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Balance Training using Virtual Reality as Compared to an Activity-Based  
Exercises Program for Adults with Traumatic Brain Injury

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BALANCE TRAINING USING VIRTUAL REALITY AS COMPARED TO AN ACTIVITY-BASED  
EXERCISE PROGRAM FOR ADULTS WITH TRAUMATIC BRAIN INJURY

BY

MARIANNE THORNTON

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## SUMMARY

Exercise has been considered important in the management of functional balance problems although there are limited data supporting effectiveness after traumatic brain injury (TBI). This thesis compared two functional balance retraining programs: a virtual reality (VR) generated program and an activity-based (AB) program. Participants (n=33, age 18-66) had sustained a moderate or severe TBI (initial Glasgow Coma Scale [GCS] <12) 6 months or more before the start of the study. Participants were quasi-randomly assigned to either an intervention group or a control group that received no intervention. Groups were matched on initial Berg Balance Scale scores (BBS), years since TBI, and age. Static standing balance (using a force plate), functional balance (using the Community Balance and Mobility Scale [CB&M]) and perceptions of balance and function (using the Activity-specific Balance Confidence Scale [ABC] and the Lower Extremity Functional Scale [LEFS]) were measured at baseline, after six weeks of intervention, and 3 months later. BBS and CB&M scores improved for the exercise groups after six weeks. Some of the improvements were still present at three months. Functional balance improvements were supported by increased scores on the ABC, the LEFS, and by participant focus group comments. The focus groups also indicated the multidimensional benefits of both types of exercise. While not statistically significant, the VR group reported higher scores of functional balance and mobility, balance confidence, and more positive comments from participants than the AB group. This supports the use of VR as a potentially effective method of delivering exercise.

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**LIST OF ABBREVIATIONS**

AB: activity-based method of balance retraining exercise also referred to as conventional exercise and ABE (activity-based exercise).

A/P: anterior-posterior direction

ABC: Activity-specific Balance Confidence Scale

BBS: Berg Balance Scale

C: control group

CB & M: Community Balance and Mobility Scale

COP: center of pressure

GCS: Glasgow Coma Scale

LAT: lateral

LEFS: Lower Extremity Functional Scale

RMS: root mean square

TBI: traumatic brain injury

VE: virtual environment

VR: virtual reality computer generated approach to balance retraining also referred to as VRE (virtual reality exercise)

## CHAPTER I

### INTRODUCTION

This thesis addresses the topic of limited intervention options for poor functional balance after TBI by investigating two methods of balance retraining exercise. The first paper reports on how the exercise programs improved functional balance scores. The second paper explores the multidimensional effects that balance retraining programs had on participants, suggesting the need for a broad perspective when determining the overall value of these programs, and helping to differentiate between them.

#### **Statement of Purpose**

The objective of this study was to determine the effectiveness of balance retraining exercises after TBI and to ascertain if the method of exercise delivery made a difference. Virtual reality (VR), a computer-generated intervention, was compared to an activity-based (AB) exercise program for adults with residual functional balance deficits six months or more following TBI.

#### **Justification for the Study**

##### *Scope of the Problem*

Balance has importance to independence in activities of daily living, sitting, walking, leisure, and quality of life. According to the Ontario Brain Injury Association, each year more than 16,000 Ontario residents have acquired permanent damage from TBI (Ontario Brain Injury Association, 2000). Many have been left with life-altering, long-term disabilities. Balance problems have been found to be common following TBI (Black et al., 2000). Health professionals working in the area of brain injury, and individuals with TBI have identified balance difficulties as a chronic health issue, leading to disability or loss of independence (Hillier, Sharpe, & Metzger, 1997; Quinn & Sullivan, 2002).

Traumatic brain injury has resulted in physical, cognitive, and psychosocial problems that significantly affect ability to work, live independently, or maintain pre-injury lifestyle. Life-long quality-of-life issues have been a common problem in this mostly young population. Although rehabilitation commonly has taken place in the first few months after an injury (partly due to funding limitations, lack of research, and lack of recognition of the need), TBI has often lead to a lifetime of disability. One main goal of rehabilitation has been functional independence (Carr & Shepherd, 2002). There has been a need for effective and accessible interventions for this population over the different stages of rehabilitation (Gordner & Tuel, 2002).

According to basic mechanisms of central nervous system (CNS) plasticity, the neurological system can adapt to the demands placed on it (Wainberg, 1988). The CNS is expected to become more functional as specific training aids the process of plasticity (Wainberg, 1988). Because of the multiple structures involved and limited treatment options, functional balance problems may not resolve, or may be present for a long time after TBI (Mann & Black, 1996). There is a need to study the relative effectiveness of different interventions on balance and functional independence.

While few interventions have been documented to improve functional balance after TBI, one accepted intervention has been exercise (Mann et al., 1996; Tse & Bailey, 1992). Suggested exercises for poor balance have been published for a non-specific population based primarily on studies of people who are elderly with no specific reference to TBI (Brody, 1999), but there has been little data in the published literature about the best type, frequency, or duration of exercise with this population.

#### *Significance of the Study Results*

In order to determine the effect of exercise on functional balance resulting from a TBI, two approaches that have received attention in the literature were chosen. The AB intervention was designed by a physiotherapist, while the computerized VR program used the rationale of the AB approach, as delivered through the medium of a computer. This study investigated the effects of VR and AB exercise interventions initiated six months or more after a TBI. Intervention at this stage of recovery has been unavailable to people with TBI due to limitations in the health care system (lack of funding for specific programs or trained individuals). Effective VR interventions could offer: 1) availability at all stages of recovery; 2) financial attractiveness (the need for continual instruction is often not required); and 3) more accessibility (equipment could be made available in areas where centres of rehabilitation cannot easily be accessed).

#### **Hypothesis**

For the purpose of this study, three experimental groups were defined. The VR group included individuals who participated in the VR-based balance retraining exercise program. The AB group consisted of individuals who participated in the balance retraining exercise program, which involved commonly used tools to retrain functional balance such as balls of various sizes, a wobble board, and an obstacle course. The control (C) group included those individuals for whom no additional intervention was instituted (beyond therapies in place before the beginning of this study).

The Null hypothesis was that there would be no significant difference between the measures of the VR group, of the AB group and of the C group.

It was expected that the VR group would have greater carryover to functional measures of balance tasks, as measured by the BBS and the CB&M. It was anticipated that the VR group would have greater carryover to measures of perceptions of balance confidence and general function, as measured by the Activity-specific Balance Confidence Scale (ABC) and the Lower Extremity Functional Scale (LEFS). It was expected that the VR group would have a greater increase in static postural stability than the AB group and more positive reaction through focus group sessions to support the data from the functional and postural stability measures. Overall, the goal of these studies was to learn about the effects of balance training for adults with TBI.

## CHAPTER II

### REVIEW OF THE LITERATURE

#### **General Overview**

This thesis was designed to examine the effects of two types of balance retraining exercises on people with decreased functional balance resulting from a TBI. The first part will examine the physical effects of balance exercise, comparing two approaches to balance retraining and measuring functional balance skills to determine if one approach is more effective. The second part will examine the perceptions of people with TBI (and their caregivers) to the two types of exercise to determine if there are additional benefits over the functional improvements. It was expected that the combination of physical measures of balance and perceptions of the benefits of the two programs would help in understanding the value of these methods of retraining balance.

#### **Relation of Balance to Gait, Falls and Function**

It has been shown that unsafe ambulation and decreased balance may put an individual at high risk of falling and further trauma (Lehmann et al., 1990). Hillier (1997) found that for people with TBI there are many long-term problems that are under-reported in the literature. After a TBI, physical limitations have affected community independence, including a wide range of areas from self-care to employment (Powell, Machamer, Temkin, & Dikmen, 2001). Even five years after a TBI, many people have required assistance to walk, which was partly to blame for many being unable to work if the job included more strenuous activities (Hillier et al., 1997). Physiotherapists who have worked with individuals with TBI frequently identified balance as a significant problem even after a mild TBI (Quinn et al., 2002). There has been limited literature published on the subject of TBI and balance training.

People who are elderly have shown some shared physical attributes with people with TBI. Both have been found to have challenges with physical function, and there can be similar areas of the brain effected (Allison, 1999). In a study of the elderly (Shumway-Cook, Gruber, Baldwin, & Liao, 1997) it was shown that multidimensional exercise (with goals such as improving postural alignment, developing coordinated strategies to regain balance, and developing more skill in making anticipatory adjustments to balance) decreased the risk of falls and improved functional balance. The degree of loyalty to the exercise program influenced how effective the program was in lowering risk of falls and improving scores in functional balance and mobility.

### **Complexity of the Concept of Balance**

Balance has been shown to require the finely tuned interaction of vestibular, visual, and somatosensory systems along with a motor response performed through the musculo-skeletal system (Brody, 1999). As a result of a brain injury, any one or all of these may have been affected (Hibbard, Uysal, Sliwinski, & Gordon, 1998). Each component must work well independently, and there must be central integration of the information (Black et al., 2000). This complexity has been found to be due to not only the many physical aspects of balance, but also the psychosocial components. For example, paying attention to the task (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997) and having confidence in balance skills (Myers et al., 1996) were also shown to be variables affecting balance.

Balance, which has been found to relate to depression, fear of falling, and limited ability to participate in social activity, plays a role in one's self concept—in how we define ourselves (Miller, Speechley, & Deathe, 2002). Self-concept has been thought to be useful to understanding problems and finding solutions as part of the rehabilitation process (Man, Tam, & Li, 2003). Activities that were fun and generated a good feeling could contribute to improved self-concept. VR has been found to be an activity that can be fun, allow practice of skills in ways that are interesting, encourage movement, and provide exercise (Reid, 2002). In a recent pilot study, one male subject two years after TBI, demonstrated better balance (through more symmetrical weight distribution as measured on a force plate) after 25 one-minute trials of VR (McComas & Sveistrup, 2002). In addition to showing better balance, this subject demonstrated good attention and focus through the full period of exercise, and indicated that it was challenging for the full 25 minutes.

### **Methods of Balance Retraining**

Balance problems after TBI have been found to be challenging to treat due to balance complexity, the many structures damaged, and the scarcity of interventions that have proven effective (Mann et al., 1996; Tolfts & Stiller, 1997). Research about balance training has mainly focused on people with stroke or those who are elderly. Ways to practice, how to achieve better compliance to a program, and the importance of specificity of training have been discussed in the literature (Shumway-Cook et al., 1997) along with interventions used for balance retraining such as Tai Chi (Wolf, Coogler, & Xu, 1997).

There have been limited details of balance training methods. Tai Chi, for example, has been found to improve balance confidence (Wolf, Bernhart, Ellison, & Coogler, 2002), but details such as the intensity and

frequency of exercise to achieve improvement are unclear (Shumway-Cook & Woollacott, 2001; Wu, 2002). A study using dance training for people with TBI showed improved balance, but did not explain the method in sufficient detail to be able to repeat the result, and the sample size was too small to achieve sufficient power to make the results convincing (Dault & Dugas, 2002). Visual feedback, another approach for balance retraining, has not shown significant improvement in functional balance scores (Geiger, Allen, O'Keefe, & Hicks, 2001; Grant, Brouwer, Culham, & Vandervoort, 1997; Liston & Brouwer, 1996). According to Carr and Shepherd (2002), for the majority of people the best approach has been to train with the type of action used in everyday life, such as getting up and down from a chair, walking, and reaching. There has been a need for clear guidelines and well-documented approaches to balance retraining for people with TBI.

This thesis compares two types of balance retraining. The first type is a more traditional approach, using tools of balance retraining commonly used in rehabilitation. This AB program of balance exercise is modelled after a balance retraining program designed by a physiotherapist for people with stroke (Grant, 1996). The technology for the VR approach is becoming more commonly available in rehabilitation settings. This advanced type of computer interface allows one to "interact" with the computer-created environment (Rizzo, Buckwalter, & Wiederhold, 1998). Described as fun and innovative and having the potential to keep someone's attention longer, the VR approach may be a good way to encourage regular attendance (Reid, 2002; Rose, Attree, Brooks, & Johnson, 1998).

VR offers an experience which can be meaningful, involving, and rewarding, shifting the focus from the person's efforts to the interaction with the VR environment (Reid, 2002). Through this medium, routine tasks can be broken down into smaller components and practiced in interesting ways. Elements that might be unsafe in the real world can be introduced in a less threatening way (McComas et al., 2002). VR provides a tool that can be used to introduce challenges in a controlled environment. An approach to exercise which is safe, interesting, engaging, and focused on an enjoyable activity (rather than on specific attributes to be improved), may encourage regular attendance. People may respond with improved balance, better self-concept, and more confidence in their physical skills, potentially leading to more opportunities for community involvement. More will be discussed about both the VR and the AB balance exercises in the following chapters.

Community reintegration after TBI requires not only physical skills such as balance and endurance, but also cognitive and behavioural skills to plan, function, and socialize in often challenging situations, such as

those encountered in employment. From a study of people with spinal cord injury, personal relationships and employment are not only important to social participation but contribute to the overall health of the individual (Noreau & Fougereyrollas, 2000). It has been proposed that strategies to create accessible community resources for fitness and recreation for people with neuromuscular disease should lead to improved psychosocial and physical health (McDonald, 2002). Similarly, providing opportunities for having fun while safely exercising may contribute to better balance and mobility while improving community integration for people with TBI.

### **Summary**

The high incidence of TBI; the prevalence of balance problems in individuals with TBI; the fact that poor balance is linked to risk of falls, re-injury and quality of life; and the lack of literature about balance training methods with this population all indicate the need to study innovative ways to manage balance problems found in adults with TBI.

This thesis addresses the topic of poor balance after TBI by investigating two methods of balance retraining exercises to determine if they are effective in changing functional balance scores. If so, is one more effective than the other? Do the perceptions of participants confirm the results of the measures of functional balance? Finally, do the perceptions of participants elicit new ideas about the effects of balance exercise for this population?

CHAPTER III  
ARTICLE SUBMITTED TO THE  
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A Virtual Reality Exercise Program Improves  
Functional Balance and Mobility in Community-Living  
Adults with Traumatic Brain Injury

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Key Words: neurological injury, intervention, treatment outcome, rehabilitation, TBI management

## **Abstract**

**Background and Purpose.** Exercise is a basic part of the management of balance problems although there are limited data supporting effectiveness after traumatic brain injury (TBI). This study compared a virtual reality (VRE) to an activity-based (ABE) exercise program for balance retraining. **Subjects.** Adults (n=33, age 18-66) with a moderate or severe TBI (initial Glasgow Coma Scale <12) sustained at least 6 months prior to the start of the study. **Methods.** Subjects were quasi-randomly assigned to an exercise or a Control (C) group. Groups were balanced on initial Berg Balance Scale scores (BBS), age and years post-TBI. Quiet stance and functional mobility of subjects were measured before, after six weeks of exercise and 3 months later. **Results.** Exercise groups improved on BBS and Community Balance and Mobility scale (CB&M). Improvements after six weeks were still present at three months. **Discussion and Conclusion.** The VRE group showed higher scores of functional balance and mobility supporting use of VR as a potentially valid method of delivering exercise.

A Virtual Reality Exercise Program Improves Balance and Mobility  
in Community-Living Adults with Traumatic Brain Injury

According to the Brain Injury Association of America,<sup>1</sup> 5.3 million Americans are currently disabled by the effects of a TBI. Each year 1.5 million people sustain a TBI and of these 80,000 begin the process of long-term recovery. The estimated costs associated with TBI are \$48.3 billion annually although it is not possible to measure the strain (physical and emotional) from disability that the injured person and those close to them endure. Adolescents and young adults are most at risk for a TBI. After a TBI has occurred, the risk of a subsequent TBI is three times higher.<sup>2</sup>

Common physical deficits following a TBI include decreased muscle strength and joint range of motion as well as loss or modification of sensory input such as vision. The broad nature of these deficits is partly due to the extensive injuries resulting from the initial accident and importantly, all of these deficits can contribute to impaired balance.<sup>3</sup> In fact, functional abilities including balance and postural control after TBI are often limited and long-term problems are under-reported in the literature.<sup>3</sup> Although significant improvement in motor function and balance is often evident in the first few months following a brain injury, the residual balance deficits following a TBI often lead to a lifetime of disability. Moreover, Allison<sup>4</sup> would argue that balance problems are “universal” and affect all persons with TBI. In separate surveys of persons with TBI and physiotherapists working with persons with mild TBI, residual balance deficits were identified as a common health challenge after TBI.<sup>3,5,6</sup> The impact of these balance deficits is obvious in many aspects of everyday function including independence in activities of daily living, sitting, walking, leisure activities and quality of life. Limitations in balance and mobility significantly limit work and leisure participation and conservative estimates are that thirty percent of adults need assistance to walk after a TBI.<sup>3</sup> Moreover, the inability of many adults with TBI to undertake work or leisure activities that depend on strenuous physical activity has been suggested as one reason for increased unemployment even five years after a TBI.<sup>3</sup> Postural imbalance can also pose a high risk of falling that may result in additional trauma and disrupt an individual’s ability to return to normal daily routines. Finally, many adults with TBI are left with life-altering long-term cognitive and/or physical disabilities with balance deficits common at least as long as 5 years post injury.<sup>3,5</sup> It is clear that the ongoing cost to the individual, their family and society is great. Given that rehabilitation needs vary over time,<sup>7</sup> there is a need for ongoing effective and accessible rehabilitation interventions for this population yet there is

little in the published literature regarding the benefits of different types of exercise, frequency or duration of exercise for community-dwelling adults with TBI.

While it is relatively commonplace to diagnose balance problems, it is complicated to treat these problems in part due to complex structures working together to maintain balance and in part due to the lack of documented effective interventions for adults with TBI.<sup>8-10</sup> Exercise, however, has been identified as an important part of rehabilitation.<sup>11</sup> In fact, it has been shown that multidimensional exercise, including combinations of lower extremity strength and flexibility exercises, balance exercises (static and dynamic) and aerobic activity can improve balance in older adults and persons with stroke.<sup>12</sup> In effect, the majority of exercise training and physiotherapy programs for balance retraining have focused on older adults or persons with stroke.

Tai Chi is an example of one type of exercise that could improve balance<sup>13</sup> although exercise intensity, length of exercise program and duration of benefits are unclear.<sup>14</sup> The results are equivocal following exercise interventions using biofeedback training for persons with stroke. Certain studies have reported benefits of using visual feedback from a force platform to train balance for persons with stroke although with no evidence of significant carryover to ambulation<sup>15,16</sup> while others have reported no additional benefits when biofeedback is used in conjunction with physiotherapy.<sup>17</sup> Training with visual feedback may improve balance after TBI.<sup>18</sup> Practicing different ways to complete a task may help individuals transfer the skill to other situations. Practice may also help with planning and problem solving to develop balance skills, with avoiding falls and with regaining the ability to do complex activities.<sup>19</sup> Rose<sup>20</sup> recommends the design of multidimensional interventions that target the sources of balance or mobility problems, to challenge the system in various ways. The specificity of training will dictate the exercise response. Balance retraining therefore requires a constant overload stimulus that stresses the systems involved in the control of both static and dynamic balance. Moreover, the degree of compliance and loyalty to an exercise program affects scores in balance, mobility and falls risk.<sup>12</sup>

Postural sway and performance of functional tasks during rehabilitation have been studied to a limited degree with patients with TBI. Significant improvements in standing balance, walking, standing up, and stair climbing have been reported following relatively short periods of rehabilitation after severe TBI.<sup>21</sup> The high incidence of injury, the significant long-term impact of balance on quality of life, the prevalence of residual balance problems in adults with TBI many years post injury combined with the lack of evidence for effective

rehabilitation of balance indicate the need to study innovative ways to treat the balance problems found in adults with TBI.

VR allows a variety of activities to be used to challenge different components of balance and, as a novel technology, is becoming more available in rehabilitation settings. VR is defined as an advanced form of computer interface that allows the user to “interact” with and become “immersed” within a computer generated environment.<sup>22</sup> After a brain injury, a person may not have as much interaction with the physical environment. Many have mobility restrictions and limited cognitive and social interaction. Virtual reality has an advantage over other balance training systems in that it places the individual in a “natural” environment that could be similar to their home, work or a setting they may encounter in daily living. Levels of difficulty of the task to be completed can be set to meet individual needs. It may also be easier to keep a person’s attention for a longer period of time, allowing for the possibility of increased compliance and fun.<sup>23,24</sup> VR could provide a device to allow use of new strategies in everyday situations, reliable data collection and a training protocol.<sup>25</sup>

The purpose of this study was to determine the effectiveness of two exercise programs as intervention options for balance rehabilitation in community-dwelling adults who had sustained a TBI at least 6 months prior to the start of the study. We hypothesized that subjects in both exercise groups would demonstrate improvements in measures of standing balance and in measures of functional mobility and balance compared to a group of similar subjects who received no intervention. We also hypothesized that there would be significantly greater improvements recorded for subjects in the VRE group compared to the ABE group, and that these differences would be evident up to three months following the exercise intervention. Preliminary findings have been reported previously.<sup>26</sup>

## **Methods**

### **Subjects**

Ethical approval for the study was received from the Research Ethics Board of the local rehabilitation center. Eligible individuals were recruited from a list of patients from the Rehabilitation Center outpatient acquired brain injury clinic with additional individuals recruited through announcements at local organizations and in newsletters. Informed consent was obtained from the subject or where necessary, a proxy.

Subjects were included in the study if they: 1) sustained a TBI at least six months prior to the start of the study; 2) had an initial Glasgow Coma Score (GCS) at the time of injury of 12 or less; 3) were not participating

in acute inpatient rehabilitation at the time of the study; 4) had self-identified or physician-identified residual balance deficits as a result of the TBI; 5) were able to stand independently for two minutes without the need for a mobility aid; 6) were able to understand and follow instructions in English or French; and 7) were able to interact with a computer system. Exclusion criteria were vestibular deficits, benign postural vertigo and orthopedic problems that severely limited mobility. Subjects meeting the inclusion criteria completed a screening session to rule out visual problems which could limit use of the computer monitor and to provide information on age, use of a gait aid, falls history and normal activity level. Sensory, motor and cognitive information was documented to monitor for subjects who might be limited in their physical abilities (e.g. pain or joint limitations) or those whose physical abilities might be influenced by other issues (e.g. cognitive).

Subjects were assigned to one of three groups: virtual reality exercise (VRE), activity-based exercise (ABE) or control (C). Initial group assignments were balanced as closely as possible based on baseline Berg Balance Scale (BBS) scores (see Table 1). The subjects were asked to maintain their regular activity patterns for the study period and approximately equal percentages of subjects in each group continued with outside activities including Tai Chi or individual therapy. The C group was small, seven subjects, and served to reflect natural recovery on the specific measures we tested. No statistically significant change in any of the outcome measures for the C group over the study period was noted. Since we were interested in the effect of exercise, and in order to maximize the number of subjects in the exercise groups, no further assignment to the C group was made. In addition, once the subjects in the C group completed the full series of outcome measures identified in the experimental protocol, they were invited to continue their participation in one of the exercise groups. We reviewed specifically the data from the two subjects in the C group willing to continue. Neither had a clinically important change on any outcome measure tested. Thus, both were assigned as per study protocol to an exercise group. Travel and parking expenses were reimbursed for each study session a subject attended.

#### Outcome Measures

A licensed physiotherapist, blinded to the group assignments, completed evaluations of clinical outcome measures. Research assistants completed laboratory outcome measures. Outcome measures were recorded at baseline, immediately post-intervention and 3-months post-intervention. Multiple measures were used to determine changes on the different dimensions of balance targeted in the intervention.<sup>20,27</sup> The balance and functional mobility of the subjects in the study were extremely variable resulting in some difficulty when

selecting a primary balance outcome scale. Specifically, subjects with severely limited balance were unable to complete items from the primary outcome measure, the Community Balance and Mobility scale (CB&M) while subjects with high-level balance control usually scored perfect on a second scale, the Berg Balance Scale (BBS). Thus, both balance measures were included in the study protocol to permit evaluation of exercise effect in subjects with either high- or low-level of balance.

#### *Community Balance and Mobility Scale (CB&M)*

The CB&M is a performance-based measure developed for use with community-living adults who have sustained a mild to moderate TBI and who have higher-level balance abilities.<sup>28</sup> The 13 items ranging from timed one-legged stance to descending eight steps carrying a laundry basket, measure postural instability in high-functioning ambulatory individuals. Test items were designed to reflect necessary skills for functioning well in the community. Test content and construct validity<sup>28</sup> as well as high test-retest reliability<sup>29</sup> have been reported. The tool is currently undergoing further reliability and validity studies.<sup>28</sup> Personal communication with the co-developer of the instrument determined minimal clinically important change to be greater than 5 points.<sup>30</sup>

#### *Berg Balance Scale (BBS)*

The BBS is a measure of balance for persons with some balance impairment. This measure has been reported to be valid<sup>31</sup> and reliable<sup>32</sup> for subjects who have sustained a brain injury at least one month prior to assessment. The BBS is a 14-item measure of functional balance designed to evaluate response to treatment. A 5-point change is clinically important for this population.<sup>32</sup>

#### *Gait Speed*

Changes in gait speed were quantified using a 5-meter comfortable walking pace timed test. This format was the most responsive for persons with stroke who were high-functioning in acute care and expected to be discharged home.<sup>33</sup> Subjects were asked to walk 7 meters at a comfortable pace with gait speed measured over the middle 5 meters. Gait speed has been reported to have a significant positive correlation with steadiness of sway and weight-shifting ability.<sup>34</sup> Based on data from a sample of patients with stroke, an improvement of 0.17 m/s is clinically important.<sup>33</sup> For persons with stroke there is good inter-rater reliability when measured using a 6-meter test ( $r=1.00$ )<sup>35</sup> and test-retest reliability is good for 5-meters ( $r=0.95$ ).<sup>36</sup> One subject in the ABE group was unable to complete the task and his data were not included in analysis of this measure.

### *Force Platform Measures*

Laboratory measures of quiet stance were recorded using a Kistler force plate<sup>†</sup>. The intent was to measure subtle changes in postural control in addition to the functional mobility measures to better distinguish between the groups and the patterns of change in postural stability. This measure has been used extensively in research to document limits of stability, and to understand balance reactions in various populations.<sup>37,38</sup> The measures are sensitive to changes in stance difficulty and have been used as indices of postural steadiness giving reliable results sensitive to discriminating changes in steadiness.<sup>39</sup>

All force platform measurements were carried out in a quiet, well-lighted, comfortably heated room. Subjects stood in stocking feet on the platform. For each subject, a comfortable stance position was recorded by tracing the foot position on paper. This template was used to place their feet in the same position each time they stepped onto the platform both within and between testing sessions. Subjects were asked to stand as quietly as possible in an upright position with their arms at the side. Four conditions with varying visual and somatosensory information were tested: 1) firm surface eyes open 2) firm surface eyes closed 3) compliant surface eyes open 4) compliant surface eyes closed. Eyes open and closed conditions were chosen to determine reliance on vision for balance. Firm and compliant surfaces were used to determine proprioceptive sensory reliance. Four one-minute trials were recorded for each condition. Data from a minimum of 3 trials for each condition were analyzed and averaged for each subject. The eight components of ground reaction force obtained from the force platform (20 Hz) were processed off-line to provide translation of the centre of pressure (COP) in the lateral (LAT) and anterior/posterior (A/P) directions. Two variables were computed for each direction of COP translation; range and root-mean-square (RMS).

### *Balance Retraining Exercise Programs*

Subjects in the exercise groups completed between fifteen and eighteen sessions consisting of fifty minutes of exercise three times per week. Subjects exercised with one-on-one supervision and direction from one of the authors (MT) or a research assistant. Exercise supervision and direction consisted of providing instructions, answering questions, assisting subjects when necessary to avoid losses of balance and falls and setting exercise intensity levels for individual subjects. Subjects alternated sessions between exercise supervisors. Subjects wore a safety belt during exercise sessions to enable the exercise supervisors to assist with balance when necessary.

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<sup>†</sup> Kistler Mobile Force Plate (Type 9286) 75 John Glenn Drive, Amherst, New York 14 228-2171

Sessions started and finished with five minutes of a preset routine of stretching exercises.

Balance retraining exercises were mainly designed to normalize stance symmetry, increase standing stability, increase ability to shift away from the midline, and improve timing and control of weight shifts. Subjects were challenged by increasing the complexity of the balance activities, while remaining within the ability levels of each individual. The progression of activities included changing: a) tasks such as standing, walking, running, hopping, jumping; b) foot or limb placement such as standing with feet shoulder width apart, tandem stance, single limb stance, four-point kneeling; and/or c) support surface such as normal floor, medium-density foam, stool or Swiss ball. A seven-inch wooden step was used for stepping activities.

Scores on specific tasks were recorded where possible and used to motivate the subject from one session to the next. Once subjects accomplished a task for a preset amount of time and were able to repeat the activity at a subsequent session, they progressed to a task at a higher level of difficulty. A short rest, if required, followed each one- to two-minute activity. Between 10 and 20 different activities were performed within the 40 minutes. Although the amount of exercise was not formally quantified, subjects in both groups exercised similar amounts as determined by length of exercise session, number of exercises completed and length of time spent on each exercise.

#### *Activity-Based Exercise Group*

The ABE program was based on a protocol previously used for balance retraining in patients with stroke.<sup>40</sup> Additional equipment used included a wobble board, stationary bicycle, balls of various sizes, hockey sticks, badminton rackets, obstacle courses, Frisbee, beanbags and balloons. Preset guidelines were used to standardize task progression as much as possible.

#### *Virtual Reality Exercise Group*

The VRE group used a computerized exercise program (Figure 1; IREX – Interactive Rehabilitation & Exercise Systems).<sup>\*</sup> Five specific VR applications were used to encourage the movements by the subject such as reaching within and outside of the base of support that would achieve the goal of the game. Each activity could be adjusted to increase the reach distance and/or speed of movement. The activities could be done with one hand, hands working independently or hands together.

*(Insert Figure 1 approximately here.)*

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<sup>\*</sup> IREX Interactive Rehabilitation & Exercise Systems, [www.irexonline.com](http://www.irexonline.com)

The subjects wore red gloves and stood in front of a monochrome wall. A video camera captured the image of the subject, which was then sent to a computer-processing unit. Color subtraction software was used to remove the background from the video image and the isolated subject image was then combined with a virtual environment (VE). The subject viewed him/herself in the VE on a 29-inch television monitor. The subject interacted in real-time (i.e. same time and speed as events in the real world) with virtual objects that appeared in the VE.<sup>41</sup> One subject with a tight spastic hand wore a red mitt instead of a glove. Another subject had a sore shoulder and completed all activities with one arm only.

Five virtual scenarios and tasks were used. In Orbosity, the subject reached out to touch virtual balls that, once touched, turned into birds that flew out of the VE. In a second exercise, the subjects viewed themselves underwater with stars floating and dolphins swimming around them. A juggling exercise required the subject to reach out to juggle one or more virtual balls on the screen. A fourth scenario, Conveyor, required the subject to move boxes from a conveyor belt on one side of the screen to the other. The fifth exercise required that the subjects defended a soccer net while balls came towards them. In all scenarios, subjects moved their image to the left or right in the VE by reaching or leaning sideways. Moving their arms and trunk up and down, squatting and standing, or stepping up onto a stool or foam surface resulted in vertical movement of the image in the VE. In all exercises, larger movements increased the amount of weight shifting and could change the balance exercise from a quasi-static exercise with a stable base of support to a dynamic exercise requiring foot movement and continuous establishment of a new base of support. The magnitude of weight shift and motion required to succeed at the task was preset by the exercise supervisor. For each exercise, the position, speed and number of virtual objects to contact could be modified.

#### *Control Group*

The Control group received no intervention. They were asked to continue their normal activity level during the course of the study.

#### *Data Analysis*

Descriptive statistics and frequencies were calculated using SPSS (version 11)<sup>‡</sup> for appropriate demographic variables. *A priori* analysis of differences on outcome measures within groups across the three time periods were tested, using repeated measures ANOVAs with a Huynh-Feldt adjustment. Follow-up paired

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<sup>‡</sup> SPSS Inc., 444 Michigan Ave, Chicago, IL 60640

t-tests, were done where necessary to test for significant differences on the BBS, CB&M and gait speed measures with factors Group (3 levels) and Time (3 levels). Repeated measures ANOVAs were also run on the COP displacement and RMS with factors Group (3 levels), Time (3 levels) and Sway Direction (2 levels). Subsequent pairwise comparisons were made using the Least Significant Difference post-hoc test. All statistical analyses were completed using a p value of 0.05.

## Results

### Study Subjects

Thirty-three adults with TBI participated in the study. Two subjects initially assigned to the C group agreed to participate in an exercise group once the three-month follow-up C data were obtained. The groups were balanced based on initial BBS scores that, on follow-up analysis, were not statistically different at the beginning of the study ( $F(2,32)=0.74$ ,  $p=0.485$ ) (see Table 1). The groups also were similar in age and years post-TBI. One subject in the ABE group withdrew from the study due to scheduling problems. Thus, data from thirty-four full sets of outcome measures are included in the study results. The final numbers of subjects in the C, ABE and VRE groups were 7, 12 and 15, respectively.

*(Insert Table 1 approximately here)*

### Clinical Outcome Measures

A floor effect was evident on the CB&M scale since five subjects, two in the C, two in the ABE and one in the VRE group, were unable to complete any of the tasks in the scale. The data from these five subjects are not included in group comparisons of the CB&M. Baseline, post-intervention and three-month follow-up scores for the CB&M are plotted for the three groups (Figure 2a). The CB&M scores at post-intervention and 3-month follow-up were significantly greater than baseline for both the ABE ( $p=0.002$ ) and VRE ( $p=0.014$ ) groups with no change recorded in the C group ( $p=0.152$ ). The post-intervention mean CB&M scores were 5.9 and 9.7 points greater than baseline for ABE and VRE groups, respectively. Clinically important improvements of six points or greater between the baseline and post-intervention evaluation were recorded for one, four and ten subjects in the C, ABE and VRE groups, respectively (Figure 2c).

*(Insert Figure 2 approximately here)*

One subject in the control group practiced BBS tasks between the baseline and post-intervention evaluation sessions and his data were thus removed from analysis. Since a clinically important change on the measure is

five points, the scale is not sensitive enough to register change in subjects scoring greater than 51 at baseline. A ceiling effect was evident in the BBS scores for 17 subjects. Once the scores from these individuals were removed from analysis, the subject numbers were relatively small with four, five and seven subjects in the C, ABE, and VRE groups, respectively. Group baseline, post-intervention and three-month follow-up scores on the BBS are shown in Figure 2b. The single statistically significant BBS score change was recorded between baseline and post-intervention measures in the ABE group ( $p=0.025$ ) however, the improvement was not clinically important. Five subjects, one in the C group, two in the ABE group and two in the VRE group, made clinically important improvements of five points or more between the baseline and post-intervention evaluation (Figure 2d).

Group mean gait speed for the C and ABE groups decreased slightly from baseline to post-intervention (C = -0.03 m/s, ABE = -0.02 m/s) while a slight increase was recorded in the VRE group (0.03 m/s). These changes were not statistically significant. Specifically, the scores (m/s) at baseline and post-intervention were 0.9 and 0.87, 1.04 and 1.02, 1.13 and 1.16 for the C, ABE and VRE groups, respectively. Five subjects had clinically important improvements on gait speed from the baseline to post-intervention evaluation. The two subjects in the ABE group improved from 1.27 m/s to 1.45 m/s and 1.13 m/s to 1.38 m/s. The three subjects in the VRE group improved on gait speed (m/s) from 1.34 to 1.74, 1.39 to 1.68, and 0.77 to 0.95.

The cognitive, attention and physical characteristics of the study subjects were highly variable with a subgroup of subjects unable to stand quietly for the required amount of time to measure COP. Data for two C subjects, one ABE subject and one VRE subject, were excluded from analysis of quiet standing because these subjects were unable to complete any of the quiet standing tasks. A further two C subjects, one ABE subject and four VRE subjects were unable to complete the quiet standing trials while standing on the compliant surface. The remaining 23 subjects were able to complete all measures. Trials were eliminated from the analysis if at any point during the one minute of quiet standing, the subject needed physical support or opened their eyes in the no-vision conditions. On average, a maximum of one trial per condition per subject was eliminated leaving three trials for data analysis. One subject in the C group completed only two trials in the eyes open, compliant surface condition.

*(Insert Table 2 approximately here)*

Separate three-way ANOVAs (Group x Condition x Time) were run for each of the four dependent

variables, range and RMS of A/P and LAT sway. A significant Condition main effect was identified for each of the dependent variables with significant Time main effects identified for A/P range and A/P RMS only. Significant Condition x Time interaction effects were identified for LAT range and LAT RMS. Follow-up analyses collapsed across Group revealed significantly larger sway range and RMS in both A/P and LAT directions in the Compliant versus Firm surface conditions. The added destabilization resulting from closing the eyes on the Compliant surface was statistically significant for both Range and RMS in the A/P direction at baseline, post-intervention and 3-month follow-up and for Range in the LAT direction at baseline only. Although there appears to be a tendency for the COP Range and RMS in the Compliant surface conditions to be smaller at post-intervention and at 3-month follow-up than at baseline, the differences were not statistically significant.

*(Insert Figure 3 approximately here)*

## **Discussion**

Despite the small sample size and the large variability of balance skills in the study sample, community-dwelling adults with TBI who took part in a VR-based and a more traditional 6-week exercise program made improvements in functional measures of balance which were maintained for at least 3 months. Subjects with higher-level balance skills at the start of the study had the greatest improvement following the 6-week exercise program while subjects with lower levels of initial balance improved, although to a lesser extent. Notably, improvements in the higher functioning subjects were more evident in the VRE than ABE group. Although recovery is reported to be slow after six months following a neurological event<sup>42</sup>, our sample was between 1 and 32 years post injury and subjects still showed significant gains.

Impaired balance and mobility are major factors leading to falls and the potential for subsequent TBI. An important emphasis in rehabilitation is the development of interventions that are effective in improving balance and functional mobility as a method for decreasing fall risk<sup>12</sup> and prolonging the time to the first fall.<sup>43</sup> For example, studies have demonstrated that exercise can reduce falls or falls-risk in community-dwelling older adults.<sup>12,44</sup> Given that the large proportion of adults with TBI ultimately lose therapy services and live in the community, community-based interventions with demonstrated efficacy must be developed. Our study demonstrates that VR is as effective as traditional-based exercise. Ease of implementation of a VR exercise program in the community appears feasible given the current state of technology.

## Who can use VR? Considerations and Benefits

We chose to use flat screen technology to provide the virtual environment for several reasons. First, we wanted to minimize the possibility of motion sickness potentially caused by the use of head-mounted display units. Despite this, there was a single instance of dizziness and nausea during one VRE session. It is possible that the symptoms were induced by the conflict between the real motion of the subject and the perception of apparent motion induced by the VR system. Cf. Stanney KM, Kennedy RS, Kingdon K, 2002.<sup>45</sup> However, given the isolated incident, it seems more likely that the subject was showing signs of a common post-TBI vertigo incident. Specifically, the symptoms were manifested only once during a two-minute period in a single session. Following a short rest, the subject was able to continue with the exercise program. This suggests that motion sickness will not limit the usefulness of the system for similar individuals.

Second, our goals are to move novel technologies including VR delivered intervention into the community to facilitate access by individuals no longer receiving rehabilitation services as well as to provide a means for individuals to augment, where appropriate, their current treatment. One obvious difficulty is the degree of monitoring and supervision required for appropriate use of the system in a community setting. We began individual ABE and VRE programs with 1:1 supervision. All subjects through the full 6-week program of ABE required this level of supervision. Constant supervision was necessary to introduce each activity, give cues regarding the level of activity, and provide feedback on performance. In contrast, all subjects in the VRE group were able to complete the exercises, albeit with different degrees of cuing required, yet overall there was a tendency to decrease the direct supervision as subjects quickly became familiar with the activities. The constant need for frequent cuing by the exercise supervisors in the ABE program was provided by the computer in the VRE program. Moreover, the VR exercise parameters could be set for each user separately before their exercise session allowing for regulation of exercise difficulty. Specifically, the speed and number of virtual objects could be set and the extent of reach required to contact virtual objects could be limited, thus providing a measure of control and safety over the exercise activity.

Third, in order to maximize possible balance improvements, subjects worked at or near their limits of balance stability during the exercise periods. This required a degree of supervision based on the potential for falls during exercise since the foremost worry of any health professional working with unstable people is the risk of falls. Thus, the degree of challenge in the exercise programs was balanced with the need for safety. In

the ABE program there was limited ability to control the environment and exercise equipment. For example, a ball could bounce away from the subject who might chase after it creating an unsafe situation. Constant supervision was therefore necessary to maintain exercise safety. In contrast, the VRE environment was constrained by the program. The use of a harness or body weight support system in both ABE and VRE situations for subjects with greater balance instability or higher risk for falls, such as the most inactive and the most active,<sup>46</sup> may have provided an additional degree of safety. While research has been done to show the body weight support system improved the effects of gait training (functional balance, walking speed and endurance) of persons with stroke,<sup>47</sup> it is unclear whether balance improvements demonstrated when external support is provided would transfer to unsupported activity in adults with TBI. This question will be addressed in an ongoing study with adults with acute acquired and traumatic brain injury.

Are there additional benefits to exercise?

An individual's response to exercise is more clearly successful if there is better compliance with the exercise program.<sup>12</sup> Attrition rates for intervention studies range significantly. For example, a 14% attrition rate was reported within the first 3 weeks of a falls prevention program with community dwelling older adults<sup>12</sup> while a significantly greater dropout, 45%, was reported in an exercise program with subjects without known pathology.<sup>48</sup> Often the reasons for attrition were either unknown or of medical origin but in many instances were dependent on the reason for exercise, the length and frequency of exercise sessions, the variety in the program, and the delay between the end of the program and the final evaluation. In the above studies, exercise sessions lasted for 60 minutes and continued 2 to 3 times/week for 8 to 12 weeks, with re-assessment after 3 to 6 months and in some cases 1 year.

In the current study, subjects reported that both the VRE and ABE programs were interesting, novel and geared to their needs although the VRE was received with more enthusiasm. An earlier study<sup>49</sup> using similar technology to IREX reported that individuals with cerebral palsy who used the VR system showed enthusiasm each time they worked with it and suggested that the intervention could lead to increased self-esteem and a sense of empowerment. The novelty and interest generated by the exercise delivery system may, in fact, serve to increase compliance and continued participation in exercise sessions. Qualitative reports of exercise benefit and interest from the current study will be the subject of a subsequent paper. In general, many subjects wanted to continue with both programs past the 6-week study period. In fact, only one subject, who was from the ABE

group, dropped out of the study due to scheduling problems. All other subjects completed 15-18 exercise sessions and returned for the 3-month follow-up measures.

The regular attendance of subjects may indicate that there was some perceived benefit in study participation. However, Brouwer<sup>50</sup> reported that the social interaction, attention and information provided through an education program did not result in balance improvements. Rather, the active participation in an exercise program is necessary. Improvement in functional mobility was verbalized as a goal by subjects, many of whom self-reported balance improvements. Safety issues were also identified with several subjects indicating that they were concerned they might fall and were thus participating in the study to address this concern. Subjects also commented that there was a lack of community-based programs available to them for improving balance. For many subjects, the opportunity to socialize, have a routine and a schedule during the week, to help themselves and others were identified as reasons for participating.

Although the less functionally independent and mobile subjects did not show significant improvements in balance, they also verbalized that they felt they benefited both mentally and physically from participation in the study. One of the more mobile subjects in the ABE group commented that he felt confident that he no longer required assistance to travel and was ready to start taking the public transit system. While these changes do not necessarily reflect improvements in the primary outcome measure, there is a possible impact of the study across multiple domains. Specifically, the effect of exercise participation on perceptions of confidence and independence will be reported in a subsequent paper.

How do the ABE and VRE programs compare to other balance programs?

Certain types of exercise are more effective in delaying falls and improving balance. The Frailty and Injuries: Cooperative Studies on Intervention Techniques (FICSIT) trial explored multiple interventions designed to have an impact on falls in elderly people.<sup>51</sup> A common finding was that interventions focusing on a balance component were more effective in delaying onset of first falls than strength or endurance-training interventions.<sup>52</sup> In fact, strength training has not been found to affect balance although strength is correlated with gait speed.<sup>53</sup> Certain forms of coordination and endurance exercise that have been studied and found to improve balance include dance<sup>54</sup> and swimming.<sup>46</sup> Tai Chi has also been demonstrated to delay the time to a first fall.<sup>52</sup> Tai Chi encompasses many aspects of balance (static or dynamic, vision, weight shifting and activities at variable speeds). The duration of Tai Chi exercise does not seem to affect the stability measures of

older people.<sup>55</sup> Several authors have also reported variable effects of different biofeedback programs on measures of quiet stance in distinct populations. For example, computerized visual biofeedback resulted in improved balance for rehabilitation inpatients with stroke, although the outcome was similar with a conventional therapy program.<sup>15</sup> Given that the subjects were also completing their regular inpatient rehabilitation, it is possible that the generic benefit was simply an effect of regular therapy. Shumway-Cook A, Anson D, Haller S<sup>56</sup> demonstrated a greater effect with biofeedback than conventional physiotherapy in outpatients with stroke. Specifically, they reported increased loading of the weaker leg and greater stance symmetry following biofeedback training. Reductions in postural sway have also been reported in older adults living in the community following biofeedback training.<sup>57</sup>

We did not find a similar significant increase in quiet stance stability although there was a tendency for subjects in both exercise groups to sway less following the exercise intervention and at the 3-month follow-up. The lack of significant effect may be in part due to the difficulty of this task for persons with TBI and the variability of the individual scores. We have previously demonstrated greater stance symmetry and increased loading of the weaker leg in a single community-living individual with TBI in dynamic stance using a VR intervention.<sup>41</sup> This measure was not included in the current study yet may provide a better evaluation of postural sway control.

The current study used the guidelines of exercise selection and progression in both the VRE and ABE programs as proposed by Grant.<sup>40</sup> Both the VRE and the ABE used in this present study have similarities to Tai Chi in that they also incorporated coordination and endurance to improve balance. They included, where appropriate, running, jumping and hopping and a full spectrum of activities involving coordinated movements of the whole body that could be tailored to those with low or high-level balance skills. Both the VRE and the ABE groups significantly improved on the CB&M functional measure of balance indicating that there was carryover to function. The added advantage of the ABE is the use of actual tools like balls and sports equipment that was more directly applicable to real life and perhaps allowed easier transference to those skills.

#### Limitations of the Study

According to Patla AE, Frank JS, Winter DA,<sup>27</sup> no single measure can capture the complex nature of balance control. Measures should be kept as simple as possible ensuring that all important information is collected. A variety of measures is the best option while trying to minimize the time required for the complete

testing to be done. The need for multiple outcome measures was clear in the current study, given the wide variability in functional mobility of the study subjects. This resulted in difficulty identifying a single primary outcome measure for the whole group. The BBS was not sensitive enough to show significant change, in part due to the number of subjects with a high-level of balance in this study. On the other hand, the CB&M turned out to be too challenging for some subjects. In addition, the measures of quiet stance were challenging for the subjects both physically and cognitively. Although multiple trials of quiet stance (three to four repetitions) improves the reliability of the measures,<sup>58</sup> the amount of time required to do the test also increases significantly. The validity and reliability of the data may be influenced by factors such as fatigue and inability to attend for long periods. In fact, a systematic review by Harstall<sup>59</sup> was inconclusive regarding validity and reliability for clinical use of this measure.

Other limitations of this study include the small sample size and the large variability of balance skills within the sample population. Although subjects with higher level balance demonstrated the greatest effect, restricting the study population was not a primary goal as we were interested in identifying individuals who could potentially benefit from community-based intervention. A larger randomized control trial is needed to confirm the results.

### **Conclusion**

Balance is a significant problem contributing to lack of employment, decreased quality of life, risk of falls and decreased independence for community-dwelling adults with TBI. Balance exercises using VR offer a different approach to balance retraining, one that may be an effective alternate to activity-based exercise. This modality may offer new opportunities for health care personnel to employ different methods to train balance for adults with TBI who have ongoing balance problems.

This study demonstrates that subjects more than six months after a TBI have the potential to improve in functional mobility and balance and that delivery of exercises using VR can be as effective as traditional exercise programs for retraining in this population. Virtual reality may offer an innovative strategy, which could be cost effective, motivating, and goal directed to maintain or advance the mobility, independence and safety of individuals with TBI. Further work should be done to confirm the effectiveness of this intervention with this population at this and earlier stages of recovery.

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### Figure Legends

**Figure 1.** Image of experimental setup. a) A participant standing in front of the camera and television monitor works on one of the activities involving reaching. Photo from [www.irexonline.com](http://www.irexonline.com). Used with permission.

b) The subject's view of the activity on the television monitor. Photo from Sveistrup H. et al, 2003. Used with permission.

**Figure 2.** Balance outcome measures. Mean Group Data (+/- SE) for CB&M (A) and BBS (B) at three time periods illustrates the effect of the exercise program. C) and D) Illustrate the magnitude of the difference in individual subject scores between baseline and post-intervention measures. Each icon represents the change for a single subject. The horizontal line on each graph indicates the value corresponding to a minimal clinically important difference for the specific measure.

**Figure 3.** Group mean scores (+/- SE) of force plate data showing values for measures for the four conditions of eyes open firm (EOF), eyes closed firm (ECF), eyes open compliant (EOC), eyes closed compliant (ECC). Conditions indicated with an arrow are significantly different from conditions indicated by the beginning of each horizontal line. Filled arrows indicate significant findings at all three time periods. Open arrows indicate significant findings only at baseline and post-intervention for A/P Range and only at baseline for A/P RMS and LAT Range.

### Table Legends

**Table 1.** Subject demographics by group.

**Table 2.** Force Plate measures indicating main effects and interaction effects for group, time and condition.

\* Indicates significant p values at  $p < 0.05$ .

FIGURE 1

A



B



FIGURE 2

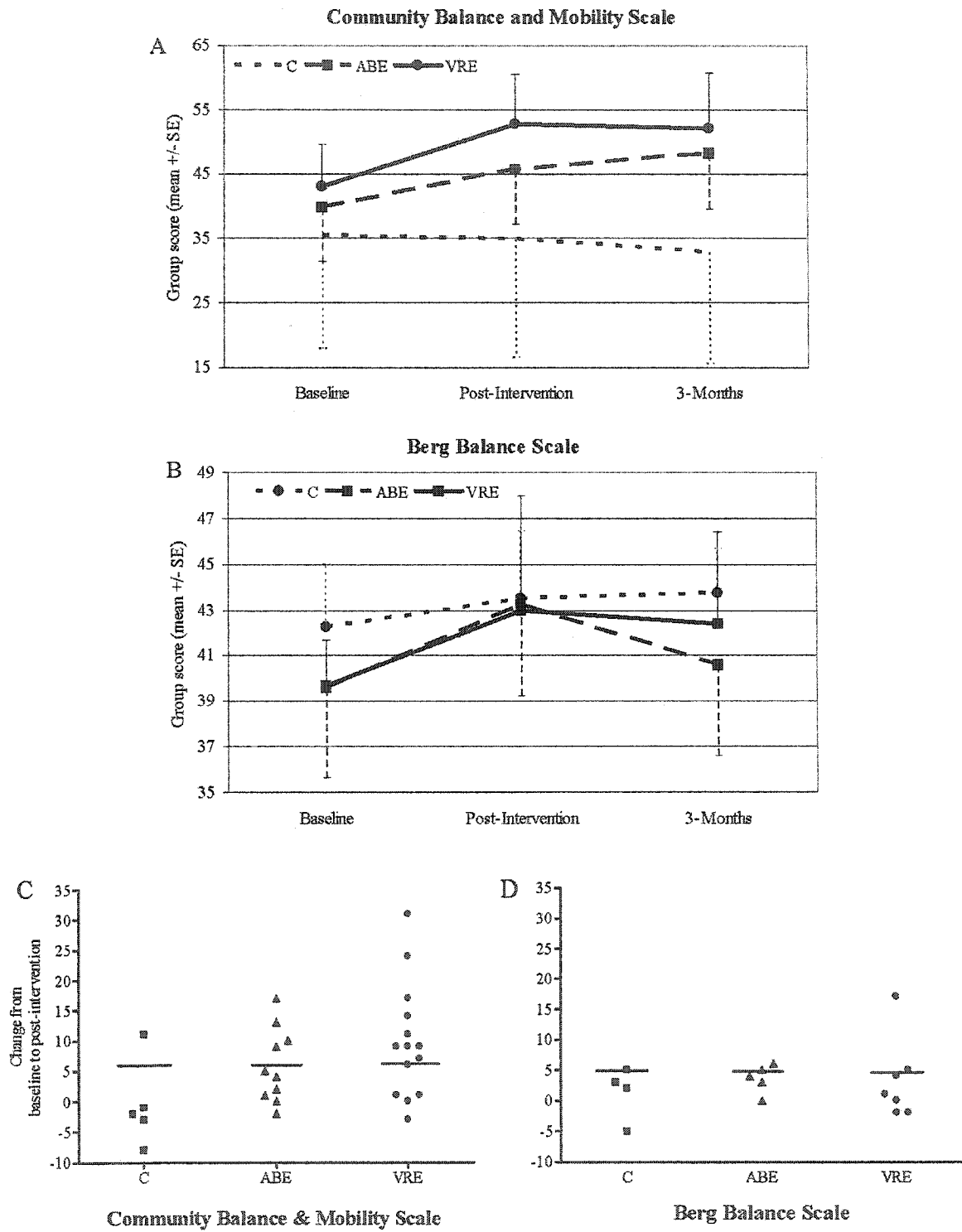


FIGURE 3

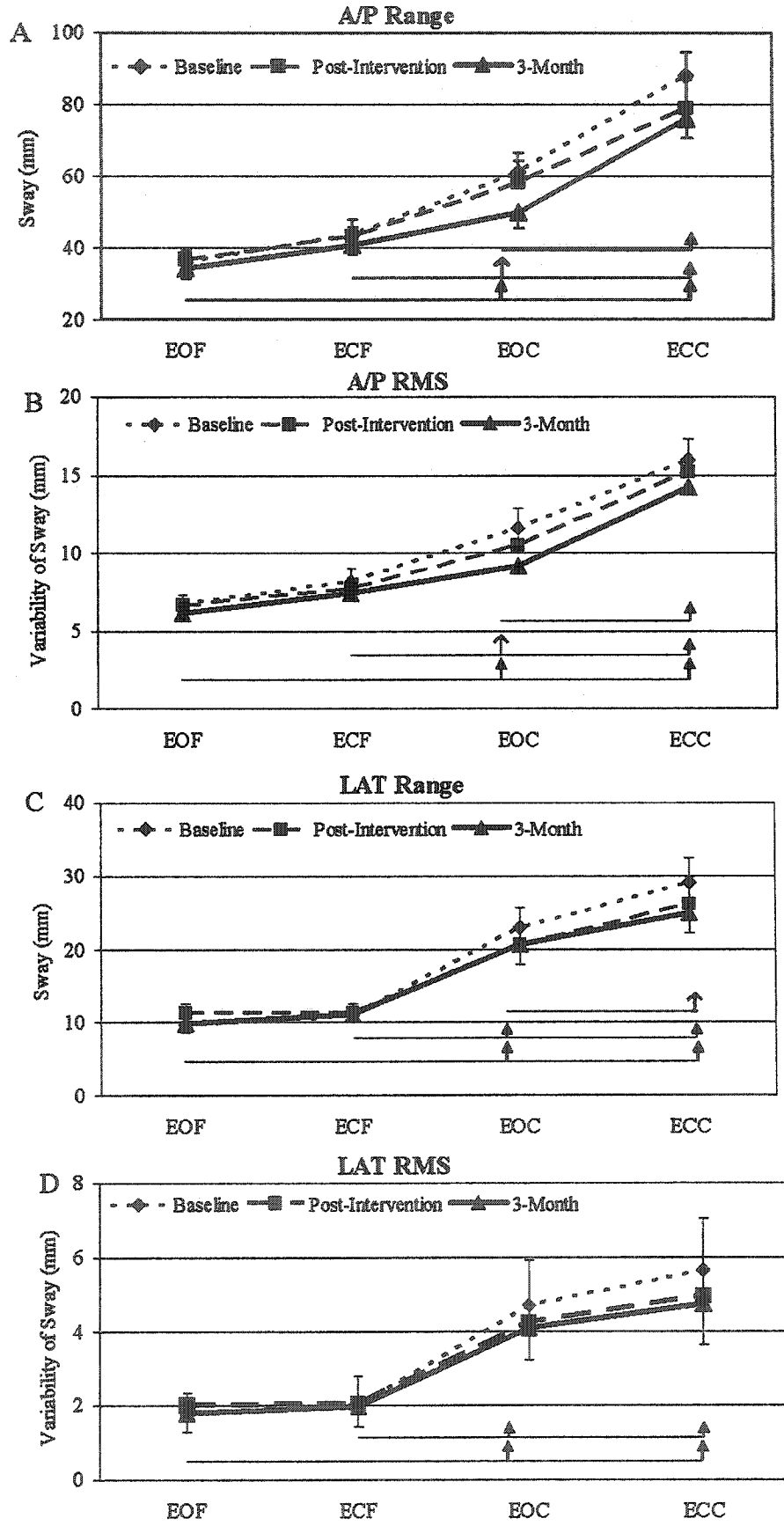


TABLE 1

Group	Gender	Age range ( $\bar{x}$ )	# Subjects $\leq 3$ years post TBI	Initial GCS range ( $\bar{x}$ )	Number of subjects using a mobility aid	Number of subjects reporting falls / near falls in previous year	Baseline BBS range ( $\bar{x}$ , median)	Need for prompting: indep completely / indep once at rehab / needs help to training room
C	7 males	22-62 (43)	3	3-9 (5.6)	2 cane 1 wheelchair & cane	2 / 4	19-56 (43, 46)	5 / 1 / 1
ABE	10 males 2 females	18-66 (37)	3	3-9 (5.7)	2 cane 2 wheelchair & cane	7 / 9	28-56 (49, 53)	6 / 3 / 3
VRE	9 males 6 females	19-64 (42)	4	3-10 (4.2)	4 cane 2 walker	6 / 11	21-56 (48, 52)	10 / 2 / 3

TABLE 2

Main Effect	A/P Range	A/P RMS	LAT Range	LAT RMS
Group	F(1,15)=0.097; p=.76	F(1,15)=0.027; p=.871	F(1,15)=0.037; p=.849	F(1,15)=0.009; p=.924
Condition	F(3,45)=66.669; p<.001*	F(3,45)=46.862; p<.001*	F(3,45)=52.193; p<.001*	F(3,45)=58.166; p<.001*
Time	F(2,30)=4.455; p=.032*	F(2,30)=5.270; p=.015*	F(2,30)=2.380; p=.128	F(2,30)=2.902; p=.081
<u>Interaction Effect</u>				
Group x Condition	F(3,45)=2.420; p=.114	F(3,45)=1.930; p=.177	F(3,45)=0.739; p=.467	F(3,45)=0.957; p=.381
Group x Time	F(2,30)=1.435; p=.255	F(2,30)=1.626; p=.217	F(2,30)=1.425; p=.257	F(2,30)=1.499; p=.242
Condition x Time	F(6,90)=1.399; p=.244	F(6,90)=0.849; p=.471	F(6,90)=3.705; p=.012*	F(6,90)=3.268; p=.021*
Group x Condition x Time	F(6,90)=0.584; p=.679	F(6,90)=0.894; p=.448	F(6,90)=0.889; p=.469	F(6,90)=0.420; p=.774

BENEFITS OF ACTIVITY AND VIRTUAL REALITY BASED BALANCE EXERCISE PROGRAMS FOR  
ADULTS WITH TRAUMATIC BRAIN INJURY:  
PERCEPTIONS OF PARTICIPANTS AND THEIR CAREGIVERS

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Key Words: virtual reality, self-efficacy, self-concept, physiotherapy, balance confidence, community integration

### **Abstract**

*Objective:* To explore multidimensional benefits of exercise participation perceived by adults with traumatic brain injury (TBI) and their caregivers. *Methods:* Adults (n=27, ages 18-66) with moderate or severe TBI 6 or more months earlier participated in focus groups following six weeks of an activity-based (ABE) or a virtual reality (VR) delivered balance exercise program. Family members and care providers participated in separate focus groups. Perceptions related to program participation as well as balance confidence and lower extremity function were extracted from focus group verbatim and quantitative scales, respectively. *Outcomes:* Benefits in three domains, psychosocial, physical and program were identified from transcription and analyses of focus group verbatim. Improvements were noted in balance confidence and function in both groups. Substantially greater enthusiasm and knowledge was expressed by participants in the VR group and their caregivers. *Conclusions:* Both exercise programs offered benefits in addition to improved balance. The VR participants had greater improvements on quantitative measures and provided more comments expressing enjoyment and improved confidence. Applications in terms of community reintegration and quality of life are discussed.

## **Benefits of activity and virtual reality balance exercise programs for adults with traumatic brain injury:**

### **Perceptions of participants and their caregivers**

According to the Brain Injury Association of America [1], 5.3 million people living in the USA are currently disabled by the effects of a traumatic brain injury (TBI). Each year an additional 1.5 million people sustain a TBI and of these 80,000 begin the process of long-term recovery. While the estimated costs associated with TBI are \$48.3 billion annually, it is not possible to quantify the physical and emotional strain that the injured person and those close to them experience. Adolescents and young adults are most at risk for a TBI. Strikingly, after a TBI has occurred, the risk of a subsequent TBI increases threefold [2].

Common functional deficits after TBI include balance and postural control problems that can persist for years, and significantly affect quality of life [3]. These long-term problems are under-reported in the literature [4] even though their impacts are considerable. For example, impaired confidence in balance skills has been related to depression, fear of falling, and limited ability to participate in social activity [5]. Physical limitations resulting from a TBI have also been shown to affect community independence, including a wide range of life habits from self-care to employment [6]. This suggests an important role for the provision of exercise programs and balance rehabilitation for individuals with TBI.

In general, physical activity and exercise can improve one's health through lowered risk of cardiovascular disease, diabetes, obesity, cancer and musculoskeletal conditions [7]. Exercise can decrease the functional decline of aging and improve balance and muscle strength [8-10] while physical activity can reduce the risk of falls in older people if it is moderate in intensity, and directed towards flexibility, strength, coordination, reaction time and balance [11, 12]. Even if falls are not reduced through exercise participation, other benefits that are important to independent living occur. These include improved confidence in balance and better strategies to cope with a fall (for example calling for help and staying warm) [13]. Exercise can also help neurons to survive, generate new neurons, and recruit neurons [14]. A positive relationship has been noted between exercise and cognition [15] and people who exercise often tend to be less depressed [16, 17].

Benefits of physical conditioning for people with TBI have been suggested and include increased endurance, reduced depression, help with self-confidence (by promoting independence) and improved individual autonomy [18]. These factors contribute towards better reintegration into the community, better behaviour (health and lifestyle), more recreational involvement and better social acceptance. In addition,

exercise can improve sleep patterns and reduce fatigue which may increase an individual's ability to find and keep a job [19]. Even years after the injury, rehabilitation and exercise can increase function [20]. We have recently reported improvements in functional balance and mobility from two balance retraining exercise programs in people six months or more after a TBI [20]. Although improvements on balance scores were similar between the activity-based (AB) and the virtual reality (VR) exercise participants, more individuals from the VR exercise group demonstrated clinically important change suggesting a possible advantage of the VR system.

Physical impairments are clearly not the only major deficits resulting from TBI. Limited self-awareness of the effects of the injury on cognition, emotions and behaviour may create obstacles to rehabilitation [21] and achieving a sense of quality of life after TBI can be difficult. Self-concept, a way of defining one's self, is thought to be a useful model to understand problems and find solutions after brain injury [22]. Five self-concepts have been identified as the most highly valued to people with TBI: family self, physical self, moral self, personal achievement and social self [22]. Attaining satisfaction with valued areas of life can improve quality of life [23]. Strategies to improve spheres of self-concept, for example improving physical health through exercise, may also improve community integration by helping individuals with TBI develop positive self-images [22].

Finding strategies to improve self-concept after TBI can be challenging as there are often multiple systems damaged including cognitive, behavioural and movement [24] resulting in complex disorders. Furthermore, after a TBI, individuals may be forgetful of new information, show decreased attention and organization, and may poorly judge their own abilities [25]. Balance problems for example, can be worse if cognitive problems exist. In fact, people with TBI tend to overestimate their abilities, especially if they are unsure of them [25]. Persons with brain injury most likely to overestimate their abilities are those who tend to have more severe brain injuries, for example bilateral or multi-site brain lesions [26]. Individuals who are less aware of their areas of impairment may try to do activities that are beyond their ability, putting them at greater risk of falls [3].

Durgin [27] describes an intervention approach consisting of graduated 'real-world' trials where a person with TBI is able to work towards more challenging tasks in the community through progressively increased demands, helping them move towards their previous level of skill or to learn new skills. Virtual reality may provide such a vehicle allowing for added flexibility in designing interventions that will address social and

cognitive impairments and disabilities after TBI. The technology has the potential to offer experiences that are engaging and rewarding. Virtual Reality shifts the focus from the person's efforts to that of interaction with the VR environment and allows enjoyment of a meaningful activity [28]. Specifically, it can improve cognitive function and concentration through an individual's interaction with a pleasant activity [29]. The enjoyment experienced while working with VR may increase the level of participation. In addition to generating realistic situations for testing, intervention and collection of data [30], the provision of positive feedback through VR has been shown to increase self esteem and empowerment in adults with various impairments including cerebral palsy, spinal cord injury (SCI) and stroke [31].

The Disability Creation Process Model (DCPM) [32, 33] is a model which identifies factors that limit ability to perform daily activities and fulfil social roles valued by an individual. The DCPM stresses all aspects that affect one's ability to perform daily activities and social responsibilities, for example personal and environmental factors. Noreau and Fougereyrollas [34] reported that aspects such as personal relationships and employment were not only important to social participation but contributed to overall health of the individual, in this case persons with SCI. Where there is more disability, there is generally more difficulty with daily activities. Restrictions in areas like fitness, mobility, recreation and employment most disrupted an individual's feeling of accomplishment. Strategies to create accessible community resources for fitness and recreation could lead to improved self-concept and overall better health.

The purpose of this study was to 1) determine if qualitative perceptions from participants and their caregivers or families identified exercise benefits beyond the initial targeted goal of improving functional mobility and balance, for example in expressions of confidence and pleasure and to 2) compare the groups (VR, AB and caregivers) to see if perceptions of exercise participation differed as a function of program delivery.

### **Methods**

This project was undertaken as part of a larger exercise study regarding balance retraining after TBI. Further details on participant selection and methods can be found in Thornton et al [20].

#### *Participants*

The sample in the current study included 27 individuals from a possible 34 individuals who participated in the initial balance retraining programs. These individuals had sustained a TBI at least six months prior to their participation. In addition, individuals were included if they had a Glasgow Coma Score at the time of injury of

12 or less, were no longer involved in inpatient rehabilitation, had ongoing balance problems since their TBI, were able to stand independently for two minutes with no mobility aid, could understand instructions in English or French, and were able to interact with a computer system. Exclusion criteria included vestibular, vertigo or orthopaedic problems that severely limited mobility. Participants were quasi-randomly assigned to one of two balance retraining groups using baseline Berg Balance Scale Scores. The AB exercise program incorporated conventional tools of balance retraining with activities such as walking and running, supplemented with equipment including balls and stools. The VR approach used a modified IREX\* computerized program that required participants to make large full body movements to interact with virtual objects in a virtual environment. The 50-minute exercise sessions took place three times per week for six weeks in a designated room at a regional rehabilitation center.

Participants completed two questionnaires at baseline and after the exercise programs: The Activities-specific Balance Confidence Scale (ABC) and the Lower Extremity Functional Scale (LEFS). Upon completion of the exercise programs, participants and caregivers including family members were invited to participate in focus groups. Travel and parking expenses for study participants were covered. The research ethics board of the rehabilitation center approved the study methodology. Participants were asked to sign a consent form that allowed for proxy consent if the participant was unable to fully understand certain details.

#### *Measures*

*Balance and Function Questionnaires:* Each participant completed two questionnaires at three measurement times: prior to, immediately after and 3-months after the exercise program. The approach of using several measures was taken to determine changes on the different aspects of balance and function being addressed in the interventions [35, 36].

The Activities-specific Balance Confidence Scale (ABC) identifies an individual's level of confidence in performing activities of daily living (ADL). Participants were asked how confident they were that they would not lose their balance or become unsteady when doing 16 functional activities of varying levels of difficulty. Scores ranged from not confident (0%) to completely confident (100%) [37]. While the ABC was not designed for the TBI population it is a reliable and valid, objective measure of confidence in balance designed for older adults who live in the community [37-39], who often demonstrate both cognitive and physical limitations similar to those seen in individuals with TBI.

The Lower Extremity Functional Scale (LEFS) is a 20-item self report functional status measure designed for individuals with musculoskeletal conditions of the lower extremity [40]. Participants were asked to indicate whether their lower extremity function resulted in difficulties with activities such as walking, putting on shoes, squatting and running. No previous work has been published using this scale with the TBI population, however reliability and validity testing has been done with individuals with a wide spectrum of lower extremity orthopaedic conditions. The tool was intended for use with all patients with lower extremity disability [41, 42]. Descriptive statistics were calculated for the ABC and LEFS using SPSS (version 11) to determine group trends.

*Focus groups:* Two separate focus groups were carried out for each exercise group and consisted of 1) participants in the balance retraining program, 2) family members including partners, children or caregivers. Four individuals who could not make the scheduled focus group sessions were interviewed separately. Each one-hour focus group session was held in the balance testing room. Participants in the focus groups were informed that the purpose of the session was to obtain broad feedback on the exercise program. Predetermined open-ended questions provided a structure to the focus group sessions (see table 1). Moderators, experienced with qualitative research and focus group facilitation, led the sessions. Individuals directly involved in the balance exercise programs were not involved in the focus groups. Sessions were tape-recorded and manually recorded notes were printed on flip charts visible to all participants during the session. Concurrence with written concepts was determined by reviewing flip chart notes at the end of each focus group session. Verbal consent for participating and audio taping was requested prior to starting the session.

Analysis of focus group materials was done by listening to and transcribing the audio tapes and carefully studying the verbatim and notes taken from the sessions. A coding system was applied to the comments, which were then grouped according to themes. Perceptions of participants regarding their experiences, comparing participant and family comments, grouped according to intervention type were examined, to identify common themes and distinctions that emerged.

*Insert table 1 approximately here*

## **Results**

Baseline, post intervention and three-month follow-up scores for ABC (figure 1a) and LEFS (figure 1b) are plotted for the two groups. The ABC group mean scores for the AB group increased slightly each time from

74.6 to 76.4 and 78.2. Mean group scores for VR also increased each time from 74.8 to 80.2 and 81.2. The LEFS group mean scores for the AB group improved from 55.8 to 57.4 and 60. For the VR group the group means initially improved from 57.1 to 59.2 and then decreased slightly at three-month follow-up to 58.8. Although both exercise groups improved on both measures, the changes were not statistically significant or clinically important. Three participants in the AB group and five in the VR group made clinically important improvements of seven points or more on the ABC between the baseline and post-intervention testing (figure 1c). Two participants in each exercise group made clinically important improvements of nine points or more on the LEFS between the baseline and post-intervention testing (figure 1d).

*Insert figure 1 approximately here*

The comments from the focus groups were coded and grouped by themes. The themes derived from the comments were categorized into the following three domains: psychosocial, physical and program.

#### *Psychosocial comments*

The psychosocial comments included the following themes: enjoyment, confidence, self-esteem, purpose/structure, attitude, and awareness.

*Enjoyment:* The focus group data clearly indicated that one of the benefits of both balance retraining programs was enjoyment. Both programs were said to offer the participants an enjoyable experience that improved their confidence, allowed them to socialize and become more organized and added structure to their lives. In general, the VR participants expressed greater enjoyment. One participant wanted to share the VR experience with her children, so asked if her children could try the activities. FF's son noted:

*We have tried in the past to have him involved in things but he seemed uninterested... with these exercises he was trying to explain what he was doing, he was interested in what he was doing, he was looking forward to going.*

RS (VR) had seen some of the AB participants working and he commented that the VR seemed more enjoyable:

*When you are doing exercise without the computer, there is failure, when you drop a ball for example. With the computer, it's ok, the ball goes off the screen, another one arrives, and you just go on.*

While several comments in the AB group reflected enjoyment of the overall experience, some participants indicated disappointment at not being part of the VR group and a desire to try those exercises.

*Confidence:* Both AB and VR participant groups discussed confidence with reference to broad implications. Using the local bus system and keeping appointments were discussed as confidence builders. JL's husband (VR group) commented:

*Eighteen times she drove the route where the accident happened and was successful. This gave her ... confidence that we were returning to normal life again... Rather than being unsure of her abilities, now she says, "I can do this. I am capable".*

The VR group indicated more strongly that their balance was better due to increase in confidence. FL said:

*I just feel more confident. I am supposed to use my cane in the winter but I looked at it this morning and thought, "Do I really need it? I feel very confident going without it." The exercises helped me feel confident in my balance.*

RS said, 'I am more likely to try something that I wouldn't have before'. JL's partner spoke of his wife as being quite inactive since the accident. 'She is exercising again and that has improved her self-image. It was exactly what she needed'.

JL said:

*Last week I went to one of my son's hockey games and I stepped down a distance that I hadn't done ... I thought, "Wait a minute, I never stopped to try to figure out how far I had to step". It was more like what I would have done [before the accident]. That's confidence ... I credit this program with improvements, the structuring of the day, exercising again, driving again, driving where the accident happened. It was a real confidence builder.*

Other comments about confidence reflected the potential for over confidence and increased risk-taking. For example, one participant from the VR group indicated he felt more confident and would like to try waterskiing, which was a new sport to him. It is possible that by offering safe ways to do more challenging activities, a person's awareness might be heightened, increasing their attention to the task, as well as to the choices they make in how to safely challenge themselves. These ideas were evident in the following comments. RS (VR group) thought trying new activities did not necessarily mean risk-taking. Increased awareness from the exercises meant that you could try things more safely. 'It is probably better because you are more aware of it or paying more attention to how you do it'. BL's family member was afraid that the confidence and other benefits would regress to pre-study status, when the study was over.

From the AB group, QQ said:

*My confidence definitely improved. Before, my wife used to go with me everywhere, whereas now, I don't need her to lead me around; I can get somewhere on my own.*

*Self-Esteem:* This theme emerged from the VR group and is illustrated by comments such as one by RS who said:

*It was just nice being around other people who have gone through a similar experience...to see that they are living with their problems and its ok.*

KA said, 'I think it makes you feel better about yourself, that it is not just you', referring to doing activities with other people with TBI.

*Purpose/Structure:* Another psychosocial theme was having a sense of purpose and structure. For one individual this was described as a willingness to try new things. From the VR group, ZKF said:

*I have motivation to do different things or to look into doing other things. I've always been active, but this gave me new enthusiasm to keep trying. I feel like I am letting myself down if I let myself get back into a slump.*

While volunteering was suggested by FL as one way to stay active, participants in both groups mentioned the idea of 'helping science' and having a sense of importance through being involved in the study. FL said:

*It's not the same to simply volunteer or go to a social group ... We [referring to participants in the study] are all struggling to make ourselves better [referring to herself and other individuals with TBI and their ability to contribute to development of improved intervention strategies].*

The most strongly expressed comments about purpose and structure were in the VR group. For example, II said:

*I really enjoyed the program. I liked being out early in the morning; it added structure to my day. The structure helped organize the day and the week.*

FF's son from the VR group said:

*Because FF is not working now, he found it like a job. There was structure to the day, purpose, a reason to get up and be somewhere by a set time that had significance.*

FL commented on the value and purpose of the exercise program for her. 'I can't do a lot of sports because of my balance, but this helped me work on some of the skills I need for sports'.

*Attitude:* The theme of attitude includes feelings of organization, wellness, fatigue, fitness and appreciation. This theme was apparent in the comments of several participants in the AB group especially. Several felt the program helped them and that early intervention would be better. XC said, 'I found it very useful and it's too bad it didn't start ... years ago right after my accident'. QQ talked of feelings of organization and fitness being important to him. He said:

*You had to find your way around the building. You had to ... allow time to get to the exercises by bus.*

*Even to get out and do exercise is good for the body.*

#### *Physical comments*

Comments related to the perception of physical status were divided into two themes: balance/mobility, and coordination. Importantly, many comments reflected improvements in broad categories including ADL's and purposeful activities.

*Balance and mobility:* The VR group indicated more strongly that their balance or awareness of balance was better. KA spoke of correcting her balance if she was feeling unsteady. 'Because of the testing, I realize when something is not right; I know if I just change slightly, things will be alright'. Similarly CA stated, 'I saw myself moving and how much I swayed, so I saw how I did'. CA used that information to try to get more stable.

Concrete improvements in functional balance were also noted as when CR said:

*Because of my improvement in balance, my dad and I signed up for doubles badminton weekly. I don't think I would have tried it before the program.*

LV (AB group) credited the study for his balance improvement. He was able to travel by the public transit system, which he had been unable to do since the accident because of his decreased standing balance. 'I came here by bus – not Para [parallel transportation], I can get on to a regular bus now. I can stand and hold on'.

Individuals with higher-level balance skills at the start of the study tended not to notice a difference in their balance. AB family members stated that a longer study would be necessary to better demonstrate any balance differences.

Improved mobility was illustrated in comments made by FF's son (VR group). 'He is not shuffling as much when he walks'. FF's stair climbing abilities were described by his son:

*Before, he used to pull himself up ... he used to hold the banister and try to climb the stairs sideways.*

*Today, he took his steps, holding on as a regular person would.*

Since the accident, KL's husband stated that KL would not go up or down stairs alone. 'Since the balance study, she is carrying laundry to the basement without hesitating or asking for help'. FL (VR group) stated that since completing the balance retraining program she could put her shoes on in the way she used to before the accident:

*I usually [since the accident] sit on the floor to put my shoes on. This morning I put one foot up on my knee, tied my shoe while I was standing. This is the first morning since my accident that I didn't sit on the floor ... to put my shoes on.*

*Coordination:* The theme of improved coordination was more evident in comments of VR participants. RS spoke about the soccer game:

*You could see where the ball was coming from and anticipate where you had to be to stop it. At first I would just look where my hand was to block one ball but then as you got used to the game, you could plan ahead and look for the next one. I was concentrating on where my hands were initially.*

*Afterwards, I didn't have to think about it so much, you could see the ball coming on one side of the screen, be ready for it and still be watching the next one.*

RS (VR group) continued:

*My spatial sense is notably better. I was prone to spilling coffee when I reached for one. I haven't spilled any like that in about a month. There is better hand-eye coordination. Soccer and juggling seemed to help me that way.*

#### *Program comments*

The program comments included themes such as space, the exercise providers, equipment, and logistics of time distance, travel and location.

*Exercise providers:* Comments regarding the exercise providers emphasised the socialization resulting from program participation. The AB group tended to have more comments about the exercise providers, perhaps because there was more contact and direction required for this type of session. QQ said, 'The instructors were both excellent. They could talk and laugh and they almost duplicated the exercises'.

*Activities and Equipment:* There were more comments from the AB group identifying limitations in equipment such as the balls being too small or not well inflated and that overall space was limited. Significantly, fewer comments about equipment were made by VR participants. While ‘Some games did not behave the way you would expect them to each time’ only one participant had trouble seeing the screen well while a second complained of feeling dizzy while doing some of the activities. KA said:

*It depends how fast you are doing some of the movements. If you are going up and down, sometimes I needed to stop ... The problem came mostly with the up and down movements, or stop and go.*

Some activities were identified as boring in both programs. People expressed a need to have variety and progression of the level of difficulty. RS said of the VR program, ‘In 6 months it would have to go somewhere, more difficult or something’. The opposite was also mentioned. Some participants thought the routine was more important than the activity. Familiarity was comfortable for some people.

In response to the question ‘If you had access to these VR games at home, how confident would you feel about using them on your own?’ CR replied, ‘I would play with them 24/7’ while other participants indicated a preference for working under supervision.

Generally all AB activities were thought to be useful as they were similar to daily activities (stairs, walking, reaching, lifting), although sometimes the activities were thought to be too simple. Many of the activities used related to sports, which were not identified with by some individuals.

Some people in the AB group indicated that they would have preferred to be in the VR group. QQ said, ‘Initially I was disappointed. I wanted to be in the VR group because I thought the conventional program would be boring but it actually ended up ok’.

*Logistics (time, distance, travel, location):* Comments in this area generally reflected interest in having the equipment more accessible. For many individuals, study participation required a large time commitment due to travel in addition to program time. However, most VR participants agreed, ‘It was enjoyable enough to put up with the travel time’. While it was a big time commitment, comments indicated that because it was enjoyable, it was worth the inconvenience of travel distance and location. In fact, some people travelled for an hour in winter to participate three times per week for six weeks. The significant commitment of time required and the fact that only one participant (from the AB group) out of 34 was unable to complete the study protocol due to scheduling problems speaks to the value placed on the program by the participants.

### *Overall Benefits*

Overall benefits of the VR program were expressed by FB:

*My participation not only helped me physically but it also helped me with my ability to be social, with interacting with people [4 participants agreed], with my mental ability, like my ability to remember things.*

The VR family members expressed a strong desire for follow-up both in respect to an ongoing program of exercises and wanting to know the results. They were more likely to want to have access to the program on an ongoing basis. There were substantially more comments reflecting overall feelings of confidence, balance and enjoyment made by VR group participants.

Facilitator IL, commenting about the AB program, said:

*Generally, family had less knowledge of the specific activities that were being done by the participants. No exercise really stood out and families were not very aware of the exercises the subjects were doing at sessions.*

The AB group participants tended to have more negative comments and suggestions for improvements that could be made to the program. In contrast, the VR group participants showed greater enthusiasm and excitement with the exercise program. In general, family members were appreciative of study organizers for involving them and participants reported that they would like to have started sooner after their accident. Both approaches to balance retraining offered an opportunity to contribute to scientific research and to experience balance retraining in a way not currently available.

### **Discussion**

Determining the effectiveness of two exercise programs on functional balance was the primary reason for bringing participants together in this study. The study had importance and meaning to the participants because residual balance deficits were identified as problematic. However, our study shows that many other benefits in addition to changes in balance were accrued. The focus group comments identified three primary domains affected by the balance retraining interventions: physical, psychosocial and program. The five self-concepts identified earlier [22] as important for adults with TBI directly relate to two domains identified, specifically psychosocial and physical. The psychosocial domain, incorporated themes such as enjoyment and confidence, which reflected the concepts of family self, social self and moral self proposed by Man et al [22]. These themes

highlighted the relationship between social participation and the individual's physical well-being. The importance of meeting people and socializing was stressed in the current study. Themes grouped within the physical domain included comments about balance and coordination that relate to Man's [22] proposed concepts of personal achievement and physical self. The program domain incorporating themes such as location and exercise equipment does not appear in the model proposed by Man [22].

#### *Disability Creation Process Model*

A more comprehensive model, the DCPM [32, 33], incorporates all domains identified in this study. The DCPM provides a paradigm to explore how the relationship between personal factors and environmental factors influence life habits. In general, risk factors, the cause of disease or trauma, such as TBI, affect personal factors that define degrees of integrity/impairment, and ability/disability. The interaction of these personal factors with environmental factors influence life habits including activities of daily living. For example, for individuals with TBI, their balance (a personal factor), in combination with environmental factors (such as a steep stairwell), facilitate or limit accomplishments of life habits (such as laundry, a component of household maintenance). Other life habits include working, travelling, staying fit and interacting in society.

In the current study, bringing people together for the purpose of balance exercise drew attention to the broader, multidimensional effects of balance and exercise. For instance, social roles incorporating life habits such as employment and social integration (interpersonal relations) were specifically mentioned by participants in both exercise groups. These are among the categories of life habits that most disrupt a person's level of accomplishment [34]. The regular routine imposed by study participation required personal commitment, travel and a degree of social interaction. For several participants, the perception of employment provided additional value to them which, along with functional independence has been reported to be highly associated with quality of life after TBI [43] and SCI [34]. In addition, participants commented that interactions arising with others as a result of study participation improved their self-esteem. Participants identified better relations with family and attributed these to their involvement with something they wanted to talk about and that gave purpose to their day.

In addition, many of the comments were associated with aspects of fun and health. Participation in the program was perceived as recreational, involving fitness and mobility. These life habits have been categorized as ADL's by Fougeyrollas and colleagues [32] and can either allow social participation or create a handicap

situation. We have previously shown that functional balance improves with a balance exercise program in this population [20]. While not statistically significant, confidence and function ratings in both exercise groups improved after the six weeks of exercises with the VR group, showing a greater average improvement in confidence. The relationship between exercise participation and improved confidence was reflected in comments by many participants. For example, several participants in our study stated that their balance or ambulation was better. Other individuals indicated stair climbing was easier. Mobility can also involve travelling longer distances. Several participants in this study commented that they were better able to take public transit, to go places unsupervised and to find their way to appointments more independently since they were involved in the study. Finally some participants indicated that their mobility was better because there was more confidence in their abilities (both self-confidence and from others), while others indicated that the improvement in their balance or organisational skills allowed them to be more mobile. Thus, it is clear that while the initial goal of this study was one-dimensional, the effects were multidimensional and interactive.

Outcome after TBI has been defined based on one's level of independent living, the control one has over one's life and the need to rely on others [44]. Social isolation, common after TBI, affects community re-entry and has been attributed to inactivity and decreased agility after TBI [45]. Improved mobility through developing better balance may help with social isolation. It has been recommended that interventions be found that address functional independence and ultimately attempt to improve quality of life [43]. The participants and family members indicated that their study participation resulted in a positive impact on all of these factors.

#### *Virtual Reality*

Virtual Reality is a computer technology that simulates real-life learning while providing augmented feedback. The VR activities used in the current study could be graded for different levels of complexity. Moreover, virtual environments provide individuals with safe access to interactive situations that could otherwise be inaccessible to them due to motor, cognitive and physiological limitations.

Careful study of the focus group verbatim and extraction of quotes clearly demonstrated a stronger perception of balance improvements by individuals in the VR than the AB group. There were substantially more comments about the various VR activities improving ones abilities to do day to day activities as was evident in one comment indicating that the participant could put their socks on more easily. The VR approach was seen as more positive in general by participants and there were stronger comments about balance and

confidence improvement. Participants in the VR group talked more about improved structure and purpose being added to their day. The visual feedback on the screen was seen as more positive.

Moreover, when comparing comments regarding the two exercise delivery modalities VR was noticeably perceived as fun, novel and interesting. In a previous study with a small cohort of young adults with CP, it was found that participants had a preference of one game over another [46]. In the present study, people liked Soccer, as it was more fatiguing and challenging than the other scenarios. Individual interest varied however, with one individual reporting a lack of interest in sports, the focus of certain VR applications. Alternatively, one participant had strong reactions, screams and large avoidance movements, to the sharks appearing in Shark Bait. In general, comments indicated that if the VR were more available, it would be used.

A positive reaction to the novel technology was also reported by the AB group participants, since both groups met in the same space (although they did not exercise at the same time). There was heightened interest in the VR and enthusiasm to try the new technology. In fact, several AB participants indicated that they would like to try the VR program. It is possible that the enthusiastic comments from both VR and AB participants were a function of the novelty of the approach, and that the effect would disappear when the novelty wears off. Moreover, comments from the present study may have been influenced by the shorter length of the exercise program (6 weeks with a 3-month follow-up). Previous studies have used exercise interventions ranging from 8 weeks to 3 months with follow-up after 6 months, 1 year or 3 years. Dropout in one study was seen to occur after 6 weeks [47]. Whether the novelty of the approach would increase the compliance to longer exercise regimes and whether there are certain types of people who might best respond to VR exercise remain to be determined.

It is significant that comments from the VR group suggested that there was family interest in the intervention. The spouse of a VR participant commented that 'The kids would really like to have the program available at home to play with'. While the opportunity exists for home use, the benefits and challenges of using it independently should be carefully weighed. A strong theme in this analysis was the social benefit of interacting with people that was afforded by exercise participation. Additional arguments in favour of making VR available in a community center rather than in a person's home came from a family who indicated the benefit of some respite time when the participant was involved in the program of exercise. This participant was

motivated to attend the exercises and wanted to talk about his experiences when he returned, providing a very positive experience for both the participant and family.

In addition to the benefits potentially afforded for socialization, there is the need to consider the safe use and appropriate exercise progression. Guidelines for safe, independent use and greater accessibility would be important issues to consider in future studies addressing length of the program, location, and accessibility (having it available at home or in community centres).

### **Conclusions**

This study demonstrates that people with TBI will participate in exercise activities that have meaning and value for them. Although participants in both exercise programs reported broad impact when asked about their participation in the balance study, there was evidence of substantially stronger, more positive perceptions of impact elicited from the VR group participants. The VR group participants were more enthusiastic and knowledgeable about their program. In addition they expressed greater interest and excitement and appeared more engaged during the exercise sessions than did the AB group participants. Finally, the VR participants indicated strongly that their participation increased their independence and confidence. Importantly, while both groups demonstrated improved functional balance scores, balance confidence scores and positive participation comments, the greater degree of interest and excitement elicited through VR could potentially impact on the desire and ability of adults with TBI to continue an exercise program when supervised programs are no longer available.

In view of these results and the vast amount of information recommending exercise to maintain a healthy lifestyle, active living in general should be encouraged. This is consistent with the literature about the elderly, which encourages active living for greater safety in mobility [9, 48]. By finding activities, with guidance from health care professionals, that are accessible, enjoyable and appropriate based on level of function, interests and fitness, people with TBI will show improved levels of community integration. A general focus on activity may be the most realistic approach at present, given funding constraints and time required to implement new programs. Condeluci [49] suggests focusing on capacities, relationships and community services. There is a need for opportunities in the community for people to find activities that are meaningful to them that allow them to stay involved and active.

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**Figure and Table Legends**

**Figure 1.** Outcome measures. Mean Group Data (+/- SEM) for ABC (a) and LEFS (b) at 3 time periods illustrates the effect of the balance retraining programs. The baseline to post intervention difference in individual scores for the ABC is illustrated in (c) and for the LEFS in (d). The dotted horizontal line on each graph (c and d) indicates the value corresponding to a clinically important change for the specific measure.

**Table 1.** Focus group questions.

FIGURE 1

ABC and LEFS scores

figure 1 (a)

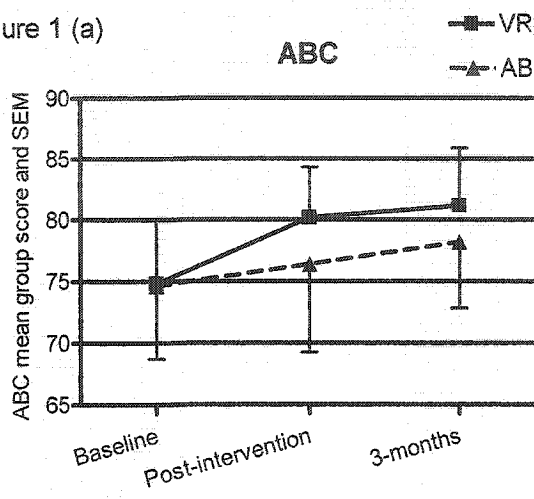


figure 1 (b)

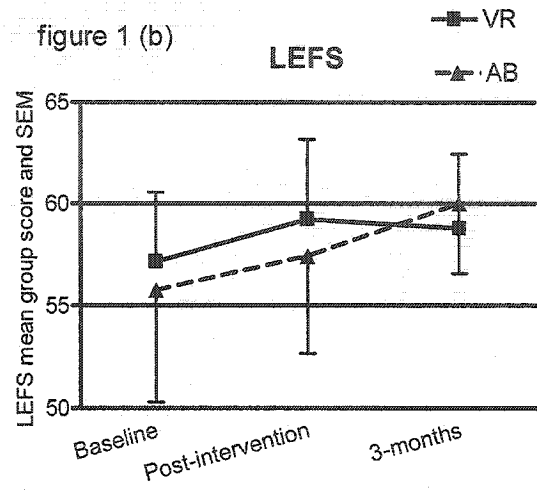


figure 1 (c)

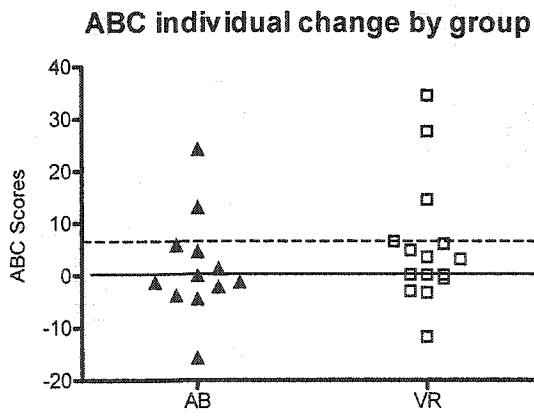


figure 1 (d)

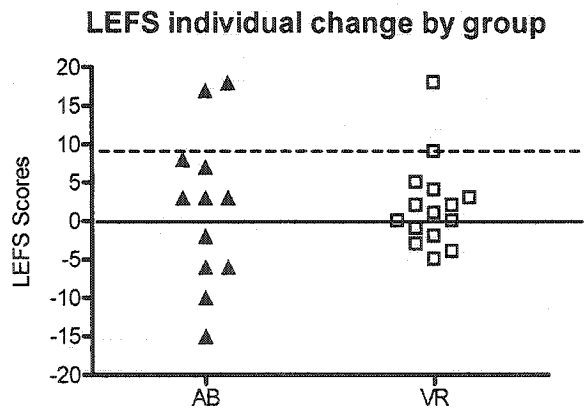


TABLE 1

1. How useful did you (your family member) find the exercise sessions?  
What things were good?  
What things were bad?
2. Have you noticed any differences in your balance  
(the balance of your family member)?  
Give specific examples if possible.
3. Did participating in the exercise sessions change anything else in your life  
(the life of your family member)?  
Give specific examples if possible.
4. Are there specific things that we could do better?
5. What was the most important exercise that you did and why?
6. Thinking about the whole experience of participating in the study,  
what was the best part?
7. Again, thinking about the whole experience of participating in the study,  
what was the worst part?

## CHAPTER V

### CONCLUSION

After TBI, poor balance is a common problem that contributes to risk of falls and re-injury. Overall quality of life can also be affected. This research looks at two specific balance exercise programs to determine their value for people with TBI.

While the first paper shows no statistically significant differences between the two types of exercise, it is apparent that six weeks of balance exercise improves balance in people with TBI, with some improvement maintained at three months. It is interesting to note that, while not statistically different from the AB group, the VR group averages of physical balance were higher than the AB group scores. The second paper demonstrates that there are effects of the exercise programs beyond the physical functional balance improvements. Although the exercises are intended only for functional balance improvement, themes emerge as important results of participating in the exercises, such as psychosocial and other physical benefits. In addition to better balance, these comments reflect improved confidence, organisational skills, and community involvement as a result of participation. This is consistent with the literature that describes obstacles and facilitators to community integration. Providing the exercise programs to people with TBI allows them to overcome obstacles to community involvement, such as limited planning and organizational skills (including scheduling appointments and arranging transportation).

While one cannot conclude that VR exercise is superior to AB in improving balance in this population, the importance of exercise in general and the value of these two approaches are evident in the improved functional balance scores and the comments. The many effects of exercise are well documented, ranging from physical benefits, such as lowered risk of heart disease and obesity (National Center for Chronic Disease Prevention and Health Promotion, 2003) to psychosocial benefits, like lowered risk of depression (van Gool et al., 2003). Yet while people may begin an exercise program with good intentions, there is no guarantee that they will continue on in an exercise program (National Center for Chronic Disease Prevention and Health Promotion, 2003), especially beyond six weeks (Gettman, Pollock, & Ward, 1983). With the added factors of limited mobility and accessibility for people with TBI, one would expect it to be even more challenging to begin an exercise program, let alone commit to one over a period of six weeks or more. Given the right type of

exercise, people will commit to the program. In this study, only one individual did not complete the whole protocol. It would be interesting to see if people remain committed beyond the six-week period.

Either way, it is extremely important that there be ways for people with TBI to participate in exercise. A longer study may better illustrate if the effects seen are due to the novelty of the program, or due to a true change in balance and effectiveness of these approaches. In addition, a longer program of exercise may help determine if one type of exercise was more effective in improving balance and other dimensions of life.

These two papers compliment each other and fill a void in the literature about the effects of balance retraining after TBI. This work has implications for rehabilitation professionals as it indicates the importance of helping people with TBI to find ways to stay active. By encouraging more active lives and seeking out safe activities that suit their interests, people with TBI could be healthier in general, minimise effects of depression and frustration, and maintain or improve their mobility and confidence, all with minimal cost to the health care system. Until further work can be done to determine if one type of intervention should be recommended over another and what specific parameters should be set, any activity that can be safely done and is interesting to the participant should be encouraged. In the meantime, work should continue in this area to keep current with available technology and find innovative ways that are accessible, enjoyable, and low-cost, to stay active and improve balance.

There are difficulties that need to be taken into account when working with people with TBI. It is challenging to do research with this population, as they are so variable in ability (especially physical and cognitive). For many, their TBI occurs when they are young and very active, at the time in their lives when many important long-term decisions are being made with respect to career, a partner, and friendships. Exercise involves a significant investment of time for participants. Based on these studies, the low attrition rate and enthusiastic comments are an indication of the importance of the topic to the participants.

From the literature and the results of this research, a few recommendations can be made. While an active lifestyle and general exercise may both have benefits of better health and community integration, specific balance exercises should be made accessible to people with TBI. This will allow people with TBI to progress in their abilities and develop the skills they need to find a meaningful place in their community. This may not be the same role as what they had before their injury, but can still lead to a satisfactory quality of life.

It is recommended that exercise programs included in research be a minimum of 8-12 weeks in length, in order to assess compliance with the program (Gettman et al., 1983). Exercise should be multidimensional (Shumway-Cook et al., 1997), with less focus on specific tasks and feedback about errors. More emphasis should be placed on enjoyment of an activity that has meaning to the individual (McNevin, Wulf, & Carlson, 2000), and that targets the specific problem (Shumway-Cook et al., 1997).

In conclusion, both VR and AB balance retraining programs improved functional balance measures in adults with TBI. Some of the average group improvement was maintained at three months after the conclusion of the exercise program. While neither method of training yielded a statistically significant difference in functional balance outcome measures, more individuals in the VR group appeared to improve in functional balance measures. Some of the aspects of training that participants found most positive, in addition to the higher level of functional balance skills, included improved endurance, organizational skills, self-esteem, confidence and enjoyment of the experience. This study was valuable in helping to understand the effects of exercise on functional measures of balance in adults with TBI. There is evidence that, despite the small number of subjects and the variability within the population, this study shows that both VR and AB approaches to balance retraining improved functional balance for people who had sustained a TBI and who were a minimum of 6 months post injury.

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**APPENDIX 1****STATEMENT OF CONTRIBUTION OF COLLABORATORS**

The research for this thesis and article was performed by Marianne Thornton under guidance and supervision of both Dr. Heidi Sveistrup and Dr. Joan McComas. The research question and hypothesis formation were selected by Marianne Thornton in collaboration with Dr. Heidi Sveistrup, Dr. Joan McComas, Dr. Shawn Marshall, Dr. Hillel Finestone and Dr. Anna McCormack. The data collection and processing were done by Marianne Thornton, Theresa Grant and Alison Lott. The data were analyzed collectively by Marianne Thornton, Dr. Heidi Sveistrup, Dr. Joan McComas, Allison Lott and Shane Smith. Finally, this thesis and corresponding articles were also written by Marianne Thornton, but the content of both articles were edited by Dr. Heidi Sveistrup, Dr. Joan McComas, Dr. Shawn Marshall, Dr. Hillel Finestone and Dr. Anna McCormack. The content of the thesis was edited by Dr. Heidi Sveistrup, Dr. Gordon Robertson, and Dr. Yves Lajoie.

**Virtual Reality Group**

If I am assigned to the VR exercise group, I will spend part of my exercise time using a computer system, which will instruct me in my balance exercises.

**Control group**

If I am assigned to the control group, I will not need to go to any exercise sessions. I will be asked to go to 3 testing sessions within 3 months. At the end of that time, I will receive information about balance.

**Evaluation Sessions**

I will be asked a series of questions at the beginning, at the end, and 3 months after the end of my exercise sessions. These questions will ask me how safe I feel when doing certain tasks, and about my general health. I may skip any questions that I do not feel comfortable answering. Once only, at the beginning of the study, I will be asked to answer questions that will ask about my personality. This will take an extra 30 minutes to complete. The information will be used to see if the new exercise is better for certain types of people.

I will also be asked to stand on a metal plate and on a piece of foam that will measure how stable I am with my eyes open and closed. I will be asked to do certain activities such as hopping on one foot, standing and turning, walking down stairs (while carrying a basket) and running. Finally, the strength and movement of my legs and body will be measured.

All the questionnaires, testing and exercises will take place at either The Rehabilitation Centre or at the University of Ottawa Health Sciences Building (right beside The Rehabilitation Centre). If I am in an exercise group, I will be asked to attend 3 exercise sessions per week a 6-week period. Testing for the study will be done during the week before, right after and 3 months after my exercises.

**Possible Side Effects and/or Risks**

There are no side effects connected to my taking part in the study. There is a risk that I may fall during my exercise or my testing sessions. I will be provided with a walking belt to wear around my hips. The walking belt has loops that the research assistant is able to grab and hold that will help stop me from falling.

**Benefits of the study**

There are no proven benefits for me related to my taking part in the study. My taking part in the study will help to know if the exercises used will help my balance.

**Withdrawal from the Study**

I may stop being involved in the study at any time. This will not make a difference to my care. I may also choose to remove all the information about me from the study by asking the research assistant.

**Study Expenses**

I will be reimbursed for my participation in the study. I will receive \$20 for each exercise session and testing session that I complete.

**Confidentiality**

All the results of this study will be kept confidential. Only the complete data will be presented or published. I will not be identified in any scientific papers or presentations about this study. Study information about me will be kept using only my initials and a study number. All information that leaves the hospital will be coded by number and not by my name. No records with my name will leave The Rehabilitation Center. All data and records (questionnaires, videotapes and other files from this study) will be stored in a locked cabinet available only to the researchers and research project staff. Records will be retained at The Rehabilitation Center for 10 years.

Initials: \_\_\_\_\_

**Voluntary Participation**

It is my choice to participate in this study. I may choose not to participate in the study. I may withdraw from the study at any time without giving the researchers a reason. I have been assured that my decision will not affect the level of care I receive at The Rehabilitation Center now, or in the future.

**New Information about the Study**

I have been assured that if new information about the study becomes available that might affect my willingness to participate in the study, I will be informed as soon as possible.

**Questions about the Study**

If I have any questions about the study, I can call Dr Heidi Sveistrup (562-5800 extension 8016) or Dr Shawn Marshall (737-7350 extension 5590). If I have any questions about my rights as a research subject, I may contact Dr Jeff Blackmer, the Vice-Chair of The Rehabilitation Centre Research Ethics Board at (613) 737-7350 extension 5596.

**I have been informed about the purpose of this study. I have received the information about the study. All information has been explained. I have been given a chance to ask all questions about the study with the understanding that information will be collected and used for research purposes only and will be treated as private. I have been informed about the purpose of this study and realize that it is my choice to participate and I may withdraw at any time. Refusal to participate or withdrawing from the study will in no way affect my present and/or future treatment at The Rehabilitation Center.**

**I acknowledge that I have had the study and the contents of this consent form explained to me. I understand this information. I have received a copy of the consent form for my records should I want to review the information at a later date. I have been given information about contact people for the study.**

**Signatures**

Participant's or Substitute Decision Maker's Signature:

\_\_\_\_\_

Date: \_\_\_\_\_

Investigator's Signature: \_\_\_\_\_

Date: \_\_\_\_\_

Initials: \_\_\_\_\_

## APPENDIX 5

### Warm-Up Exercises to be Done Prior to Balance Retraining

Do the following exercises sitting comfortably in a chair with your back, arms and feet supported. Do each exercise 5 times. Do not do an exercise if it is painful. If you feel any discomfort stop the exercise, reposition yourself. If pain persists, move on to the next exercise. Begin by breathing in deeply 5 times. Hold each breath for 2-3 seconds.

#### Sitting Stretches:

1. Keeping your foot and heel completely on the floor, slide each foot slowly under the chair, one at a time.
2. Bring one knee to the chest. Place your foot back on the floor. Repeat with the other leg.
3. Straighten one knee and pump your ankle (5 seconds). Repeat with the other side.
4. Heel tapping. Lift your heels up and down slowly, keeping the balls of your feet on the ground. Alternate your right and left heels.
5. Toe tapping. With your heel on the ground, lift the rest of your foot up and down. Slow down the exercise to ensure you are stretching the ankle as much as possible. Try alternating your right then left toes.
6. Turning the foot in and out. Keeping your heel on the ground, lift the rest of your foot to tilt the side of your foot in and out. Turn your foot in towards the big toe. Turn your foot out towards the little toe. Do both feet together.
7. Foot and ankle circles. Straighten your right or left leg and rotate that ankle in smooth circles in one direction then in the other. Repeat with the other foot.
8. Foot stretches. Grab a towel or tissue on the floor with your toes and scrunch it up. (5 seconds with each foot.) Move the towel right and left.
9. Lift your toes as far off the ground as you can while keeping the rest of your foot on the ground. Hold for 5 seconds.

#### Posture exercises:

1. Sit tall, away from the back of the chair, shoulder blades should be down and pulled slightly together. (hold for a few seconds)
2. Sitting forward in a chair, slowly turn to look over your right shoulder (hold for a few seconds). Repeat to your left.
3. Relax, slump down with poor posture for a few seconds, then sit tall again for a few seconds.
4. Shift your weight from your right hip to your left. Try not to lean.
5. Shift your weight forward and backward.

#### Arm exercises:

Use both arms together where possible for the following exercises. If that is too difficult, do them with one arm at a time.

1. Raise arms up in front. Reach forward and hold for a few seconds. Relax.
2. Reach overhead and hold for a few seconds. Relax.
3. Moving your arms out to the side, in opposite directions, reach out and hold for a few seconds. Relax.
4. Take your arms out to the sides and follow through reaching up overhead and hold for a few seconds. Relax.

#### Preparation for standing:

1. Moving your legs alternately as though stepping while sitting. 10 seconds.

**Cool-Down Activities to be Done After Balance Retraining**

Please take 5 minutes to do all of these exercises while sitting comfortably in a chair. Your back, arms and legs should be supported. Repeat each exercise 5 times.

1. Sit and lift your legs one at a time in a stepping motion.
2. Sitting, bring one knee to the chest. Hold for 2-3 seconds. Repeat with other leg.
3. Straighten each knee holding for 2-3 seconds.
4. Go up on your toes, back on your heels.
5. Sit tall and reach forward holding for a few seconds.
6. Sit tall and turn to look over each shoulder. Hold for a few seconds.
7. Sit tall and shift your weight to your right hip. Hold for a few seconds. Shift to your left hip for a few seconds.
8. Sit with poor posture, then stretch tall again. Hold for a few seconds each.
9. Take a slow deep breath hold for 2-3 seconds.
10. Sit quiet for 5 seconds.

October 3, 2002

MT

## APPENDIX 6A

## 40 minute ACTIVITY-BASED EXERCISE PROGRAM

## LEVEL 1

<b>SIT TO STAND</b>	1	1. Stand at table, pick one of the following activities: connect-the-dots, coloring, crossword, puzzle, Lego, rings, imagine an ironing board and wrinkled towel 2. wipe and polish the table with a cloth (+/- water)	60 seconds (sec) 60 sec
	2	Stand at wall and clean window/wall (no reaching outside of base).	60 sec
	3	Take ball from researcher and return reaching right, left, up and down. 2 to right up down, 2 to left up then down.	60 sec

## LEVEL 2

<b>SHIFTS AND TURNS FEET ANY POSITION</b>	1	1. Hands on the Swiss ball (without stepping or reaching) turn and look behind 2. move body right and left while keeping ball still 3. keep centered while moving ball (R, L, circle) 4. bounce a ball on the table.	120 sec
	2	Darts (without stepping or reaching).	60 sec
	3	Bean-bag toss (without stepping or reaching) 1. into hoop/basket. Score.	60 sec
	4	Balloon toss (without stepping or reaching) 1. bounce off wall 2. up overhead with/without racket.	60 sec
	5	Small ball (without stepping or reaching) 1. Bounce on floor 2. Bounce off wall 3. Throw up overhead and catch it.	60 sec

<b>CHANGE SENSORY INPUT FEET ANY POSITION</b>	1	Wear sunglasses or swim goggles, rest hands on Swiss ball on table in front of you 1. move Swiss ball while keeping balance 2. keep Swiss ball still, move body or white board wipe.	60 sec
	2	Stand on foam 1. wash table 2. wash window 3. move Swiss ball while keeping balance 4. move body while keeping Swiss ball still.	120 sec

<b>NARROW BASE, SINGLE STANCE</b>	1	Stand with feet closer together (narrow base) 1. Wash table 2. Wash window 3. Move Swiss ball while keeping balance 4. Move body while keeping Swiss ball still.	120 sec
	2	Stand with one foot on stool 1. Move Swiss ball while keeping balance 2. Keep Swiss ball still and move body.	60 sec

<b>DIFFERENT SURFACE</b>	1	Wobble board 1. Stand still 2. Move the board. 3. light or no hand support if possible	60 sec
	2	Stand on foam; shift weight onto heels then toes 1. Stand still 2. Shift right then left.	60 sec
	3	Sit on Swiss ball 1. Sit still with good posture 2. Move the ball in small movements right and left 3. Move the ball in small circles 4. Alternately lift one foot then the other	120 sec

<b>WALKING</b>	1	1. Walk slowly 2. Walk more quickly 3. Speed up, then slow down 4. Walk around the outside of the room to the right then left. 5. Walk to end of room and back at a comfortable pace (timed).	120 sec
	2	Walk carrying an item 1. on back (backpack) 2. on side (shoulder bag). 3. in front	90 sec

<i>MOVING FEET AND DOING ACTIVITY</i>	1	Dribble ball 1. Standing, one hand, other hand, alternate hands 2. Walking, one hand, other hand, alternate hands.	60 sec
	2	Ball throw; as walk throw ball back and forth off the wall (score)	60 sec
	3	Ball kick; kick against wall or target then retrieve (score)	60 sec
	4	Balloon; step/reach and tap with racket	60 sec
	5	Jumping Jacks	30 sec

**LEVEL 3**

<b>STOOL</b>	1	- Step up on stool to reach for items or touch dot. (score)	30 sec
	2	- Step up on stool in different patterns (forwards/sideways) Touch dot. (score)	30 sec
	3	Pick up an object from various heights and turn to put it at a different height 10 objects timed.	60 sec

<b>JUMPING and RUNNING</b>	1	- Hop scotch walk (than jump if possible)	60 sec
	2	- Jump rope	60 sec
	3	- Running on the spot	30 sec
	4	- stationary bike (arms only, then feet and arms)	120 sec

<b>OBSTACLE COURSE</b>	1	2 Hula hoops; 2 steps, walk around outside of hoops (score). 1. Walk slowly 2. Walk quickly	60 sec
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Level 1: cannot walk without great effort to go a short distance, or they require a gait aid.

Level 2: able to walk, cannot run

Level 3: able to run. Awkward.

Everyone will start the first exercise session doing level one activities. They will work through as many exercises as they have time for and can safely do. If those are accomplished safely for the specified time, and the person is able to repeat those same exercises well (no indication of falls, not excessively tired) in the same way on a second day, they do not need to work on those exercises further. Each activity should be done safely and smoothly for the required time and repeated at the next exercise session to remove it from the list.

50 minutes of exercise, 3x per week, 6 weeks.

5 minutes warm-up, 40 minutes of exercise, 5 minutes of cool-down.

40 minutes of exercises: start with level one for 4 minutes. Take a 1 minute break. If done well, proceed to level 2 tasks in order with rest periods at each 4 minute period or as required. The next exercise is attempted if the previous one was done safely for the required time. The next session repeats the exercise to ensure they can do it consistently, then it is not necessary to go back to that one. It can be used as a filler at any time though.

MT October 28, 2002

## APPENDIX 6B

Activity-Based Exercise Score Sheet for: \_\_\_\_\_

Check off each level they safely achieve for the required time. Repeat on 2 successive days then move to more difficult exercises higher on the list.

Activity	Week Date Rater	start time		
Standing activities	1. Table 2. Wall 3. Reaching			
Weight shifting	1. Ball 2. Darts score 3. Bean bags score 4. Balloon score 5. Small ball score			
Change sensory input	1. Glasses 2. Foam			
Narrow base	1. Feet touching 2. Stool			
Different Surface	1. Wobble board hands 2. Wobble board no hands 3. Foam heels/toes 4. Swiss ball sit			
Walking	1. Walk speed 2. Walk carry			
Activity	1. Balloon 2. Ball throw 3. Ball kick 4. Dribble 5. Jumping Jacks			
Stool climbing	1. Step up 2. Step sideways up 3. Reach low step up			
Running	1. Hop scotch walk 2. Hop scotch jump 2. Jump rope 3. Running on spot 4. Bike			
Obstacle course	1. Walk slow 2. Walk faster			

**APPENDIX 6C****Objects Used for Activity-Based Exercise**

- Carpet or spongy mat or cafeteria tray on foam
- Parallel bars or a railing to hold on to
- 2 Tables of adjustable height or large plinth
- Rings that can be stacked onto a holder
- Beanbags through basketball hoop
- Set of wooden stools of varying heights
- Wobble board with round base
- Space to walk
- Stairs, ladder
- Ironing board
- Items appropriate for an Obstacle course
- Balloons
- Badminton racket, (birdies)
- Bowling ball (and pins), an area to set this up
- Swiss ball, preferably orange but I will try to check with Theresa what size for sure
- Soccer ball
- Basket ball (and net)
- Hopscotch set-up (tape on the floor or erasable marker could work.)
- Skipping rope
- Radio (or some form of increased noise and alternately, a quiet place to work)

## APPENDIX 7A

## Virtual Reality

SIT TO STAND	1.	Birds and Balls	120 seconds, 15-second break
	2.	Music (4 instruments slow and close) <ul style="list-style-type: none"> <li>➤ Sitting on a chair</li> <li>➤ Sitting on Swiss ball</li> <li>➤ Standing 4 instruments</li> <li>➤ Standing 6 instruments</li> </ul>	120 seconds, 15-second break each
	3.	Juggler (2 balls, light, close) <ul style="list-style-type: none"> <li>➤ Sitting on a chair</li> <li>➤ Sitting on Swiss ball</li> <li>➤ Stand</li> <li>➤ Standing 3 balls</li> </ul>	120 seconds, 15-second break each
	4.	Conveyor (slow, close, similar height) <ul style="list-style-type: none"> <li>➤ Sitting on a chair</li> <li>➤ Sitting on Swiss ball</li> <li>➤ Stand</li> <li>➤ Standing with increased speed</li> </ul>	120 seconds, 15-second break each
	5.	Shark bait (stars only) <ul style="list-style-type: none"> <li>➤ Sitting</li> <li>➤ Swiss ball</li> <li>➤ Standing</li> </ul>	120 seconds, 15-second break each
SHIFTS AND TURNS	1.	Birds and Balls	60 seconds, 15-second break
	2.	Music <ul style="list-style-type: none"> <li>➤ 4 instruments, increased reach</li> <li>➤ Right hand only</li> <li>➤ Left hand only</li> <li>➤ 6 instruments, increased reach</li> <li>➤ increased speed</li> </ul>	120 seconds, 15-second break each
	3.	Juggler <ul style="list-style-type: none"> <li>➤ 2 balls one hand (R/L)</li> <li>➤ 3 balls one hand</li> <li>➤ Both hands 2 balls</li> <li>➤ Alternating hands 4 then 5 balls</li> </ul>	120 seconds, 15-second break each
	4.	Conveyor <ul style="list-style-type: none"> <li>➤ Turn to side, reach further</li> <li>➤ Increased speed</li> <li>➤ One hand</li> <li>➤ Two hands</li> <li>➤ Change direction</li> </ul>	120 seconds, 15-second break each
	3.	Shark bait <ul style="list-style-type: none"> <li>➤ Add sharks</li> <li>➤ Add eels</li> <li>➤ Increase number</li> </ul>	120 seconds, 15-second break each
	5.	Snowboarding	120 seconds, 15-second break
CHANGE SENSORY INPUT stand on foam	1.	Birds and balls	60 seconds, 15-second break
	2.	Music (4 instruments medium speed)	120 seconds, 15-second break
	3.	Juggler (2,3,4 balls alternating hands)	120 seconds, 15-second break
	4.	Conveyor (close and slow)	120 seconds, 15-second break
	5.	Shark bait (no stepping)	120 seconds, 15-second break

NARROW BASE	1.	Music slow, close, standing ➤ narrow base ➤ Stool R/L ➤ 1 foot 30 seconds	120 seconds, 15-second break each
	2.	Juggler ➤ Narrow-base ➤ Stool ➤ Tandem 1 ball 30 sec.	120 seconds, 15-second break each
	3.	Conveyor close and slow ➤ narrow base ➤ Stool R/L	120 seconds, 15-second break each
	4.	Shark bait ➤ Narrow base	120 seconds, 15-second break

MOVING FEET and DOING ACTIVITY	1.	Birds and balls walk on spot	120 seconds, 15-second break
	2.	Music	120 seconds, 15-second break
	3.	Juggler	120 seconds, 15-second break
	4.	Shark bait	120 seconds, 15-second break
	5.	Soccer	120 seconds, 15-second break

STOOL R/L	1.	Birds and balls	120 seconds, 15-second break
	2.	Music	120 seconds, 15-second break
	3.	Juggler	120 seconds, 15-second break
	4.	Conveyor	120 seconds, 15-second break

JUMP/RUN	1	Shark bait	120 seconds, 15-second break
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OBSTACLE COURSE	1.	Birds and balls	120 seconds, 15-second break
	2.	Juggler	120 seconds, 15-second break

APPENDIX 7B

Virtual Reality Score Sheet for: \_\_\_\_\_

Check off each level they safely achieve for the required time. Check mark indicates both researcher and subject feel able to do safely for required time. Repeat on 2 successive days. If able to complete safely in required amount of time, then move to more difficult exercises higher on the list.

<u>Position</u>	<u>Activity</u>	Week	_____	_____	_____
		Date	_____	_____	_____
		Rater	_____	_____	_____
<i>Sit to Stand</i>	1. Birds and Balls	(warm up)			
	2. Music	Chair	_____	_____	_____
		Swiss ball	_____	_____	_____
		Stand 4	_____	_____	_____
		Stand 6	_____	_____	_____
	3. Juggler	Chair	_____	_____	_____
		Swiss ball	_____	_____	_____
		Stand 2	_____	_____	_____
		Stand 3	_____	_____	_____
	4. Conveyor	Chair	_____	_____	_____
		Swiss ball	_____	_____	_____
		Stand	_____	_____	_____
		Stand with speed	_____	_____	_____
	5. Shark bait	Chair	_____	_____	_____
		Swiss ball	_____	_____	_____
Stand		_____	_____	_____	
<i>Shifts &amp; Turns</i>	1. Birds and Balls	(warm up)			
	2. Music	4, increased reach	_____	_____	_____
		Right hand only	_____	_____	_____
		Left hand only	_____	_____	_____
		6, increase reach	_____	_____	_____
	6, increase speed	_____	_____	_____	
	3. Juggler	2, right and left	_____	_____	_____
		3, right and left	_____	_____	_____
		2, both hands	_____	_____	_____
		4, alternating	_____	_____	_____
		5, alternating	_____	_____	_____
	4. Conveyor	Turn, increase reach	_____	_____	_____
		Turn, increase speed	_____	_____	_____
		1 hand, each direction	_____	_____	_____
		2 hand, each direction	_____	_____	_____
	5. Shark bait	Add sharks	_____	_____	_____
		Add eels	_____	_____	_____
		increase number	_____	_____	_____
6. Snowboarding		_____	_____	_____	

<i>Foam</i>	1. Birds and Balls		_____	_____	_____	
	2. Music (4, medium speed)		_____	_____	_____	
	3. Juggler		2	_____	_____	_____
				3	_____	_____
				4	_____	_____
	4. Conveyor (close, slow)		_____	_____	_____	
	5. Shark bait (no steps)		_____	_____	_____	
<i>Narrow Base</i>	1. Music (slow, close, standing)	Narrow Base Stool, right/left 1 foot, right/left	_____	_____	_____	
			_____	_____	_____	
	2. Juggler	Narrow Stool Tandem	_____	_____	_____	
			_____	_____	_____	
3. Conveyor (close, slow)	Narrow Stool	_____	_____	_____		
		_____	_____	_____		
	4. Shark bait		_____	_____	_____	
<i>Moving Feet</i>	1. Birds and Balls		_____	_____	_____	
	2. Music		_____	_____	_____	
	3. Juggler		_____	_____	_____	
	4. Shark		_____	_____	_____	
	5. Soccer		_____	_____	_____	
<i>Stool R/L</i>	1. Birds and Balls		_____	_____	_____	
	2. Music		_____	_____	_____	
	3. Juggler		_____	_____	_____	
	4. Conveyor		_____	_____	_____	
<i>Obstacle course</i>	1. Birds and balls		_____	_____	_____	
	2. Juggler		_____	_____	_____	



Photograph releases for the images used as Figure 1B in Chapter III was obtained via e-mail communication:

Subject: RE: Permission to use IREX pictures  
Date: Fri, 1 Aug 2003 08:38:45 -0400  
From: "Francis MacDougall" <francis@jestertek.com>  
To: "Heidi Sveistrup" <hsveist@uottawa.ca>

Aok!

-----Original Message-----

From: Heidi Sveistrup [<mailto:hsveist@uottawa.ca>]  
Sent: Thursday, July 31, 2003 10:34 AM  
To: Francis MacDougall  
Subject: Permission to use IREX pictures

We will be sending Marianne's paper out in the next month or so and would like to use two of your pictures in the methods section to describe the system. I've attached the two pictures we'd like to include. Could you let me know if you're ok with this?

Heidi Sveistrup, PhD  
Associate Professor, School of Rehabilitation Sciences Career  
Scientist, MOHLTC Ontario University of Ottawa