A STEP IN THE RIGHT DIRECTION: EVALUATING THE EFFECTIVENESS OF CUSTOMIZED STEPPING GAME SOFTWARE AND NINTENDO® WII BALANCE BOARDS™ FOR BALANCE REHABILITATION THERAPY AND MEASUREMENT

by

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Abstract

Falling is a serious issue among adults over the age of 65 as the incidence and impact of falls rapidly increases with age. Traditionally, exercise interventions have proven to be effective in improving balance and strength, and in reducing the number and risk of falls. More recently, the use of gaming and virtual reality technologies have been shown to be more engaging and effective than typical exercises alone. Using the Nintendo® Wii Balance Board™ and customized software, a stepping game was developed that has previously been able to identify difference in performance between healthy participants and participants with conditions that affect balance, but the game has not been tested longitudinally.

The objectives of this study were to investigate the stepping game system for its efficacy as a supplemental balance therapy by evaluating functional outcomes and participant satisfaction; to further evaluate the stepping game as a measurement tool to quantify longitudinal changes in balance by identifying trends in performance; and to examine the presence of a possible learning effect with the technology. The stepping game was integrated into two older adult exercise classes and functional outcomes were compared between control groups, who participated in the weekly exercise class, and test groups, who received supplemental therapy with the stepping game system. It was then integrated into two additional exercise programs to analyse trends in game performance over an 8 or 10-week period.

The results of the pre-post study regarding using the stepping game as a therapy were inconclusive. The game was able to identify statistically significant changes in performance measures (response time, reaction time and step time) for some participants over the span of the exercise program; however, a larger same size and a stricter protocol is necessary to evaluate the clinical significance. One participant’s improvement in balance was reflected in both game performance and change in Berg Balance Scale score, highlighting the potential usefulness of the game as an assessment tool. A learning effect with the technology was also identified for some participants. Lastly, there were mixed responses regarding engagement as using the game every week became repetitive and boring.
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Over the course of my graduate studies, it has seemed that Murphy’s law that “everything that can go wrong, will go wrong” is specifically referring to research; However, I have learned that, in the eloquent words of Miley Cyrus, it “ain’t about how fast I get there, ain’t about what’s waiting on the other side, it's the climb”. Goodbye Queen’s!
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<th>Abbreviation</th>
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<tbody>
<tr>
<td>COM</td>
<td>Centre of mass</td>
</tr>
<tr>
<td>BOS</td>
<td>Base of support</td>
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<td>FS</td>
<td>Fixed support</td>
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<td>CS</td>
<td>Change in support</td>
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<td>BBS</td>
<td>Berg Balance Scale</td>
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<tr>
<td>COP</td>
<td>Centre of pressure</td>
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<td>WBB</td>
<td>Nintendo® Wii Balance Board™</td>
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<tr>
<td>MDC</td>
<td>Minimum detectable change</td>
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<td>FP</td>
<td>Force platform</td>
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<tr>
<td>UI</td>
<td>User interface</td>
</tr>
<tr>
<td>Keller’s ARCS Model</td>
<td>Attention, Relevance, Confidence, Satisfaction</td>
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<td>VR</td>
<td>Virtual reality</td>
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<td>OT</td>
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Chapter 1

Introduction

1.1 Context and Motivation

Falling is a serious issue among adults over the age of 65. The decline in muscle strength and balance control associated with age leads to a higher incidence of falling, such that approximately 30% of individuals over the age of 65 report falling at least once per year [1]–[5]. The impact of these falls also rapidly increases with age resulting in hospitalizations, injuries and a reduced quality of life as well as a huge financial strain on the health care system [2], [6], [7]. This issue is made even more urgent by prolonged life expectancy and the aging baby-boom generation [8].

Falls are multifactorial in origin so various factors associated with greater falls risk have been identified in different studies [6], [9]. The most commonly cited physiological risk factors are balance impairments and muscle strength [6]. Traditionally, strength and balance-training interventions have proven to be effective in improving functional balance, and in reducing the number and risk of falls [10]–[13]. A systematic review and meta-analysis by Sherrington et al. of 88 trials estimated that exercise reduced the rate of falling in older adults by 21% [10]. More recently, the use of gaming and virtual reality technologies to deliver repetitive exercises and feedback in a fun, interactive way have been shown to be more engaging and effective than typical OT/PT exercises alone [14]. In a typical therapy session, repetition is important to improve outcomes. These repetitive movements can become boring and are then performed less effectively. Virtual reality adds a component of dynamic change even if the exercises are the same. The Nintendo® Wii Balance Board™ (WBB) has the potential to provide meaningful information as a tool for rehabilitation assessment [15] and to provide rehabilitation therapy; however, many commercially available games were studied and found to not be suitable or effective for an older population because they are too difficult and are not targeted to achieve specific therapy goals [16].
Many have begun to take advantage of the WBB technology to develop and customize programs for rehabilitation therapy that address the limitations of the commercial games [17], [18]. A customized stepping game was developed by Mark Deacon [19] using the framework of Serious Game design. The objective of the game is to step from one WBB with the indicated foot into targets on another. The centre of pressure (COP) data is recorded from the WBBs and used for analyses. The game was found to be able to identify differences in performance between healthy participants and participants with conditions that affect balance such that response times for people with balance issues were between 1.17 and 2.26 times the response times of healthy people. However, this game has not been tested longitudinally.

1.2 Research Questions and Hypotheses

To address the question of the effectiveness of the game longitudinally, there were two research questions for this study.

Research Question #1:
Is the stepping game system effective when used over a 10-week period as a supplemental balance rehabilitation therapy tool for older adults?

- We hypothesized that greater improvements will be seen in voluntary reaction time, step execution time and overall response time with the use of the stepping game and traditional exercise therapy compared to traditional exercise therapy alone.
- We hypothesized that the interactive experience of the stepping game will be more engaging and will motivate participants to exercise.

Research question #2
Can the stepping game be used as a tool to measure and quantify changes in balance by analyzing the results during weekly use of the game over an eight to ten week period and identifying trends in performance? Is there evidence of a learning effect?
• We hypothesized that the game will be able to identify changes in performance that are more sensitive than changes in BBS score
• We hypothesized that the learning effect in week 1 will be visible when compared to the rest of the data

1.3 Thesis Layout

The chapters of this thesis following the introduction are:

Chapter 2
This chapter presents background information regarding falling in the older adult population, balance control strategies, methods to improve balance, gamification and virtual reality for balance rehabilitation, Nintendo® Wii Balance Boards™ and a customized stepping game.

Chapter 3
This chapter explores the procedure, analysis, results and discussion for a pre/post matched control study we conducted using the Nintendo® WBBs and accompanying stepping game software to evaluate the functional outcomes and participant satisfaction.

Chapter 4
This chapter describes the procedure, analysis, results and discussion for a longitudinal study we conducted using the Nintendo® WBBs and accompanying stepping game software to investigate the stepping game system’s ability to measure and quantify changes in balance longitudinally. This was examined by identifying trends in performance over 8 or 10 weeks.

Chapter 5
This chapter presents the limitations of the stepping game system encountered during clinical testing and analysis. This chapter also contains the conclusions to the posed research questions.
Chapter 6

This chapter contains recommendations of future work regarding the design of the game and of further research into the efficacy of the system.
Chapter 2

Background

This chapter provides an introduction into falls risk and balance in the elderly population. It explores the causes of falling and various traditional methods that have been implemented to measure or reduce the risk. It also discusses innovative methods of balance rehabilitation using virtual reality and gaming with an emphasis on research using the Nintendo® Wii Balance Boards™, and their suitability in rehabilitation therapy. Lastly, it contains an explanation of the custom stepping game design and set-up utilizing the Bluetooth capabilities of the Wii Balance Boards™ and the results and limitations from the first study conducted using the system by Mark Deacon in 2013 [19].

2.1 Falls

2.1.1 Incidence and Impact

Falling is a serious issue among the elderly population. The incidence rate of falls increases rapidly with age such that approximately 30% of individuals over the age of 65 report falling at least once per year [1]–[5]. For this age group, falls are the most common cause of injury [6], [7], accounting for nearly 70% of emergency room visits [5]. Similar to the frequency, the impact and associated complications of falls increases steadily with age, also making falls the leading cause of death due to injury for this population [5], [6], [20]. Other consequences of falls include hospitalizations, impaired mobility, reduced quality of life and chronic pain [2], [6], [7]; however, one of the most costly and common consequences of falls for this population are hip fractures.

Hip fractures are a very serious health care problem facing the aging population arising primarily from falls. During the year 2000, in the United States more than one third of fall-related injuries among seniors involved a hip fracture, however they accounted for almost two-thirds of the cost of non-fatal fall injuries [21]. Similar numbers have been reported in Canada [7]. Of those who sustain hip fractures,
almost 20% die within 3-6 months of sustaining the injury, and of those who survive, half acquire a longstanding impairment [22]. For those 80 and older, life expectancy is reduced by 25% after sustaining a hip fracture and 17% of their remaining life is spent in a nursing facility [23]. Hip fractures greatly reduce quality of life and are responsible for a large portion of the health care cost of falling.

With hospitalizations, emergency room visits, medication, rehabilitation and other treatment in outpatient settings, the total financial strain that falls place on the health care system is enormous. In Canada, nearly $2 billion is spent annually for falls in the elderly, a figure which is 3.7 times greater than that of younger adults [7].

This issue is made even more urgent because of Canada’s rapidly aging population. In 2015, the number of Canadians over the age of 65 surpassed the number of Canadians younger than 14, making up over 16% of the population. With prolonged life expectancy and the aging baby-boom generation, this number is expected to rise. It is projected that by 2025 we will join the ranks of “super-aged” countries such as Japan and Germany in having more than 20% of the population over 65 [24]. Furthermore, in 2030, it is predicted that one in four Canadians will be over the age of 65 [8].

2.2 Balance

Preventative measures to reduce the incidence of falling may lighten the financial load that falls have on the health care system as well as increase the quality of life of the aging population. To be able to implement such measures, it is essential to understand the biomechanics of balance and the environmental and physiological factors associated with aging that are predictive of falling.

2.2.1 Inverted Pendulum and Control Strategies

The body is often modelled as an inverted pendulum because of the inherent instability of having the body mass located above the body’s pivot point, the ankle [25]. To maintain balance of this unstable system, regulation of the static and dynamic relationships between one’s centre of mass (COM) and base of support (BOS) is required [26]. This regulation involves the implementation of balance strategies such
as fixed support (FS) reactions and/or change in support (CS) reactions. FS strategies refer to the deceleration or compensatory movement of one’s COM by the ankle and/or hip joints with respect to an unchanging BOS to restore balance. The ankle strategy applies during small perturbations. It requires plantarflexion or dorsiflexion of the ankle to restore balance. When the ankle muscles are not strong enough to counter the perturbation, a hip strategy or a combined strategy is used. The hip strategy involves the hip being flexed or extended to move the COM posteriorly or anteriorly respectively, back over the BOS [25].

With large perturbations, balance recovery will only occur if the border of the base of support is quickly relocated ahead of the displaced COM [27]. It is then necessary for a CS strategy to be applied. CS strategies refer to rapidly moving one’s limbs to alter the BOS, such as stepping or grasping [26] (Figure 1). In addition to increasing the BOS, both stepping and grasping both slow the momentum of the COM, making it easier for one to regain balance. Unsuccessfully implementing these control strategies in response to a perturbation will result in a fall. Stepping and grasping are more difficult to execute, especially for older adults, however, they are critical for preventing falls because they are favourable in many situations [26].

![Diagram of control strategies](image)

**Figure 1:** FS and CS control strategies for maintaining balance (Maki and McIlroy)
2.2.2 Causes of Falling

Falls are usually multifactorial in origin so various factors associated with greater falls risk have been identified in different studies. Environment-related causes of falling are the most frequently cited (31%); however, many of these falls actually occur as a result of the combination of environmental hazards and increased individual susceptibility [6], [28], [29]. A review article by Rubenstein (2006) found that the next most commonly identified risk factors (17%) are reduced muscle strength [2], [6], [28]–[31] and problems with gait and balance [4], [6], [28]–[32]. Gait and balance impairments associated with greater falls risk have been further characterized by declines in postural control [33], decreases in response execution or walking speed [31], [34]–[38] and reductions in step length [38]. Disease [20], [31], [39], [40], medication use [20], [41] and dysfunction of one or more of the body systems [20], [41] have also been shown to have a negative effect on balance. All of these factors affect components in Yim-Chiplis and Talbot’s model of balance control (Figure 2) [9]. Furthermore, similar to the impact of the falls themselves, most of these identified risk factors have been shown to worsen with age [26], [34], [35], [38], thereby explaining the increase in incidence mentioned in section 2.1.1.

2.2.3 Measuring Balance

Assessments of falls risk is challenging because of the various factors that dictate balance. Numerous methods of quantifying a person’s balance have been developed, each with their own strengths and limitations. One such method, the Berg Balance Scale (BBS), is a standardized assessment tool developed and widely used in clinical situations to measure functional balance in the elderly [42].

Figure 2: Model of components of balance control (Yim-Chiplis and Talbot)
consists of 14 tasks that increase in difficulty, from standing to sitting to standing on one foot. For each task, the participants are given a score on a scale from 0 to 4 depending on their ability to complete the task. The criteria for the score is explicitly outlined on the scale (Appendix A). The scores for each task are then added together to yield a total score out of 56. A higher score indicates better balance and a score of less than 50 has been shown to be predictive of multiple falls [43]. The BBS takes 15 minutes to administer and has been shown to be more sensitive to change in healthy older adults than other functional balance assessments, such as Tinetti’s Performance-Oriented Assessment of Mobility or the Timed get-up-and-go test. For a full review of these assessments see [9].

Advancements in technology have made it possible to attain more sensitive quantitative measurements of balance. Force plates are now the most widely reported method of quantitative balance measurement in the literature and work by reporting the position and magnitude of the centre of vertical forces or centre of pressure (COP). Force platforms evaluate four aspects of balance: postural sway, the ability of an individual to remain still and steady; symmetry, the distribution of weight evenly between the two feet; dynamic stability, the ability to move the COP to remain in a stationary position; and the automatic motor responses to disturbances on the platform surface [9]. Force platforms, however, are bulky, expensive and require specific knowledge of the software and thus are often not available or feasible for clinical use.

Understanding balance control strategies, the multifactorial nature of falls and methods of quantifying balance as a combination of factors makes it possible to identify the factors associated with greatest falls risk for each individual. By identifying these factors, effective and target-specific interventions can then be developed to improve balance in the aging population.

2.3 Methods of Improving Balance

Many studies have been conducted in attempt to combat some of the aforementioned causes of falling associated with aging. One study by Nikolaus and Bach investigated the efficacy an intervention based on minimizing environmental factors that increase falls risk and found that by educating older
adults about environmental hazards in their home and offering resources to make necessary modifications, the intervention group had 31% fewer falls than the control group [44]. Most of the studies, however, focus on physiological risks rather than environmental risk and have investigated the effect of different exercise interventions such as strength training, balance training, step training and perturbation-based training on parameters associated with falls risk. Randomized control trials (RCTs) reported that in comparison with the control groups, the intervention groups performed significantly better in balance and postural stability measures [12], [13], [45]–[47], had a reduced rate and risk of falling [10], [11], [45], [47]–[50], improved in the assessments of gait parameters such as speed and stride length [11], [47], [51], and exhibited a decreased step initiation and reaction time [11], [52]. A systematic review and meta-analysis on the effect of exercise for the prevention of falls by Sherrington et al. reported a pooled estimate that exercise reduced the rate of falls in older adults by 21%, with greater effects seen from interventions that challenged balance and involved more than 3 hours/week of exercise [10].

2.3.1 Gamification and Virtual Reality

Gamification and virtual reality are being used more frequently for rehabilitation purposes as a means of transforming the repetitive nature of rehabilitation exercises into interactive entertaining games [14]. Serious games, digital games used for purposes other than mere entertainment [53], are a growing innovative means of delivering therapy with the primary focus of improving the user’s performance in a specific area. These systems have the potential to greatly benefit users by providing the user with instant feedback and a more engaging experience [17], [54]. Furthermore, the ability for these systems to be used at home with remote supervision or check-ups could increase adherence to rehabilitation and exercise [14][55].
2.4 Nintendo® Wii Balance Boards™

Nintendo® released the Wii game console in November 2006. This innovative console introduced new ways for users to interact with the system, most notably by the introduction of a motion sensing remote control, known colloquially as the Wiimote. The Wiimote combined the functionality of the push buttons and joysticks of a typical controller with the ability to sense acceleration along three axes through the use of accelerometers and gyroscopes. This allows for players to use realistic physical movements to influence the game.

In May 2008, two years after the initial release of the Wii gaming console, Nintendo® released the Wii Fit exergaming video game. The Nintendo® Wii Fit package features activities designed to engage the players in physical exercise, such as yoga and balance exercises, with the use of a unique platform peripheral called the Wii Balance Board™ (WBB) (Figure 3) [56]. The WBBs work by measuring the user’s weight and detecting the user’s COP with four piezoresistive strain gauges mounted on cantilevers on the four corners of the WBB. Similar to the Wiimote, the WBB allows users to interact with the gaming system using body motions, providing users with a more immersive gaming experience.

Although exergaming is the primary purpose of the Nintendo® Wii Fit package, it has since been adopted for use in balance rehabilitation and physiotherapy. Studies have reported the efficacy and reliability of using WBBs to assess and train balance as a portable and less expensive alternative to research grade force platforms [15]–[18], [57]–[61].

Figure 3: Nintendo® Wii Balance Board™
2.4.1 Sensor Accuracy and Reliability

The Wii Fit and WBB technology have been well received and effective in an entertainment setting, however, the wide availability and portability of the system make the WBB appealing for use in a rehabilitation environment. The WBB could allow for more sensitive monitoring of change in balance over time than other assessment protocols, that often cannot detect the subtle outcome measures important for quantifying balance [62]. To validate this potential, it is important to investigate whether the WBB system can accurately and reliably quantify the user’s COP.

A study by Clark et al. (2010) examined the WBB validity in comparison with the ‘gold standard’ laboratory grade force platform (FP)[15]. In this study, subjects performed different balance tests on two separate occasions on the platforms to examine their test-retest reliability. Both devices exhibited a good to excellent test-retest reliability within device and between device on all testing protocols, however, the minimum detectable change (MDC) values of the WBB did exceed those of the FP in 3 of 4 tests. Clark et al. claimed that although this should be considered if the WBB is to be implemented for balance assessment, it should not disqualify the WBB from usage in further research. The study concluded that the WBB is a suitable assessment tool for clinical setting and has the potential to provide meaningful information as a rehabilitation tool at a fraction of the cost of a laboratory grade FP.

2.4.2 Nintendo® Wii Fit Plus Usability

The Nintendo® Wii Fit package includes one WBB and software with more than 40 strength training, balance and aerobic games. The Nintendo® Wii Fit Plus was released a year later in 2009 and is an enhanced version of Wii Fit, containing 75 different activities using the WBB. Both the Wii Fit and Wii Fit Plus have begun to be been studied to evaluate their contribution toward improving user balance in a rehabilitation setting. These initial case studies have found that using the Wii Fit system has improved balance and strength in older adults[61], [63]–[65], people with vestibular impairments and other neurological diseases [60], people who have recently suffered a stroke [58], [66], and even healthy female adults [67]. More research is needed with larger sample sizes and more rigorous methodologies to
validate these preliminary findings. These studies have also reported high levels of usability and enjoyment compared to typical physiotherapy exercises [60], [64]. Sugarman et al. reported that the patient greatly enjoyed using the Wii Fit system in her therapy sessions as she felt she was receiving very “up-to-date” treatment and could tell her grandchildren that their grandmother was “with-it” [64]. This enhanced engagement could help motivate users in their rehabilitation and encourage higher levels of physical activity.

Although enjoyment is important for rehabilitation, not all studies have found the Wii Fit and Wii Fit Plus activities appropriate and effective. A study by Harvey and Ada investigated the suitability of using the commercial games and found that of the 75 Wii Fit Plus activities, only five were suitable for people with a severely impaired ability to stand, six were suitable for people with moderately impaired standing and nine were suitable for people with mildly impaired standing ability [16]. Furthermore, in study by Agmon et al. participants reported being discouraged by the fast pace of one game and by the high cardiovascular demand of another [63]. Since the system is designed to be engaging for a young and active audience, many of the games are inappropriate for older adults with lower levels of ability.

Another limitation of the Wii Fit Plus system is that the current commercial games are not suitably targeted to achieve specific therapy goals [68]. Studies have presented results that the Wii Fit games are not as effective as PT training [69] or only improve static balance in bipedal conditions [70]. With regards to system feedback, a study by Wilkstrom et al. found that the Wii Fit balance activity scores had poor validity relative to postural sway and COP excursions and were not reliable [57]. This information is thus a poor reflection fitness level and is not useful to a therapist or the user.

2.4.3 Custom Software

The previous section discussed the use and suitability of the Nintenodo Wii Fit system as a whole for rehabilitation therapy. It highlighted limitations regarding game difficulty for an older population and
lack of effectiveness for specific therapy goals. However, the ability to retrieve raw data from the system can enable the manipulation of the system to develop games that are tailored for rehabilitation purposes.

The WBB uses Bluetooth technology to connect and transmit measured data to the Nintendo® Wii console for these commercial games; however, it also has the capability of using the Bluetooth connection to instead transmit raw data to other Bluetooth compatible devices. Connecting a WBB to a computer normally requires the user to hold the reset button, located on the underside of the WBB in the battery compartment, while the computer detects the device. This process has to be repeated each time the connection is broken or the computer turned off. An open source program called ‘WiiPair’ [71] can instead be used to achieve a stable connection that is automatically re-established at each use. People have begun to harness the Bluetooth connectivity of the WBBs to develop and customize programs for rehabilitation therapy that address the limitations of the commercial games [17]–[19], [59], [68]. A study by Lange et al. introduces the ideal of a user-centered, iterative design approach (Figure 4) whereby the key stakeholders (patients, therapists and caregivers) are involved at all stages of the design process to evaluate and optimize the specific therapeutic goal of the application [68].

These customized software and rehabilitation systems use weight-shifting, foot tapping and muscle-strengthening activities to achieve game and rehabilitation goals [17], [18], [54], [59], [68]. The WeHab is one system centered around the Nintendo® WBB that has been investigated for its potential to enhance rehabilitation for patients with balance disorders [18]. It enables therapists to lead patients through normal exercises with the added benefit of visual biofeedback. Another project by Albiol-Pérez et al. referred to as the Vestibular Virtual Rehabilitation (V2R) uses auditory cues instead of visual due to
the features of the patients’ disorders [17]. These systems are all flexible in their designs such that the level of difficulty can be adjusted to accommodate people with varying levels of balance, are designed to engage and motivate the user to complete each task and are able to record the raw data from the WBB to use in post analysis. Small pilot studies, primarily survey based, of these systems have yielded positive feedback from both therapists and patients suggesting the systems provide a perceived benefit; however, the effectiveness of these systems needs further investigation as clinical cohort testing has not been undertaken [18], [54], [68].

2.5 Stepping Game

For our study, a customized stepping game was designed for balance rehabilitation purposes using two Nintendo® Wii Balance Boards™ (WBBs) [19]. A user is prompted to take steps from one WBB onto targets on the other WBB and the game increases in difficulty by means of requiring increased accuracy in target stepping as the game progresses. The Centre of Pressure (COP) data is collected from each WBB over the span of the game and is analyzed for response time, reaction time and step time performance.

2.5.1 Set-Up

The stepping game system uses two WBBs, a standard laptop computer and a television screen. The WBBs are laid on the floor and aligned one in front of the other. The TV screen is placed in front of them on a table or counter of appropriate height to clearly see the display. A compiled version of a game developed in Labview is run on the PC. The computer is connected to a television screen with an HDMI cable to increase the size of display for the participants. The full set-up is visible in Figure 5. The WBB closer to the user is henceforth referred to as WBB1 and the other is referred to as WBB2. The WBBs are connected to the system via Bluetooth using a modified version of the ‘Wii Pair’ program that allows for multiple WBBs to be permanently paired to the computer [19].
2.5.2 User Interface

The main user interface (UI) of the game can be seen in Figure 6. It is comprised of three main components: the WBB target display, the left or right stepping foot indicators, and the achievement meter. The WBB target display is located in the center of the UI. The display includes an image of two WBBs laid out one in front of the other, mimicking the physical WBB arrangement on the floor. The yellow rectangle on top of WBB2 is used to visually prompt and direct the participants’ step to a specific location on WBB2.

The next components of the interface are the stepping foot indicators, which are the two white boxes in the upper left and right corners that are labelled “Left” and “Right” accordingly. During the game, a green foot print appears in one of the two boxes to indicate with which foot the user should step.
Lastly, the carnival ‘hammer and bell’ style achievement meter, located in the bottom right corner of the UI (Figure 6), tracks the users progress in each level. It will be further discussed in the Feedback section that follows. The step attempts setting, level settings, and pause button are also visible on the UI and will be discussed in the coming subsections.

2.5.3 Game Design

The stepping game was designed in 2012 by Mark Deacon within the framework of serious game design [19]. The key aspects of serious game design are motivation, feedback, adaptability and monitoring [72]. The following section will illustrate how the stepping game uses these concepts to maintain user engagement and to improve the rate of learning and efficacy of therapy for a wide range of users whilst playing a serious game.

2.5.3.1 Motivation

Keller’s ARCS Model [73] was designed as a method for improving the motivational appeal of learning in education and has since overlapped into aspects of video game design to improve motivational appeal in gaming [74], [75]. The model contains four categories that incorporate concepts characterizing human motivation: Attention, Relevance, Confidence and Satisfaction. All four of these categories are
necessary for people to become and remain motivated. The first category, Attention, refers to the challenge of gaining and then sustaining the attention of a user. The stepping game uses prompt screens and increases the difficulty of the game as the levels progress. Relevance is important because users must feel there is a purpose to what they are doing. Users are able to see the relevance of the stepping game as stepping exercises are reminiscent of traditional balance therapy. Confidence must be instilled in users so they attribute causes of success to ability and effort rather than luck or task difficulty. This is provided through positive reinforcement after the completion of a step and a level and with the ability to adjust the difficulty of the game. Finally, satisfaction is necessary so the users perceive the benefits of what they accomplished. This satisfaction can be drawn from an improved fastest step as the levels of the game progress and by the long-term benefit of increased balance.

2.5.3.2 Feedback

Feedback is an important aspect of a serious game as the rate at which people learn while performing an activity is increased when feedback is given [76]. Feedback mechanisms can be visual, auditory and tactile and can occur in real-time, during an activity, or delayed, after the activity is complete. The stepping game utilizes both real-time and delayed visual feedback, including successful target stepping and scoring system, to inform users about different aspects of their performance.

Stepping Target

The stepping game provides visual feedback in real-time as the user takes each step, as well as at the completion of a level. The first two forms of feedback are given within the WBB target display. Upon completion of a step the target changes colours and a box appears over WBB2 that reads “Good Job!” (Figure 7). This feedback assures the users that they are have successfully performed the step and can now step off of WBB2. A box will also appear to tell the participant if he or she has stepped with the incorrect foot. The participant can then try again for a successful step with the correct foot. In addition to
this feedback at the completion of a step, each WBB is overlayed with a small red circle depicting realtime feedback of the user’s COP on the WBB. This visual feedback enables users to see the proximity of their COP relative to the target as they step and indicates to them to either reattempt the step or shift their weight accordingly. These red circles are visible in Figure 6.

Score System

The next forms of visual feedback are associated with stepping performance. In the bottom right-hand corner of the UI (Figure 6) there is a carnival ‘hammer and bell’ style achievement meter. As a user successfully completes steps in a level, the meter will fill; however, the meter will empty with each unsuccessful step. When the bar fills, the level is complete. This feedback is helpful for the user to gauge his or her progression throughout the level. Once a level is completed, the user is notified by a congratulatory screen, show in Figure 8. This screen provides positive reinforcement for the completion of a level, as well as the fastest timed step and the total time taken to complete the level. These times offer...
incentive to the user to improve in the next levels by performing quicker steps and allow the user to quantify the improvement.

2.5.3.3 Adaptability

Developing a system that can accommodate a range of ability levels allows the system to provide a suitable challenge for any user. The stepping game has a wide range of variables that can be modified to increase or decrease game difficulty or customize the UI to better suit the user. These variables can be accessed during gameplay within the settings option in the pause menu and include changes to the number of attempts, the start level, the target size, location and colour, and the amount of weight applied to WBB2 to indicate a successful step.

Attempts allowed

For the game, an attempt is considered to be the application of a specified amount of the user’s bodyweight onto WBB2. This includes a successful attempt into the target location, an unsuccessful attempt with the incorrect foot or an unsuccessful attempt with the correct foot in the wrong location. The program counts the number of attempts that the user makes while trying to reach a target and if the number of attempts made is equal to the number set in the ‘attempts allowed’ variable (default value is 2), it is considered a failed step and the target is moved to the next location. This failed step will decrease the achievement meter and consequently increase the number of successful steps needed to complete the level. Increasing the number of allowed attempts reduces the difficulty as it gives the user more chances to succeed, while lowering the value makes the game more challenging as it requires better accuracy. An additional benefit of this feature is that minimizing the number of attempts allows a user to progress through the game even if there is a specific target that they are unable to reach.
**Set level**

The stepping game is comprised of 10 levels, each increasing in difficulty from the one before by shrinking the size of the stepping target. A smaller target requires more accurate stepping. The level can be set manually to more appropriately challenge the user by changing the ‘set level’ value on the UI.

**Target Size and Location**

The size and location of the targets can be modified throughout the stepping game, regardless of level. The size can be changed in the settings menu by adjusting the value of height (in pixels) of the rectangle. The width of the rectangle is set to be 75% of the target height. With regards to location, the default of the stepping game is to only display targets on the same side of the WBB as the stepping foot because maintaining balance is more challenging in a tandem stance (i.e. one foot directly in front of the other) [25]. The setting can be adjusted with a slide bar in the target setting menu to prompt more confident users to step across the midline of the WBB to increase the game’s difficulty.

**Target/COP Colour**

The colour of the initial target, the target reached and the small circle that represents the COP locations can all be changed on the settings menu. While changing these colours does not affect the difficulty of the game, it can be useful to improve contrast and make the interface features more discernable.

**Weight applied**

The stepping game has a threshold for the amount of pressure on WBB2 required to register a step. The default value is 50% of the user’s total weight; however this parameter can easily be adjusted to change the level of difficulty. A step can be more easily completed when there is lower threshold as the users can then keep the majority of their weight on WBB1.
2.5.3.4 Monitoring

In serious games, monitoring refers to the process of collecting data from a user’s performance to improve feedback and monitor change. This enables therapists and researchers to make quantitative analyses rather than relying on the observed performance of a user. The elapsed time, COP and weight on the WBBs is collected at a frequency of 20Hz from each use of the stepping game. The game also records information regarding the target, the stepping foot, the number of attempts and the level. By restarting or quitting the program, this raw data is saved into an ‘.lvm’ file. A MATLAB program is used to interpret the raw data to provide useful information about the user’s stepping performance, such as response time, reaction time and stepping time for each step taken [19]. The theory behind how a step is identified and how these variables are calculated is discussed in 2.5.4. These results can be used to identify differences between interventions or trends over time.

2.5.4 Identifying a Step

The MATLAB program uses the raw data to identify performance characteristics about each step taken by the users. The response time for each step is defined as the total time between the appearance of the visual cue and the transfer of the individual’s body weight to WBB2. It is fairly straightforward to identify response time as these boundaries are easily defined; however, response time is further divided into reaction time, the time it takes for the individual to react to the visual cue, and step time, the time it takes for the individual to execute the physical motion of stepping, and their shared boundary is more challenging to isolate without a motion capture system. Instead, the beginning of a step is calculated from the lateral movement of the COP away from the midpoint of the minimum and maximum locations of COP on WBB1, towards the non-stepping foot [19]. This movement is depicted in Figure 9. Reaction time and step time are quantified by the time before and after this COP movement respectively.
2.5.5 Previous Studies

The stepping game system has already been used in a study by Mark Deacon to investigate its ability to measure balance by identifying trends in the performance of people with various conditions that affect their balance [19]. For his study, 104 participants were grouped according to the reason for referral. The diagnostic groups were Balance, people with poor balance and/or mobility with or without a falls history; Deconditioned, participants who have become weak and/or frail and present below their baseline normal; Stroke, those who have suffered a stroke and are experiencing balance or mobility concerns as a result; Other, people with other neurological conditions; and Healthy, participants with a BBS greater than 53/56. Each participant was briefed on how the game worked and then used the stepping game for 5 minutes.

Deacon et al. concluded that the system was able to identify differences between the response time of healthy participants and participants with conditions that affect balance, such that response times for people with balance issues were between 1.17 and 2.26 times the response times of healthy people; however, it was unable to distinguish among conditions. A relationship between a decrease in median response time and an increase in BBS was found as well as strong evidence that people with a history of falls correlated to a higher mean response time than those who did not have a history of falls.
Chapter 3

Pre-Post Matched Control Study

This chapter explores the first of our two testing procedures, analyses and discussions using the Nintendo® WBBs and accompanying stepping game software. Clinical testing took place in two older adult exercise programs in Odessa and Kingston, Ontario outlined below. The objective of this testing was to evaluate the functional outcomes and participant satisfaction over a ten-week period using the stepping game in addition to traditional therapy compared to traditional therapy alone. We also sought to further assess the usability and efficacy of the system as a rehabilitation tool.

3.1 Methods

3.1.1 Participants

Individuals over the age of 60 years who attend a weekly or bi-weekly exercise program were asked to participate in this study (n=12). The participants were recruited from two different older adult exercise programs in Kingston, Ontario. Nineteen participants from the programs agreed to participate in the study. Seven participants did not complete the study as a result of loss of interest or illness.

Ethics clearance was granted by the Queen’s University Health Sciences & Affiliated Teaching Hospitals Research Ethics Boards (HSREB) (Appendix B). Once verbal and written informed consent (Appendix C) was obtained from each individual, a short health form (Appendix D) was completed to collect personal health information regarding conditions or injuries that may affect one’s balance or vision. Participants were excluded from the study if they were unable to mobilize independently with or without aid, to undertake a functional activity assessment or to shift weight bilaterally pain free (or within tolerable pain levels) with or without aid. Individuals with epilepsy or severe visual impairments were also excluded to avoid issues with the video/screen-based technology.
3.1.2 Programs

The two different programs from which participants were recruited, program A and program B, differed slightly in structure. These programs were already established with older adults choosing to increase activity levels by registering in such community-based programs. We undertook convenience sampling to engage participants in our gaming system. For practical reasons, we chose to attend programming that already existed (Figure 10) as our weekly intervention using the stepping game required only fifteen minutes.

Program A was a weekly, 90-minute class that took place in a common room within the building where the participants lived. It was a 12-week program that included a registration and fitness assessment class in week 1 and a social at the end in week 12. The exercise portion of the program only lasted for ten of the 12 weeks. The program took a multifaceted approach to fall prevention that combined fitness and falls risk education with gentle, low impact strength and balance exercises for seniors who were not able to participate in traditional exercise programs. This was the first introduction to older adult exercise for most of the participants.

Program B was 60 minutes long, twice a week, and took place in a community centre. The program was continuous throughout the year and was not divided into sessions; however, this study was conducted for ten weeks of the program to be consistent with program A. It was a gentle exercise program for community residents who need help attaining a physically active lifestyle. Some participants were new to this program, while others had become regulars. The programs and the number of participants from each are summarized in Table 1.

![Diagram](image)

Figure 10: Diagram of the test group divisions for each program in the first study.
Table 1: Summary of participants and their respective programs

<table>
<thead>
<tr>
<th>Program</th>
<th>Times/Week</th>
<th>Class Length</th>
<th>Original Number of Participants</th>
<th>Final Number of Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Test</td>
<td>Control</td>
<td>Dropouts</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>Test</td>
<td>Control</td>
<td>Dropouts</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>90 min</td>
<td>8</td>
<td>4 4 1*</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>60 min</td>
<td>11</td>
<td>6 5 6**</td>
</tr>
</tbody>
</table>

*The participant experienced a fall prior to the beginning of data collection

**Two subjects gave their consent to participate but did not attend the first week of the class, three subjects were either absent or did not wish to complete the study in week ten and one subject was hospitalized for an unrelated condition and unable to attend the remainder of the classes.

3.1.3 Procedure

Berg Balance Scale assessment was completed one week prior to the study and the participants from exercise programs A and B were stratified randomly into control and test groups based on these initial BBS scores. The goal was to reduce bias by randomising the participants while ensuring a matched or similar distribution of BBS scores. At the end of the test protocol however, from program A, there were four test and three control participants and from program B, there were three test and two control (Table 1) (due to dropouts). The control group underwent baseline assessments using the stepping game in week one and once more at the end of the program in week ten for comparison of stepping performance. Between the assessments, they participated in their regularly scheduled exercise classes. The test group was assigned balance exercises using the WBBs and stepping game technology, once a week, throughout the ten weeks, which supplemented their regularly scheduled exercise class. BBS assessments were repeated on the last week for each participant to evaluate whether clinical observable changes in balance could be detected.

The game took between 10-15 minutes to complete each week for each participant. For logistical reasons, participants in program A would miss a small portion of the 90-minute exercise class to play the
game but completed the game in a different order each week as to not repeatedly miss the same portion. Participants in program B chose to come slightly early to their classes each week to complete the game, as they did not want to take time away from their exercise. The set-up in program A and program B are visible in Figure 11. Participants were allowed to use their walking aids for support as required. A chair was placed beside the WBBs upon request in case a participant needed to grip the back to steady themselves. Attendance was tracked for all participants.

Figure 11: System set-up at program A [left] and program B [right]
3.1.4 Analysis

The data from weeks one and ten for the control and test groups of programs A and B were investigated in a pre and post intervention format. A mixed linear model with SAS software was used to make statistical inferences about the means of the data while still accounting for covariance and repeated measures. Data was transformed to satisfy the assumption of normality necessary for a mixed linear model. The Tukey-Kramer method was used post-hoc to compare the mean response time between programs, weeks and test groups. To satisfy normality for these variables, the data points that resulted in large residuals were removed and the data was inverted for both response time and reaction time, and logarithmically transformed for step time.

3.2 Results

3.2.1 Berg Balance Scale

The pre- and post-program BBS scores for all the participants, as well as BBS score means for each program and group are shown in Table 2 below. The participants were originally stratified into control and test groups based on their BBS scores (BBS = 52-53), however, after dropouts there was a larger variation of mean BBS scores across groups (BBS = 50.3-54.5). At the end of the study, for program A, the mean BBS score decreased by 0.5 points for the test group and increased by around 1.3 points for the control group. For program B, there was a noticeable increase of approximately 2.67 in mean BBS score for the test group, while the mean BBS score for the control group remained unchanged.
Table 2: Berg Balance Scale scores for participants and programs

<table>
<thead>
<tr>
<th>PROGRAM</th>
<th>Group</th>
<th>Individual Berg Balance Scale Score</th>
<th>Mean Berg Balance Scale Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>WEEK1</td>
<td>WEEK 10</td>
</tr>
<tr>
<td>A</td>
<td>TEST</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>54</td>
<td>54</td>
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<td></td>
<td>52</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>CONTROL</td>
<td>49</td>
<td>51</td>
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<tr>
<td></td>
<td></td>
<td>52</td>
<td>--</td>
</tr>
<tr>
<td>B</td>
<td>TEST</td>
<td>52</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>43</td>
<td>49</td>
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<td>CONTROL</td>
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<td>53</td>
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<td></td>
<td></td>
<td>53</td>
<td>54</td>
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</tbody>
</table>

3.2.2 Response Time

The mean response times in week 1 and week 10 for both the control and test participants for program A and program B are plotted in Figure 12 (these are the non-transformed data for graphical representation to enable a better understanding of meaningful differences). Significance was found statistically using the inverted values to satisfy the normality assumption and is represented in Figure 12 by dashed lines and asterisks. The mean response times decreased from week 1 to week 10 for three of the four program and group combinations. The test group from program A, the test group from program B and the control group from program B, all appear to have improved response times. The control group from program A, however, did not improve and actually increased in response time from week 1 to 10.
3.2.3 Reaction Time

The mean reaction times for the group and program combinations are similar to the response times. Once again, the reaction times decreased from week 1 to week 10 for the test group from program A and the test and control groups from program B and increased for the control group from program A (Figure 13). The reaction time data was also inverted to satisfy the assumption of normality and the significant differences between means were found from the transformed data.
3.2.4 Step Time

Step time data was logarithmically transformed to satisfy normality. Unlike the reaction time and response time, there does not appear to be a difference in mean step time between the control and test groups from a statistical perspective, thus the group data is collapsed in Figure 14. From week 1 to week 10, there appears to be a significant decrease in mean step time for program B and no significant change for program A. Significance is again denoted with a dashed line and asterisks.

Figure 13: Reaction times in week 1 and week 10. Dashed line denotes significance. * denotes significance difference in means with program B test in week 10.
3.2.5 Qualitative

In addition to obtaining quantitative data with the balance boards, qualitative observations of the participants were also recorded. Upon observation it was evident that some participants appeared to have poor spatial awareness resulting in the inability to consistently step towards the target location. From a cognitive processing perspective, the participants had to observe an event on a television screen mounted in front of them and translate that information into the task of stepping in the right direction towards the target. This was difficult for several participants. A few participants did not understand the interface at the beginning of the study and were confused about with which foot to step with. Performance appeared to improve towards the end of the test session in week 1 and was noticeably more consistent in week 2 in the test group.

Figure 14: Step times in week 1 and week 10. Dashed line denotes significance. * denotes significance difference in means with program B week 10.
It is also important to note that attendance was not consistent among all participants. One participant in the control group for program A missed two weeks of the exercise class to go on vacation and another had surgery on her eye, which resulted in her absence for two weeks and a very limited level of physical exertion during the remaining 3 classes. A test participant in program B was absent for one week to accompany another participant to the hospital for an unrelated injury. The hospitalized participant was reported as a dropout. Another test participant in program B was in attendance but did not complete the game in one of the test weeks as a result of technical difficulties. Lastly, one control participant in program B was absent from 2 classes and another was absent for 5, however their exercise class was twice a week so in total they attended 18 and 15 classes respectively.

3.3 Discussion

3.3.1 Berg Balance Scale

Although there were some small BBS changes observed between weeks 1 and 10, it is difficult to conclude that an improvement in physical function resulted. A study that investigated the test-retest reliability found that despite the BBS having a high intraclass correlation coefficient, a change of 8 points is required to reveal a genuine change in clinical function between 2 assessments rather than a change due to measurement error [77]. The largest change observed in this study was 6 points for one individual and less than 3 for the mean of a group, thus suggesting that the improvements may not be significant. Other studies have found that absolute reliability of the BBS varies across the scale, in that it is stronger at the ends and weaker towards the middle [42], [78]. In a study by Donoghue et al. it was found that the MDC is 4 points in a patient with an initial score within 45-56, 5 points in a patient with an initial score within 35-44, 7 points in a patient with an initial score within 25-34 and 5 points in a patient with an initial score within 0-24 [78]. By these MDCs, the participant’s improvement from 43 to 49 (Table 2) can be considered a significant change, however, the group BBS means still do not appear to be significant. Downs identifies a limitation of the BBS that may explain these results. In his paper, he acknowledges the
presence of a ceiling effect for the BBS when used in people younger than 75 who do not have a specific condition that negatively affects balance, regardless of whether they have an increased risk of falling [42]. Thus, the BBS may not be a good screening tool for this purpose and a more dynamic assessment may have been preferable. This limitation was not identified prior to testing.

3.3.2 Game Performance

Although the group mean BBS scores did not significantly change from weeks one to ten, the stepping game appears to be more sensitive to changes and can be used to isolate the contribution of the reaction time as compared to the step time as an indicator of cognitive processing. Statistically significant improvements were found when analyzing response time, reaction time and step time data. Reductions in response time and reaction time occurred in both the control and test groups in program B and in the test group in program A. This agrees with previous studies that show exercise can produce benefits with regards to improved sensorimotor function [79] and a reduced risk of falls [80]. The control group in program A, however, did not improve, suggesting that attendance at a program twice a week is more beneficial than once a week. This finding is further supported by the significantly decreased step time for participants in program B. There was also no difference in step times between control or test groups for either program suggesting that the effect of exercise is more significant to step time than the effect of the stepping game. It is also important to note that the data from the control group in program A may be less reliable because of the lack of attendance from two of the participants.

3.3.3 Limitations

It is difficult to draw conclusions regarding the effect of the stepping game as this study is limited by the possible presence of a learning curve. It was observed, especially in program A, that the participants had a much stronger grasp on the stepping game during the second use of the game. The control participants may have forgotten how to use the stepping game over the 10 weeks, resulting in an inaccurate representation of their progress. It may then be more beneficial to investigate the progression
of the test group data over the span of the experiment instead of attempting to draw conclusions in a pre and post intervention style.
Chapter 4
Longitudinal Study

This chapter describes the second of our two testing procedures, analyses and discussions using the Nintendo® WBBs and accompanying stepping game software. Clinical testing took place in four older adult exercise programs in Odessa and Kingston, Ontario outlined below. This study was undertaken concurrent with the study previously discussed, however, the number of participants in programs C and D (to be further discussed) did not permit the stratification among test and control participants. Only test participants were recruited from these programs. The purpose of this testing was to investigate the stepping game system’s ability to measure and quantify balance by analyzing data longitudinally and identifying trends in performance. It was also of interest to us to evaluate the presence of a possible learning effect identified in Chapter 3 and monitor engagement.

4.1 Methods

4.1.1 Participant & Programs

Participants over the age of 60 were recruited from two additional senior exercise programs, in addition to those already recruited from program A and program B. In total, 14 older adults with a mean age of 77 from the four programs participated in the study. One participant from program B dropped out due to health reasons (n=13). Consent and health information were obtained from each individual. For descriptions of program A and program B please refer to Chapter 3.

Program C was a 60-minute, twice-weekly program held in a nearby gym. This program was divided into eight-week sessions, which included one yoga class and one aqua-fit class. Program C is longstanding and thus most of the participants had been attending the classes for years. It offered medium impact exercise and customized workouts for its participants. There was also a cognitive exercise aspect in the form of weekly brain teasers and riddles.
Program D was also a twice weekly, 60-minute class, held in a recreational centre. The class was geared to seniors new or returning to fitness. It was a gentle, low impact class that incorporated both seated and standing flexibility and balance exercises. This program was continuous and was not divided into sessions. Table 3 and Figure 15 below summarize all four exercise programs. To be consistent with program C, the study was conducted over the span of eight weeks for program D as well.

Table 3: Exercise program characteristics and participants (*post drop-out)

<table>
<thead>
<tr>
<th>Program</th>
<th>Times/Week</th>
<th>Class Length</th>
<th>Program Length</th>
<th>Intensity</th>
<th># of Participants</th>
<th>Mean Age ±SD</th>
<th>Mean BBS Score ±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>90 min</td>
<td>10 weeks</td>
<td>Low</td>
<td>4</td>
<td>74 ±5.8</td>
<td>52 ±3.4</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>60 min</td>
<td>10 weeks</td>
<td>Low</td>
<td>3*</td>
<td>80 ±7.3</td>
<td>50 ±5.4</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>60 min</td>
<td>8 weeks</td>
<td>Medium</td>
<td>4</td>
<td>76 ±3.5</td>
<td>54 ±2.3</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>60 min</td>
<td>8 weeks</td>
<td>Low</td>
<td>2</td>
<td>80 ±0.5</td>
<td>55 ±1</td>
</tr>
</tbody>
</table>

4.1.2 Procedure

The data collection for this study overlapped with the pre/post matched control study so similarly, each participant’s balance was assessed using the BBS prior to week one and immediately after week ten. All participants used the stepping game software and WBBs for 10-15 minutes, once a week within their regularly scheduled exercise programs. Participants in program A and C opted to miss a small portion of their exercise class to play the game but completed the game in a different order each week as to not repeatedly miss the same portion. Participants in program B and D did not want to take time away from their exercise and instead opted to arrive 15 minutes early for their class each week to complete the game.
The set-up is the same as in chapter 2 (Figure 11). Participants were permitted to use their walking aids for support. A chair was placed beside the WBBs upon request in case a participant needed to grip the back to steady themselves. Attendance was tracked for all participants. At the end of the 10 weeks, the participants were given a short survey to assess their engagement and collect their thoughts regarding the stepping game system (Appendix E).

4.1.3 Analysis

The response time, reaction time and stepping time for each set of trials from weeks one to ten for all test subjects (n=13) was analysed for trends using SAS analytical software. To satisfy the normality assumption, large residuals were removed, the response and reaction time data was inversely transformed and the step time was transformed using a logarithmic transformation. The mean response, reaction and step times for each participant over the 10 or 8-week sessions were then calculated. The data from each participant was both collapsed into the corresponding exercise program and fitted with a general linear model regression, to investigate the pre-planned group comparisons, and fitted individually to explore the participant effect. Week 1 was removed from further analyses to eliminate a potential learning effect, however, the fit of the models with and without week one was also calculated to evaluate the presence of such an effect. Regressions for each exercise program and participant were then analyzed for significance.

4.2 Results

4.2.1 Berg Balance Scores

The BBS scores for every participant and mean BBS scores for each program taken in week 10 were compared with the scores taken in week 1. The mean BBS score decreased by 0.5 points for program A, increased by 2.67 points for program B, increased by 1.5 points for program C and remained unchanged for program D. Individually, the greatest change in BBS was for participant 6, whose score increased by 6 points. Increases of 4 and 2 points were seen in participant 11 and participant 5 respectively. All of the BBS scores and changes are summarized in Table 4.
Table 4: Program and participant pre and post BBS score

<table>
<thead>
<tr>
<th>Program</th>
<th>Participant</th>
<th>Age</th>
<th>Individual Berg Balance Scale Score</th>
<th>Mean Berg Balance Scale Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Week 1</td>
<td>Week 8/10</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>68</td>
<td>47</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>75</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>83</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>70</td>
<td>52</td>
<td>51</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>87</td>
<td>52</td>
<td>54</td>
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<tr>
<td></td>
<td>6</td>
<td>83</td>
<td>43</td>
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<tr>
<td></td>
<td>7</td>
<td>70</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>70</td>
<td>54</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>79</td>
<td>55</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>76</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>78</td>
<td>50</td>
<td>54</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>79</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>90</td>
<td>54</td>
<td>54</td>
</tr>
</tbody>
</table>

4.2.2 Program Trends

The means of the transformed data for each participant were collapsed into the corresponding exercise programs and plotted over the 8 or 10-week span of the program. They have been divided into response time, reaction time and step time below.

4.2.2.1 Response Time

The mean inverted response times for each exercise program are plotted below in Figure 16. The equations of the linear regressions, represented by the trendlines in Figure 16, are given in Table 5. This table also contains the R^2 value of regression, which is the proportion of variance in the variable; the P value, an indicator of the significance of the results; and the change and percent change in the response time predicted over the span of the study. Significance is denoted with a solid trendline in Figure 16 and
by asterisk in Table 5. The linear regression of response time provides strong evidence that there was a significant change in response time for program B over the course of the 10 weeks. This regression accounts for 81% of the variation in response time and predicts an improvement of 21%. The change in response time for programs A, C and D are not statistically significant.

![Program regressions of inverted mean response times](image)

**Figure 16: Program regressions of inverted mean response times**

4.2.2.2 Reaction Time

The inverted mean reaction times and corresponding trendlines are plotted in Figure 17 and regression fit characteristics, significance interactions and predicted values for reaction time are summarized in Table 6. Again significance is denoted by a solid trendline in Figure 17 and an asterisk in Table 6. As with response time, there is evidence that the slope of the trendline for program B for reaction time is not equal to zero, thereby suggesting that a significant improvement occurred (the null hypothesis that change in reaction time is equal to zero is rejected). The regression explains 64% of the variation in response time and predicts an improvement of 19%. Again, no statistically significant improvements were identified for programs A, C and D, however program A was approaching significance with a P value of 0.07.
4.2.2.3 Step Time

Figure 18 shows the means of the logarithmically transformed step times for each exercise program. The solid trendlines denote significance. The regression equations, and values of fit, significance and change are given in Table 7 below. Significant regressions are denoted with an asterisk. The regressions of the logarithmic transformations of step time for program B and program C were found to be statistically significant with $R^2$ values of 83% an 66% respectively. An improvement of 25% was seen by program B, while an improvement of 18% was predicted for program C. There was no evidence against the slope of the trendlines of program A and program D being equal to zero (the null hypothesis could not be rejected).
**Figure 18:** Program regressions of logarithmically transformed mean step times
Table 5: Program regression equations, fit characteristics and changes in response time

<table>
<thead>
<tr>
<th>Program</th>
<th>1/Resp_T=(m*Week)+b</th>
<th>P Value</th>
<th>R²</th>
<th>Predicted Response Time (s)</th>
<th>%Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>b</td>
<td></td>
<td>Week 1</td>
<td>Week 8</td>
</tr>
<tr>
<td>A</td>
<td>0.003</td>
<td>0.548</td>
<td>0.2250</td>
<td>0.202</td>
<td>1.818</td>
</tr>
<tr>
<td>B*</td>
<td>0.020</td>
<td>0.637</td>
<td>0.0009*</td>
<td>0.810</td>
<td>1.524</td>
</tr>
<tr>
<td>C</td>
<td>0.013</td>
<td>0.800</td>
<td>0.0787</td>
<td>0.493</td>
<td>1.231</td>
</tr>
<tr>
<td>D</td>
<td>0.002</td>
<td>0.805</td>
<td>0.7682</td>
<td>0.019</td>
<td>1.239</td>
</tr>
</tbody>
</table>

Table 6: Program regression equations, fit characteristics and changes in reaction time

<table>
<thead>
<tr>
<th>Program</th>
<th>1/React_T=(m*Week)+b</th>
<th>P Value</th>
<th>R²</th>
<th>Predicted Reaction Time (s)</th>
<th>%Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>b</td>
<td></td>
<td>Week 1</td>
<td>Week 8</td>
</tr>
<tr>
<td>A</td>
<td>0.0101</td>
<td>0.9167</td>
<td>0.0693</td>
<td>0.396</td>
<td>1.079</td>
</tr>
<tr>
<td>B*</td>
<td>0.0269</td>
<td>1.0235</td>
<td>0.0101*</td>
<td>0.635</td>
<td>0.952</td>
</tr>
<tr>
<td>C</td>
<td>0.0080</td>
<td>1.1862</td>
<td>0.2929</td>
<td>0.216</td>
<td>0.837</td>
</tr>
<tr>
<td>D</td>
<td>0.0224</td>
<td>1.2038</td>
<td>0.0608</td>
<td>0.538</td>
<td>0.816</td>
</tr>
</tbody>
</table>

Table 7: Program regression equations, fit characteristics and changes in step time

<table>
<thead>
<tr>
<th>Program</th>
<th>Log(Step_T)=(m*Week)+b</th>
<th>P Value</th>
<th>R²</th>
<th>Predicted Step Time (s)</th>
<th>%Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>b</td>
<td></td>
<td>Week 1</td>
<td>Week 8</td>
</tr>
<tr>
<td>A</td>
<td>0.005</td>
<td>-0.350</td>
<td>0.5102</td>
<td>0.064</td>
<td>0.708</td>
</tr>
<tr>
<td>B*</td>
<td>-0.032</td>
<td>-0.567</td>
<td>0.0007*</td>
<td>0.827</td>
<td>0.550</td>
</tr>
<tr>
<td>C*</td>
<td>-0.029</td>
<td>-0.972</td>
<td>0.0262*</td>
<td>0.661</td>
<td>0.367</td>
</tr>
<tr>
<td>D</td>
<td>0.022</td>
<td>-0.903</td>
<td>0.1229</td>
<td>0.407</td>
<td>0.414</td>
</tr>
</tbody>
</table>
4.2.3 Participant Trends

The trends from the means of the data were investigated for each individual participant over the span of the exercise programs and are again divided into response time, reaction time and step time below.

4.2.3.1 Response Time

The trend lines of the transformed mean response times for each of the individual participant’s regressions are shown in Figure 19. All the individual regression characteristics and changes in response time are given in Table 8. Significance in this table is denoted by an asterisk (P<0.05). Five of the 13 participants exhibited a statistically significant decrease in response time over the course of this study. These participants include participants 5 and 6 from program B, participants 9 and 10 from program C and participant 13 from program D. For these participants, the general linear model explained 51-77% of the variance in response time and presented individual improvements from 10-42%. None of the participants in program A statistically improved their response times, however, participant 4, showed improvement that was approaching significance with a P values of 0.06.

Figure 19: Participant regression lines for inverted mean response times
4.2.3.2 Reaction Time

The regression lines for the inverted reaction time data for each participant are visible in Figure 20. Five participants, participants 1 and 4 from program A, participants 5 and 6 from program B and participant 13 from program D showed a statistically significant decrease in reaction time over the course of their respective exercise programs. These improvements ranged from 10-42\% of their initial mean reaction time and the regression explains 47-75\% of the variation in reaction time. None of the participants in program C exhibited a statistically significant improvement in reaction time. The regression fit characteristics and changes in reaction times are summarized in Table 9. Significance is again denoted with an asterisk (P<0.05).

![Figure 20: Participant regression lines for inverted mean reaction times](image)

4.2.3.3 Step Time

Figure 21 displays the regression lines for the logarithmically transformed step time data. The equations of regression, fit characteristics and changes in step time for each participant are given in Table 10. Statistically significant changes are denoted with an asterisk (P<0.05). As with the results from response time, there was no significant change in step time from any participant in program A.
Improvements in step time are exhibited by four out of 13 participants, participant 6 and 7, from program B and by participants 9 and 10, from program C. These four participants decreased their stepping time by 25-40%. From program D, participant 12 significantly increased in step time throughout the course of the study by 56%. The regression models explain 70-81% of the variation in step time for these five participants.

Figure 21: Participant regression lines for logarithmically transformed mean step times
Table 8: Participant equations of regression, fit characteristics and changes in response time

<table>
<thead>
<tr>
<th>Program</th>
<th>Participant</th>
<th>$\frac{1}{\text{Resp}_T}=(m\times\text{Week})+b$</th>
<th>P Value</th>
<th>$R^2$</th>
<th>Predicted Response Time (s)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>m</td>
<td>b</td>
<td></td>
<td>Week 1</td>
<td>Week 8</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>0.001</td>
<td>0.506</td>
<td>0.4523</td>
<td>0.083</td>
<td>1.969</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.000</td>
<td>0.627</td>
<td>0.9425</td>
<td>0.001</td>
<td>1.595</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.002</td>
<td>0.569</td>
<td>0.8064</td>
<td>0.009</td>
<td>1.753</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.007</td>
<td>0.486</td>
<td>0.0598</td>
<td>0.418</td>
<td>2.026</td>
</tr>
<tr>
<td>B</td>
<td>5*</td>
<td>0.009</td>
<td>0.710</td>
<td>0.0304*</td>
<td>0.511</td>
<td>1.392</td>
</tr>
<tr>
<td></td>
<td>6*</td>
<td>0.036</td>
<td>0.419</td>
<td>0.0043*</td>
<td>0.767</td>
<td>2.196</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0.017</td>
<td>0.751</td>
<td>0.0974</td>
<td>0.391</td>
<td>1.301</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>0.027</td>
<td>0.878</td>
<td>0.1803</td>
<td>0.326</td>
<td>1.106</td>
</tr>
<tr>
<td></td>
<td>9*</td>
<td>0.023</td>
<td>0.697</td>
<td>0.0478*</td>
<td>0.576</td>
<td>1.389</td>
</tr>
<tr>
<td></td>
<td>10*</td>
<td>0.015</td>
<td>0.725</td>
<td>0.0380*</td>
<td>0.700</td>
<td>1.351</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>-0.012</td>
<td>0.877</td>
<td>0.2700</td>
<td>0.290</td>
<td>1.156</td>
</tr>
<tr>
<td>D</td>
<td>12</td>
<td>-0.020</td>
<td>1.017</td>
<td>0.1008</td>
<td>0.447</td>
<td>1.004</td>
</tr>
<tr>
<td></td>
<td>13*</td>
<td>0.027</td>
<td>0.569</td>
<td>0.0234*</td>
<td>0.761</td>
<td>1.678</td>
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</tbody>
</table>
Table 9: Participant equations of regression, fit characteristics and changes in reaction time

<table>
<thead>
<tr>
<th>Program</th>
<th>Participant</th>
<th>I/React_T=(m*Week)+b</th>
<th>P Value</th>
<th>R²</th>
<th>Predicted Reaction Time (s)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Week 1</td>
<td>Week 8</td>
</tr>
<tr>
<td>A</td>
<td>1*</td>
<td>0.011 0.866</td>
<td><strong>0.0197</strong></td>
<td>0.564</td>
<td>1.141</td>
<td>1.026</td>
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<tr>
<td></td>
<td>2</td>
<td>0.006 1.104</td>
<td>0.730</td>
<td>0.018</td>
<td>0.901</td>
<td>0.861</td>
</tr>
<tr>
<td></td>
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<td>0.011 0.898</td>
<td>0.178</td>
<td>0.243</td>
<td>1.100</td>
<td>0.990</td>
</tr>
<tr>
<td></td>
<td>4*</td>
<td>0.013 0.797</td>
<td><strong>0.0413</strong></td>
<td>0.471</td>
<td>1.235</td>
<td>1.083</td>
</tr>
<tr>
<td>B</td>
<td>5*</td>
<td>0.018 1.121</td>
<td><strong>0.0269</strong></td>
<td>0.527</td>
<td>0.878</td>
<td>0.770</td>
</tr>
<tr>
<td></td>
<td>6*</td>
<td>0.056 0.639</td>
<td><strong>0.009</strong></td>
<td>0.706</td>
<td>1.440</td>
<td>0.837</td>
</tr>
<tr>
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<td>0.775</td>
<td>0.726</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
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<td>0.752</td>
<td>0.669</td>
</tr>
<tr>
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<td>9</td>
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<td>0.873</td>
<td>0.814</td>
</tr>
<tr>
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<td>0.501</td>
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<tr>
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<td>11</td>
<td>-0.011 1.165</td>
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<td>0.867</td>
<td>0.931</td>
</tr>
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<td>12</td>
<td>-0.009 1.420</td>
<td>0.6110</td>
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<td>0.709</td>
<td>0.741</td>
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<td>0.750</td>
<td>0.962</td>
<td>0.713</td>
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Table 10: Participant equations of regression, fit characteristics and changes in step time

<table>
<thead>
<tr>
<th>Program</th>
<th>Participant</th>
<th>Log(Step_T)=(m*Week)+b</th>
<th>P Value</th>
<th>R²</th>
<th>Predicted Step Time (s)</th>
<th>%Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>m</td>
<td>b</td>
<td></td>
<td>Week 1</td>
<td>Week 8</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>0.011</td>
<td>-0.273</td>
<td>0.2592</td>
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<td>0.770</td>
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<td>0.094</td>
<td>0.627</td>
</tr>
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<td>-0.240</td>
<td>0.1499</td>
<td>0.272</td>
<td>0.777</td>
</tr>
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<td>B</td>
<td>5</td>
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<td>-0.695</td>
<td>0.6186</td>
<td>0.037</td>
<td>0.496</td>
</tr>
<tr>
<td></td>
<td>6*</td>
<td>-0.057</td>
<td>-0.293</td>
<td><strong>0.8024</strong></td>
<td>0.808</td>
<td>0.705</td>
</tr>
<tr>
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<td>7*</td>
<td>-0.044</td>
<td>-0.630</td>
<td><strong>0.8101</strong></td>
<td>0.695</td>
<td>0.509</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>-0.046</td>
<td>-1.115</td>
<td>0.0907</td>
<td>0.467</td>
<td>0.313</td>
</tr>
<tr>
<td></td>
<td>9*</td>
<td>-0.072</td>
<td>-0.608</td>
<td><strong>0.8157</strong></td>
<td>0.720</td>
<td>0.507</td>
</tr>
<tr>
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<td>-0.762</td>
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<td>0.709</td>
<td>0.448</td>
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<tr>
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<td>11</td>
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<td>-1.362</td>
<td>0.072</td>
<td>0.596</td>
<td>0.266</td>
</tr>
<tr>
<td>D</td>
<td>12*</td>
<td>0.064</td>
<td>-1.364</td>
<td><strong>0.8055</strong></td>
<td>0.813</td>
<td>0.273</td>
</tr>
<tr>
<td></td>
<td>13</td>
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<td>-0.352</td>
<td>0.123</td>
<td>0.487</td>
<td>0.682</td>
</tr>
</tbody>
</table>
4.2.4 Learning Effect

It was of interest to evaluate the presence of a learning effect between weeks 1 and the remaining weeks in the program. Upon visual examination of the spread of the plotted untransformed response times, reaction times and step times for each step, there does appear to be a larger variation in week 1 compared to the other weeks for participants 1, 2 and 3 in program A. Upon examination of the plotted transformed values for these participants, the variation is most apparent in step time.

The slopes of the regressions for all participants were compared with and without week 1 using all of the data was for each participant, as opposed to the means. For response time, the slopes of the regression lines for 9 of the 13 participants are significantly different; for reaction time, only 2 of the 13 slopes significantly changed; and for step time, 9 of the 13 regression line slopes were statistically different.

4.2.5 Surveys

The survey results presented mixed attitudes towards engagement, motivation and perceived benefit (Figure 22). Although the majority of participants found the stepping game to be more engaging than typical exercises or therapies they have done before and would like to continue using the game in the future, some participants did not find the game challenging enough and were bored of doing the same thing each week. One participant commented that her motivation to keep playing the game stemmed from wanting to honour her commitment to the study rather than wanting to improve at the game. Another participant stated that she found the game annoying at first but it grew on her. Most participants found the game instructions to be straight-forward; however, some participants were confused by specific aspects of the interface, such as the red COP circle and the stepping foot indicators.
Figure 22: Responses to participant engagement survey

4.2.6 Qualitative/Attendance

Participant attendance was tracked throughout the study. Most of the participants were committed to their respective fitness programs and were thus keen to attend every class. Some participants missed one or two of their classes for health-related problems or short vacations as this study took place over the summer months. Participant 11 experienced a mild heart attack prior to week 5 of data collection (unrelated to the study). He and his spouse, participant 10, missed both of their exercise classes in week 5 but returned in week 6 ready to resume where they left off. It is also important to note that participant 11 has multiple sclerosis (MS). Participant 7 took another participant to the hospital and was consequently absent in week 9. The hospitalised participant could not continue with the study and was reported as a dropout. Participant 12 had an appointment and missed an exercise class that was not on a data collection
day. Participant 13 went on vacation and missed a week of the exercise program. Lastly, participant 6 was in attendance in week 2 but did not complete the game as a result of technical difficulties.

4.3 Discussion

4.3.1 Berg Balance Scale

The BBS scores for the participants averaged over corresponding exercise programs yielded small improvements for program A and B. It has already been discussed in Chapter 3 that there is contention within the clinical community over how large an observed change in score must be to reveal a genuine change in function rather than a change due to measurement, and even so, the largest average improvement of the four programs of 2.67 points for program B is not considered significant by any source [42], [77], [78]. This point change is largely due to the 6-point improvement of participant 6 and similarly, the 1.5 point improvement of program C was largely due to the 4 point improvement of participant 11. This suggests that information is lost by collapsing the data into exercise programs and that it may be more useful to look at the data for each participant separately. Donoghue et al. suggests that the MDC is 4 points in a patient with an initial score within 45-56 [78]. The change in individual BBS score between assessments for participant 6 and participant 11 can both considered significant. The ceiling effect discussed in chapter 2, regarding people younger than 75 who do not have a specific condition that negatively affects balance, must also be taken into consideration for the other participants.

4.3.2 Game Performance

Two participants improved significantly in BBS scores, participant 6 and participant 11; however, only one of their improvements is reflected in the stepping game measures. Participant 6 improved significantly in all measures reported in this study. Her improvement in response time, reaction time and step time is in agreement with her change in BBS score, suggesting that the stepping game system can in fact be used to measure changes in balance longitudinally, rather than as a therapy, and that response time, reaction time and step time correlate with falls risk. Furthermore, this supports the finding that
exercise can greatly improve balance control and reduce falls risk in older adults [10]–[13], [45], [51], [80]–[83].

Participant 11 also improved in BBS score, however, he did not significantly improve in any measures from the stepping game system. It is important to consider that his lack of improvement in overall response time, reaction time and step time could be a reflection of his Multiple Sclerosis (MS) rather than of his balance. MS is an unpredictable inflammatory disorder of the brain and spinal cord which causes damage to the myelin sheaths that surrounds nerve fibres and in turn disrupts the flow of information between the brain and the body and slows neurological function [84]. It has been reported that the Choice Step Reaction Time (CSRT) test has excellent discriminant and predictive validity in relation to falls in people with MS [85]; however, a study by Barr et al. found that fatigue can significantly impact this result. In the study by Barr et al. participants with a diagnosis of MS completed CSRT tests before and after a six minute walk and response time was found to be significantly slower following the six minute walk [86]. Participants in program C completed the stepping game at different points in their workout each week so it is entirely possible that participant 11’s reaction time varied based on his level of fatigue before testing. This would result in an inconsistent week to week measure of reaction time. Participant 11 also suffered a minor heart attack in week 5 that also may have also had a negative effect on his response times.

Interesting trends have been identified in the components of response time for the remaining participants (excluding participants 6 and 11). It is more meaningful to look at the improvements in reaction time and step time rather than overall response time, to separate the planning phase from the execution phase. It was found that the four participants that significantly improved in reaction time over the course of the study also had the lowest baseline BBS and thus the highest falls risk. These participants had baseline BBS scores between 43 and 52 and two of the participants were from program A, which was only once a week and had very low baseline activity levels. A study by Rogers et al. concluded that a 3-week period of voluntary step training reduced the initiation time in older adults [52], thus this decrease in
reaction time using the stepping game could be a reflection of the game itself rather than the quantity or intensity of exercise. The other participants tended to have lower reaction times to begin with and thus the game could have not been as useful to them.

Conversely, the three participants whose step times significantly decreased had three of the highest BBS scores in the study and were thus at the least risk of falling. This could be explained by the ceiling effect for the BBS discussed by Downs. None of them could show improvement in BBS score because their scores were all perfect or near perfect (56/56, 55/56 and 56/56). These participants also tended to have lower baseline reaction times and be more active compared to the participants with lower BBS scores, agreeing with past studies that correlate falls risk with response time [87] and also suggesting that there is a certain level of activity one must do before increases in step time are apparent. This improvement in step time exhibited by the more active participants is a reflection that step time is affected solely by the exercise not the game itself. It is further supported by the finding in Chapter 3 that there was no difference between control and test group for step time. This may be a more sensitive measure of balance than BBS for older adults without a specific balance impairment.

Participant 12 also had a perfect BBS score but actually increased in step time over the course of the study. A possible explanation for this could be a gradual decline in motivation over the 8 weeks. If the participant was bored and did not see the value in the game, she may have lost focus, which could have resulted in a longer step execution time.

Participant 5 only exhibited an increase of BBS score of 2, which is not clinically significant, but she did experience a decrease in the stepping game measures of response time and reaction time. This introduces the question, how large of an increase in game performance reflects a clinically significant change in balance? Studies have been conducted to investigate the correlation of CSRT or voluntary execution steps test to falls risk and to evaluate the measures’ usefulness in predicting falls [37], [87], [88]; however, none of these studies examine how much of a change corresponds to a meaningful improvement in balance.
4.3.3 Learning Effect

There was concern with the pre-post matched control study in Chapter 3 that the presence of a learning effect when using the stepping game for the first time, or for the first time in a while, may negatively impact a participant’s performance. Upon visual inspection of the performance data, a learning effect did seem apparent for participants in program A between weeks 1 and week 2. The change in slope of regression lines provides more evidence of the presence of a learning effect for response time and step time. It does not appear there was a learning effect associated with reaction time. This suggests that in week 1 some participants took longer to understand how to use the technology. For example, when prompted to step, some participants attempted to tap their feet on WBB2 and did not understand at first that a weight transfer is necessary for the program to register a step. It is difficult to quantify how much of an effect this has on the overall game performance, however, if the pre-post study were to be repeated, it would be better to have a trial run of the stepping game before the first data collection and a refresher trial after an extended period of time without using the system.

4.3.4 Game Reception

The participants’ comments and survey responses suggest that the game interface in need of a redesign. Many were confused or distracted by the red circle that represented the centre of pressure (COP). The circle was intended to help participants know where they stepped in relation to the target, however maybe it would be less distracting if the COP circle were to only appear on WBB2 if the participant steps in the incorrect spot. It may also be useful to have more feedback messages (like the ‘Good Job!’ messages) telling the participant to step more to the left or step harder. With regard to the stepping foot indicators, it may be less confusing if the target were to be shaped like a foot and would then itself be the foot indicator. This would lessen the need of the participant to look at different areas of the screen before executing the step.
Most participant reported that they enjoyed using the stepping game; however, this study was only 10 weeks long and even so some participants were already commenting on their boredom. To maintain engagement for this audience longitudinally and be used as a therapeutic tool the game must be able to either increase more in difficulty or be one of many balance therapy games. The primary purpose of using gaming and virtual reality technologies for rehabilitation therapy is to deliver repetitive exercises in an engaging fashion, which cannot be achieved by playing the same simple game every week. The game could incorporate a time component, similar to the arcade game “Dance Dance Revolution” or a story line with better animation, such as walking across a rickety rope bridge. Audible feedback may also be beneficial for motivation. It is imperative that the participants feel as though they are improving and it may be better to include additional tools such as incorporating challenges with a saved high score that the participant can attempt to improve on each week.

4.3.5 Limitations

A big limitation for this study was sample size. We were unable to recruit enough people from each exercise program to compare and make statistical inferences between programs regarding the intensity and quantity of exercise. Furthermore, a number of the participants were not new to exercise and had been attending their exercise classes for extended periods of time, while some were fairly inactive to begin. The characteristics of the sample are also not entirely representative of the target population. The sample was predominantly female and comprised of adults without specific conditions that affect balance. The system measures cannot be directly correlated with falls risk as no one experienced a fall and could be classified as a faller.

This study was also limited by time. It is possible that more significant changes in balance and response time could have occurred had this study been conducted over the course of 6 months or a year; however, logistically this was not possible.
Chapter 5

Limitation and Conclusions

This chapter presents the limitations of the stepping game system as well as limitations encountered during clinical testing and analysis. This chapter also contains the conclusions discussed in the previous chapters that answer the research questions posed at the beginning of this thesis study.

5.1 Limitations

5.1.1 System

Throughout this study, limitations were identified within the stepping game system. The first limitation of the system is the difficulty determining the beginning of a step using a single COP value for each WBB. The WBBs are unable to identify the individual COPs for each foot and therefore the precise moment that one foot is lifted from the board cannot be accurately determined. Instead, the method used during data analysis is an approximation. Integration of a portable motion capture system, such as the Microsoft Kinect, or an accelerometer attached to the participant’s shoes, may improve the system’s ability to more accurately identify toe-off.

Another limitation that was identified was the occasional game lag. At some points during testing the game would significantly slow down, taking an extra few seconds between each cued step. Not only was this an annoyance but it also could have negatively impacted the response time as the timing prompts were less predictable and the participants were bored of waiting. Twice the system lagged so badly that the game had to be cut off after 8 levels so the participants didn’t miss their exercise class. This was at first thought to be a computer issue so a new computer was brought to testing; however, when the game continued to lag on the new computer it was discovered that the WBB were low on battery. The WBB itself does not have a low battery indicator, rather the battery level can only be monitored using the Wii console.
5.1.2 Clinical Testing

During clinical testing, this study was firstly limited by the allocated space. None of the four programs could offer a space outside of where the exercise was conducted, free of noise and distraction, for the stepping game set-up. In some programs, the allocated area was slightly distanced from the class and instructor and in others the game was completed within feet of the class. Additionally, the height and distance away of the television screen could not be standardized as the room size and space available varied for each exercise program.

The next limitation arose during recruitment. Some individuals did not want to participate because they didn't want to commit to 8 or 10 weeks. The data collection should perhaps not have taken place over the summer or rather this could reflect that the older adults that agreed to participate were already more committed to exercising. Other individuals stated they did not want to miss part of their exercise class to use the game. Another chose not to participate claiming that her balance was not good enough. Ideally, we would have been able to design and create an exercise program with the integrated stepping game component. This would have enabled us to recruit and test within our own program and have control over more variables such as space, exercise intensity and time of day. This was unfortunately not feasible within the scope of the project.

While playing the game it was observed that occasionally as the participants returned their feet from stepping, they would gradually move towards one side of WBB1. As a consequence, when the participant stepped, his or her non-stepping foot would be on the opposite side of the board, which would register as a wrong-footed step. This was more apparent if the participant was using a chair for support as they would creep towards the side of the WBB where the chair was standing. This did not happen often; however, it was discouraging for the user nonetheless.
5.2 Conclusions

It was found that a stricter protocol is necessary to examine whether using the stepping game as a balance rehabilitation tool is an effective therapy; however, the game needs to be updated, be made more challenging and have more variation in order to maintain participant engagement and motivation longitudinally. A learning effect was also identified in week 1 for some participants suggesting that trial runs with the system prior to data collection should be encouraged for future studies.

The game was successfully able to identify changes in performance measures (response time, reaction time and step time) for the participant whose change in BBS score indicated a clinical improvement in balance with 10 weeks of twice-weekly exercise. This is suggestive of the potential for using the stepping game as a tool for rehabilitation assessment. However, the game was unable to detect changes in performance measures for a participant with Multiple Sclerosis whose BBS score also significantly improved. This could be a reflection of the nature of the disease rather than the exercise intervention.

The game identified changes in reaction time for participants with lower baseline BBS scores whom did not exhibit changes in BBS score post intervention. The game also identified changes in step time for participants with higher baseline BBS scores whom did not exhibit changes in BBS score post intervention. More research with a larger sample size, conducted over a longer time period is necessary to draw firm conclusions regarding how these changes in game performance parameters correlate to balance and falls risk.
Chapter 6
Future Work

This chapter contains recommendations of future work regarding the design of the game and of further research into the efficacy of the system.

6.1 Game Redesign

For future use of the stepping game, some aspects of the user interface should be redesigned or updated, such as the red circle depicting the COP on the front WBB, the stepping foot indicators and the feedback messages. The overall graphics of the interface could also use an update. If the game is to be used in longitudinal trials, more variation in the game, a story line and/or a goal system must be added to maintain attention and engagement. The game must be made more difficult if it is to be used as a therapy tool for an older population without specific conditions that affect balance. A method to monitor battery level of the WBB without using the Wii console should also be investigated and integrated into the system. Furthermore, integration of the Microsoft Kinect or accelerometers may assist in more accurately determining the beginning of a step.

6.2 Research

A substantial amount of data was collected from the WBB over the course of this study and it may be beneficial in the future to investigate unexplored game performance parameters such as COP excursions during a step, accuracy of stepping location in comparison to the target location, or the difference in response, reaction or step time between dominant and non-dominant feet.

To further evaluate the efficacy of using the stepping game as a balance therapy to improve participant balance, a stricter protocol is necessary with a larger sample size. Practice trials to familiarize participants with the system are also recommended to prevent a learning effect associated with the new technology.
In the future, the system should be used over a longer period of time to further evaluate the accuracy of using the system for quantifying changes in balance and predicting falls risk. It should also be used in conjunction with a falls diary to enable direct correlations with falls risk. A future study should also aim examine how much of a change in response time, reaction time or step time corresponds to a meaningful improvement in balance.
References


[70] C. Toulotte, C. Tourse, and N. Olivier, “Wii Fit® training vs. Adapted Physical Activities: which


Appendix A
Berg Balance Scale

### Berg Balance Scale

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>SCORE (0-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting to standing</td>
<td></td>
</tr>
<tr>
<td>Standing unsupported</td>
<td></td>
</tr>
<tr>
<td>Sitting unsupported</td>
<td></td>
</tr>
<tr>
<td>Standing to sitting</td>
<td></td>
</tr>
<tr>
<td>Transfers</td>
<td></td>
</tr>
<tr>
<td>Standing with eyes closed</td>
<td></td>
</tr>
<tr>
<td>Standing with feet together</td>
<td></td>
</tr>
<tr>
<td>Reaching forward with outstretched arm</td>
<td></td>
</tr>
<tr>
<td>Retrieving object from floor</td>
<td></td>
</tr>
<tr>
<td>Turning to look behind</td>
<td></td>
</tr>
<tr>
<td>Turning 360 degrees</td>
<td></td>
</tr>
<tr>
<td>Placing alternate foot on stool</td>
<td></td>
</tr>
<tr>
<td>Standing with one foot in front</td>
<td></td>
</tr>
<tr>
<td>Standing on one foot</td>
<td></td>
</tr>
</tbody>
</table>

**Total** ________________________________________________

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

In most items, the subject is asked to maintain a given position for a specific time. Progressively more points are deducted if:
- the time or distance requirements are not met
- the subject’s performance warrants supervision
- the subject touches an external support or receives assistance from the examiner

Subject should understand that they must maintain their balance while attempting the tasks. The choices of which leg to stand on or how far to reach are left to the subject. Poor judgment will adversely influence the performance and the scoring.

Equipment required for testing is a stopwatch or watch with a second hand, and a ruler or other indicator of 2, 5, and 10 inches. Chairs used during testing should be a reasonable height. Either a step or a stool of average step height may be used for item # 12.
Berg Balance Scale

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

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

If a subject is able to stand 2 minutes unsupported, score full points for sitting unsupported. Proceed to item #4.

SITTING WITH BACK UNSUPPORTED BUT FEET SUPPORTED ON FLOOR OR ON A STOOL
INSTRUCTIONS: Please sit with arms folded for 2 minutes.
( ) 4 able to sit safely and securely for 2 minutes
( ) 3 able to sit 2 minutes under supervision
( ) 2 able to sit 30 seconds
( ) 1 able to sit 10 seconds
( ) 0 unable to sit without support 10 seconds

STANDING TO SITTING
INSTRUCTIONS: Please sit down.
( ) 4 sits safely with minimal use of hands
( ) 3 controls descent by using hands
( ) 2 uses back of legs against chair to control descent
( ) 1 sits independently but has uncontrolled descent
( ) 0 needs assist to sit

TRANSFERS
INSTRUCTIONS: Arrange chair(s) for pivot transfer. Ask subject to transfer one way toward a seat with armrests and one way toward a seat without armrests. You may use two chairs (one with and one without armrests) or a bed and a chair.
( ) 4 able to transfer safely with minor use of hands
( ) 3 able to transfer safely definite need of hands
( ) 2 able to transfer with verbal cueing and/or supervision
( ) 1 needs one person to assist
( ) 0 needs two people to assist or supervise to be safe

STANDING UNSUPPORTED WITH EYES CLOSED
INSTRUCTIONS: Please close your eyes and stand still for 10 seconds.
( ) 4 able to stand 10 seconds safely
( ) 3 able to stand 10 seconds with supervision
( ) 2 able to stand 3 seconds
( ) 1 unable to keep eyes closed 3 seconds but stays safely
( ) 0 needs help to keep from falling

STANDING UNSUPPORTED WITH FEET TOGETHER
INSTRUCTIONS: Place your feet together and stand without holding on.
( ) 4 able to place feet together independently and stand 1 minute safely
( ) 3 able to place feet together independently and stand 1 minute with supervision
( ) 2 able to place feet together independently but unable to hold for 30 seconds
( ) 1 needs help to attain position but able to stand 15 seconds feet together
( ) 0 needs help to attain position and unable to hold for 15 seconds
Berg Balance Scale continued...

REACHING FORWARD WITH OUTSTretched ARM WHILE STANDING
INSTRUCTIONS: Lift arm to 90 degrees. Stretch out your fingers and reach forward as far as you can. (Examiner places a ruler at the end of fingertips when arm is at 90 degrees. Fingers should not touch the ruler while reaching forward. The recorded measure is the distance forward that the fingers reach while the subject is in the most forward lean position. When possible, ask subject to use both arms when reaching to avoid rotation of the trunk.)
( ) 4  can reach forward confidently 25 cm (10 inches)
( ) 3  can reach forward 12 cm (5 inches)
( ) 2  can reach forward 5 cm (2 inches)
( ) 1  reaches forward but needs supervision
( ) 0  loses balance while trying/requires external support

PICK UP OBJECT FROM THE FLOOR FROM A STANDING POSITION
INSTRUCTIONS: Pick up the shoe/slipper, which is in front of your feet.
( ) 4  able to pick up slipper safely and easily
( ) 3  able to pick up slipper but needs supervision
( ) 2  unable to pick up but reaches 2-5 cm(1.2 inches) from slipper and keeps balance independently
( ) 1  unable to pick up and needs supervision while trying
( ) 0  unable to try/needs assist to keep from losing balance or falling

TURNING TO LOOK BEHIND OVER LEFT AND RIGHT SHOULDERS WHILE STANDING
INSTRUCTIONS: Turn to look directly behind you over toward the left shoulder. Repeat to the right. (Examiner may pick an object to look at directly behind the subject to encourage a better twist turn.)
( ) 4  looks behind from both sides and weight shifts well
( ) 3  looks behind one side only other side shows less weight shift
( ) 2  turns sideways only but maintains balance
( ) 1  needs supervision when turning
( ) 0  needs assist to keep from losing balance or falling

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

PLACE ALTERNATE FOOT ON STEP OR STOOL WHILE STANDING UNSUPPORTED
INSTRUCTIONS: Place each foot alternately on the step/stool. Continue until each foot has touched the step/stool four times.
( ) 4  able to stand independently and safely and complete 8 steps in 20 seconds
( ) 3  able to stand independently and complete 8 steps in > 20 seconds
( ) 2  able to complete 4 steps without aid with supervision
( ) 1  able to complete > 2 steps needs minimal assist
( ) 0  needs assistance to keep from falling/unable to try

STANDING UNSUPPORTED ONE FOOT IN FRONT
INSTRUCTIONS: (DEMONSTRATE TO SUBJECT) Place one foot directly in front of the other. If you feel that you cannot place your foot directly in front, try to step far enough ahead that the heel of your forward foot is ahead of the toes of the other foot. (To score 3 points, the length of the step should exceed the length of the other foot and the width of the stance should approximate the subject’s normal stride width.)
( ) 4  able to place foot tandem independently and hold 30 seconds
( ) 3  able to place foot ahead independently and hold 30 seconds
( ) 2  able to take small step independently and hold 30 seconds
( ) 1  needs help to step but can hold 15 seconds
( ) 0  loses balance while stepping or standing

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

( ) TOTAL SCORE (Maximum = 56)
Appendix B

Ethics Clearance

QUEEN’S UNIVERSITY HEALTH SCIENCES & AFFILIATED TEACHING HOSPITALS
RESEARCH ETHICS BOARD (HSREB)

HSREB Initial Ethics Clearance

February 14, 2017

Miss Alannah Lax-Vanek
Department of Mechanical and Materials Engineering
Queen’s University

ROME/TRAQ #: 6020251
Department Code: MECII-057-17
Study Title: Balance Rehabilitation using Nintendo Wii Balance Boards and a Stepping Game to Reduce the Risk of Falls Among Older Adults
Co-Investigators: Dr. C. Davies, Ms. R. Lopez
Review Type: Delegated
Date Ethics Clearance Issued: February 14, 2017
Ethics Clearance Expiry Date: February 14, 2018

Dear Miss Lax-Vanek,

The Queen's University Health Sciences & Affiliated Teaching Hospitals Research Ethics Board (HSREB) has reviewed the application and granted ethics clearance for the documents listed below. Ethics clearance is granted until the expiration date noted above.

- Protocol
- Berg Balance Scale
- Four Step Square Test (FSST)
- Clinical Test of Sensory Organization and Balance (CTSIB)
- Short Physical Performance Battery Protocol and Score Sheet (SPPB)
- Questionnaire – Participant Satisfaction – End of Study
- Borg Perceived Exertion Scale
- Health Information Form – v.2
- Omission of Scientific Peer Review Document
- Photo Release Form
- Information/Consent Form – Version 3

Documents Acknowledged:

- CORE Certificates – R. Lopez and A. Lax-Lanek
Amendments: No deviations from, or changes to the protocol should be initiated without prior written clearance of an appropriate amendment from the HSREB, except when necessary to eliminate immediate hazard(s) to study participants or when the change(s) involves only administrative or logistical aspects of the trial.

Renewals: Prior to the expiration of your ethics clearance you will be reminded to submit your renewal report through ROMEO. Any lapses in ethical clearance will be documented on the renewal form.

Completion/Termination: The HSREB must be notified of the completion or termination of this study through the completion of a renewal report in ROMEO.

Reporting of Serious Adverse Events: Any unexpected serious adverse event occurring locally must be reported within 2 working days or earlier if required by the study sponsor. All other serious adverse events must be reported within 15 days after becoming aware of the information.

Reporting of Complaints: Any complaints made by participants or persons acting on behalf of participants must be reported to the Research Ethics Board within 7 days of becoming aware of the complaint. Note: All documents supplied to participants must have the contact information for the Research Ethics Board. Investigators please note that if your trial is registered by the sponsor, you must take responsibility to ensure that the registration information is accurate and complete.

Yours sincerely,

[Signature]
Chair, Health Sciences Research Ethics Board

The HSREB operates in compliance with, and is constituted in accordance with, the requirements of the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations, Canadian General Standards Board, and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The HSREB is qualified through the CTO REB Qualification Program and is registered with the U.S. Department of Health and Human Services (DHHS) Office for Human Research Protection (OHRP). Federalwide Assurance Number: FWA#:00004184, IRB#:00001173

HSREB members involved in the research project do not participate in the review, discussion or decision.
Participant Informed Consent Form

Balance Rehabilitation using Nintendo Wii Balance Boards and a Stepping Game to Reduce the Risk of Falls Among Older Adults

STATEMENT: I have read and understood the letter of information for this study. The study has been explained to me, including all possible harms and discomforts and the possible benefits (if any), and all my questions have been satisfactorily answered.

I understand that my participation in this research study is completely voluntary. I will suffer no penalty and lose no benefits to which I am entitled if I decide not to participate, or if I change my mind after starting to participate.

I understand that I have a choice to not answer any specific questions and that I am free in the future to ask any questions about the study.

I understand that no information that would identify me will be released or printed.

I understand that release or publication of any photographic images of me are subject to my separate approval, and in no case will these images reveal my identity.

I understand that my personal records and information will be kept confidential, except where release of information is required by law.

I understand that I will receive a copy of the letter of information and this consent form for my own use. I also understand that all the information gathered in this study will be accessible to only those who will be collecting and analyzing the data for this study.

By signing this consent form, I am indicating that I agree to participate in this study.

Participant Name: ________________________________

Participant Signature: ________________________________

Date: ________________________________

Person obtaining consent: ________________________________
Appendix D
Health Information Form

Participant Code: __________

Health Information Form

Age: _______  Sex (circle): Male  Female  Other
Height: _______ ft/cm  Weight: _______ lbs

I have previously experienced a fall from which I have had to see a doctor (circle):  Y  N
If yes, how many times? ______________

I have previously experienced a stroke (circle):  Y  N

I have a neurological/ degenerative/ inner ear condition that affects my balance (circle):  Y  N
If yes, please specify ______________

I have undergone surgery for hip or knee replacements (circle):  Y  N
If yes, please specify ______________

I have corrected vision with prescription glasses and/or contact lenses (circle):  Y  N

I have a visual impairment (e.g. Glaucoma, Diabetic Retinopathy, Cataracts) (circle):  Y  N

I have been diagnosed with epilepsy (circle):  Y  N
Appendix E

Engagement Survey

**Questionnaire**

For the following statement please choose how much you agree or disagree by circling the numbers on the scale provided. (Choose only one number for each statement)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would like to use this game in my therapy/exercise program.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>The game was more engaging than typical exercise or therapies I have done before.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>This game was more strenuous than typical exercise or therapy I have done before.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I could see myself playing this game in the future.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>It was hard to understand the directions for playing the game.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I felt frustrated while playing the game.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I was motivated to keep playing the game.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I feel as though I have benefitted from playing this game</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I feel as though I could benefit in the future from playing this game</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Comments:__________________________________________________________

______________________________________________________________

______________________________________________________________

Balance Rehabilitation using Nintendo Wii Balance Boards and a Stepping Game to Reduce the Risk of Falls Among Older Adults