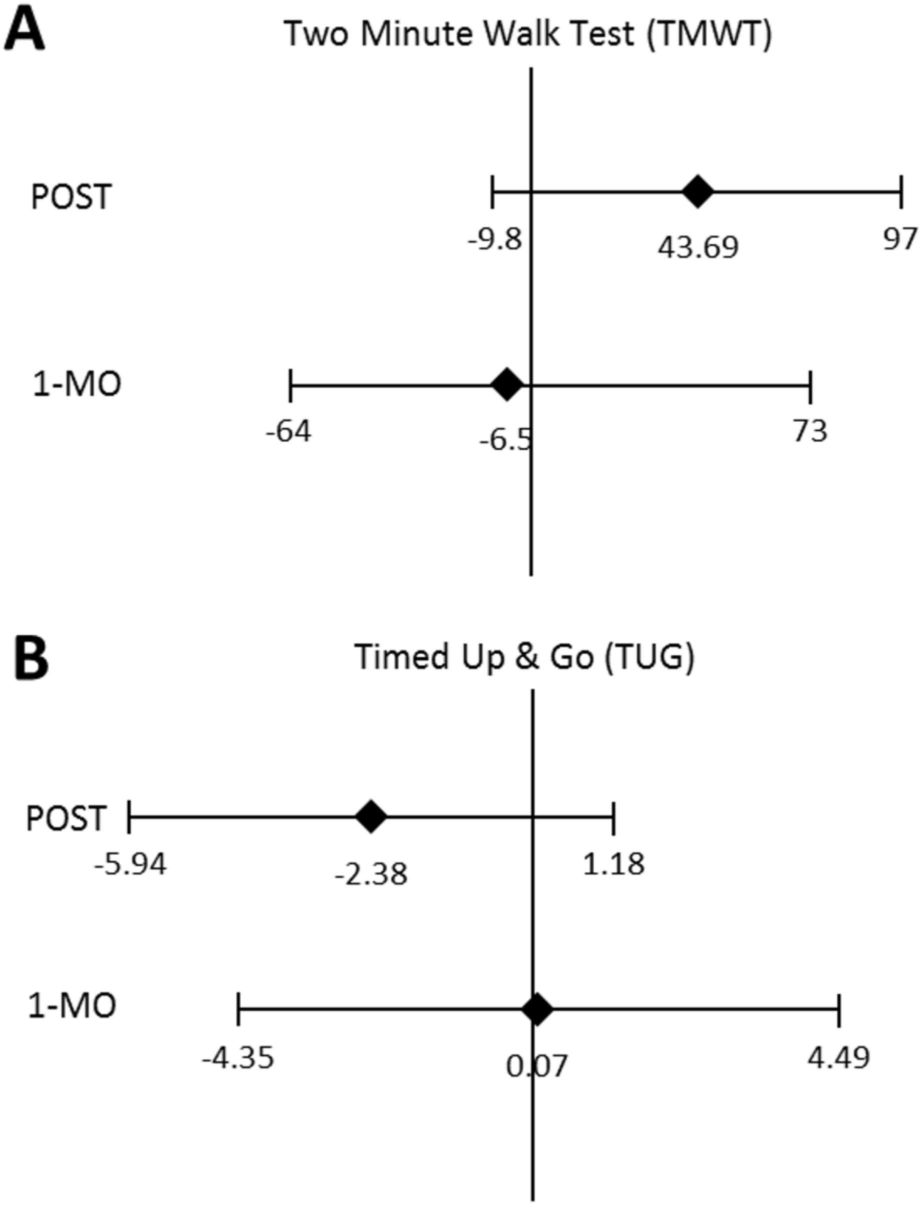

Figure 1: 95% confidence intervals and effect size (black diamonds) for the difference in improvements at POST and 1-MO are shown. For the TMWT (panel A), the effect size to the right of the zero line indicates an improvement whereas for the TUG (panel B), the effect size to the left is indicative of improvement in favour of the treatment group.

Online Supplemental Material

IREX Games Used in the Intervention

VR games which trained mobility, lateral weight shifting and reaching were chosen for the intervention. The parameters of the games were modified according to group allocation. The game parameters for the treatment group were programmed to require the participants to reach for virtual objects located at extreme locations on the screen (up in the corners at the top, for example) which required the participant to laterally weight shift and reach to the limits of their standing balance. These participants were instructed to step and reach as far as they could. No such weight shifting or reaching movements were required by the control group because the virtual objects were programmed to appear in the center midline area of the screen and the instructions to these participants were to contact the virtual object only when it was in front of their body. The following games were played by both the treatment and the control groups:

1) Soccer goaltending: the participant stood in front of a “virtual soccer net” and attempted to prevent any goals being scored by blocking the ball with any part of his/her body. The treatment group was required to weight-shift, step and reach laterally towards the extreme areas of the net while the control group’s soccer balls required no body movements because their “virtual soccer balls” were being directed towards the midline of the body. ;

2) Birds & Balls: the participant was required to reach with their paretic hand and gently touch a variety of floating, coloured balls which caused them to weight shift and gauge the force with which they contacted the ball and transform it into a bird. The treatment group was instructed to reach for the balls as soon as they appeared in any area of the screen while the control group was instructed to not reach for the balls but rather touch them when the balls were positioned in front of their trunk;

3) Juggler: the participant was in a circus environment with balls floating down from the top of the screen and was required to “juggle” (keep the balls in the air) for as many consecutive hits as possible. The standing group had a wide play area requiring lateral stepping and reaching while the juggled balls in the control group were specifically programmed to fall within the centre (midline) area of the screen ;

4) Conveyor: the participant was in a factory setting located between two conveyor belts and was required to move boxes using the paretic arm from the non-affected to the affected side. The treatment group was required to lean and reach from a variety of heights and distances while the control group was limited to horizontal movements within the body area;

5) Sharkbait: the participant was immersed ‘underwater’ and needed to collect stars while avoiding sharks and eels. The treatment group was required to lean, squat and extend upwards to move around the water while the control group were able to move through the immersed “underwater “areas by moving one hand in front of their waist.

Additional games were played by the treatment group only as these games required full body movements which could not be adapted to a sitting posture. These games included the following:

Snowboarding, in which the participant was going down a ski hill and had to go over as many jumps as possible while avoiding other objects (i.e. rocks, trees, snowmen) by leaning side to side;

Formula Racer, where the participant was in a formula-1 race car and was required to navigate a track using lateral weight shifting while avoiding other racers as well as the sides of the track.

Supplemental Figures:

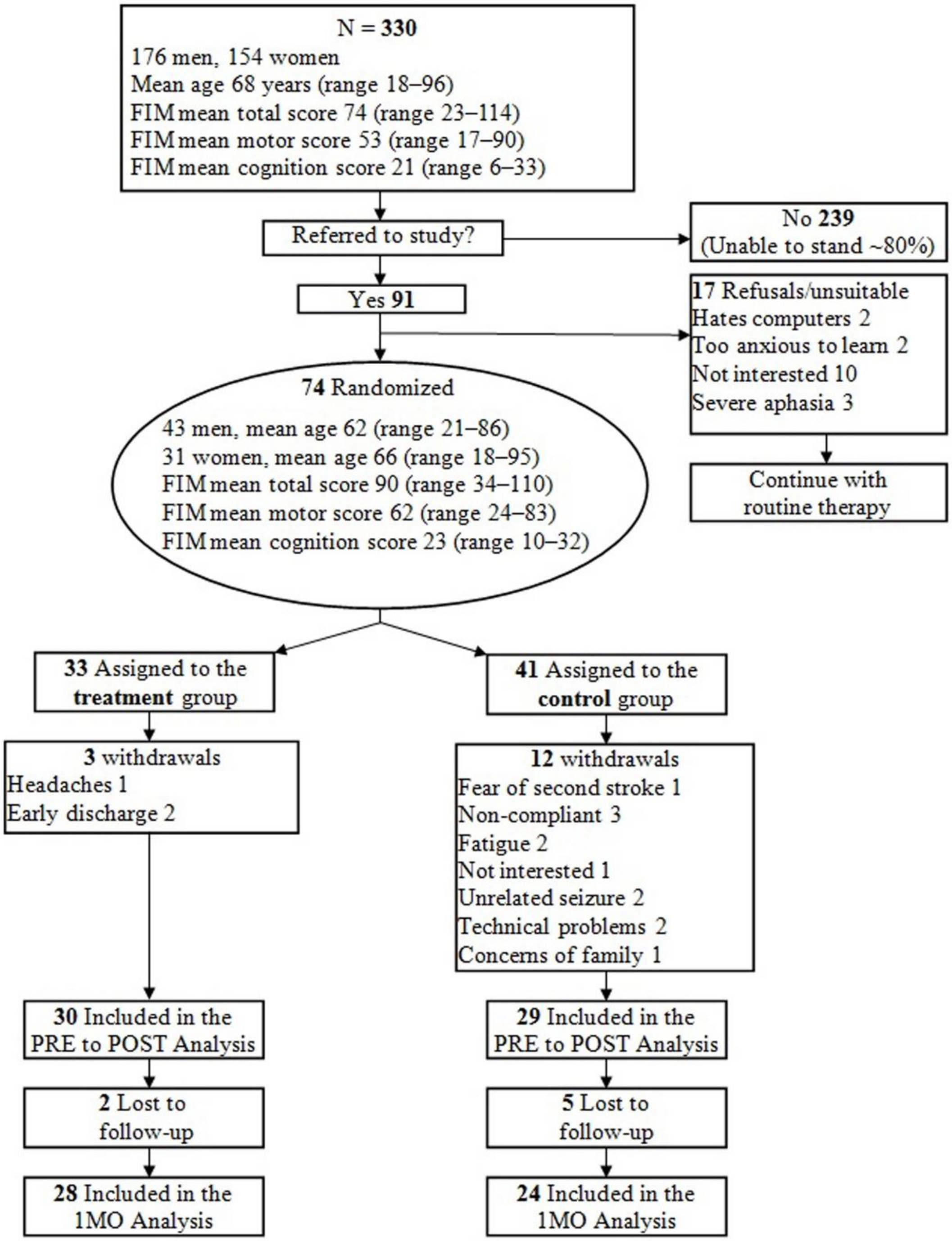

Figure I: Flow of participants through the study.

Figure II: VRRASS participant playing the soccer application. *LEFT*: Participants stood in front of a green screen with a physio belt around their waist while being monitored by a researcher (behind the participant). *RIGHT*: The participant sees himself immersed in a soccer net. Above the TV is the camera that captures the image of the participant. Photo used with permission of the participant.

Chapter 4: Comparing flow, presence and immersion and relevance to virtual reality rehabilitation.

To Be Submitted to Cyberpsychology

Full Title: Comparing flow, presence and immersion and relevance to virtual reality rehabilitation.

Authors:

Daniel McEwen, MSc [1,2], Judith Deutsch, PT PhD[2] , Martin Bilodeau, PhD[1,2,4], Heidi Sveistrup*, PhD[1,2,4]

Affiliations:

1 Bruyère Research Institute, Ottawa, Ontario, CAN

2 School of Rehabilitation Sciences, University of Ottawa, Ottawa, Ontario, CAN

3 Rivers Lab, Department of Rehabilitation and Movement Sciences, Rutgers University, Newark, NJ, USA.

4 School of Human Kinetics, University of Ottawa, Ottawa, Ontario, CAN

Running Title: Flow, Presence & Immersion.

Corresponding Author(*):

Heidi Sveistrup, PhD
200 Lees Avenue (A121)
Ottawa, ON
K1N 6N5
Canada
hsveist@uottawa.ca

Abstract:

This paper provides a review of three terms (flow, presence and immersion) and highlights overlapping concepts for comparisons. In the context of virtual environments (VE), the terms have been used interchangeably which does not facilitate clear understanding or quantification of a user's experience and interaction in a VE. While the flow state describes a subjective, optimal experience during VE exposure, presence remains solely the sense of mentally 'being there' (in a VE) while physically in another place which may all be complimented by objective immersion capabilities of a virtual reality (VR) environment. Although the terms share similar concepts and may facilitate one another, they should be well defined and understood prior to describing an individual's experience in a VE.

Words: 119

Virtual reality (VR) game-play is an interactive form of gaming using a human-computer interface (Holden & Dyar, 2002) that presents users with opportunities to engage in virtual tasks that have naturalistic interactive characteristics. VR has been used to engage individuals for recreation purposes (Frostling-Henningsson, 2009), vocational training (Francis et al., 2012) and physical rehabilitation (Laver, George, Thomas, Deutsch, & Crotty, 2011). The rich stimulus (i.e. auditory, visual, tactile) provided by the VR system can draw people in to the point at which they feel the scenario is 'real' (Walshe et al., 2005). These feelings of reality may elicit physiological responses (i.e. skin resistance, heart rate variability) (Wiederhold, Jang, Kim, & Wiederhold, 2002) similar to responses in similar physical world scenarios. A VR interface provides opportunities to become more than just an observer, but rather an active agent in an environment that may require attention, concentration in order to interact with virtual objects and/or avatars (virtual people).

The user's experience with and the extent to which they are drawn into a virtual environment (VE) has been described in the scientific literature with many terms buried in different theories. This has been done through studying the factors that influence and encourage VR experiences. However, terms are often used in convoluted ways that conflict prior understanding and use of that term. Therefore, clarification of terminology surrounding one's experiences during VR activities can encourage more consistent use of terms for future scientific research and facilitate deeper understanding of how to optimally engage an individual in a VE if, for example, it is used for purely recreational enjoyment (Sherry, 2004) or to facilitate rehabilitation of a health disorder (e.g. (Laver et al., 2015)).

Optimally engaging an individual in VEs would help structure the VE/VR experience so that the impacts when used with populations are maximized. This is due to the interactive nature of VR which provides a platform for encouraging repetitive movements graded at an appropriate level during rehabilitation for various conditions. As VR technology improves, outcomes may be optimized whether VR is used, for example, as a distraction during painful treatments (Malloy & Milling, 2010) or to encourage movements during virtual rehabilitation gaming (Sveistrup, 2004).

Therefore, this paper seeks to summarize and define three major terms that are currently used to describe a VR rehabilitation experience: flow, immersion and presence. A secondary aim of this paper is to present sample (non-exhaustive) methods for quantification of these terms for recommended use in clinical populations.

Flow

Early in his career Mihaly Csíkszentmihályi began to study how individuals participate in an activity to a level at which they have an optimal experience. He observed individuals becoming involved in their activity to the extent which they had no sense of the passing time nor any external distractions. Artists, specifically painters, got so involved with their work that they would disregard their need for food, water and even sleep. He titled this involvement as 'Flow' as this was the term that interviewees would most often use in their descriptions of how it felt to be in "top form". Therefore, flow is a state of being that one experiences.

Csíkszentmihályi (M Csikszentmihalyi & Csikszentmihalyi, 1988) identified the following 9 factors as encompassing an experience of flow: (i) intense and focused concentration on the present moment, (ii) merging of action and awareness, (iii) a loss of reflective self-consciousness, (iv) a sense of personal control or agency over the situation or activity, (v) a distorted sense of passing time, (vi) experience of the activity as intrinsically rewarding, also referred to as an autotelic experience, (vii) clear goals of the activity, (viii) good balance between perceived challenges and perceived skills and (ix) the task must have clear and immediate feedback. These factors were mentioned repeatedly to describe the feeling during an enjoyable experience (Csikszentmihalyi & LeFevre, 1989). It is possible to have these aspects appear independent of each other, but only when they are present at the same time do they elicit a true flow experience. Therefore, flow may be considered by some as the extreme end of involvement in an activity when all the factors are active.

Figure 1 represents the flow state in which an optimal and maximal balance between challenge and skill (factor viii, above) elicits flow (top right quadrant in the figure) while a discrepancy in either component reduces the likelihood of flow. If the challenge/skill ratio is uneven in any direction, the participant will not be in flow but rather relaxation (high skill, low challenge), anxiety (low skill, high challenge) or apathy (low skill, low challenge).

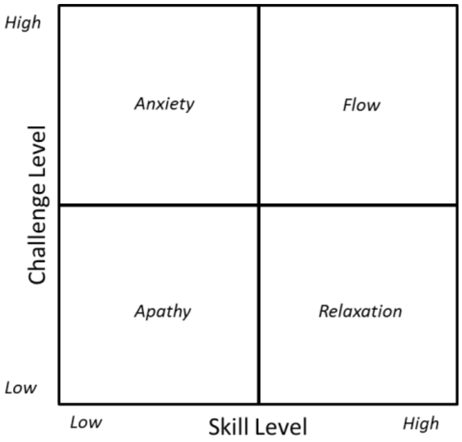

Figure: Flow state as an optimal challenge/skill balance. (Mihaly Csikszentmihalyi, 1975)

Since its original conception, the original flow theory has since been incorporated into different disciplines from its early beginnings in psychology, most consistently in the context of play/leisure and gaming (Cowley, Charles, Black, & Hickey, 2008). The flow state has been observed when individuals become engaged in video game play (Klasen, Weber, Kircher, Mathiak, & Mathiak, 2012) as well as during immersive, interactive rehabilitation using VR-game play (J.-H. Shin et al., 2014).

VR game-play whether for rehabilitation or recreational purposes, provides an opportunity to promote flow as it may consist of goal-directed interactive activities that require attention and concentration to control an active component through first person, avatar or object representation in the virtual environment (VE). Concentration on the task often draws a player in, to the point of becoming part of the environment without a sense of how long the dissociation from the physical environment has lasted (Wood, Griffiths, & Parke, 2007). Depending on the characteristics of the VE, the goals and objectives could also be clear, for example, saving soccer balls in a goaltender game which can provide immediate feedback of results.

In summary, flow, although not developed based on VR experiences, can be applied to an individual's subjective experience during VR game-play (Sherry, 2004). If all 9 of the aforementioned factors are present and active simultaneously, a flow state may be experienced during a VR task.

Quantification of the flow state:

Quantification of the flow state has been predominantly accomplished through subjective self-reports used to identify the "inherently unstable un-self-conscious, subjective phenomenon" (Nakamura & Csikszentmihalyi, 2002). Since the flow state requires a loss of reflective self-consciousness, quantification methods are limited to post-participation measurements.

For example, the Flow Questionnaire (FQ) (Csikszentmihalyi & Csikszentmihalyi, 1988) proposes definitions of the flow state and asks individuals to describe situations in which they experienced those descriptions and rate their subjective experience when they are engaged in those particular situations. Overall, the FQ is recognized as a good measurement for studying flow, but has limitations when measuring a subjective experience and lacks the ability to measure the depth or intensity of the flow experience. The Flow questionnaire has been used in virtual reality research (Urech, Krieger, Chesham, Mast, & Berger, 2015) with individuals experiencing social anxiety indicating a high association of reported flow experiences during participation in a VE.

In the physical activity domain, Susan Jackson interviewed elite athletes post-competition asking them to describe their flow experience. Through qualitative analysis of these interviews, Jackson was able to extract dimensions of Csíkszentmihályi's flow state that represented optimal engagement for the athletes. She proposed the Flow State Scale (FSS) (Jackson & Marsh, 1996) which was subsequently tested (Tenenbaum, Fogarty, & Jackson, 1999) through Rasch analysis of the original data (Jackson & Marsh, 1996) (N = 394) plus a new data set of older adult athletes. Results demonstrated the FSS subscales had a high degree of consistency across and within samples, supporting the reliability and generalisability of the FSS scale. This scale was then modified and enhanced to improve the measurement of flow dimensions at both the conceptual and statistical levels as the Flow State Scale-2 and confirmed to have good psychometric properties (Jackson & Eklund, 2002) through high mean item loadings on the first-order factor for both an item identification sample (.78) and a cross-validation sample (.80). The FSS-2 assesses flow within a particular event and relies on the participant's recollection of the event post-participation. It has been applied to measure flow within a VR experience during training for individuals with Parkinson's (Galna et al., 2014) as well as during rehabilitation after knee surgery (Lee et al., 2016) which revealed a stronger correlation with individuals that were experiencing more severe pain or physical dysfunction indicating higher levels of flow during VR.

For situations with practical constraints (e.g. time), that prevent the use of the aforementioned multi-item scale, two measurement scales have been developed with the purpose of applicability across various settings. The Core Flow Scale (Martin & Jackson, 2008) captures the central subjective optimal experience based on verbal expressions used by participants in pervious flow research. Similarly, the Short Flow scale was created from selecting a target item from each of the nine flow factors from the long scale (i.e. a brief version of the global higher order flow state). These two scales, although highly correlated, have sufficient variance to show they offer complementary but distinct perspectives on flow. While the Core Flow Scale measures the subjective optimal experience, the Short Flow scale assesses factors that comprise and facilitate a flow state. Therefore, if the goal is to quickly assess if flow is present, the Core Flow scale should be used. If parameters that facilitate flow (e.g. challenge-skill balance) are of interest, then the Short Flow scale would be optimal. They have been applied in numerous domains (e.g. work, athletics, music) but have yet to been used for assessing flow during VR exposure.

In addition to measurement following activities, Csíkszentmihályi presented a real-time method for identifying flow states. The Experience Sampling Method (ESM) (Larson & Csikszentmihalyi, 1983) was presented as a tool that asks individuals to provide self-reports at random occasions during activities of interest. It has been applied in work and leisure (Csikszentmihalyi & LeFevre, 1989) and psychosocial rehabilitation (Bassi, Ferrario, Ba, Delle Fave, & Viganò, 2012). However, since the ESM sessions usually last one week or more, it would not be applicable to measure flow within a VR activity, but rather compliment other flow measures (e.g. FSS-2) to provide information on an individual’s propensity to allocate attention to any task at hand.

In summary, there is no gold standard flow state measurement methodology. This is due to the nature of a flow experience since interruptions have negative impacts on flow and retrospection is dependent on an individual’s recall. More research into the mechanisms and possibly measurement of physiological responses to VR immersion (Peifer, Schulz, Schächinger, Baumann, & Antoni, 2014) may enhance the accuracy of quantification for this phenomenon.

Presence

The term presence is ill-defined, as it is a psychological construct that is difficult to quantify (Slater, 2004). It has been explained as a “multidimensional parameter that is arguably an umbrella term for many inter-related perceptual and psychological factors” (Kalawsky, 2000). Papers have referred to presence using numerous definitions, theories and subtypes of presence including personal presence, environmental presence and social presence although pleas for one consolidated term of “presence” have been made (Lee, 2004).

For the purpose of this paper, we accept the most commonly recurring and most valid definition of presence as “the subjective experience of being in one place or environment even when one is physically situated in another” (Schuemie, van der Straaten, Krijn, & van der Mast, 2001). In the VR literature, Slater and colleagues (2009) affirm that a key result of presence is that a person remembers the virtual environment as a place rather than a set of viewed images, .

Presence in VR is also facilitated by the ability of the participant to interact and control a VE. As Sanchez-Vives and Slater (2005) state, “the sense of ‘being there’ in a VE is grounded on the ability to ‘do’ there”. Presence becomes an experience in which interactions with virtual objects are perceived to fit expectations as if the same task was done in a physical environment. As the perceived fit is enhanced, feelings of presence are enhanced (Jin, 2011). However, it is also possible to feel present in a VE that does not require active movement/participation as with a virtual rollercoaster ride (Baumgartner, Valko, Esslen, & Jäncke, 2006).

A non-interactive VE may elicit presence depending on characteristics of both the individual as well as characteristics of the VE. It is believed that the more senses (visual, tactile etc.) that are stimulated (Bystrom, Barfield, & Hendrix, 1999) from the VE, the greater the capability of the VE to produce a sense of presence (Lombard & Ditton, 1997). Recommendations for effective VR designs have been made to facilitate a sense of presence (Seo & Kim, 2002). These can be considered as constraints/abilities of a medium in, for example, haptic feedback, visualization techniques or high quality auditory stimuli. It is also possible that the software design may use a real-time image of the participant within the VE (for example: Glegg, Tatla, & Holsti, 2014), thereby possibly increasing a sense of presence without higher quality system characteristics.

When presented with the same VE, each individual may experience a different level of presence due to their individual differences. Steur (1992) mentions the willingness to suspend disbelief as a precursor to experiencing presence. VEs may present unique scenarios that may require an individual to believe that it is possible for them to be present in that environment. A cognitive theory of presence to support this notion was presented by Wirth (2006) who proposed that presence has two different cognitive steps. The first step involves the allocation of attention to the stimuli presented by the VE. The participant builds a convincing mental model of the simulated space. Secondly, there is a loss of self-consciousness as the participant accepts the model as their own egocentric viewpoint. Once this is achieved, a virtual state of presence within the VE is created resulting in a distorted passage of time. Both steps are unconscious processes of spatial cognition.

In summary, the sense of presence is a subjective state of being and only quantifiable by the user experiencing it (Schubert, Friedmann, & Regenbrecht, 2001). It can be facilitated by characteristics of the virtual reality medium as well as influenced by characteristics of the individual which engages the participant to feel present in the VE. If the characteristics of the VE are optimal, the participant can then believe an egocentric viewpoint within the VE and feel present. However, some individuals have a propensity to become engaged with VEs over others.

Quantification of Presence

A compendium of presence measures was compiled in 2004 (van Baren & IJsselsteijn, 2004) which highlights both objective (physiological measures, behavioural measures, task performance measures, and neural correlates) and subjective (questionnaire, continuous assessment, psychophysical methods, qualitative methods, and subjective corroborative measures) quantification methods.

The quantification of presence has been studied in the context of VEs predominantly through subjective questionnaires, which may have limitations as they fail to truly verify whether presence was experienced during the task but rather may conjure up feelings of presence during questioning following VE exposure (Freeman, Avons, Pearson, & IJsselsteijn, 1999). However, since they are administered post-hoc, there is no interruption or distraction during the virtual experience. For example, the 32-item Presence Questionnaire (PQ) (Witmer & Singer, 1998) is a widely used full-length self-report measure of presence during VR rehabilitation research. The questionnaire has been found highly reliable by its authors (α=.88), and it was said to be a valid measure of presence in VR gamers (Witmer & Singer, 1998).

If the participant truly feels as though the VE is their current environment, behavioural responses to environmental stimulus would be expected and could be measured as a quantification of presence. For example, Held & Durlach (1992) propose a ‘looming response’ or postural perturbation responses to virtual flying objects that an individual may believe will hit them may indicate a sense of presence in the virtual environment.

Validation of presence through objective neuro-imaging measures (physiological, neural correlates) have become increasingly popular in research (Alcañiz, Rey, Tembl, & Parkhutik, 2009). For example, Clemente et al (Clemente, Rodríguez, Rey, & Alcañiz, 2013) have attempted to identify neural mechanisms of presence in virtual environments. Using EEG during VR activity, it was found that the activity of the right insula (related to stimulus attention and self-awareness) was significantly higher when the healthy young adult was able to control the navigation (high presence) of the virtual environment as opposed to automatic navigation. Other EEG studies (Baumgartner et al., 2006) have found higher activation of prefrontal areas responsible for executive function during feelings of presence in stimulating VE (e.g. virtual rollercoaster with loops and turns) as compared to a simple control condition (e.g. virtual rollercoaster with only horizontal movements).

In summary, since presence is a subjective psychological construct, quantification remains difficult and uncertain due to differences in opinions about the true definition of presence and methodological limitations of quantification. To truly understand this concept, it has been suggested that increased data collection and analysis of an individual's actions and responses within a VE is essential.

Immersion

Immersion is most readily defined as an objective description of what the system can deliver (Slater et al., 2009; Slater & Wilbur, 1997). As such, immersion exists in variable intensities depending on the technology used. Considering all the potential modifications to characteristics of the software/hardware, virtual reality has been presented in a wide spectrum from 2D flatscreen computer/tv displays (Glegg et al., 2014; Weiss et al., 2009) to highly immersive systems like CAVE (Chen et al., 2015). Head mounted displays (Chen et al., 2015) engulf the entire field of vision while adapting the virtual image to the orientation of the participant's head to further increase immersion.

Certain barriers such as game construction or environmental distractors can prevent an individual from progressing down the spectrum to total immersion. These barriers have long been cited as factors that are instrumental for deeper immersion: interactivity, fast update rate, high image complexity, engaging, 3D sound, head-mounted display; stereoscopic; large field of view and head tracking (Pimentel & Teixeira, 1992). These concepts are limited to the characteristics of the VR system as they can facilitate total immersion.

Possibly the most debated definition of the three terms in this paper is for immersion. Often compared to and contrasted with presence, immersion remains a separate yet instrumental aspect of VR exposure. The extent to which the individual's characteristics facilitate immersion divides the debate. It is widely accepted that immersion can objectively exist at variable intensities (Slater & Wilbur, 1997) and therefore may not require an individual to actively participate. However, to reach the end of the spectrum at full immersion, the individual must begin to exhibit characteristics reminiscent of the previous two terms (e.g. focused attention).

Some (McMahan, 2003) will disagree in that the degree of immersion is solely dependent on the physical characteristics of the medium as it is quite possible to become highly immersed in a desktop VR system. Although total immersion (E. Brown & Cairns, 2004) is possible with low immersion characteristics of the system, it is difficult to debate the fact that the more senses (auditory, visual, tactile etc.) that are engaged by the system, the fewer distractions from the physical environment act on the individual and thus the greater chance for immersion.

The level of immersion that is necessary to draw someone in to the VE may vary between individuals. As a result of being immersed, the individual may begin to be drawn into the scenario and become an engaged viewer or active participant in the VE. This involves cognitive abilities as the individual begins to invest attention which may lead to a distortion of time. As the individual becomes more immersed, they may reach a point of total immersion, which has been equated to presence (E. Brown & Cairns, 2004) in which the individual becomes fully focused on the task with a loss of self-awareness feeling as though they have become part of the VE (presence). Full immersion can therefore be defined as “the sensation of being surrounded by a completely other reality that takes over all of our attention, our whole perceptual apparatus.”(Murray, 1997).

A clear distinction can be made between VR systems that facilitate presence (e.g. role playing games) and those that do not (e.g. puzzle games) (Nunez & Blake, 2006) (Jennett et al., 2008). Also, an individual may be immersed in a virtual environment but they may remain aware of physical environment and thus, not in flow nor feel present in the VE. It is only at the stage of full immersion does the VE take over the entire perceptual apparatus and, provided the VE is facilitates it, the participant may feel present within the VE. The sense of presence may therefore be the outcome, or the result of, immersion.

In summary, although definitions are blurred and concepts are debated, immersion remains primarily an objective description of the characteristics of the VE that tend to draw us into an illusion of reality. Depending on the objective nature of the VR system, immersion may be presented at variable intensities. As a result of immersion, the individual may begin to engage cognitive involvement (focused attention) resulting in the stimulus/information from the physical environment being distorted (e.g. time). Immersion therefore facilitates presence and possibly flow, as the participant is drawn into and reacts to the surrounding VE (Slater et al., 2009).

Quantification of Immersion

As the concept of immersion overlaps both characteristics of the VR system as well as some individual characteristics, quantification of this concept proves difficult. As mentioned previously, 3D sound, large field of view increases the likelihood of an individual's feelings of immersion in a virtual environment. However, scales to compare the characteristics of the VR do not exist as they are straight comparisons of technological constructs that vary from system to system. Thus, the attempts at immersion quantification focus on the characteristics of the individuals.

For example, to measure immersion, a 32 item questionnaire (Jennett et al., 2008) has been used. Questions ask participants how much (strongly disagree-strongly agree) they agreed with the statements. For example "To what extent did you lose track of time?" and "To what extent did you feel you were focused on the game?" and "I did not feel like I was in the real world but the game world". However, these questions provide examples of how terms are used interchangeably as ‘feeling as though you were in the game world’ would imply presence in a VE rather than solely immersion.

As Slater (2009) pointed out, questionnaires in this domain can be problematic as “they rely on participant’s subjective opinions”. IJesselsteijn et al (IJsselsteijn, de Ridder, Freeman, & Avons, 2000) offer an alternative in that objective measures could accompany subjective measures. Objective measures quantify user responses that are produced automatically for example, eye tracking during immersion which measures the number of fixations (visual stimulus focused upon) per minute during game play. A highly immersive environment may increase the number of fixations as visual attention becomes more focused on the encompassing visual stimulus important to the objective of the game.

Immersion should remain as an objective term describing the characteristics of the VR medium. Immersion has been quantified between using both qualitative subjective reports as well as objective physiological measures. However, care must be taken to not assess presence during subjective measures as well as take the individuals’ characteristics (willingness to become engaged) as it may result in varying reported levels of immersion for the same VE.

Discussion

In summary, the three concepts of flow, presence and immersion are distinct terms that can describe a user's experience during VR exposure. While the flow state is a feeling of optimal performance that one experiences, presence remains as a subjective experience and immersion is predominantly an objective description of the VR system. Therefore, it is possible that in certain VR environments, the participant may feel immersed in a VE, losing track of time with all their attention focused on the activity but yet be challenged beyond their capabilities (unbalanced skill/challenge (figure 1)), thus be immersed, feel present in the virtual environment, but subsequently not in flow.

It has been argued that the concepts are clearly distinct from each other (Jennett et al., 2008) yet remain complimentary. Research supports the notion that, although these concepts share common themes and factors, they should remain separate. Each term has distinct characteristics that differentiate it from the next; for example, immersion is the only term that presents in variable intensities.

If a system with high immersion capabilities allows interaction with the virtual stimuli, an individual with a propensity to suspend disbelief may become 'engaged' with the VE to the point of feeling present in the VE. If then the factors necessary for a flow state are provided from the VE (appropriate challenge point framework etc.) the system may provide an opportunity to enter a flow state. For example, following a highly immersive 3D interactive VR experience (Cheng, Chieng, & Chieng, 2014), participants completed a questionnaire that was created using previous research on flow (Novak, Hoffman, & Yung, 2000), telepresence (Novak et al., 2000) interactivity (Novak et al., 2000; Steuer, 1992), vividness (Witmer & Singer, 1998), involvement

(Laurent & Kapferer, 1985) and focused attention (Ghani & Deshpande, 1994). The structural model revealed strong ($p<0.001$) support from vividness (immersion) to (tele)presence and from (tele)presence to flow. Thus, the higher the immersion, the greater the feeling of presence which has been shown to facilitate (but not necessary for) a flow state during VR activity.

Therefore, in order to clearly understand the different concepts and how they impact an individual’s virtual experience, it is important for consistent definitions and terminology to be used. Flow, presence and immersion, although sharing similar concepts should remain distinct entities when used in VE literature that at most, facilitate each other.

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Chapter 5: Focus of attention during dynamic postural movements for individuals post-stroke.

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Focus of attention and dynamic postural control in individuals post-stroke.

Authors:

Daniel McEwen, MSc[1, 2], Martin Bilodeau, PhD[1, 2, 3], Heidi Sveistrup, PhD [2,3].

1 *Bruyère Research Institute, 43 Bruyere St., Ottawa, Ontario, Canada, K1N 5C8

2 School of Rehabilitation Sciences, University of Ottawa, Roger-Guindon Hall, 451 Smyth Road, Rm 3071, Ottawa, Ontario, Canada K1H 8M5

3 School of Human Kinetics, University of Ottawa, 25 University, Rm 241, Ottawa, Ontario, Canada, K1N 6N5.

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Corresponding Author:

Heidi Sveistrup, PhD
Bruyère Research Institute
451 Smyth Rd, Room 1123A
Ottawa Ontario, Canada, K1H 8M5
Tel: 613-562-5800 ext 8016
hsveist@uottawa.ca

Abstract

Objective: To test the hypothesis that an external focus of attention produces larger center of pressure (CoP) movements during dynamic postural tasks than an internal focus of attention for individuals post-stroke and to compare these effects to those of healthy age-matched older adults and healthy young adults.

Design: Within-between group comparison.

Setting: Inpatient stroke rehabilitation research laboratory.

Participants: Convenience sample of individuals post-stroke (n=10), healthy older adults (n=10) and healthy young adults (n=10).

Intervention: Not applicable.

Main Outcome Measures: Both the PS and OA groups underwent clinical measures of balance (BERG) and cognition (MoCA). The centre of pressure (CoP) variables included mediolateral (ML) sway velocity (cm/s); mediolateral standard deviation (cm) and total CoP ML range (cm) for the resultant CoP for all three groups. Additionally the outcome measures were repeated for between-limb comparison for the post-stroke group with the addition of average weight-bearing asymmetry.

Results: The post-stroke group had lowest postural stability in both clinical (BERG) and static measures of balance (mean velocity, 95% ellipse area) which was evident with group differences during the dynamic postural tasks. Main effect of focus was found for ML range and ML SD with no post-hoc differences. Average weight-bearing under the paretic limb was greater in the VR task for the post-stroke group.

Conclusions: Maintaining an external focus of attention (as with VR) will elicit greater range and faster movements during dynamic movements, while encouraging increased weight-bearing on the paretic limb post-stroke. Additional studies are needed prior to clinical application.

Key Words: Postural Balance, Stroke, Virtual Reality.

Introduction

A major component of stroke rehabilitation is retraining standing balance. Falls become a primary medical concern after acute stroke (Holloway et al., 2007) and remains a health concern throughout the post-stroke lifespan (Weerdesteyn et al., 2008). Individuals post-stroke are at a high risk of falls following discharge from inpatient rehabilitation (Mackintosh et al., 2005). Therefore, inpatient services must maximize the balance abilities of individuals prior to discharge.

Virtual reality (VR) has been shown to be an effective modality to improve balance and gait impairments during stroke rehabilitation (Laver et al., 2015; McEwen et al., 2014). VR interventions allow the participant to become immersed in a stimulus-rich environment with novel experiences in visual, auditory and even tactile senses. The participant becomes an actor in the environment that may require attention, concentration and interaction with virtual objects and/or virtual people. As such, it is inherent that an individual will remain externally focused on the virtual environment while engaging in a virtual environment.

One potential factor leading to improvements, for example, reduced impairment of the paretic limb following VR training protocols (McEwen et al., 2014), may be related to the influence of an external focus of attention. Remaining focused on the virtual environment rather than internally on how the body is moving, may have led to greater challenge in balance abilities, for example lateral movements and weight-bearing. Increased use (e.g. forced use) of the paretic limb during rehabilitation exercises has been shown to be more effective than traditional rehabilitation in increasing gait and mobility (Yu, Liu, Kuen Wong, & Al., 2015) and may be favored with VR.

In the context of motor learning/performance, remaining externally focused (on the effects of the body's movements) has been shown to be advantageous over an internal focus of attention (focus on the body) (Wulf, 2013). For example, during a golf swing (Wulf & Su, 2007), the player may focus on the movements of their arms and body throughout the swing (internally focused) or they may externally focus on the movement of the club through space to make contact with the ball. This external focus advantage has been supported in basketball free throws (Zachry et al., 2005), standing long-jump (Porter et al., 2012), sprint starts (Ille et al., 2013) as well as a study of balance training for older adults (Chiviacowsky et al., 2010). Also, individuals post-stroke have been shown to improve the immediate maximum lateral body weight shift while in a sitting posture (Mückel & Mehrholz, 2014) when instructed to shift towards a green circle (placed 20 cm lateral from the participant) (external focus task) as opposed to shifting towards their healthy side (internal focus). However, an external focus of attention has not been studied during standing postural tasks for individuals post-stroke.

Therefore, the purpose of this study was to compare the performance, as measured by mediolateral (ML) center of pressure (CoP) variables and the ability to bear weight on the paretic limb, between dynamic standing postural control tasks involving internal and external focus of attention, as well as a VR task in individuals post-stroke (PS). These effects were then compared to those from both a healthy, age-matched control group (OA) and a healthy, young adult group (YA). Three groups were recruited to participate in order to facilitate understanding of how the effects of a stroke and an aging effect impact an individual's lateral movements during the different focus of attention tasks.

Methods

Three groups (n=10 per group) were recruited; post-stroke adults, healthy young adults (18-30 years) and healthy older adults age-matched to the post-stroke group. Data collection for each participant was performed on-site at the Elisabeth Bruyere Hospital (Ottawa, Canada) in one, 1-hour session in the Tony & Elizabeth Graham Virtual Reality Rehabilitation Research and Training Centre. Participants were included in the present study if they 1) were aged 18 or over, 2) could stand unaided for 1 minute at the time of enrolment and 3) could provide informed consent. Participants were excluded if they presented with 1) severe cognitive impairments (unable to follow instructions), 2) an unstable medical condition 3) vestibular deficits, vertigo and/or 4) seizure activity in the previous 6 months. Participants presenting with aphasia were not excluded from this study. The investigator carrying-out the sessions completed the Aphasia Institute online learning module on Supportive Conversation for Adults (SCA) and used these techniques to ensure understanding during tasks. All participants signed informed consent forms approved by the Research Ethics Boards of Bruyère Continuing Care and the University of Ottawa with a modified, aphasia friendly consent form for individuals with aphasia.

Participants in the older adult group and the post-stroke group underwent cognitive and clinical mobility screening prior to the postural tasks. The MOCA Version 3 (Nasreddine et al., 2005) and the Berg Balance test (Berg et al., 1992) were administered for documentation and between group comparisons.

All participants completed 4 postural tasks while standing on two AMTI force platforms; one per foot. Participants were instructed to keep their feet in the same place during and between all trials. All tasks were 1 min long and force platform data were collected at 100 Hz. The first task consisted of 2 trials of quasi-static posture during which the participants were instructed to remain as still as possible while looking at a target 3 m in front of them. Following the 2 static trials, 3 dynamic tasks were performed, 3 times each. The tasks consisted of an internal focus task, external focus task and a VR task and the order of all tasks was counterbalanced.

During the internal task, the participants were asked to look at the same target as was used in the static trial. They laterally moved their body as far as they felt was possible, while still remaining safe. They were asked to maintain their focus internally on where their body is in space.

The external task used the same postural stance while the participants remained focused on a line displayed on the same TV that was used to display the virtual environment which was positioned 3 metres in front of the participants. The line represented a live display of the Fz (vertical force) component extracted from the force plate under the right foot (Figure 1, left). The line was placed in the middle of the screen and was set up to allow the participants to move it from side to side through weight shifting as it scrolled up the screen. As the participant increased weight-bearing on the right platform, the line would follow to the right side of the screen as if it were following the participant (Figure 1, left). The participants remained externally focused on this line as they moved it as far as they felt was possible while still remaining safe.

The final task was the VR task. The Interactive Rehabilitation Exercise software (IREX™; Gesturetek, Toronto, Ont.) (Glegg et al., 2014) was used (Figure 1, right). The system uses green screen technology with a camera to display the participant's image in a virtual environment on a 132cm television. The soccer application was used which displays the participant standing in front of a virtual soccer net. The purpose is to prevent any goals by blocking the ball with his/her body. To prevent confounding factors of arm-use due to paresis, the participants in all groups were asked to keep their arms by their body and just use a postural lean to make the saves.

Before each trial, the participants were reminded of the instructions to ensure understanding and that the focus remained on the proper place. As recommended, the instructions for the internal/external tasks differed in very few words in order to avoid confounds with other variables (Wulf, 2013). The instructions were as follows:

Internal focus of attention: *With your hands by your side, I want you to focus on* ***leaning your body*** *from side to side as far as you can. When you reach the furthest point, please pause for a moment then return to the middle and pause again for a moment before leaning the other direction. Go at a pace that you feel safe and comfortable with.*

External focus of attention*: With your hands by your side, I want you to focus on* ***moving this line*** *from side to side as far as you can. When you reach the furthest point, please pause for a moment then return to the middle and pause again for a moment before leaning the other direction. Go at a pace that you feel safe and comfortable with.*

VR Task: *With your hands by your side, I want you to save as many soccer balls as you can by leaning your body to stop them from going into the net. Always return to the middle after a save.*

To ensure safety, all participants were required to wear a physio belt around the waist. A research associate remained in close proximity to intervene if a fall was possible. All trials were done in bare or stocking feet. Following all dynamic tasks, the participants were asked to rate their perceived level of focus on the instructed task from 0-100%. Any tasks that were reported at less than 75% focus were repeated.

Postural data were collected from the AMTI platforms using Netforce software (Watertown, MA, USA). When a participant reduced the weight on one platform below a 5N threshold, an erroneous signal (noise) would be recorded. Linear interpolation was used to replace the brief (no more than 0.4 seconds) noisy signal segments using BioProc2 version 3.06 (Ottawa, ON, CAN). Resultant CoP outcome measures were derived using MatLab version 7.1 (MathWorks Inc., MA, USA) and included static measures: mean velocity (cm/s), 95% ellipse area (cm^2); and dynamic measures: mediolateral (ML) range (cm), ML mean velocity and ML standard deviation (SD (cm)).

Individual platform analysis was also completed for the post-stroke group to compare the performance of each limb during the various tasks. All aforementioned resultant CoP variables were calculated with the addition of average weight-bearing (Fz) on each limb.

Statistical analysis was performed using SPSS version 20 (Chicago, IL). Group demographics (e.g. age, height, weight) were assessed using a one-way ANOVA with Bonferonni corrections for post-hoc analysis to determine any differences between groups. Differences in clinical data (BERG and MOCA) between the OA and PS groups were tested using independent sample t-tests. Group (3 levels) and condition (3 levels) differences in CoP outcome measures were tested using mixed-model repeated measures ANOVAs. Between-limb analysis for the PS group was done with two-way repeated measures ANOVA. An alpha of 0.05 was used for all analyses. During post-hoc testing, Bonferroni correction for multiple comparison was used adjusting the p-value to 0.016 (0.05/3 comparisons). All results presented are mean ± standard deviation with confidence intervals indicated where appropriate.

Results

Demographics and Clinical Variables

All groups were found to be similar with regards to demographic variables (Table 1), with the exception of an age difference ($p<0.05$) between the YA and both OA (CI -48.09 to -26.51 years) and PS groups (CI -55.08 to -33.51 years). The PS group scored significantly lower on the Berg Balance Scale (44.7± 6.3) than the healthy older adults (55.8 ± 0.6) ($p<0.05$; CI 6.82 to 15.32). There was no difference in MOCA scores between the PS (27.8±0.75) and OA (28.5 ± 1.35) groups ($p=0.165$; CI -0.36 to 1.72).

Static Postural Variables

One-way ANOVAs found significant between-group differences for mean velocity ($F(2,27)=8.44$, $p=0.001$) as well as the 95% ellipse area ($F(2,27)=12.82$, $p<0.001$). Post-hoc analysis found the PS group to have a larger 95% ellipse area than both the YA ($p<0.000$; CI 2.16 cm^2 to 7.46 cm^2) and OA ($p=0.001$; CI 1.60 cm^2 to 6.90 cm^2). The PS group also had a faster mean velocity than the YA group ($p=0.003$; CI 0.46 cm/s to 2.48 cm/s) as well as the OA group ($p=0.007$; CI 0.32 cm/s to 2.34 cm/s) (Figure 2). The OA group was no different than the YA group on either variable.

Post-Stroke Between-Limb Comparison

Results of the two-way repeated measures ANOVA indicated that on average, the PS group placed 49.61% of total body weight on the paretic limb during the VR task which was higher than both the external (45.58%; $p=0.016$; CI 0.94 to 7.13) and internal (45.71%; $p=0.011$; CI 1.17 to 6.88) focus of attention tasks (Figure 3). A main effect between limbs was found for ML velocity ($F(1,9)=10.76$, $p=0.010$) with the paretic limb consistently showing lower velocity than the non-paretic limb. No other task effect or interactions for any variable were statistically significant.

Between Group Comparisons

Two-way mixed-model ANOVAs of CoP variables (Figure 4) found an interaction between group and focus for ML SD (F(2.99,40.30)=5.92, p=0.002). Paired sample t-tests found ML SD to be lower in the VR task as compared to both the internal and external task for both YA ((p<0.001; CI 2.48cm to 4.65cm) and (p<0.001; CI 2.01cm to 4.60cm) respectively) and OA ((p=0.002; CI 0.80cm to 2.62cm) and (p=0.001; CI 0.78cm to 2.26cm) respectively). In contrast, the PS group only showed a trend towards lower ML SD during the VR task as compared to the external focus task (p=0.079; CI -1.51cm to 2.29cm). A main effect for ML SD was found for both focus (F(1.49, 40.30)= 41.72, p<0.001) and group (F(2,27)=21.73, p<0.000) but will not be described further due to the interaction effect. No other significant interactions were found and thus main effects are described below.

A main effect of focus was found for ML range, (F(1.53,42.21)=3.88, p=0.039). However, post-hoc pairwise comparisons with Bonferroni corrections found no significant differences, with only trends depicted between internal and VR ML range (p=0.067; CI -4.26cm to 0.11cm) with greater ML range for the latter task.

In addition, group differences were found for mean velocity (F(2,27)=0.96, p=0.001); ML velocity (F(2,27)=12.69, p<0.000) and ML range (F(2,27)=21.88, p<0.000). Pairwise comparisons indicated that the PS group was continuously lower than both the YA and OA groups on ML velocity (YA: p<0.001, CI -11.07cm/s to -3.51cm/s; OA: p=0.007, CI-8.79cm/s to

-1.23cm/s) and ML range (YA: p<0.001, CI -23.97cm to -10.47cm; OA: p=0.001, CI -18.06cm to -4.55cm). There were no between group differences between YA and OA.

Discussion

This study sought to investigate differences between dynamic postural tasks performed under an internal and external focus of attention as well as a VR task for individuals post-stroke and to compare these differences to those of younger and older adults. The instructions for the internal versus external focus of attention tasks were designed according to suggestions from previous literature (Wulf, 2013) to reduce confounding factors. These two tasks were compared to a task involving another form of external focus, VR. The VR task involved participants playing a game (soccer) that required, on average, the same number of lateral body movements as the internal/external tasks. The VR task was implemented as it represents and ideal method of promoting an external focus of attention during dynamic balance training. Since VR is more stimulating than a simpler external task (e.g. looking at a dot, focused on a line) it may increase the effects of an external focus of attention and thus, warranted investigation.

It was found that the post-stroke participants had poorer postural control in the clinical balance measure (BERG) as compared to the OA group, as well as larger 95% ellipse area and CoP velocity during static postural control when compared to both the OA and YA groups (Figure 2). This altered postural control was also noted in the dynamic tasks as the PS group did not move as fast (ML velocity) or as far (ML range) across the three tasks. Both lower scores on clinical measures as well as an inability to control postural sway in a static posture, specifically higher oscillation frequencies, have been shown to be a strong predictor of falls (i.e. ability to control dynamic postural perturbations) in an older adult population (Lajoie & Gallagher, 2004).

Although no significant correlations have been found when comparing static postural sway to dynamic balance abilities for individuals post-stroke (Cho, Lee, Lee, Lee, & Lee, 2014), decreased dynamic balance ability is correlated with falls post-stroke (Cho & Lee, 2013).

During quiet stance, a significant amount of weight-bearing asymmetry in favor of the non-paretic leg is commonly observed and greater weight-bearing asymmetry has been associated with increased postural sway, specifically larger CoP velocities (Kamphuis et al., 2013) for individuals post-stroke, which was observed in the static trials for this study. As noted previously, the inability to control static posture becomes a major risk factor for falls (Cho & Lee, 2013) which is a common problem post-stroke (Weerdesteyn et al., 2008). In that context, and specifically for the PS group, the VR task decreased weight-bearing asymmetry as compared to the internal and external focus of attention task potentially due to the fact that it is an engaging form of external focus of attention. Therefore, a VR task could be considered an interesting clinical modality for encouraging the use of the paretic limb through increased weight-bearing during dynamic postural training.

Shifting the focus of attention during dynamic movements did impact the participants' ability to achieve the goal of the task: “move your body as far as you can…”. The participants, as a whole, had the greatest ML range during the VR task which represents a greater ability to move further from side to side, as well as a lower ML standard deviation during VR. However, all groups responded the same way. A lack of group differences may indicate that it may be beneficial to use an external focus or VR in the post-stroke population as much as in healthy young and older adults.

The VR task may not have facilitated the largest range possible on every stimulus (i.e. soccer ball) due to variations in gaming parameters as they were set-up according to each participant's abilities in order to facilitate task achievement while still encouraging maximal body leaning. Therefore, not all soccer balls were presented at the maximal lean-point leading to more time spent closer to the trial's average CoP location (centre). This resulted in a decreased ML SD (i.e. CoP variability) in the VR condition as compared to the internal and external focus of attention tasks.

An external focus of attention has been shown to improve movement effectiveness and efficiency (Wulf, 2013), increase postural stability (Rotem-Lehrer & Laufer, 2007) and improve gross motor performance (Zachry et al., 2005). In this study, using an external focus of attention and a VR task did improve task performance as a main effect was found for ML range and encouraged increased weight-bearing on the paretic limb for the post-stroke group.

Study Limitations:

As the PS group was, on average 82.9 days post-stroke with a large variability within that population (± 59.3 days), the applicability of these results to the entire population cannot be made. As with any study that modifies an individual's focus of attention during a task, it is impossible to verify whether or not the individuals remained completely focused on the task or not. To address this, any trial with a self-reported focus of less than 75% of the trial duration were repeated (n=2 trials).

Conclusion

In conclusion, using an external focus of attention/VR task resulted in greater CoP ML range and weight-bearing on the paretic limb compared to using an internal focus of attention.

However, the effects were not as large as reported in previous literature and all three groups (young adults, older adults and post-stroke) generally responded the same way to the change in focus of attention. The VR task provided an engaging form of external focus (Wood et al., 2007), that may retain attention to a greater extent and has been shown to be an effective clinical modality for postural training post-stroke (Laver et al., 2015). Future research should look at the effects of focus of attention in the context of training dynamic movements post-stroke to maximize intervention effectiveness.

		Young Adults	Older Adults	Post-Stroke
Age (y)		25.3 ± 3.9*	61.0 ± 10.9	69.6 ±12.2
Sex		5F/5M	5F/5M	2F/8M
Height (cm)		171.6 ± 9.7	170.4 ± 8.8	169.7 ± 9.8
Weight (kg)		69.8 ± 11.6	72.7 ± 16.2	78.3 ± 14.1
Time Post-Stroke (days)				82.9 ± 59.3
Type of Stroke	**Ischemic**			4 Left, 3 Right
	Haemorrhagic			2 Left, 1 Right

Table 1: Demographic table for all three groups with means ± SD. The groups were not statistically significant on any variable other than age between YA and OA/PS ($p<0.05$). Grey boxes represent data that is not appropriate for that group.

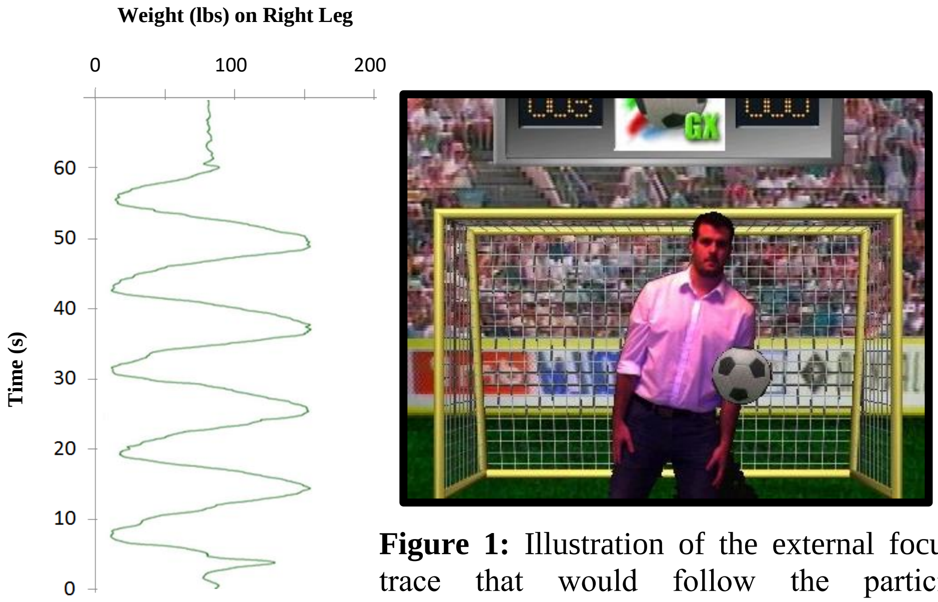

Figure 1: Illustration of the external focus task trace that would follow the participants' movements (on left) which was displayed on the TV screen, with the VR task shown (on right).

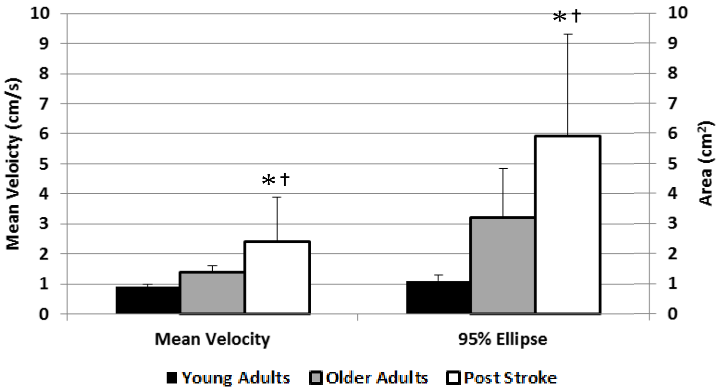

Figure 2: Mean ± standard deviation. During the static trials, the post-stroke group had a larger mean velocity and larger 95% ellipse area of CoP movements. † Indicates significant difference from younger adults while * indicates significant difference from the older adult group.

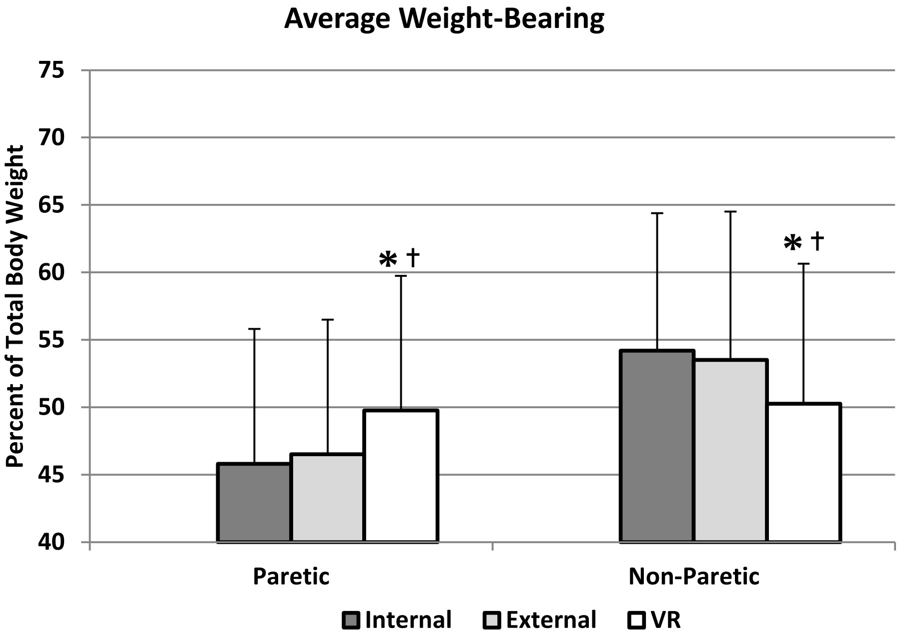

Figure 3: Mean ±SD showing the PS group placing a higher average amount of weight on their paretic limb during the VR task when compared to the internal task (*) and the external task (†).

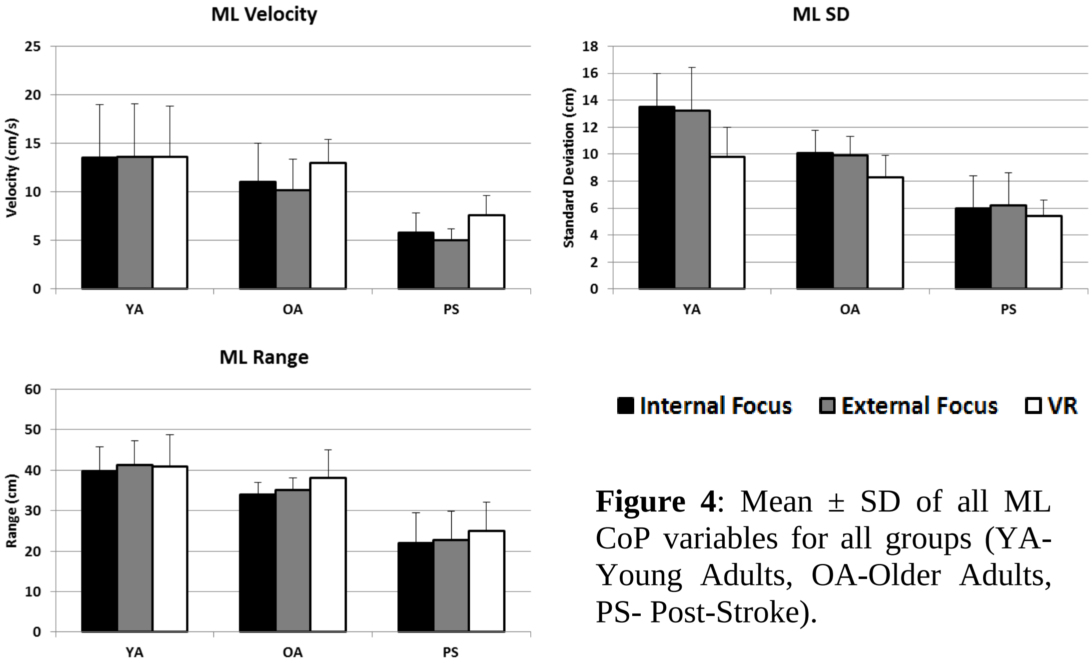

Figure 4: Mean ± SD of all ML CoP variables for all groups (YA-Young Adults, OA-Older Adults, PS- Post-Stroke).

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Chapter 6: General Discussion

This thesis provides novel information on the applicability of virtual reality (VR) as a clinical modality and elucidates potential mechanisms that are likely to contribute to the effectiveness of VR in retraining balance and mobility post-stroke. Three studies and one review of terminology were designed and implemented to quantify changes in balance abilities during VR training while the review sought clarity in definitions of terminology. The data from each of these studies have been addressed in detail in the manuscripts presented in this dissertation and thus, the focus of this discussion section is the integration of the findings with respect to the general aims and hypothesis presented in the introduction section as well as with each other. Finally, future research and conclusions will be highlighted in the last sections of this dissertation.

Virtual Reality as a Clinical Modality

This dissertation assessed the use of virtual reality as a clinical modality as an adjunct to conventional inpatient stroke rehabilitation. At the time study implementation, virtual reality had not been previously studied on an inpatient stroke rehabilitation unit (see literature review table in the introduction). As such, there were numerous victories and challenges to implementation that warrant mention.

The use of hospital space on the units is always a concern. We sought the cooperation of the unit management as well as the close involvement of key stakeholders to be able to have the VR system on the unit. This facilitated visibility of our project to the staff, made participation easier by avoiding long ‘commutes’ to the VR lab for the mobility impaired participants and insured safety of the participants through having medical care staff close by. Our team strongly believes this was an important aspect of the RCT.

Understanding of patient’s needs is the utmost importance to a successful intervention. Individuals post-stroke often struggle with the recent life-altering events that have come upon them. Participation at an intensive inpatient rehabilitation unit is an adjustment period for many individuals as they may not be used to such a high level of daily activity. Therefore, our team ensured patients had at least a week of acclimatization to the unit prior to being approached regarding the study. This also allowed a schedule to be made with the numerous clinicians prior to establishing a VR training schedule. Even when the VR training schedule is set, continued flexibility with patient’s needs (e.g. fatigue, priority of visiting family) or clinician’s needs (e.g. change of time for physiotherapy session) is necessary at the risk of not attaining the research goals of session number or intensity.

Although the technology that was used in study number 1 and 2 is no longer commercially available, the practical knowledge gained can be applied in future studies or clinical settings. Ensuring the collaboration and involvement of key stakeholders of the unit is of utmost importance to successful implementation. Understanding of the needs of the participants can ensure continued participation and enjoyment of the intervention. The field of virtual reality in health care is forever adapting and advancing with new technologies. It may not be advantageous to use the most immersive, head mounted display as individuals may need to remain aware of their surroundings and avoid cybersickness. This dissertation used a camera based VR system that provided patients an enjoyable experience that reduced physical impairment. It is important that the effectiveness, safety and specific components of all VR systems are adequately assessed to facilitate optimal use in clinic.

Effectiveness of VR Training

VR has been shown to be an enjoyable, safe and effective clinical modality for balance and mobility. However, not all participants are responsive to training potentially due to cognitive difficulties with understanding and/or learning the activities. This became apparent in study #1 as the individual had a low MoCA score (12/30) and required instructions before every VR activity. Mr. YZ (client in study #1) did however enjoy the activities and did not experience any negative effects of the VR such as cybersickness, dizziness, loss of balance, or falls.

A low MoCA score indicates cognitive impairment which could present in multiple ways. It seemed as though Mr. YZ had executive function difficulties including maintaining focus of attention during a task. As shown in manuscript #3, sustained attention is necessary for immersion. Understanding the concept of the VE and the method of interaction would facilitate presence and engagement into the task. Without the ability to comprehend, and successfully interact with the VR task, Mr YZ would become distracted during VR play and would not elicit optimal challenge, resulting in minimal improvements on physical outcome measures. A potential lack of memory made it difficult to return to the task when distractions occurred and hindered progressions between sessions.

Study #2 utilized this knowledge for the implementation of a large-scale RCT on the inpatient stroke rehabilitation ward. Participant inclusion criteria ensured participants would be adequate level of cognitive abilities (i.e. ability to provide informed consent). The training protocol proved challenging at times to coordinate with participant’s busy rehabilitation schedule. However, the majority of participants were able to tolerate the increased activity time and found enjoyment during the study.

The purpose of study #2 was to determine whether VR training as an adjunct to conventional inpatient stroke rehabilitation is effective in improving balance and mobility. Clinical measures of balance and mobility (Appendix B) were used to quantify improvements following training and allow comparisons to be made between the two groups. Results indicate that training standing balance in a virtual environment (VE) facilitates improvements in favour of the treatment group on both the TUG and the Two-Minute Walk Test possibly through decreased impairment in the lower extremity as seen by the Chedoke McMaster Stroke Assessment. Improvements on these clinical measures can improve safety and quality of life post-discharge. However, the control group was able to continue improvements post-discharge to eliminate any between group differences. Using a single-blind randomized controlled trial methodology facilitated strong research outcomes to support the conclusions. Both groups were exposed to the same VE and had the same amount of VR exposure time (treatment group=176.6 minutes ± 27.8; control=179.1 minutes ± 14.6; p=0.584) over the same number of sessions (treatment group=9.9 sessions ± 2.2; control=9.8 ± 2.3). Using a seated control group ensured any potential improvements to the outcome measures seen in the treatment group can be attributed to standing VR exercise and not to other factors such as increased daily activities (i.e., travel to and from VR sessions), increased social interactions (i.e., conversation with RA running the training) or exposure to the VE. VR activities for the seated control group were designed to prevent any movements of the core while the treatment group performed standing balance activities that required leaning, reaching and at times, lateral stepping.

Of all the outcome measures used in study #2, the Chedoke McMaster Stroke Assessment (CMSA) (Gowland et al., 1993) leg domain demonstrated the biggest between group differences following training. The CMSA quantifies physical impairment in 6 domains for individuals post-stroke. Scoring is based on 7 stages of motor recovery (expanded from the 6 stages proposed by Brunnström (Brunnström, 1970)). These stages show the progression of a patient's motor rehabilitation as proper levels of tone are restored, spasticity increases (stage 3) and begins to decrease (stage 4) and is resolved (stage 6) to enable the patient to potentially regain full, voluntary function of the affected musculature (stage 7). Although a patient may plateau at any of these stages as recovery slows, recovery patterns will generally follow these stages.

As such, VR training was effective for this population as individuals had adequate levels of tone and synergy patterns were resolving. The pre-intervention CMSA scores for the entire group in study #2 were 5.8 ± 0.46 for the leg domain and 5.3 ± 0.60 for the posture domain. Tasks in the VE encouraged dynamic controlled movements as the participant achieved the VR task that required planned action and movement through space.

Because participants' scores on the CMSA domains range from 5 to 7, the data in study #2 were transformed to a count data set in which a participant's score improved (+1), remained the same (0), or decreased (−1) from before the VR training to POST. The Fisher Exact test for count data indicated more individuals in the treatment group than the control group had improvements on the CMSA Leg domain ($p<0.02$). Using a standing posture during VR training that elicits lateral learning, reaching and stepping to both the paretic and non-paretic side would require increased use/dependence on the affected leg thereby reducing impairment.

Clinical improvements following training did not reach our anticipated levels. We hypothesized both clinically meaningful and statistically significant improvements in favour of the treatment group on multiple outcome measures. For example, the Berg Balance Scale (BBS) was measured for all participants. This is used to measure both static and dynamic balance for individuals with balance impairment by assessing performance of functional tasks. Although all participants had clinically meaningful improvements on the BBS from pre-post, between group differences failed to reach significant levels. Other results indicate that there was a greater improvement in the treatment group, albeit not significant, for the TUG and the TMWT. It is interesting to note that the increase in mobility (TUG) and endurance (TMWT) may have resulted from the reduced impairment of the affected limb as seen by the CMSA as lower limb motor impairment is strongly correlated with post-stroke gait asymmetry (Patterson et al., 2008) Other results indicate that there was a greater improvement in the treatment group, albeit not significant, for the TUG and the TMWT. It is interesting to note that the increase in mobility (TUG) and endurance (TMWT) may have resulted from the reduced impairment of the affected limb as seen by the CMSA as lower limb motor impairment is strongly correlated with post-stroke gait asymmetry (Patterson et al., 2008) Other results indicate that there was a greater improvement in the treatment group, albeit not significant with small effect size, for the TUG ($\eta^2 = 0.038$) and the TMWT ($\eta^2 = 0.030$). It is interesting to note that the increase in mobility (TUG) and endurance (TMWT) may have resulted from the reduced impairment of the affected limb as seen by the CMSA as lower limb motor impairment is strongly correlated with post-stroke gait asymmetry (Patterson et al., 2008). The two groups were not significantly different (p=0.414) on the CMSA prior to the intervention. Correlation analysis from data in study #2 indicated that the Chedoke leg assessment and the TMWT were significantly correlated at pre (.318, p=0.009) and post (.463, p<0.001) and 1-month (.542, p<0.001).

The lack of group differences can be attributed to two limitations of this study. Firstly, it is likely that the study was underpowered. Post-hoc power analysis suggests 20 additional subjects per group would have been required to reach statistical significance. This should be addressed in future studies. Secondly, the training time per session as well as the number of sessions may not have been adequate to elicit physical changes in functional balance abilities. On average, the participants increased their physical activity by just less than 3 hours over an average of 10 sessions. Granted, the participants were undergoing concurrent physical daily therapies which may take them over their pre-stroke physical activity levels. Also, chronic fatigue post-stroke (Wu, Mead, Macleod, & Chalder, 2015) is a major limitation for increased intensity during rehabilitation. However, while the brain is primed for repair, rehabilitation intensity should be stressed to ensure maximal gains. This can possibly be addressed outside of conventional rehabilitation hours (i.e. nights and weekends).

Following discharge from the hospital, the participants in the control group demonstrated continued improvements in balance and mobility, while the treatment group maintained their previous gains, resulting in no statistically significant between-group differences at 1-month post discharge. This may be attributed to the lack of control for continued physical therapies post-discharge from the inpatient unit.

To the best of our knowledge, the RCT in study #2 was the first VR intervention for balance and mobility as an adjunct to conventional inpatient stroke rehabilitation. It can be concluded that, VR as a clinical modality, is effective in reducing physical impairment of the lower extremity for individuals post-stroke undergoing rehabilitation treatment. Reduction in lower extremity impairment can facilitate better participation in ADLs, for example gait. Given the relationship between walking and falls (Lee, Geller, & Strasser, 2013) and the improvement in TUG/TMWT as seen in study #2, a standing VR-exercise training program may be a medium which can contribute to falls prevention in the post-stroke population.

Psychological Involvement in VR Training

Unpublished, qualitative results (Appendix G) from study #2 indicate that participants in both groups highly enjoyed their time spent in the VR lab. A recurring theme in these results show that participants found the sessions to go by very quickly and that they found it hard to believe each game was 2 minutes in length. Direct quotations from this qualitative feedback (Appendix G) indicated:

"*I really enjoy my time in the VR lab. While they get me to focus on specific things in PT and OT, here I just get to play the games….and the time flies by!"*

"I can't believe how fast my VR sessions seem to go."

This obscured knowledge of the passing of time indicates that there are psychological mechanisms at play during VR training.

Manuscript #3 sought to outline these psychological mechanisms and clearly delineate definitions of three terms (flow, presence and immersion) thought to be descriptive of an individual's experience in a VE as well as to provide sample methods for measurement of each term. Although the three terms influence each other, it is concluded that the terms must remain separate entities. In the context of VR, while the flow state describes a subjective, optimal experience during VE exposure, presence remains solely the sense of mentally 'being there' (in a VE) while physically in another place which may all be complimented by objective immersion capabilities of a VR environment.

It is possible that due to the large screen TV with high quality sound as used in study #2 with the IREX system, individuals were immersed into a VE that displayed their image within the VE (Online Supplemental Material for Study #2). Using green screen technology to use the individuals’ images in the VE is advantageous over avatar or object representation as it facilitates a sense of presence in the task. This sense of being within the VE, involves the allocation of attention to the stimuli presented by the VE. The participant builds a convincing mental model of the simulated space. Secondly, the participant accepts the model as their own egocentric viewpoint. Once this is achieved, a virtual state of presence within the VE is created resulting in a distorted passage of time that participants describe in qualitative feedback.

Provided the settings of the virtual tasks are properly established, for example using the challenge point framework (Pollock, Boyd, Hunt, & Garland, 2014) considering both abilities of the learner and the difficulty of the task, a flow state may be achieved during training. This is considered an optimal experience in time with full focus on the virtual task, loss of self-awareness and distortion in time. As mentioned in manuscript #3, VR game-play provides an optimal opportunity to engage in flow as it consists of goal-directed activities that requires attention and concentration to control an active component through first person representation in the VE. Engaging in a flow state may help facilitate both enjoyment and effectiveness during VR training as it may maintain an external focus of attention during dynamic postural movements.

Focus of Attention during VR Training

Upon discharge from the inpatient rehabilitation unit, patients may go home to resume their activities of daily life with remaining post-stroke deficits. Research has suggested that individuals post-stroke are at a higher risk of falls when walking requires high level of cognitive control (i.e. less automatic) due to the inability to complete concurrent tasks while walking (Weerdesteyn et al., 2008; Hyndman & Ashburn, 2004). Therefore, it would be advantageous to enable dynamic balance and mobility to become automatic for individuals post-stroke. This would require training in an environment that engages the individual's attentional resources in a concurrent task which is done while standing. Standing VR training has been shown to be effective in reducing impairments of the lower extremity while increasing mobility (study #2). This may be attributed to the feelings of presence in the VE that, provided the concurrent task is at an optimal challenge point, engages an individual in a flow state (study #3). Maintaining attention on the concurrent task, or externally from the body, has been shown to be effective in motor learning (Wulf, 2013) and may encourage better movements for individuals post-stroke.

Study #4 therefore investigated the effects of an external focus of attention during dynamic lateral postural movements. If a patient's focus is on objects presented in a VE rather than their physical body during training, then their focus can be considered as external (focused on the effects of the movement). Focusing on the movement effect, may encourage the motor system to more naturally self-organize without conscious control attempts. This would result in more effective learning. The alternative, internal focus of attention, would result in “freezing” or “constraining” the degrees of freedom (Vereijken et al., 1992) causing less fluid interactions of body mechanics and less automatic movement execution. This would have a less positive effect on motor performance and motor learning.

As shown in study #3, VEs provide a method for maintaining an external focus of attention during dynamic postural movements. Therefore it can be suggested that an individual post-stroke who is immersed into a VE and encouraged to focus on the events/objects of that VE may have optimal improvements to clinical balance and mobility measures (as seen in study #2) due to the higher efficiency and effectiveness of an external focus of attention. Therefore, the addition of a VR task in study #4 allowed comparison to both an internal and external task.

Although the results of study #4 do not replicate the strength of an external focus of attention as shown in previous work (Mückel & Mehrholz, 2014), positive improvements to the dynamic movements were noted. This previous research using individuals post-stroke found an increased mean lateral seated weight shift from internal focus of attention (4.5 ±3.3 cm) to external focus of attention (8.7 ± 2.6 cm). Participants in study #4 increased the absolute mean lateral weight shift from internal focus of attention (32.19 ± 9.2cm) to external focus of attention (during VR) (34.27 ± 9.7cm).

However, on average, the post-stroke group placed 49.61% of total body weight on the paretic limb during the VR task which was higher than both the external (45.58%; p=0.016; CI 0.94 to 7.13) and internal (45.71%; p=0.011; CI 1.17 to 6.88) focus of attention tasks. This increased weight bearing on the paretic limb during a VR task may illustrate a potential mechanism that facilitated improvements on the CMSA Leg domain in study #2.

It has been proposed that embedding a dynamic postural task within a VR environment for young adults results in distraction from a potential for loss of balance, whereas an internal focus of attention may result in increased fear of falling and underestimation of true ability (Lott et al., 2003). This effect is greatest when immersion was highest (i.e. using a head mounted display over a flat screen IREX software). It is possible that due to a high postural instability as seen by clinical (average BERG =44.7± 6.3) and CoP measures during static posture (i.e. greater 95% ellipse area, higher velocity) of the post-stroke participants in study #4, the fear of falling and avoidance of the paretic side was too great to overcome through an external focus of attention to elicit higher mediolateral CoP range.

Summary

As mentioned in the introduction to this thesis, neuroplastic properties of the brain are what make stroke rehabilitation so effective. Ensuring maximal functional reorganization prior to teaching of compensatory mechanisms facilitates optimal rehabilitation. It has been proposed that "repetitive motor activity alone does not produce functional reorganization…instead we propose that motor skill acquisition or motor learning, is a prerequisite factor in driving representational plasticity." (Plautz, Milliken, & Nudo, 2000). The authors define motor skill learning "…as a change in motor behavior, specifically referring to the increased use of novel, task-specific joint sequences and combinations, resulting from practice and/or repetition". Therefore to improve the lives of individuals post-stroke, the practice of functional motor learning tasks should be encouraged during rehabilitation to drive the neuroplasticity of the injured brain.

VR is an optimal rehabilitation modality for facilitating functional motor learning (Turolla et al., 2013) as it can engage an individual in challenging, novel, functional tasks that require repetition. Training in VEs also has been shown to induce neuroplastic changes which were associated with improved functional motor skill performance (i.e. reaching, self-feeding) (You, Jang, Kim, Kwon, et al., 2005) for children with cerebral palsy as well as improved locomotion for individuals post-stroke (You, Jang, Kim, Hallett, et al., 2005).

In the context of standing balance as a functional motor task, VR can be used to facilitate implicit motor learning, which is defined as “learning which progresses with no or minimal increase in verbal knowledge of movement performance (e.g., facts and rules) and without awareness” (Kleynen et al., 2015). This is in contrast to explicit motor learning as “learning which generates verbal knowledge of movement performance, involves cognitive stages within the learning process and is dependent on working memory involvement” (Kleynen et al., 2015). If the individuals are required to stand during VR training (as the experimental group was in study #2 of this thesis), the attentional resources are consumed by the VR task (i.e. saving a soccer ball) over the balance task at hand. They were provided with no feedback on their balance performance after the VR game was completed. Maintaining an external focus of attention can therefore help facilitate implicit motor learning.

However, implicit motor learning may not be an advantageous strategy for all individuals. When seeking to improve functional motor abilities, various factors must be accounted for including the individual’s abilities, the type of task and the stage of motor learning. In early stages of motor skill development, training utilizes explicit or conscious control which eventually becomes more implicit using an automatic control. Peh, Chow, & Davids (2011) support this notion in that it may be beneficial to adopt a comparative outlook of external and internal foci of attention as a function of skill level. Fitts and Posner’s 3-stage model of motor learning (Figure 2) provides a clear theoretical framework for a comparative attentional approach. Three stages presented are cognitive, associative and autonomous. As rehabilitation continues, the performance becomes more ‘natural’ as the movements are done with less variability resulting in more consistent outcomes.

Three Stages of Motor Learning

STAGE	PROCESS	CHARACTERISTICS	OTHER NAME
Cognitive	Gathering information	Large gains, inconsistent performance	Verbal-motor stage
Associative	Putting actions together	Small gains, disjointed performance, conscious effort	Motor stage
Autonomous	Much time and practice	Performance seems unconscious, automatic and smooth	Automatic stage

Figure 2: Fitts and Posner’s stages of motor recovery progressing from a high cognitive stage to an autonomous stage.

The first cognitive stage requires an internal focus of attention directed to the body segments in question. In a study (Johnson, Burridge, & Demain, 2013) of direct nonparticipation observations of stroke inpatient rehabilitation treatment sessions, it was confirmed that 67% of the statements were internally focused, 22% were externally focused, and 11% were of mixed focus. This internal focus allows the patient to gather the information (cognitive stage) required while attempting to restore the proper levels of tone in the affected periphery.

This is in line with the aforementioned Bernstein model in which the lowest level of tone (to maintain posture) forms the foundation for further movement. Early stroke rehabilitation requires specific training localizing movement to one joint or muscle group which may be accompanied by a high cognitive demand (cognitive stage). The patient may be asked to direct their attention internally towards the specific muscle group being addressed. The movements increase in complexity as tasks are introduced to engage the patient in continued practice.

As the rehabilitation process continues and the number of repetitions increases, the patient should then be encouraged to progress to an associative and eventually autonomous stage of movement to be able to successfully move through the space around them. It is at this stage therefore that implicit motor learning (i.e. utilizing an external focus of attention) should be implemented.

Study #4 manipulated the participant's focus of attention during dynamic postural tasks. Results indicate that individuals post-stroke use the affected limb more during VR tasks than when they are internally focused on their body or externally focused on a line. This may be due to the fact that the VR system immerses them into an environment that they feel present in (study #3). This increased use of the paretic limb while maintaining focus externally on the VR system would involve theoretical constructs of implicit motor learning and assist in negating the fear of destabilization. This increased use of the limb during dynamic tasks during an intensive training program (study #2) has been shown to reduce impairments, which results in better mobilization and gait. Additionally, dynamic balance can become an automatic motor task that alleviates cognitive resources for concurrent tasks. This in turn helps the individual post-stroke to safely return to valued activities of daily living.

Future Research Directions

As identified in this dissertation, virtual reality provides an ideal opportunity to engage someone's focus of attention as they become immersed by the system and may feel present, potentially in flow during VR activity. Therefore, it would have been advantageous to assess presence during the intervention study (manuscript #2). As highlighted in manuscript #3, presence, by definition, requires an individual's concentration and focus. With over 76 participants the use of a presence questionnaire, for example, the 32-item Presence Questionnaire (PQ) (Witmer & Singer, 1998) could facilitate understanding of the psychological mechanism at play during VR activity. It would have then been possible to correlate scores on an individual's sense of presence in the virtual environment and their resulting outcomes on clinical measures. This would facilitate understanding of the 'engaging' term that is constantly used to describe virtual reality and how it impacts outcomes.

A major limitation to study # 2 was the inclusion criteria. The ability to stand unaided for 1 min (necessary for VR standing balance training) proved difficult for a majority (70%) of inpatients at the time of the study. A recent change to the Canadian Best Practice inclusion criteria for inpatient stroke rehabilitation drastically lowers the FIM (Functional Independence Measure) score of inpatients. The average admission FIM score for participants in study #2 was 84.07 ± 15.89. Current criteria states that patients with a FIM between 40 and 80 should be admitted to inpatient therapy. This results in participants with a FIM over 80 (as was included in study #2) referred to outpatient therapy. As such, VR training should be assessed using a lower functioning population perhaps in terms of seated balance training. Improving dynamic seated balance for individuals post-stroke has been shown to be effective and to have positive indications for standing balance (Dean, Channon, & Hall, 2007). Therefore, VR training in a seated position would be more appropriate for the current inpatient population and should be assessed regarding its safety, feasibility and effectiveness. For individuals post-stroke with a higher FIM score (as with the participants in study #2), adoption of a home or community based VR training program may prove effective for maintaining gains or continuing improvements.

VR has been shown to be a safe and effective clinical modality that patients thoroughly enjoyed. Therefore, adoption into clinical practice may prove advantageous. The process of knowledge translation (KT) is defined as “the process by which specific research-based knowledge (science) is implemented in practice.” (Estabrooks, 2003). Therefore a knowledge translation study focused on the proper training of health care providers can ensure smooth uptake of the use of VR for future clinical treatments of patients post-stroke.

A major concern for healthcare providers that were treating the participants on the inpatient ward was that the VR games would induce and encourage potentially harmful movement patterns, specifically during reaching movements using an at-risk shoulder. As the VR environment induces a competitive and engaging task, participants may be overly ambitious to achieve the goal of the game if the settings are not appropriate for that specific participant’s abilities. Ensuring optimal settings would be difficult if VR becomes a home based therapy modality where healthcare providers are not present. Thus, prior to the adoption of VR as a home based exercise program, future research should look at quality of movements during game play and how to ensure improper movements are not elicited perhaps through synchronous supervision by a therapist through live stream observations.

Conclusions

Optimal motor re-learning for individuals post-stroke must be a central goal of stroke rehabilitation. Maximizing a patient’s balance abilities will help prevent falls upon their return to the home environment. Through this thesis, VR has been shown to be an effective modality for decreasing impairment and improving balance which can be observed through clinical and laboratory based assessments of postural control. Due to the immersive nature of VEs, and the technology used for the IREX software, it is possible that participants felt present in the VEs. Provided the settings were optimally set to meet the participant’s abilities, a flow state may have been experienced during VR training. As such, the participants would have had their entire perceptual apparatus focused on the task at hand during dynamic postural movements rather than internally on how or where their body was in space. This may have facilitated larger movements and increased weight bearing on the paretic limb which has been shown to reduce physical impairments. Training in this way would maximize training effectiveness, ultimately improving physical functional abilities and safer participation in day to day activities.

General References for Introduction and Discussion

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Appendices

Appendix A: Literature Search Strategy.

Search Strategy for CINAHL (Cumulative Index to Nursing and Allied Health Literature)

S14 AND S20	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	88
S15 OR S16 OR S17 OR S18 OR S19	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	72,247
TI (postur* OR balanc* OR gait OR walk* OR mobility) OR AB (postur* OR balanc* OR gait OR walk* OR mobility)	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	62,973
(MH "Posture")	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	6,102
(MH "Gait") OR (MH "Gait Disorders, Neurologic") OR (MH "Gait Apraxia") OR (MH "Gait Training")	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	5,427
(MH "Walking")	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	10,950
(MH "Balance, Postural") OR (MH "Balance Training, Physical")	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	7,549
S5 AND S13	Expanders - Apply related words Search modes -	Interface - EBSCOhost Research Databases Search Screen - Advanced Search	353

	Boolean/Phrase	Database - CINAHL	
S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	5,689
TI "video games" OR AB "video games"	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	330
TI wii OR AB wii	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	246
TI wii OR AB "virtual reality"	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	760
TI "virtual reality" OR AB "virtual reality"	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	913
(MH "Therapy, Computer Assisted")	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	2,256
(MH "Video Games")	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	1,524
(MH "Virtual Reality")	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	1,693
S1 OR S2 OR S3 OR S4	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	49,586

TI "cerebrovascular accidents" OR AB "cerebrovascular accidents"	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	224
TI "cerebrovascular accident*" OR AB "cerebrovascular accident*"	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	785
TI stroke OR AB stroke	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	38,937
(MH "Stroke Patients") OR (MH "Stroke") OR (MH "Stroke, Lacunar")	Expanders - Apply related words Search modes - Boolean/Phrase	Interface - EBSCOhost Research Databases Search Screen - Advanced Search Database - CINAHL	36,233

Search Strategy for Medline

Database: Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations and Ovid MEDLINE(R) <1946 to Present>

Search Strategy:

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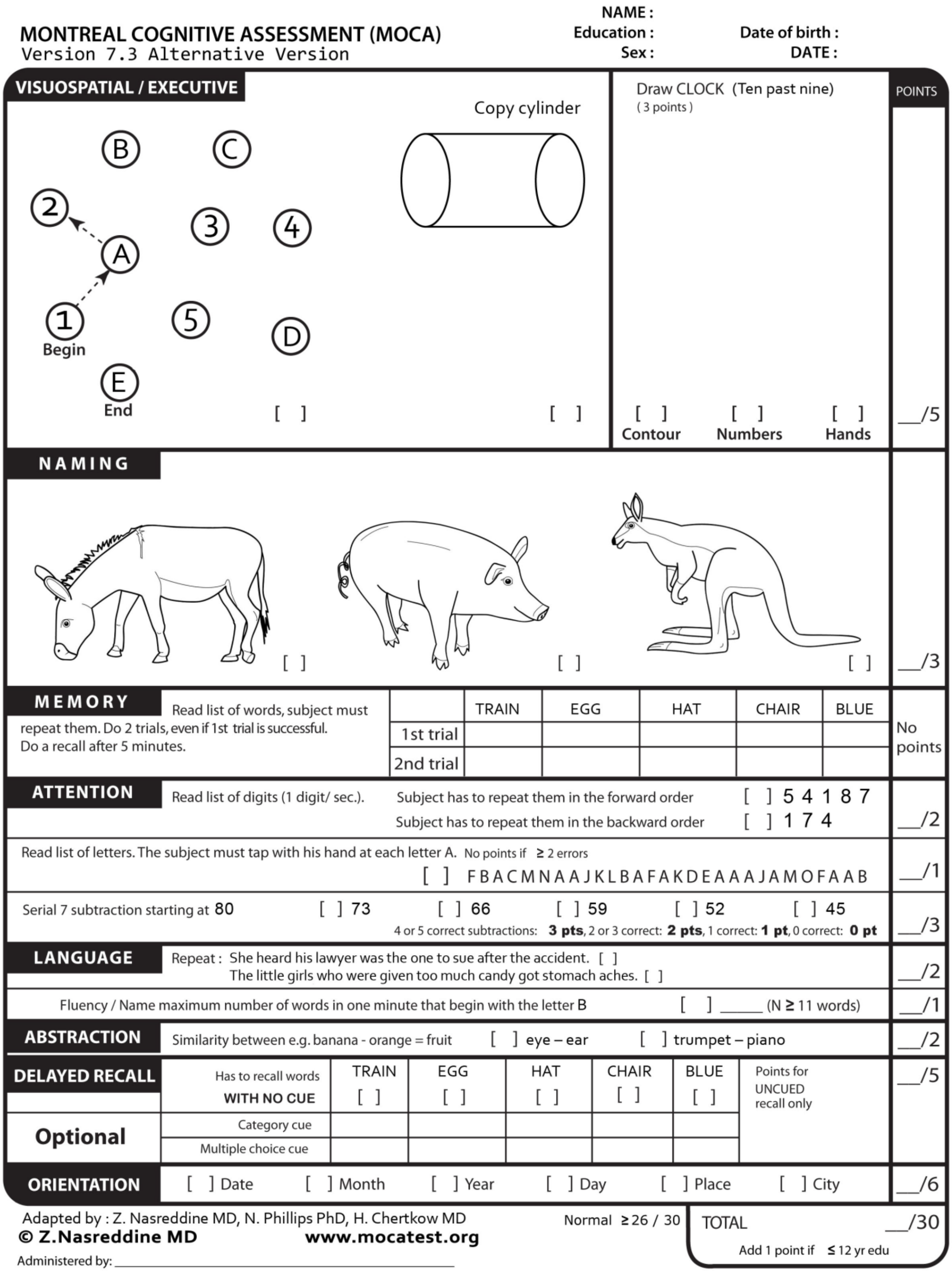
1 exp Stroke/ (96185)
2 cerebrovascular accident*.ti,ab. (5481)
3 stroke.ti,ab. (164998)
4 or/1-3 (199524)
5 virtual reality.ti,ab. (5084)
6 video game*.ti,ab. (1871)
7 wii.ti,ab. (512)
8 Virtual Reality Exposure Therapy/ (210)
9 Therapy, Computer-Assisted/ (5501)
10 Video Games/ (2708)
11 or/5-10 (13900)
12 4 and 11 (637)
13 Postural Balance/ (16237)
14 Walking/ (22545)
15 Gait Apraxia/ or Gait/ or Gait Disorders, Neurologic/ or Gait Ataxia/ (23781)
16 Posture/ or Motor Skills/ (76445)
17 (postur* or balanc* or gait or walk*).ti,ab. (343657)
18 (postur* or balanc* or gait or walk* or mobility).ti,ab. (439730)
19 or/13-18 (505608)
20 12 and 19 (177)
21 Rehabilitation/ (17111)
22 exp Physical Therapy Modalities/ (133929)
23 (physiotherap* or physical therap* or rehabilit*).ti,ab. (144509)
24 or/21-23 (258927)
25 12 and 24 (455)
26 20 or 25 (488)

Appendix B: Clinical Outcome Measures

Montreal Cognitive Assessment (Version3)



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

MONTREAL COGNITIVE ASSESSMENT (MOCA)
`Version 7.3 Alternative Version`

VISUOSPATIAL / EXECUTIVE

[ ]

Copy cylinder

[ ]

Draw CLOCK (Ten past nine)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

POINTS ___/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.

	TRAIN	EGG	HAT	CHAIR	BLUE
1st trial					
2nd trial					

No points

ATTENTION

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

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

Serial 7 subtraction starting at 80 [ ] 73 [ ] 66 [ ] 59 [ ] 52 [ ] 45
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**
___/3

LANGUAGE

Repeat : She heard his lawyer was the one to sue after the accident. [ ]
The little girls who were given too much candy got stomach aches. [ ]
___/2

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

ABSTRACTION

Similarity between e.g. banana - orange = fruit [ ] eye – ear [ ] trumpet – piano
___/2

DELAYED RECALL

		TRAIN	EGG	HAT	CHAIR	BLUE	Points for UNCUED recall only
	Has to recall words **WITH NO CUE**	[ ]	[ ]	[ ]	[ ]	[ ]	
Optional	Category cue						
	Multiple choice cue						

___/5

ORIENTATION

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

Adapted by : Z. Nasreddine MD, N. Phillips PhD, H. Chertkow MD
© Z.Nasreddine MD **www.mocatest.org**
Administered by: ____________________

Normal ≥ 26 / 30

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

Berg Balance Scale

General Instructions

Please demonstrate each task and/or give instructions as written. When scoring, please record the lowest response category that applies for each item.

In most items, the subject is asked to maintain a given position for specific time. Progressively more points are deducted if the time or distance requirements are not met, if the subject's performance warrants supervision, or if the subject touches an external support or receives assistance from the examiner. Subjects should understand that they must maintain their balance while attempting the tasks. The choices of which leg to stand on or how far to reach are left to the subject. Poor judgment will adversely influence the performance and the scoring.

Equipment required for testing are a stopwatch or watch with a second hand, and a ruler or other indicator of 2, 5 and 10 inches (5, 12.5 and 25 cm). Chairs used during testing should be of reasonable height. Either a step or a stool (of average step height) may be used for item #12.

1. Sitting to standing.

INSTRUCTIONS: *Please stand up. Try not to use your hands for support.*
( ) 4 able to stand without using hands and stabilize independently
( ) 3 able to stand independently using hands
( ) 2 able to stand using hands after several tries
( ) 1 needs minimal aid to stand or to stabilize
( ) 0 needs moderate or maximal assist to stand

2. Standing unsupported.

INSTRUCTIONS: *Please stand for two minutes without holding.*
( ) 4 able to stand safely 2 minutes
( ) 3 able to stand 2 minutes with supervision
( ) 2 able to stand 30 seconds unsupported
( ) 1 needs several tries to stand 30 seconds unsupported
( ) 0 unable to stand 30 seconds unassisted

3. Sitting with back unsupported but feet supported on the floor or on a stool.

INSTRUCTIONS: *Please sit with arms folded for 2 minutes.*
( ) 4 able to sit safely and securely 2 minutes
( ) 3 able to sit 2 minutes under supervision
( ) 2 able to sit 30 seconds
( ) 1 able to sit 10 seconds
( ) 0 unable to sit without support 10 seconds

4. Standing to sitting.

INSTRUCTIONS: *Please sit down.*
( ) 4 sits safely with minimal use of hands

( ) 3 controls descent by using hands
( ) 2 uses back of legs against chair to control descent
( ) 1 sits independently but has uncontrolled descent
( ) 0 needs assistance to sit

5. Transfers.

INSTRUCTIONS: *(Arrange chairs(s) for a pivot transfer.) Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.*

( ) 4 able to transfer safely with minor use of hands
( ) 3 able to transfer safely definite need of hands
( ) 2 able to transfer with verbal cueing and/or supervision
( ) 1 needs one person to assist
( ) 0 needs two people to assist or supervise to be safe

6. Standing unsupported with eyes closed.

INSTRUCTIONS: *Please close your eyes and stand still for 10 seconds.*

( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays steady
( ) 0 needs help to keep from falling

7. Standing unsupported with feet together.

INSTRUCTIONS: *Place your feet together and stand without holding.*

( ) 4 able to place feet together independently and stand 1 minute safely
( ) 3 able to place feet together independently and stand for 1 minute with supervision
( ) 2 able to place feet together independently and to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 15 seconds feet together
( ) 0 needs help to attain position and unable to hold for 15 seconds

8. Reaching forward with outstretched arm while standing.

INSTRUCTIONS: *Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward.*

The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)

( ) 4 can reach forward confidently >25 cm (10 inches)
( ) 3 can reach forward >12.5 cm safely (5 inches)
( ) 2 can reach forward >5 cm safely (2 inches)
( ) 1 reaches forward but needs supervision
( ) 0 loses balance while trying/ requires external support

9. Pick up an object from the floor from a standing position.

INSTRUCTIONS: *Pick up the shoe/slipper which is placed in front of your feet.*
( ) 4 able to pick up slipper safely and easily
( ) 3 able to pick up slipper but needs supervision
( ) 2 unable to pick up but reaches 2-5cm (1-2 inches) from slipper and keeps balance independently
( ) 1 unable to pick up and needs supervision while trying
( ) 0 unable to try/needs assist to keep from losing balance or falling

10. Turning to look behind over left and right shoulders while standing.
INSTRUCTIONS: *Turn to look directly behind you over toward left shoulder.*
Repeat to the right. (Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.)
( ) 4 looks behind from both sides and weight shifts well
( ) 3 looks behind one side only other side shows less weight shift
( ) 2 turns sideways only but maintains balance
( ) 1 needs supervision when turning
( ) 0 needs assist to keep from losing balance or falling

11. Turn 360 degrees.
INSTRUCTIONS: *Turn completely around in a full circle. Pause. Then turn a full circle in the other direction.*
( ) 4 able to turn 360 degrees safely in 4 seconds or less
( ) 3 able to turn 360 degrees safely one side only in 4 seconds or less
( ) 2 able to turn 360 degrees safely but slowly
( ) 1 needs close supervision or verbal cueing
( ) 0 needs assistance while turning

12. Placing alternate foot on step or stool while standing unsupported.
INSTRUCTIONS: *Place each foot alternately on the step/stool. Continue until each foot has touched the step/stool four times.*
( ) 4 able to stand independently and safely and complete 8 steps in 20 seconds
( ) 3 able to stand independently and complete 8 steps >20 seconds
( ) 2 able to complete 4 steps without aid with supervision
( ) 1 able to complete >2 steps needs minimal assist
( ) 0 needs assistance to keep from falling/unable to try

13. Standing unsupported one foot in front.
INSTRUCTIONS: *(DEMONSTRATE TO SUBJECT)*
Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject's normal stride width)
( ) 4 able to place foot tandem independently and hold 30 seconds
( ) 3 able to place foot ahead of other independently and hold 30 seconds
( ) 2 able to take small step independently and hold 30 seconds

( ) 1 needs help to step but can hold 15 seconds
( ) 0 loses balance while stepping or standing

14. Standing on one leg.

INSTRUCTIONS: *Stand on one leg as long as you can without holding.*
( ) 4 able to lift leg independently and hold >10 seconds
( ) 3 able to lift leg independently and hold 5-10 seconds
( ) 2 able to lift leg independently and hold = or >3 seconds
( ) 1 tries to lift leg unable to hold 3 seconds but remains standing independently
( ) 0 unable to try or needs assist to prevent fall

ITEM DESCRIPTION SCORE (0-4)

1. Sitting to standing _____
2. Standing unsupported _____
3. Sitting unsupported _____
4. Standing to sitting _____
5. Transfers _____
6. Standing with eyes closed _____
7. Standing with feet together _____
8. Reaching forward with outstretched arm _____
9. Retrieving object from floor _____
10. Turning to look behind _____
11. Turning 360 degrees _____
12. Placing alternate foot on stool _____
13. Standing with one foot in front _____
14. Standing on one foot _____

Date of Assessment: ____________________________

VRRASS Participant Number: ___________________

Time: ____

Circle One:

Pre Post 1 Month

Notes:_____________________________
____
____

Timed Up & Go Test (TUG)

General Information:

- The patient should sit on a standard armchair, placing his/her back against the chair and resting his/her arms chair's arms. Any assistive device used for walking should be nearby.
- Regular footwear and customary walking aids should be used.
- The patient should walk to a line that is 3 meters (9.8 feet) away, turn around at the line, walk back to the chair, and sit down.
- The test ends when the patient's buttocks touch the seat.
- Patients should be instructed to use a comfortable and safe walking speed.
- A stopwatch should be used to time the test (in seconds).

Set-up & Equipment:

- Measure and mark a 3 meter (9.8 feet) walkway
- Place a standard height chair (seat height 46cm, arm height 67cm) at the beginning of the walkway

Patient Instructions:

- Instruct the patient to sit on the chair and place his/her back against the chair and rest his/her arms chair's arms.
- The upper extremities should not be on the assistive device (if used for walking), but it should be nearby.
- Demonstrate the test to the patient.
- When the patient is ready, say "Go"
- The stopwatch should start when you say go, and should be stopped with the patient's buttocks touch the seat.

Date of Assessment: ____________________________

VRRASS Participant Number: __________________

Time: ____

Circle One: Notes:_____________________________

____

Pre Post 1 Month _________________________________

Two Minute Walk Test

General Information:

- Individual walks without assistance for 2 minutes and the distance is measured o start timing when the individual is instructed to “Go”
- Stop timing at 2 minutes
- Assistive devices can be used but should be kept consistent and documented from test to test
- If physical assistance is required to walk, this should not be performed
- A measuring wheel is helpful to determine distance walked should be performed at the fastest speed possible

Set-up and equipment:

- Ensure the hallway free of obstacles
- Stopwatch

Patient Instructions

- “*Cover as much ground as possible over 2 minutes. Walk continuously if possible, but do not be concerned if you need to slow down or stop to rest. The goal is to feel at the end of the test that more ground could not have been covered in the two minutes.”*

Date of Assessment: ____________________________

VRRASS Participant Number: ___________________

Assistive Device Used:__________________________

Distance Walked:______________________________

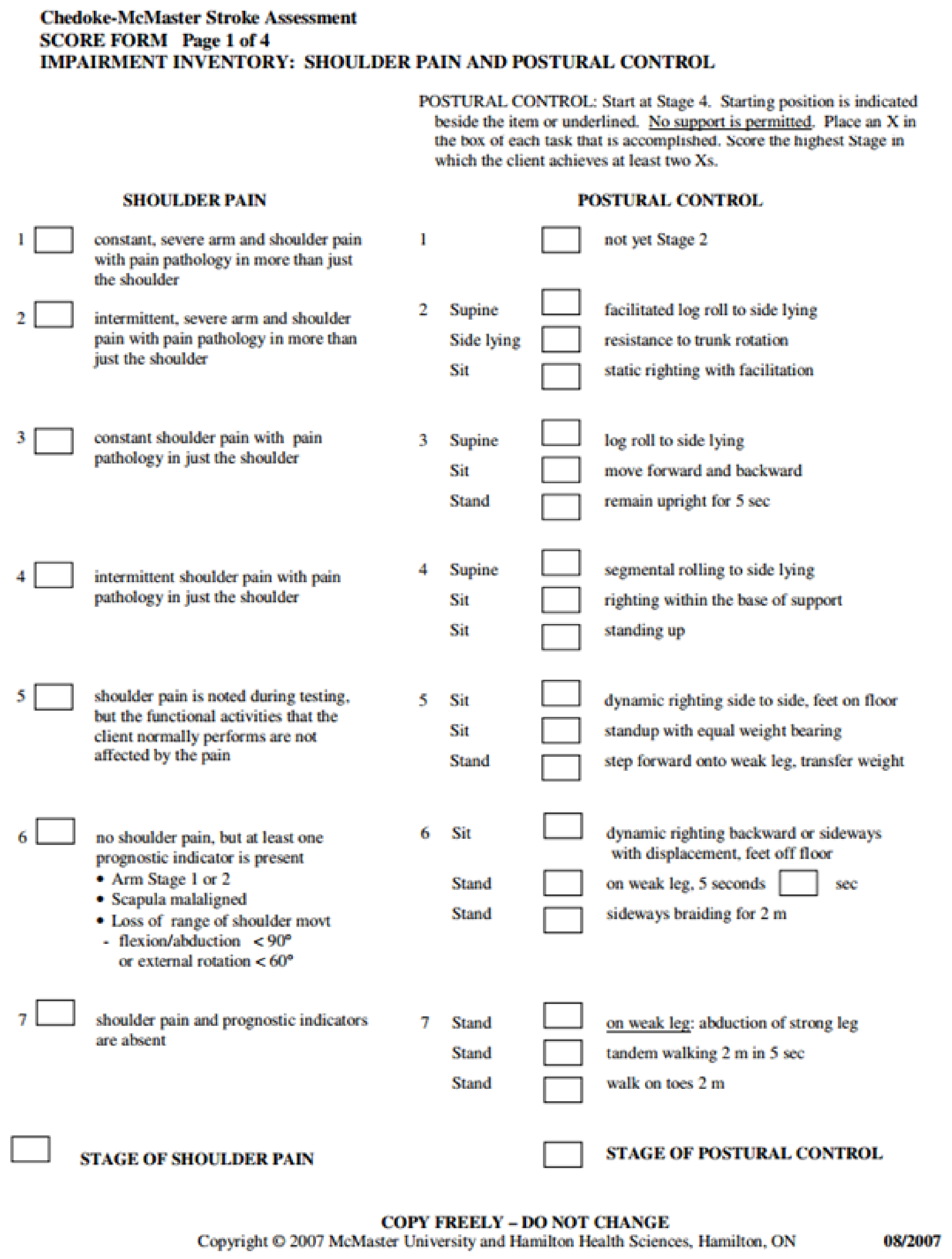
Circle One:

Pre Post 1 Month

Notes:___________________________

____

____



Chedoke-McMaster Stroke Assessment
SCORE FORM Page 1 of 4
IMPAIRMENT INVENTORY: SHOULDER PAIN AND POSTURAL CONTROL

POSTURAL CONTROL: Start at Stage 4. Starting position is indicated beside the item or underlined. No support is permitted. Place an X in the box of each task that is accomplished. Score the highest Stage in which the client achieves at least two Xs.

SHOULDER PAIN

1 ☐ constant, severe arm and shoulder pain with pain pathology in more than just the shoulder

2 ☐ intermittent, severe arm and shoulder pain with pain pathology in more than just the shoulder

3 ☐ constant shoulder pain with pain pathology in just the shoulder

4 ☐ intermittent shoulder pain with pain pathology in just the shoulder

5 ☐ shoulder pain is noted during testing, but the functional activities that the client normally performs are not affected by the pain

6 ☐ no shoulder pain, but at least one prognostic indicator is present
- Arm Stage 1 or 2
- Scapula malaligned
- Loss of range of shoulder movt
  - flexion/abduction < 90°
    or external rotation < 60°

7 ☐ shoulder pain and prognostic indicators are absent

☐ **STAGE OF SHOULDER PAIN**

POSTURAL CONTROL

1		☐	not yet Stage 2
2	Supine	☐	facilitated log roll to side lying
	Side lying	☐	resistance to trunk rotation
	Sit	☐	static righting with facilitation
3	Supine	☐	log roll to side lying
	Sit	☐	move forward and backward
	Stand	☐	remain upright for 5 sec
4	Supine	☐	segmental rolling to side lying
	Sit	☐	righting within the base of support
	Sit	☐	standing up
5	Sit	☐	dynamic righting side to side, feet on floor
	Sit	☐	standup with equal weight bearing
	Stand	☐	step forward onto weak leg, transfer weight
6	Sit	☐	dynamic righting backward or sideways with displacement, feet off floor
	Stand	☐	on weak leg, 5 seconds ☐ sec
	Stand	☐	sideways braiding for 2 m
7	Stand	☐	on weak leg: abduction of strong leg
	Stand	☐	tandem walking 2 m in 5 sec
	Stand	☐	walk on toes 2 m

☐ **STAGE OF POSTURAL CONTROL**

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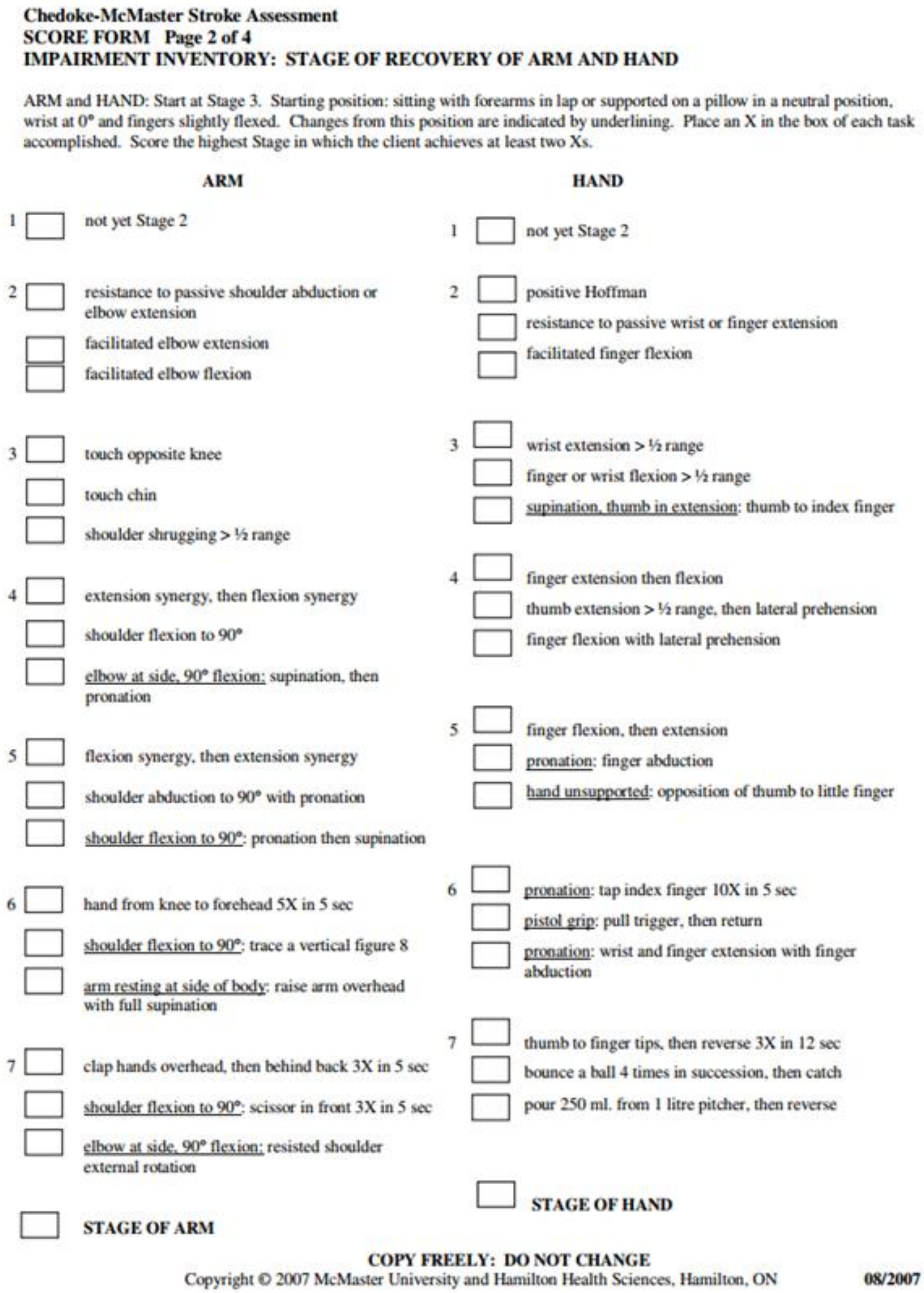

Chedoke-McMaster Stroke Assessment
SCORE FORM Page 2 of 4
IMPAIRMENT INVENTORY: STAGE OF RECOVERY OF ARM AND HAND

ARM and HAND: Start at Stage 3. Starting position: sitting with forearms in lap or supported on a pillow in a neutral position, wrist at 0° and fingers slightly flexed. Changes from this position are indicated by underlining. Place an X in the box of each task accomplished. Score the highest Stage in which the client achieves at least two Xs.

ARM

1 ☐ not yet Stage 2

2 ☐ resistance to passive shoulder abduction or elbow extension
☐ facilitated elbow extension
☐ facilitated elbow flexion

3 ☐ touch opposite knee
☐ touch chin
☐ shoulder shrugging > ½ range

4 ☐ extension synergy, then flexion synergy
☐ shoulder flexion to 90°
☐ elbow at side, 90° flexion: supination, then pronation

5 ☐ flexion synergy, then extension synergy
☐ shoulder abduction to 90° with pronation
☐ shoulder flexion to 90°: pronation then supination

6 ☐ hand from knee to forehead 5X in 5 sec
☐ shoulder flexion to 90°: trace a vertical figure 8
☐ arm resting at side of body: raise arm overhead with full supination

7 ☐ clap hands overhead, then behind back 3X in 5 sec
☐ shoulder flexion to 90°: scissor in front 3X in 5 sec
☐ elbow at side, 90° flexion: resisted shoulder external rotation

☐ **STAGE OF ARM**

HAND

1 ☐ not yet Stage 2

2 ☐ positive Hoffman
☐ resistance to passive wrist or finger extension
☐ facilitated finger flexion

3 ☐ wrist extension > ½ range
☐ finger or wrist flexion > ½ range
☐ supination, thumb in extension: thumb to index finger

4 ☐ finger extension then flexion
☐ thumb extension > ½ range, then lateral prehension
☐ finger flexion with lateral prehension

5 ☐ finger flexion, then extension
☐ pronation: finger abduction
☐ hand unsupported: opposition of thumb to little finger

6 ☐ pronation: tap index finger 10X in 5 sec
☐ pistol grip: pull trigger, then return
☐ pronation: wrist and finger extension with finger abduction

7 ☐ thumb to finger tips, then reverse 3X in 12 sec
☐ bounce a ball 4 times in succession, then catch
☐ pour 250 ml. from 1 litre pitcher, then reverse

☐ **STAGE OF HAND**

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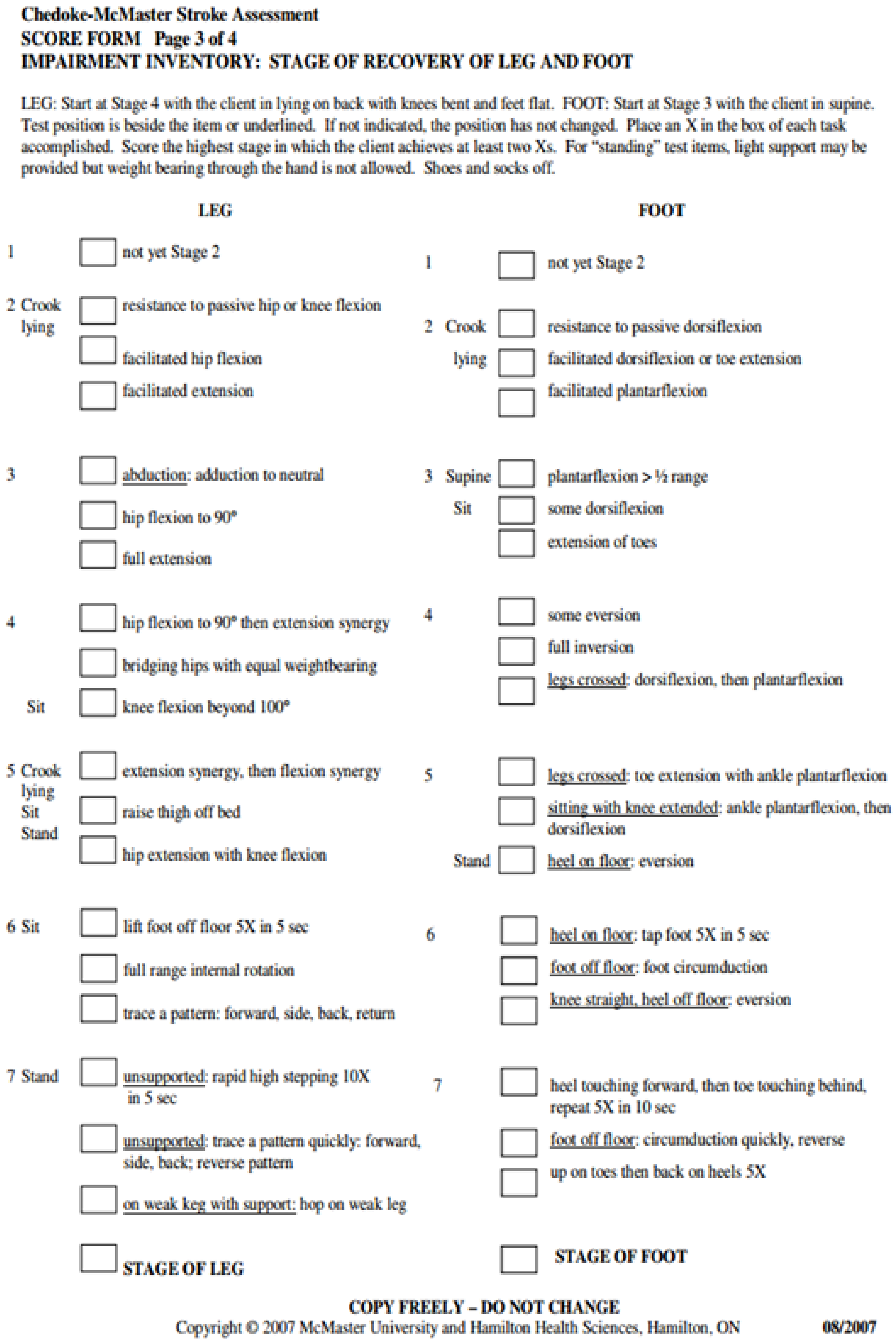

Chedoke-McMaster Stroke Assessment
SCORE FORM Page 3 of 4
IMPAIRMENT INVENTORY: STAGE OF RECOVERY OF LEG AND FOOT

LEG: Start at Stage 4 with the client in lying on back with knees bent and feet flat. FOOT: Start at Stage 3 with the client in supine. Test position is beside the item or underlined. If not indicated, the position has not changed. Place an X in the box of each task accomplished. Score the highest stage in which the client achieves at least two Xs. For "standing" test items, light support may be provided but weight bearing through the hand is not allowed. Shoes and socks off.

	LEG		**FOOT**
1	☐ not yet Stage 2	1	☐ not yet Stage 2
2 Crook lying	☐ resistance to passive hip or knee flexion	2 Crook lying	☐ resistance to passive dorsiflexion
	☐ facilitated hip flexion		☐ facilitated dorsiflexion or toe extension
	☐ facilitated extension		☐ facilitated plantarflexion
3	☐ abduction: adduction to neutral	3 Supine	☐ plantarflexion > ½ range
	☐ hip flexion to 90°	Sit	☐ some dorsiflexion
	☐ full extension		☐ extension of toes
4	☐ hip flexion to 90° then extension synergy	4	☐ some eversion
	☐ bridging hips with equal weightbearing		☐ full inversion
Sit	☐ knee flexion beyond 100°		☐ legs crossed: dorsiflexion, then plantarflexion
5 Crook lying	☐ extension synergy, then flexion synergy	5	☐ legs crossed: toe extension with ankle plantarflexion
Sit	☐ raise thigh off bed		☐ sitting with knee extended: ankle plantarflexion, then dorsiflexion
Stand	☐ hip extension with knee flexion	Stand	☐ heel on floor: eversion
6 Sit	☐ lift foot off floor 5X in 5 sec	6	☐ heel on floor: tap foot 5X in 5 sec
	☐ full range internal rotation		☐ foot off floor: foot circumduction
	☐ trace a pattern: forward, side, back, return		☐ knee straight, heel off floor: eversion
7 Stand	☐ unsupported: rapid high stepping 10X in 5 sec	7	☐ heel touching forward, then toe touching behind, repeat 5X in 10 sec
	☐ unsupported: trace a pattern quickly: forward, side, back; reverse pattern		☐ foot off floor: circumduction quickly, reverse
	☐ on weak keg with support: hop on weak leg		☐ up on toes then back on heels 5X
	☐ **STAGE OF LEG**		☐ **STAGE OF FOOT**

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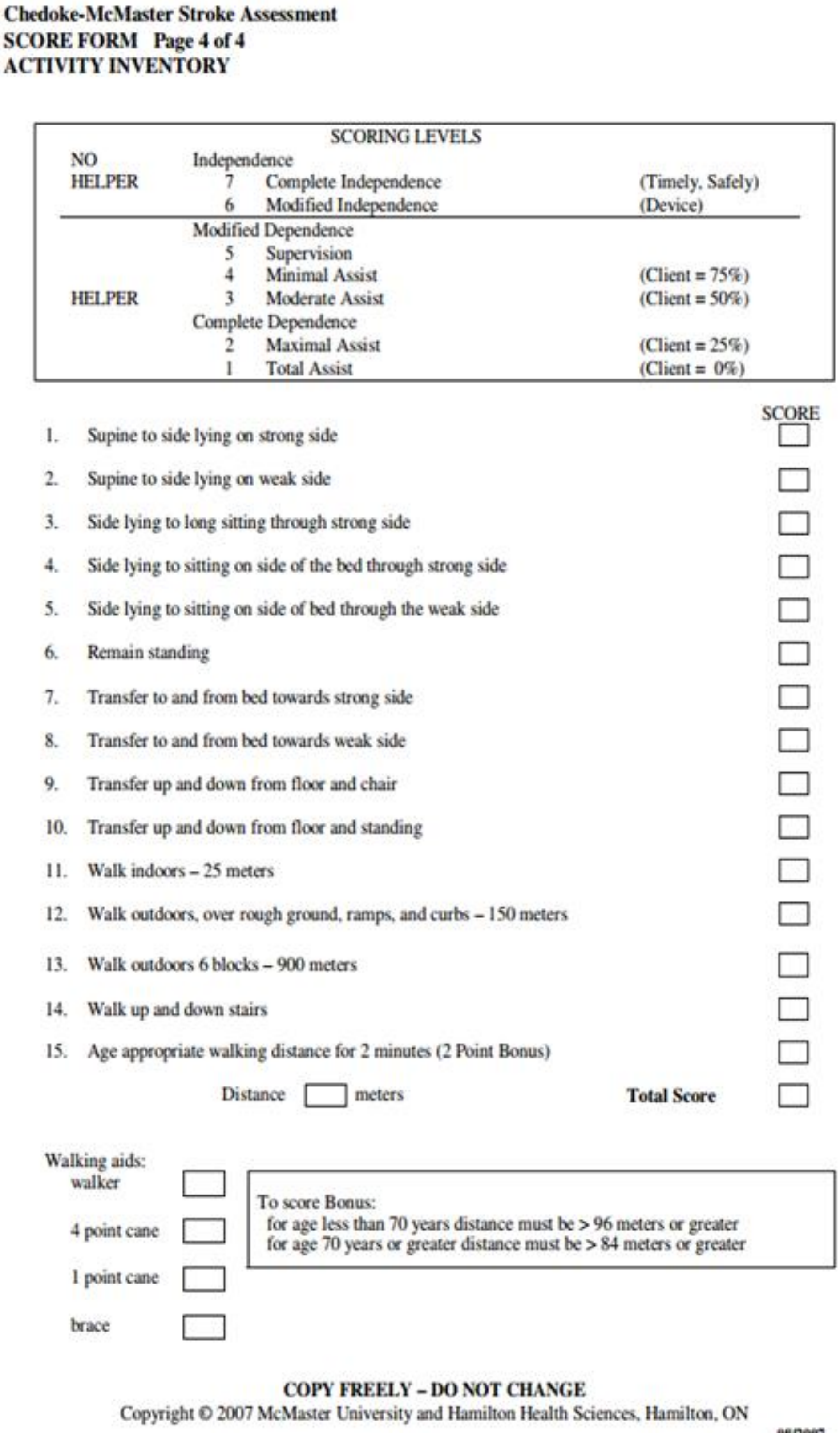

Chedoke-McMaster Stroke Assessment
SCORE FORM Page 4 of 4
ACTIVITY INVENTORY

SCORING LEVELS

NO HELPER	Independence		
	7	Complete Independence	(Timely, Safely)
	6	Modified Independence	(Device)
HELPER	Modified Dependence		
	5	Supervision	
	4	Minimal Assist	(Client = 75%)
	3	Moderate Assist	(Client = 50%)
	Complete Dependence		
	2	Maximal Assist	(Client = 25%)
	1	Total Assist	(Client = 0%)

		SCORE
1.	Supine to side lying on strong side	☐
2.	Supine to side lying on weak side	☐
3.	Side lying to long sitting through strong side	☐
4.	Side lying to sitting on side of the bed through strong side	☐
5.	Side lying to sitting on side of bed through the weak side	☐
6.	Remain standing	☐
7.	Transfer to and from bed towards strong side	☐
8.	Transfer to and from bed towards weak side	☐
9.	Transfer up and down from floor and chair	☐
10.	Transfer up and down from floor and standing	☐
11.	Walk indoors – 25 meters	☐
12.	Walk outdoors, over rough ground, ramps, and curbs – 150 meters	☐
13.	Walk outdoors 6 blocks – 900 meters	☐
14.	Walk up and down stairs	☐
15.	Age appropriate walking distance for 2 minutes (2 Point Bonus)	☐
	Distance ☐ meters **Total Score**	☐

Walking aids:
walker ☐
4 point cane ☐
1 point cane ☐
brace ☐

To score Bonus:
for age less than 70 years distance must be > 96 meters or greater
for age 70 years or greater distance must be > 84 meters or greater

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Appendix C: Information Letter, Consent Form & Ethics for Study #1

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Affilié à l'Université d'Ottawa
Affiliated with the University of Ottawa

Adresse postale
Mailing Address
43, rue Bruyère St.
Ottawa ON K1N 5C8

Bureau central
Corporate Office
Tél./Tel.: 613-562-6045
Téléc./Fax: 613-562-4266

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Palliative Care Education and Research
Tél./Tel.: 613-562-6262 poste/ext. 4008
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Tél./Tel.: 613-562-6045
Téléc./Fax: 613-562-4266

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Consent Form for the Study of Virtual Reality Exercise for Stroke Survivors

Primary Investigator:

Dr. Hillel M. Finestone, MDCM, FRCPC
Medical Director Stroke Rehabilitation
Bruyère Continuing Care, Elisabeth Bruyère Hospital
Élisabeth Bruyère Research Institute
(613)-562-6094, ext. 1358

Co-investigators:

Heidi Sveistrup, PhD.
Vice Dean (Research and Graduate Studies)
University of Ottawa
Élisabeth Bruyère Research Institute
(613)-562-5453

Martin Bilodeau, PhD
Director of the School of Rehabiliation
University of Ottawa
Élisabeth Bruyère Research Institute
(613)-562-6094 ext 1358

Research Team

Dan McEwen, MSc
Graduate Student Researcher
University of Ottawa
Élisabeth Bruyère Research Institute
(613)562-6262, ext. 1451

Anne Taillon-Hobson, PT, MSc
Research Associate, VRRASS
Élisabeth Bruyère Research Institute
(613)562-6262, ext. 1270

Invitation to participate:

You are invited to take part in a research study to see if virtual reality (VR) exercise will improve stroke patients' balance and walking. You have been invited to participate because of your recent stroke, which has affected your balance and walking.

VR exercise — similar to playing a video game, only using the whole body — has been used to rehabilitate patients with stroke and brain injury. Studies of VR exercise in stroke and brain injury patients have been shown to improve balance and walking.

VR exercise has never been tested on stroke in-patients such as you. The goal of this study is to see if VR exercise can improve balance and gait in stroke rehabilitation inpatients.

The VR exercise consists of playing games such as goaltending and snowboarding while sitting or standing. The games will make you move side-to-side, which may train your balance. If your balance improves, the difficulty of the games will be gradually increased as you improve. A research assistant will supervise the activity.

Participation:

Before you start VR exercise, the research assistant will record your age, sex and past medical history from your medical chart. The location of your stroke, type of stroke, and cardiovascular and orthopedic risks for exercise will be collected for the study.

The study will include tests measuring your balance, walking and daily function. These will be conducted three times: three times during the week before you begin the virtual reality training, three times during the week after you finish the virtual reality training and again one month after your completion of the training. These tests will take approximately 1 to 2 hours. During the two-week training period, two of the 7 clinical measures will be conducted daily just prior to your virtual reality training sessions. You will interact with the VR games for a maximum of one hour, five times per week, for a period of two weeks. The VR exercise will be done in addition to any other of your activities or therapies.

Confidentiality:

We will assign you a code so that your name and medical information will remain confidential. Your name will not be identified in any publication or presentation related to this research study.

Benefits:

The likely benefits of taking part include improved balance and walking. Your ability to do your daily tasks such as using the bathroom may improve with better balance. You may have some enjoyment with VR exercise.

Risks:

The risks of taking part include falls, dizziness and chest pain. Studies with VR exercise have shown that the risk of falls is low. Even so, the research assistant will watch you closely to ensure your safety. You are encouraged to stop the game at any time that you feel uncomfortable or unwell. Should you feel unwell, the research assistant will obtain help, and your nurse and physician will be notified.

Voluntary Participation:

Your participation in this study is voluntary, and we respect your right to refuse. There will be no penalty if you decide not to participate. Your treatment at the Élisabeth Bruyère

Hospital will not be affected by this decision. If you decide to participate, you may quit the study at any time, without an explanation.

Questions:

If you would like to discuss this study please feel free to contact the study's research associate, Anne Taillon-Hobson (613-562-6262, ext. 1270). She will be available to discuss the study and answer your questions.

If you have ethical concerns about the study, you may also contact the Chair of the Bruyère Continuing Care Research Ethics Board, Dr. Lisa Sweet (613-562-6262, ext. 1368).

At the end of the study we will send you a summary of our findings. You are welcome to contact us then to discuss issues relating to those findings.

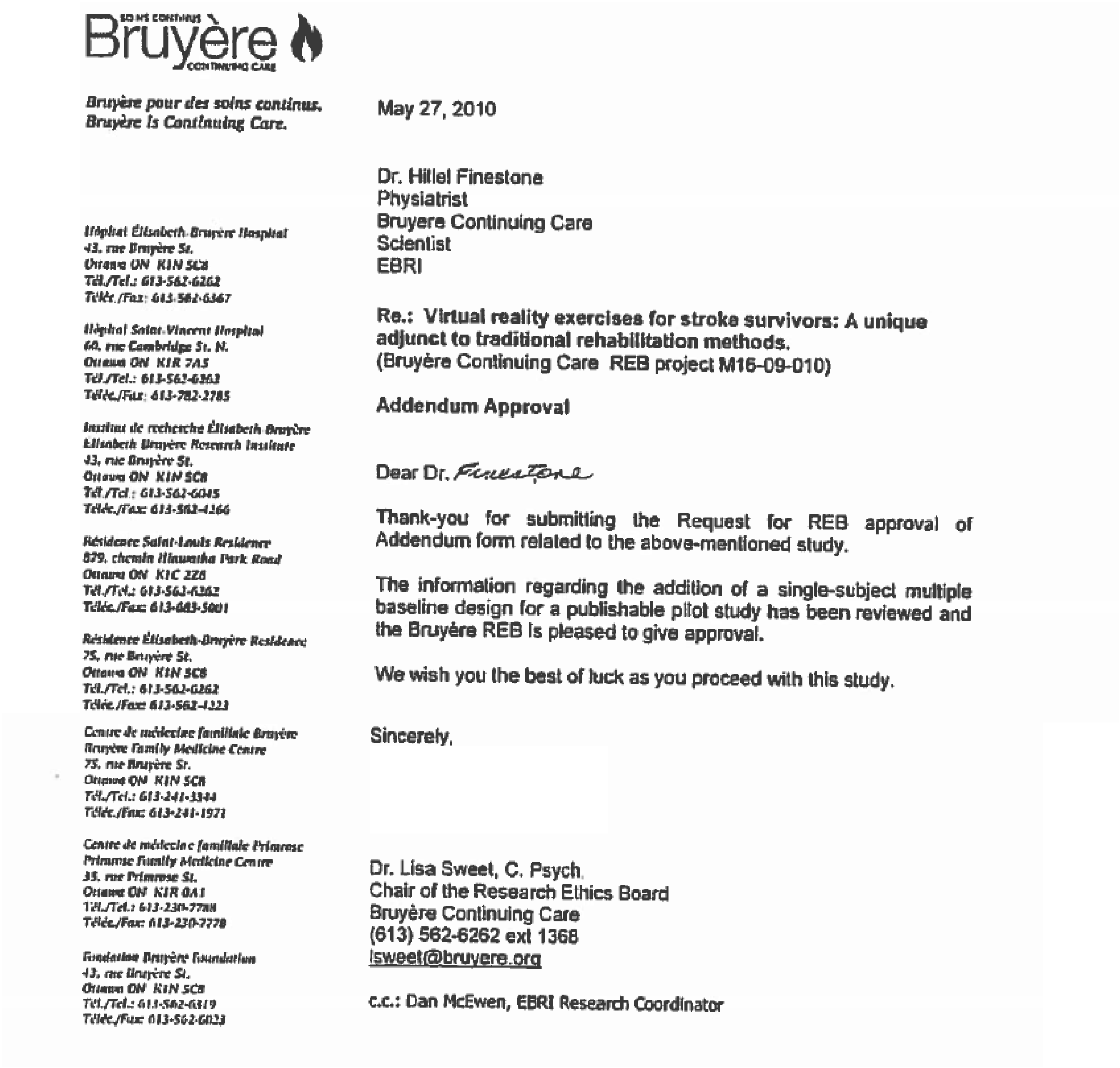
We will provide you with a copy of this form upon request.

CONSENT

I, ________________________________, voluntarily consent to participate in this research study as described above. I have had a chance to ask questions about the study, and all my questions have been answered to my satisfaction.

____ ______ / ____ / ____
Signature of participant *yyyy mm dd*

____ ______ / ____ / ____
Signature of researcher *yyyy mm dd*



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Hôpital Élisabeth-Bruyère Hospital
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-562-6367

Hôpital Saint-Vincent Hospital
60, rue Cambridge St. N.
Ottawa ON K1R 7A5
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-782-2785

Institut de recherche Élisabeth-Bruyère
Elisabeth Bruyère Research Institute
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6045
Téléc./Fax: 613-562-4266

Résidence Saint-Louis Residence
879, chemin Hiawatha Park Road
Ottawa ON K1C 2Z6
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-683-5001

Résidence Élisabeth-Bruyère Residence
75, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-562-4223

Centre de médecine familiale Bruyère
Bruyère Family Medicine Centre
75, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-241-3344
Téléc./Fax: 613-241-1971

Centre de médecine familiale Primrose
Primrose Family Medicine Centre
35, rue Primrose St.
Ottawa ON K1R 0A1
Tél./Tel.: 613-230-7788
Téléc./Fax: 613-230-7778

Fondation Bruyère Foundation
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6319
Téléc./Fax: 613-562-6023

May 27, 2010

Dr. Hillel Finestone
Physiatrist
Bruyere Continuing Care
Scientist
EBRI

Re.: Virtual reality exercises for stroke survivors: A unique adjunct to traditional rehabilitation methods.
(Bruyère Continuing Care REB project M16-09-010)

Addendum Approval

Dear Dr. Finestone

Thank-you for submitting the Request for REB approval of Addendum form related to the above-mentioned study.

The information regarding the addition of a single-subject multiple baseline design for a publishable pilot study has been reviewed and the Bruyère REB is pleased to give approval.

We wish you the best of luck as you proceed with this study.

Sincerely,

Dr. Lisa Sweet, C. Psych.
Chair of the Research Ethics Board
Bruyère Continuing Care
(613) 562-6262 ext 1368
lsweet@bruyere.org

c.c.: Dan McEwen, EBRI Research Coordinator

Appendix D: Information Letter, Consent Form & Ethics for Study #2

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RESEARCH INSTITUTE
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Consent Form for the Study of Virtual Reality Exercise for Stroke Survivors

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Medical Director Stroke Rehabilitation
Bruyère Continuing Care, Elisabeth Bruyère Hospital
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Participation:

Before you start VR exercise, the research assistant will record your age, sex and past medical history from your medical chart. The location of your stroke, type of stroke, and cardiovascular and orthopedic risks for exercise will be collected for the study.

The study will include tests measuring your balance, walking and daily function. These will be conducted three times: once at the beginning of the study, once before your discharge from the hospital and once after you have been discharged for a month. These tests will take approximately 1 or 2 hours. During the training period, you will interact with the VR games for a maximum of one hour, daily, for a period of three to four weeks, to a maximum of 10 to 12 sessions. The VR exercise will be done in addition to your current therapies. During the VR training we would like to videotape you playing the games at the beginning, during the training and at the end of training sessions. You can refuse to be videotaped and still participate in the VR training sessions.

You will be randomly placed in the experimental group or the control group (which is similar to the experimental group). You will not be told which group you belong to.

Confidentiality:

We will assign you a code so that your name and medical information will remain confidential. Your name will not be identified in any publication or presentation related to this research study.

Benefits:

The likely benefits of taking part include improved balance and walking. Your ability to do your daily tasks such as using the bathroom may improve with better balance. You may have some enjoyment with VR exercise.

Risks:

The risks of taking part include falls, dizziness and chest pain. Studies with VR exercise have shown that the risk of falls is low. Even so, the research assistant will watch you closely to ensure your safety. You are encouraged to stop the game at any time that you feel uncomfortable or unwell. Should you feel unwell, the research assistant will obtain help, and your nurse and physician will be notified.

Voluntary Participation:

Your participation in this study is voluntary, and we respect your right to refuse. There will be no penalty if you decide not to participate. Your treatment at the Élisabeth Bruyère Hospital will not be affected by this decision. If you decide to participate, you may quit the study at any time, without an explanation.

Questions:

If you would like to discuss this study please feel free to contact the study's research associate, Anne Taillon-Hobson (613-562-6262, ext. 1270). She will be available to discuss the study and answer your questions.

If you have ethical concerns about the study, you may also contact the Chair of the Bruyère Continuing Care Research Ethics Board, Dr. Lisa Sweet (613-562-6262, ext. 1368).

At the end of the study we will send you a summary of our findings. You are welcome to contact us then to discuss issues relating to those findings.

We will provide you with a copy of this form upon request.

CONSENT

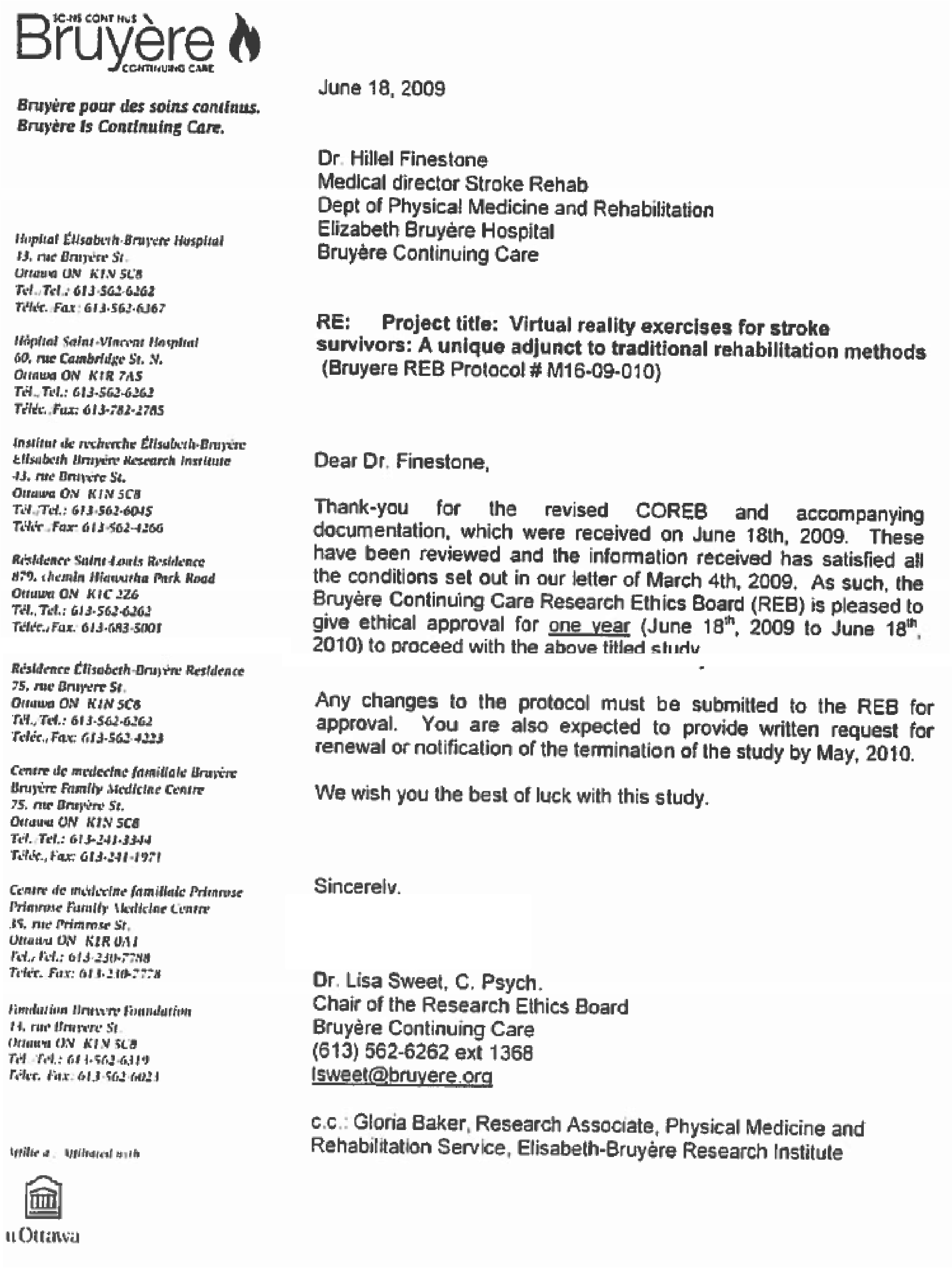
I, _________________________________, voluntarily consent to participate in this research study as described above. I have had a chance to ask questions about the study, and all my questions have been answered to my satisfaction.

____ ______ / ____ / ____

Signature of participant *yyyy mm dd*

____ ______ / ____ / ____

Signature of researcher *yyyy mm dd*



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Hôpital Élisabeth-Bruyère Hospital
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél., Tel.: 613-562-6262
Téléc., Fax: 613-562-6367

Hôpital Saint-Vincent Hospital
60, rue Cambridge St. N.
Ottawa ON K1R 7A5
Tél., Tel.: 613-562-6262
Téléc., Fax: 613-782-2785

Institut de recherche Élisabeth-Bruyère
Elisabeth Bruyère Research Institute
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél., Tel.: 613-562-6045
Téléc., Fax: 613-562-4266

Résidence Saint-Louis Residence
879, chemin Hiawatha Park Road
Ottawa ON K1C 2Z6
Tél., Tel.: 613-562-6262
Téléc., Fax: 613-683-5001

Résidence Élisabeth-Bruyère Residence
75, rue Bruyère St.
Ottawa ON K1N 5C8
Tél., Tel.: 613-562-6262
Téléc., Fax: 613-562-4223

Centre de médecine familiale Bruyère
Bruyère Family Medicine Centre
75, rue Bruyère St.
Ottawa ON K1N 5C8
Tél., Tel.: 613-241-3344
Téléc., Fax: 613-241-1971

Centre de médecine familiale Primrose
Primrose Family Medicine Centre
35, rue Primrose St.
Ottawa ON K1R 0A1
Tél., Tel.: 613-230-7788
Téléc., Fax: 613-230-7778

Fondation Bruyère Foundation
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél., Tel.: 613-562-6319
Téléc., Fax: 613-562-6023

Affilié à / Affiliated with

uOttawa

June 18, 2009

Dr. Hillel Finestone
Medical director Stroke Rehab
Dept of Physical Medicine and Rehabilitation
Elizabeth Bruyère Hospital
Bruyère Continuing Care

RE: Project title: Virtual reality exercises for stroke survivors: A unique adjunct to traditional rehabilitation methods (Bruyere REB Protocol # M16-09-010)

Dear Dr. Finestone,

Thank-you for the revised COREB and accompanying documentation, which were received on June 18th, 2009. These have been reviewed and the information received has satisfied all the conditions set out in our letter of March 4th, 2009. As such, the Bruyère Continuing Care Research Ethics Board (REB) is pleased to give ethical approval for one year (June 18th, 2009 to June 18th, 2010) to proceed with the above titled study

Any changes to the protocol must be submitted to the REB for approval. You are also expected to provide written request for renewal or notification of the termination of the study by May, 2010.

We wish you the best of luck with this study.

Sincerely,

Dr. Lisa Sweet, C. Psych.
Chair of the Research Ethics Board
Bruyère Continuing Care
(613) 562-6262 ext 1368
lsweet@bruyere.org

c.c.: Gloria Baker, Research Associate, Physical Medicine and Rehabilitation Service, Elisabeth-Bruyère Research Institute

Appendix E: Study #2 Trial Registry

Trial registered on ANZCTR

https://www.anzctr.org.au/Trial/Registration/TrialReview.aspx?id=364464&isReview=true

Trial ID

ACTRN12613000710729

Ethics application status

Approved

Date submitted

26/06/2013

Date registered

28/06/2013

Type of registration

Retrospectively registered

Titles & IDs

Public title

Virtual Reality Rehabilitation After Stroke Study

Scientific title

Virtual reality (VR) training in a standing posture as an adjunct to conventional in-patient rehabilitation to improve balance for individuals post-stroke as compared to seated VR training.

Secondary ID [1]

None

Universal Trial Number (UTN)

Trial acronym

VRRASS

Linked study record

Health condition

Health condition(s) or problem(s) studied:

Stroke

Balance, gait and functional independence.

Condition category

Condition code

Physical Medicine / Rehabilitation

Physiotherapy
Stroke
Haemorrhagic
Stroke
Ischaemic

Intervention/exposure

Study type

Interventional

Description of intervention(s) / exposure

Training was done with a virtual reality system (IREX) in a standing posture to work balance, reaching and mobility. Participants completed 10 sessions (roughly 1 hour long) which provided them with 10 to 33 minutes of actual playing time due to rests. Sessions were booked daily throughout the week for 2 consecutive weeks. Games were selected to challenge standing weight-bearing and transfer as well as controlled shifting of the centre of mass. For example, participants were in a virtual soccer net and were instructed to save the virtual soccer balls that appeared on the screen by leaning side to side and reaching to save the balls. Participants were supervised by a registered kinesiologist who ensured proper training levels and closely monitored participants by standing arms reach away from the physio belt around the participant’s waist at all times to ensure no falls. Daily VR training sheets were completed to monitor progression in the games, amount of time spent playing games as well as adherence to the program.

Intervention code [1]

Rehabilitation

Comparator / control treatment

Participants in the control group completed daily (Monday-Friday) sessions for 2 weeks for a total of 10 sessions (each roughly 1 hour long) with the same virtual reality system (IREX) as the intervention group, but participated in a seated position. Interactions with virtual objects by participants in the control group did not challenge balance and was limited to movements that did not shift the base of seated support. Sessions were monitored by a registered kinesiologist to ensure limited movements but yet and enjoyable, safe time for participants. Daily VR training sheets were completed to monitor progression in the games, amount of time spent playing games as well as adherence to the program.

Control group

Active

Outcomes

Primary outcome [1]

Timed Up & Go

Timepoint [1]

Before training, immediately after the completion of training and 1-month after training.

Secondary outcome [1]

Two Minute Walk Test

Timepoint [1]

Before training, immediately after the completion of training and 1-month after training.

Secondary outcome [2]

Chedoke McMaster Stroke Assessment

Timepoint [2]

Before training, immediately after the completion of training and 1-month after training.

Eligibility

Key inclusion criteria

1) aged 18 or over;
2) admitted to the in-patient stroke rehabilitation program;
3) could stand unaided for 1-minute at the time of enrollment into the project
4) could provide informed consent.

Minimum age

18 Years

Maximum age

99 Years

Gender

Both males and females

Can healthy volunteers participate?

No

Key exclusion criteria

1) severe cognitive impairments (unable to follow instructions);
2) an unstable medical condition
3) vestibular deficits, vertigo or
4) seizure activity in the last 6 months

Study design

Purpose of the study

Treatment

Allocation to intervention

Randomised controlled trial

Procedure for enrolling a subject and allocating the treatment (allocation concealment procedures)

The recruitment process involved the introduction of the study to a suitable patient by the admitting physician and/or primary care nurse. The patient then gave verbal permission to be contacted by the study's research associate (RA) to hear further details about the project. Written consent was obtained after detailing the study’s protocol and requirements and the patient’s chart was consulted for relevant medical and demographical information. The participant's information was then sent through email to an off-site researcher for central randomisation. The group allocation was then only sent to the kinesiologist that would be doing the training.

Methods used to generate the sequence in which subjects will be randomised (sequence generation)

Randomization of the first 37 participants occurred using the coin flip method while the second half were additionally randomized using age and Berg Balance Scale score to minimize of group differences. Both the RA and the participants were blind to the study’s group allocation to safeguard against any potential bias.

Masking / blinding

Blinded (masking used)

Who is / are masked / blinded?

The people receiving the treatment/s

The people assessing the outcomes

Intervention assignment

Parallel

Other design features

Phase

Not Applicable

Type of endpoint(s)

Efficacy

Recruitment

Anticipated date of first participant enrolment

2/05/2011

Actual date of first participant enrolment

24/05/2011

Anticipated date last participant enrolled

6/05/2013

Actual date last participant enrolled

12/03/2013

Anticipated date of last data collection

Actual date of last data collection

Target sample size

60

Actual sample size

Recruitment status

Completed

Recruitment outside Australia

Country [1]

Canada

State/province [1]

Ontario

Funding & Sponsors

Funding source category [1]

Charities/Societies/Foundations

Name [1]

The Heart and Stroke Foundation of Ontario

Address [1]

2300 Yonge Street, Suite 1300
PO Box 2414
Toronto, Ontario M4P 1E4

Country [1]

Canada

Funding source category [2]

Other Collaborative groups

Name [2]

Centre For Stroke Recovery

Address [2]

451 Smyth Rd
Ottawa, ON K1H 8M5

Country [2]

Canada

Funding source category [3]

Other Collaborative groups

Name [3]

Tony & Elisabeth Graham

Address [3]

43 Bruyere St.
Ottawa, Ontario
K1N 5C8

Country [3]

Canada

Primary sponsor type

Individual

Name

Dr. Hillel Finestone

Address

Bruyere Research Institute
43 Bruyere St.
Ottawa, Ontario
K1N 5C8

Country

Canada

Secondary sponsor category [1]

None

Name [1]

Address [1]

Country [1]

Ethics approval

Ethics application status

Approved

Ethics committee name [1]

Research Ethics Board at Bruyere Continuing Care

Ethics committee address [1]

43 Bruyere St.
Ottawa, Ontario
K1N 5C8

Ethics committee country [1]

Canada

Date submitted for ethics approval [1]

Approval date [1]

10/07/2009

Ethics approval number [1]

Summary

Brief summary

Virtual reality exercise therapy — similar to participating in a video game, only using the whole body — has been used for rehabilitation of stroke, spinal cord injury, Parkinson’s disease and traumatic brain injury. It has been shown to improve balance in patients with traumatic brain injuries and older adults. Studies of virtual reality training in stroke patients have shown similar benefits for balance and walking. The objective of this study is to compare the effects of training in a virtual environment in two positions (seated vs standing) while participants are also doing in-patient stroke rehabilitation. We hypothesize that virtual reality exercise therapy improves balance, weight bearing on the affected side, walking tolerance and certain aspects of function for those that train standing up. We also hypothesize that it is a safe and enjoyable activity for addition to the stroke rehabilitation program.

Trial website

Trial related presentations / publications

Public notes

Contacts

Principal investigator

Name

Dr Hillel Finestone

Address

Department of Physical Medicine and Rehabilitation
Bruyere Continuing Care
43 Bruyere St
Ottawa, Ontario
K1N 5C8

Country

Canada

Phone

(+1-613-562-6262)

Fax

Email

hfinestone@bruyere.org

Appendix F: Information Letter, Consent Form & Ethics for Study #4

INFORMATION LETTER AND CONSENT FORM

FOCUS OF ATTENTION DURING LATERAL REACHING

INVESTIGATORS:

Dan McEwen PhD (c)
Bruyère Research Institute
613-562-6262 ext. 1451

Martin Bilodeau, Ph. D., PT
Bruyère Research Institute, School of Rehabilitation Sciences, Faculty of Health Sciences, University of Ottawa
(613)-562-6262, ext. 1358

Heidi Sveistrup PhD
School of Rehabilitation Sciences, Faculty of Health Sciences, University of Ottawa
613-562-5800 ext. 8016

Hillel Finestone, MDCM, FRCPC
Bruyère Research Institute.
Tel: 613-562-6094

Invitation to participate: I am invited to take part in the study cited above done by the people cited in the section *investigators.* I am a) a stroke survivor or b) a healthy older adult or c) healthy young adult.

Purpose of this study: The purpose of this study is to assess and compare the effects of two focus of attention methods on how we control our balance.

Participation: If I agree to take part, it will be for one visit to the Tony & Elisabeth Virtual Reality Research Centre (441D). The visit will last about one hour. The session will proceed as follows:

1) First, my cognitive abilities will be tested with the Montreal Cognitive Assessment (MoCA). If I do not score 26 or higher, I will not be able to participate in this study.
2) Secondly, my balance will be scored with the clinical tool called the Berg Balance Scale.
3) Thirdly, my balance in a comfortable stance will be tested. I will be asked to stand as still as possible for 2 bouts of 30 seconds.
4) I will then be asked to reach my hands from side to side to test my balance. This will be done using two ways:
    a. Focus on leaning my body as far as possible from side to side.
    b. Focus on moving a line on a screen as far as possible from side to side.
5) Both tasks will be done at a pace that is comfortable for me for 1 minute. Each task will be done 3 times before going on to the next task.
6) I will also be asked to play a virtual reality game called soccer. I will be a goalie in the net. I will try to stop as many soccer balls with my body as I can from going in the net.

Risks: I know that there are possible risks involved in participation in this study. They include:

1) The loss of balance. During standing trials it may be possible. Any fall will be avoided by using physio belt with a research assistant always close by to intervene.
2) Dizziness. During virtual reality, it has been reported in rare cases. If I feel dizzy or faint, the VR exercises will be stopped immediately and I will be watched closely by the investigators.

Benefits: I understand that I may not benefit directly from being part of this study. However, we hope that through this project, others may benefit from the increased knowledge of factors affecting balance, postural control and falls.

Cost: I will not have any costs for participating in this research study. Any travel expenses including parking, taxi or bus fare will be reimbursed from the project.

Confidentiality and anonymity: I understand that the investigators will keep my participation in this research study confidential to the extent permitted by law. My identity will be kept confidential and protected by using a subject code instead of personal information. Any documents with my personal information will be stored in a locked cabinet in Dr. Bilodeau's lab at the Bruyère Research Institute.

Data Conservation: I understand that the results from this study (including mine), may be presented at scientific conferences and submitted for publication in a scientific journal. When a report is written about a study, the results will be described in a summary format as to not reveal individual participant information. I understand that the data will be destroyed after 5 years. I also understand that a debriefing session will be offered to me once the results will be accepted for publication.

Voluntary participation: I understand that taking part in this research study is completely voluntary. I may choose not to take part at all. If I decide to be in this study, I may stop participation at any time without question by verbally stating I would wish to stop. My decision to participate will not affect my current or future care at Bruyere.

Acceptance: I ______________________________*(name of participant)* accept to participate in this research conducted by Dr. Martin Bilodeau, Dr. Heidi Sveistrup and Dan McEwen from the Bruyère Research Institute and the University of Ottawa.

Questions: I am encouraged to ask questions at any time during the process. If I have any questions, I can contact Dan McEwen at the Bruyère Research Institute, 43 Bruyère Street, Ottawa, Ontario, K1N 5C8, Tel: (613) 562-4262 (ext 1451).

Please note that the Research Ethics Board has the right to audit the study files under the supervision of the researchers listed above.

If I have any questions concerning the rights of participants or I have ethical concerns about this study, I understand that I can contact Dorothy Kessler, Chair of Ethics at Bruyère Continuing Care at (613) 562-6262 ext. 1420 or dkessler@bruyere.org or I can contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland St. Room 159, Ottawa, ON. K1N 6N5, at (613) 562-5841 or at ethics@uottawa.ca.

_______________________________ _____ / ___ / ___
Signature of participant *yyyy mm dd*

_______________________________ _____ / ___ / ___
Signature of witness *yyyy mm dd*

Participant number:__________________________________

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Hôpital Élisabeth-Bruyère Hospital
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-562-6367

Hôpital Saint-Vincent Hospital
60, rue Cambridge St. N.
Ottawa ON K1R 7A5
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-782-2785

Résidence Élisabeth-Bruyère Residence
75, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-562-4223

Résidence Saint-Louis Residence
879, ch. Hiawatha Park Rd.
Ottawa ON K1C 2Z6
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-683-5001

Village Bruyère Village
879, ch. Hiawatha Park Rd.
Ottawa ON K1C 2Z6
Tél./Tel.: 613-562-6262
Téléc./Fax: 613-683-5001

Centre de médecine familiale Bruyère
Bruyère Family Medicine Centre
75, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-241-3344
Téléc./Fax: 613-241-1971

Centre de médecine familiale Primrose
Primrose Family Medicine Centre
35, rue Primrose St.
Ottawa ON K1R 0A1
Tél./Tel.: 613-230-7788
Téléc./Fax: 613-230-7778

Institut de recherche Bruyère
Bruyère Research Institute
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6045
Téléc./Fax: 613-562-4266

Fondation Bruyère Foundation
43, rue Bruyère St.
Ottawa ON K1N 5C8
Tél./Tel.: 613-562-6319
Téléc./Fax: 613-562-6023

April 14, 2015

Mr. Dan McEwen
PhD Student
Bruyère Research Institute

Re: Focus of attention during lateral reaching.
(Bruyère REB Protocol # M16-15-009)

Final Approval

Dear Mr. McEwen,

Thank you for your response to our conditional approval letter. With the revisions, the application has satisfied all ethical requirements.

As such, the Bruyère Continuing Care Research Ethics Board (REB) is pleased to give you ethical approval for the period April 14, 2015 to April 14, 2016.

The following documents have been approved:
- COREB - received April 14, 2015
- Appendix A: Exclusion Criteria - received April 14, 2015
- Appendix B: Montreal Cognitive Assessment (version 3) - received April 14, 2015
- Appendix C: Berg Balance Scale - received April 14, 2015
- Appendix D: Recruitment Letter - received April 14, 2015
- Appendix E: Recruitment Flyer - received April 14, 2015
- Appendix F: Information Letter and Consent Form - received April 14, 2015
- Appendix G: Script for Young Adults - received April 14, 2015

Please provide us with a copy of the final approval letter from the University of Ottawa once received.

The Bruyère Continuing Care REB complies with the membership requirements and operates in compliance with the Tri-Council Policy Statement: Ethics Conduct for Research Involving Humans; the International Conference on Harmonization - Good Clinical Practice: Consolidated Guideline; the provisions of the Personal Health Information Protection Act 2004; and the Food and Drug Act of Health Canada and its applicable Regulations.

Please be advised that any complaints made by participants must be reported to the REB.

All changes to the approved protocol must be approved by the REB.

Please complete an Annual Project Update/Notification of Termination form by the approval end date as noted above.

We wish you the best of luck with your research endeavors.

Sincerely,

Dorothy Kessler, M.Sc., O.T. Reg. (Ont), PhD Candidate
Chair, Research Ethics Board
Bruyère Continuing Care
(613) 562-6262 ext 1420
dkessler@bruyere.org

Appendix G: Qualitative Questionnaire Data from Study #2

All questions were based on a 7 point likert scale from
“STRONGLY AGREE” (1) to “STRONGLY DISAGREE” (7)

Post-training Questionnaire:

Question 1: “*It was easy to play the VR video games.”*

Question 2: *“I felt safe playing the VR video games.”*

Question 3: *“I did not enjoy the VR video games.”*

Question 4: *“Playing the VR video games helped me improve my balance.”*

1 Month Follow-up Questionnaire

Question 5: *“Playing the VR video games helped me with my balance at home.”*

Question 6: *“Playing the VR games helped me better perform my home activities.”*

	Post Questionnaire				**1 Month Post Questionnaire**	
	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**
Experimental Group Average	**1.9**	**1.2**	**6.7**	**1.5**	**1.7**	**1.7**
Standard Deviation	1.2	1.0	0.6	1.2	1.0	0.9
Control Group Average	**1.9**	**1.2**	**6.6**	**2.6**	**2.5**	**2.6**
Standard Deviation	1.2	0.8	0.8	1.9	1.5	1.5

Comments:

Question 1: “*It was easy to play the VR video games.”*

- “*My difficulty was with control”* (PN 4 - Control Group)
- “*The car was oddly seemingly to drive backwards”* (PN 6 – Experimental Group)
- “*Easy to figure out what to do, but hard initially to succeed due to my physical limitations. As time progressed, success improved.”* (PN 52 – Experimental Group)
- “*As it goes on it was more and more easy.”* (PN 69 – Experimental Group)

Question 2: *“I felt safe playing the VR video games.”*

- *“Dan always had control of me if I came off balance.”* (PN 52 – Experimental Group)
- *“No problems at all. Dan didn’t put any pressure on me and restrained me by the belt.”* (PN 69 – Experimental Group)

Question 3: *“I did not enjoy the VR video games.”*

- *“I did enjoy the games and the challenge they offered”* (PN 4 - Control Group)
- *“At the very least, the games were an added distraction to an otherwise empty afternoon. I’m not a gamer though, so I didn’t really “thrill” to the video experience.”* (PN 21 – Control Group)
- *“More variety”* (PN 43 – Control Group)
- *“Games were great. Simple yet challenging and competitive enough to motivate me to try to do better each time.”* (PN 52 – Experimental Group)
- *“I enjoy the VR video games and they were very good for the balance and the scores.”* (PN 69 – Experimental Group)

Question 4: ***“Playing the VR video games helped me improve my balance.”***

- *“I was not aware of the question of balance – but have improved in general.* (PN 4 - Control Group)
- *“The paraglider was hard on my RT shoulder due to an old injury (separated clavicle several years ago.”* (PN 6 – Experimental Group)
- *“It helped my mind working on different games and various movements.”* (PN 19 – Experimental Group)
- *“As one among many tools that’s used, I felt that the vR games may have contributed to the overall improvement of my strength & balance, but it is difficult to attribute any specific gains to the program.”* (PN 21 – Control Group)
- *“Saw improvements in my left arm over the 3 weeks. Some of the events provided additional exercise to the arm resulting in increased movement and flexibility.”* (PN 44 – Experimental Game)
- *“Dan’s ability to tailor each game to my needs allowed me to focus on improving my strength and coordination on my left side/overall as well as my balance.”* (PN 52 – Experimental Group)
- *“Helped with improving an automatic response”* (PN 68 – Control Group)
- *“The more I played them the more I appreciate it.”* (PN 69 – Experimental Group)

Question 5: ***“Playing the VR video games helped me with my balance at home.”***

- “*Movements improved my balance.”* (PN 18 – Control Group)
- *“Inspired my workouts”* (PN 20 – Experimental Group)
- *“Not long enough [time to play games] to say if a change or not.”* (PN 43 – Control Group)
- *“Strengthened my left arm (i.e. performing repetitive exercises actions.)”* (PN 44 – Experimental Game)

Question 6: ***“Playing the VR games helped me better perform my home activities.”***

- *“Enjoyed the games and did use exercise time. Helped perform balance activities in the hospital doing different things at home.”* (PN 19 – Experimental Group)
- *“Good motivation.”* (PN 20 – Experimental Group)
- *“The VR helped me improve my balance overall and therefore I believe it helped me to function better at home.”* (PN 52 – Experimental Group)

- *"I'm not sure that it helped more or less as compared to OT or PT."* (PN 64 – Control Group)

General comments at discharge:

- *"Thank you for the distraction."* (PN 20 – Experimental Group)
- *"Thanks for including me!"* (PN 21 – Control Group)
- *"xxxxx has enjoyed this programme very much- Dan and his associates were very professional! They were very helpful and encouraging."* (PN 36 – Control Group)
- *"It was fun"* (PN 46 – Control Group)
- *"Very nice compliment to physio. It allows us to push ourself harder in a safe and secure environment."* (PN 54 – Experimental Group)
- *"Very worthwhile exercise."* (PN 55 – Control Group)
- *"Would liked a more for harder movements."* (PN 61 – Experimental Group)
- *"Improved sight on the left (birds & balls), left hand 'seemed' to be his now."* (PN 64 – Control Group)
- *"Too many assessments all at once at the end of my time here"* (PN 70 – Experimental Group)

General comments at 1-month follow-up:

- *"Balance, awareness and confidence all improved dramatically with VR."* (PN 6 – Experimental Group)
- *"It was very enjoyable"* (PN 16 – Control Group)
- *"It is hard to make a direct correlation between activities in the lab & home. No doubt the lab work helped, because any coordinated actions will help to focus my movements. But I don't think that I can make a specific attribution for the lab program. However, the lab programs were a good diversion & break from the other physio activities."* (PN 21 – Control Group)