THE EFFECTS OF EXERGAMING TECHNOLOGY ON POSTURAL SWAY, USER-ACCEPTANCE AND FLOW EXPERIENCE IN PEOPLE WITH MULTIPLE SCLEROSIS

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A thesis submitted in partial fulfilment of the requirements

of Teesside University for the degree of

Doctor of Philosophy

April 2015

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Declaration

I declare that this thesis is entirely my own work and represents the results of my own research carried out at Teesside University. I declare that no material within this thesis has been used in any other submission for an academic award.

Acknowledgements

I would first like to thank my director of studies, Professor Denis Martin, for his guidance throughout this process. His knowledge and support has not only helped in the completion of this thesis, but has guided my career as an academic. I also owe great thanks to Professor Paul van Schaik, Professor John Dixon and Dr Alasdair MacSween for their continued support and specialist knowledge. Through your mentorship I have developed into not only a stronger academic, but also a stronger person.

I would also like to thank David Hodgson for his technical expertise, and the securing of laboratory time and equipment throughout the PhD. I also thank my fellow PhD students, Gillian Barry and Yvonne Khoo for their support and motivation during both the high and low times of completing this thesis.

I owe great thanks to the participants whom offered their time and energy to partake in these studies. Because of you my understanding of what it means to live with Multiple Sclerosis has developed far beyond the reading of a text book.

Lastly, I would like to thank my family for their relentless support and encouragement. To my mum and dad, Fiona and Tom, you are my example of hard work and sacrifice. To my sister, Rebecca, your demonstrations of leadership have been an example to me (your older brother). To my wife, Michelle, thank you for never giving up on me and even allowing me time to work on this thesis throughout the pregnancy and birth of our daughter, Harper. I owe you all more than words can express.

For my family who are no longer here, and who never complained about my absence due to work or being the ‘forever student’, your response to my continued apologies will stay with me forever – ‘…*you must live your life*’.

Abstract

Through this PhD thesis a systematic review of the literature was first performed to establish the quantity and quality of previous research specific to exergaming in people with Multiple Sclerosis (MS). This indicated the limited evidence on the effects of exergaming technology, the critiques of previous research, and the need for continued investigation in this field. The effects on balance performance were overall positive; however, the need for quantitative, reliable and accurate analyses was apparent. Additional gaps in the literature were the lack of research to establish the user-acceptance of exergaming technology, as well as the flow properties (engagement) of such technology.

The first study was an exploratory trial comparing the purpose designed IREX™ system and the game-based Nintendo Wii Fit™ in terms of postural sway, user-acceptance and flow experience in 33 healthy sedentary adults. Following a four-week intervention, there were no statistically significant post-intervention between-group differences for any of the recorded measures. However, there were statistically significant within-group improvements in both exergaming systems. These findings support the use of both the IREX™ and Nintendo Wii Fit™ as supplements to therapeutic exercise in terms of not only improving balance, but also user-acceptance and flow experience, which may assist in exercise uptake and concordance.

A second study, using the design of a definitive randomised controlled trial, was employed using two experimental conditions (Nintendo Wii Fit™, n = 20; and matched traditional balance training, n = 18) and a third control group (which received no intervention, n = 18) in 56 adults with a clinical diagnosis of MS. Both intervention groups received four-weeks of balance-orientated exercise. Postural sway and gait were measured, in addition to user-acceptance and flow experience. Secondary outcome measures were self-reported walking ability, and perceived activity and participation restrictions.

A between-group analysis found significantly higher post-intervention scores in both intervention groups for postural sway than in the control group, as well as significantly higher scores for flow experience in the Nintendo Wii Fit™ group than in traditional balance training group. There were significantly higher post-intervention scores in the traditional balance training group for self-reported walking ability than in the control group and, in both intervention groups for perceived activity and participation restriction than in the control group. Also, a within-group analysis found significant improvements over-time for both intervention groups for all the reported measures; with the exception of flow experience for the traditional balance training group.

Overall, while exergaming was not proven to be superior to traditional means of balance training, exergaming did encourage greater user-acceptance and flow experience, which may address a longstanding problem in exercise prescription – exercise concordance. These findings support the use of the Nintendo Wii Fit™ as an effective means of balance and gait training for people with MS, which is both accepted and intrinsically motivating to MS users.

Glossary of Terminology

Abbreviations

This glossary clarifies the meaning of terms that are used frequently throughout this thesis.

AE - Autotelic experience

AM - Action-awareness-merging

AP - Anterior-posterior

B - Standardized regression coefficient

BI - Behavioural intention

CB - Challenge-Skill Balance

CG - Clear goals

CoP - Centre of pressure

CT – Concentration-on-task

d - Cohen's *d;* effect size statistic

EE - Effort expectancy

FAP - Functional Ambulation Profile

FC - Facilitating conditions

FSS - Flow State Scale

FSST - Functional Reach Test and Four Square Test

LS - Loss of Self-consciousness

MBI – Magnitude Based Inferences

ML - Medial-lateral

Glossary of Terminology

MS – Multiple Sclerosis

MSWS-12 - 12-item Multiple Sclerosis Walking Scale

P - Significance level

PC - Paradox of control

PE - Performance expectancy

R - Multiple correlation coefficient

R^2 - Squared multiple correlation coefficient

SD - Standard deviation

SE - Self-Efficacy

SI - Social influences

TAM - Technology acceptance model

TPB - Theory of planned behaviour

TRA - Theory of reasoned action

TT - Transformation of time

UF - Unambiguous feedback

UTAUT - Unified Theory of Acceptance and Use of Technology

VCT - Video capture technology

WHO - World Health Organisation

WHODAS - World Health Organisation Disability Assessment Schedule

Glossary of Terminology

The information in the glossary of terminology refers to frequent use of the terms in the thesis.

Avatar - an icon or figure representing a particular person in a computer game.

Balance - term used to describe the dynamics of body posture, which occur in response to inertial forces acting on the body, in order to achieve a state of equilibrium between the body and the surrounding environment, and prevent the body from falling.

Base of support (BoS) - the area of the body that is in contact with the support surface (typically the ground).

Centre of gravity (CoG) - the vertical projection of CoM onto the ground.

Centre of mass (CoM) – ‘a point that is the centre of the total body mass, which is determined by finding the weighted average of the CoM of each body segment’ (Shumway Cook and Woollacott 2007).

Centre of pressure (CoP) - the point location of the vertical ground reaction force vector. It represents weighted averages of pressures distributed over the surface of the area when feet are in contact with the ground. To keep the CoM within the base of support requires the CoP to continuously move around the CoM (Shumway-Cook and Woollacott 2007).

Dance Dance Revolution (DDR) - an interactive dance based game created by Konami. DDR aims to get people moving on a dance mat to different music, using forward and backward and side to side arrows.

Exergame - a combination of exertion and video games play, aimed towards balance, strength, cardiovascular or flexibility training (Oh and Yang 2010).

Glossary of Terminology

Exergaming - playing exergames or any other video games to promote physical activity (Oh and Yang 2010). (Such as the Nintendo Wii™ or the XBOX Kinect™.)

Flow State or experience - a state in which an individual can become totally engaged within an activity.

Flow State Scale - a questionnaire designed to assess flow state.

Multiple Sclerosis (MS) - a chronic, typically progressive disease involving damage to the myelin sheaths of nerve cells in the brain and spinal cord, whose symptoms may include numbness, impairment of speech and of muscular coordination, blurred vision, and severe fatigue.

Nintendo Wii™ - Released in 2006, the Wii™ is a popular exergame that uses a hand held Wii™ remote to control the Avatar characters by pointing the remote at the screen.

Rehabilitation - an active process by which those affected by injury or disease achieve a full recovery or, if a full recovery is not possible, realise their optimal physical, mental and social potential and are integrated into their most appropriate environment (World Health Organisation 2001).

Postural control - involves controlling the body's position in space for enabling stability and orientation, and is active in all positions (supine, sitting and standing), and activities of daily living through keeping the centre of gravity within the base of support.

Postural sway - when reviewing the quality of postural control, this is the ability the body to shift in a forward and backward (anterior-posterior) and side-to-side (medial-lateral) motion, and termed postural sway; the magnitude or velocity of which is a measure of balance performance.

Glossary of Terminology

Unified Theory of Acceptance and Use of Technology (UTAUT) - a model designed to assess people's behavioural intention for future use; referred to as either technology acceptance or user-acceptance within this thesis.

User-intention – related to technology acceptance, and considered a measure of intention to use the technology.

Virtual reality-based interventions - defined as any kind of computer game or virtual reality technique where the participant could interact with virtual objects through physical movement (Sandlund *et al* 2009).

Wii-habilitation - the use of the Nintendo Wii™ as a method of physical therapy used within a rehabilitation setting for a variety of clinical conditions.

Table of Contents

List of Figures

List of Figures

List of Figures

List of Tables

List of Tables

CHAPTER 1: INTRODUCTION

1.1 Overview

This chapter will provide an introduction to the clinical population of interest, the concepts of exergaming technology and the thesis structure.

1.2 Multiple Sclerosis and Exergaming Technology

Multiple Sclerosis (MS) is a disease of the central nervous system. In Europe and North America MS is the most common cause of neurological disability in young adults (Sloka *et al* 2005). MS symptoms are varied, but can include depression, fatigue, muscle weakness, spasticity, balance and gait problems; all of which lead to reduced physical activity and increased risk of falls (Matsuda *et al* 2012). Physiotherapy management of people with MS aims to reduce impairment and improve functional ability (Stokes 2004) largely through increasing physical activity, participation and independence levels (Langdon and Thompson 1999). This includes therapeutic exercise prescription, which aims to balance exercise demands with energy conservation; as increasing physical activity can lead to exacerbations of MS related fatigue (Gallien *et al* 2007).

Despite this delicate balance between exercise and fatigue, UK guidelines specific to MS management include aerobic exercise for symptoms of fatigue, weakness, muscular pain and cardio-respiratory fitness (National Institute for Clinical Excellence [NICE] 2014). Due to the nature of the MS condition, physical intensity of exercise and/or therapy must be monitored closely to avoid exacerbation of the MS symptoms and fatigue (Gallien *et al* 2007; Sutherland and Andersen 2001).

Through a wish to avoid such exacerbations, a tendency for prolonged inactivity can be viewed as a means of energy conservation. However, this can increase the likelihood of said secondary health concerns, and lead to increased anxiety and/or physical de-conditioning; in a vicious circle. In fact, those with MS have been shown to undertake in significantly less physical activity than non-MS sedentary individuals (Ng and Kent-Braun 1997). Research has shown that for those with MS, prolonged inactivity leads to not only muscle weakness, but also reduced exercise tolerance and increase of fatigability (Lenman *et al* 1989), compromising balance performance and further reducing the likelihood of exercise uptake – an extension of the vicious circle.

For people with MS the ability and willingness to increase, and sustain increases in physical activity can be limited by impaired balance, which is considered one of the most disabling symptoms and estimated to affect approximately 75% of people with MS (Martyn 2005). Furthermore, impaired walking ability is estimated to affect upwards of 85% of people with MS (Scheinberg *et al* 1980). Exercise through traditional means may not only be too physically demanding, but also exacerbate MS symptoms. Therefore, for people with MS there is a need for a mode of exercise that is not only achievable and effective, but also accepted and engaging to encourage concordance.

These requirements, and more, may potentially be fulfilled through what is called – *Virtual Rehabilitation*, *Augmented Exercise,* or *Exergaming*. These terms, while computer-based, do have different meanings. Virtual rehabilitation involves a level of immersion, either through the projections of the user’s image or virtual objects, allowing a means of interaction. The term *exergaming*, which will primarily be used in this thesis, is defined as exercise using computer-gaming, normally commercially available, technology. Exergaming technology can have similar or identical elements in terms of virtual image projection; however, it is more *game*-orientated. While these terms are often used interchangeably, the subtle difference is acknowledged.

Games technology has evolved from a recreational activity, to one that is being used in the healthcare sector through the facilitation of therapeutic exercise. There is evidence emerging that highlights the positive effects of this technology in training gait (Rose *et al* 1996), reaching movements (Piron *et al* 2001), gait rehabilitation and postural sway (Thornton *et al* 2005). Initial studies were often conducted using purpose-designed virtual rehabilitation systems, aimed to address a specific physical limitation, for example, limited shoulder range of motion (Brosnan 2009). The commercial computer game industry soon realised the potential of this technology for more general use and developed the Nintendo Wii™ and Wii Fit™. This created a new option in the administration of virtual rehabilitation, and a new area of research based on commercially available technologies adapted for clinical use.

Despite the rapid growth of technology, there is a large gap in the current literature concerning the effects of this technology in healthy and clinical groups, as well as the differences between purpose-designed and commercially available systems. The current thesis reports the findings of an investigation into the physiological and psychological effects of exergaming technology when employed as a balance-oriented exercise tool through one exploratory trial (study 1) and one definitive RCT (study 2). The first study compared a purpose-designed virtual rehabilitation system to a commercially-available exergaming system in a healthy population. The recruitment of healthy participants allowed for the generation of new knowledge, from individuals who were free from clinical pathologies, medications or additional therapies, and therefore any effects were likely to be the result of the intervention. Furthermore, this allowed for an opportunity to gain insight of methodological designs and study protocols in aid of future research with the clinical group of interest.

A second study investigated the effects of exergaming technology compared to matched traditional balance training in those diagnosed with MS, a condition known to affect balance performance, gait and muscular control. This body of work is unique, as to date no study has explored the effects of exergaming in terms of postural sway, gait, and psychological indicators of user-acceptance and flow experience in people with MS. This study is also the first to employ the research design of a three-arm definitive randomised controlled trial, with a comparatively large sample size, and provides needed evidence as to the effects of exergaming technology. Moreover, this research has added to the evidence base having been peer reviewed and published in the BMC Sports Science, Medicine and Rehabilitation journal (Appendix 1, page 315).

1.3 Thesis Structure

This thesis has been divided into 11 chapters, describing two separate but related studies undertaken with healthy sedentary adults, and people with MS.

Chapter 1 the current chapter provides an introduction to the thesis and its structure.

Chapter 2 introduces the background of multiple sclerosis and exergaming technology.

Chapter 3 introduces the results of a systematic literature review.

Chapter 4 reviews the physical and psychological measurement techniques employed through both studies.

Chapter 5 discusses the methodology for the effects of exergaming on postural sway, user-acceptance, and flow state.

Chapter 6 presents the results of the effects of exergaming on postural sway, user-acceptance, and flow state in healthy-sedentary users.

Chapter 7 discusses these results.

Chapter 8 presents the methodology for the effects of exergaming on postural sway, user-acceptance, flow state and health in MS users.

Chapter 9 presents the results of the effects of exergaming on postural sway, user-acceptance, flow state and health.

Chapter 10 discusses these results.

Chapter 11 presents a general discussion and conclusions.

CHAPTER 2: BACKGROUND OF MULTIPLE SCLEROSIS AND EXERGAMING TECHNOLOGY.

2.1 Introduction

The aim of this chapter is to provide an overview of the following: multiple sclerosis (MS) and its epidemiology, common treatment methods, and the effects of exercise on balance performance and gait. It also introduces the physiological processes of postural sway in healthy individuals, as well as those with the neurological condition MS. It will provide an introduction to the conception of *exergaming* technology in general, and highlight the applications of this technology in healthy and clinical settings.

The psychological aspects of exercise prescription, specific to the concepts of user-acceptance and flow experience (a psychological state of engagement), are reviewed and related to exergaming technology. The chosen outcome measures are reported, and related to the specific measures of human functioning based on the concepts of the International Classification of Functioning, Disability and Health (ICF) in the assessment of impairments and disabilities. This chapter concludes with the aims of the thesis.

2.2 Multiple sclerosis

The term MS was first documented by Jean-Martin Charcot in 1868 when Charcot came to realise that the variety of MS symptoms – thought to be individual conditions – were actually a distinct single pathology (Martyn 2005). Understandably, at that time, the condition of MS was very poorly understood;

however, today it is known that MS is an inflammatory demyelinating condition of the central nervous system (CNS) and categorised as an autoimmune disease. The CNS consists of the brain and the spinal cord, and is responsible for the interpretation of incoming sensory information, and the initiation of an appropriate motor response, through nerve fibres (Marieb and Hoehn 2007). Nerve fibres consist of an axon and are covered with a protein-lipid sheath called *myelin*. These myelin sheaths are formed in segments of equal size, leaving an area of exposed axon known as the node of Ranvier (Stokes 2004). The main function of the myelin sheath is to increase the speed at which impulses are transmitted along the nerve fibre, as well as protect and insulate the nerve.

In MS the immune system attacks its own CNS, focused towards the destruction of the cells responsible for myelin production, the oligodendrocytes, and specifically, the myelin sheaths (Noseworthy *et al* 2000). As a result of the continued destruction of this myelin layer, lesions start to form on the axons which over time can develop into hardened *scleroses*, acting to inhibit the normal conduction of nerve impulses (Herndon 2000). Due to this process, MS is often referred to as a ‘demyelinating disease’ where lesions can occur in any location of the CNS. Therefore, people with MS can experience a wide variety of symptoms compared to other neurological conditions (Ebers 1998), which can include: depression, fatigue, muscle weakness, spasticity, balance and gait problems - all of which lead to reduced physical activity and increased risk of falls (Matsuda *et al* 2012).

Current physical interventions, such as physical therapy, are aimed to reduce impairment and improve functional ability (Stokes 2004), largely through increasing physical activity, participation and independence levels (Langdon and Thompson 1999). Such therapeutic exercise prescription must balance exercise demands with energy conservation; as increases in physical activity can exacerbate symptoms of fatigue (Gallien *et al* 2007). However, for people with MS, the ability and willingness to increase physical activity, and sustain said increases, can also be limited by impaired postural sway; considered one of the most disabling symptoms, and estimated to affect approximately 75% of people with MS (Martyn 2005). For perspective, based on this estimated percentage prevalence, 1,875,000 people will report balance disturbances. Furthermore, akin to balance, impaired walking ability is estimated to affect upwards of 85% of people with MS (Scheinberg *et al* 1980).

The general characteristics of MS are acute episodes of neurological disturbances that are separated by periods of remission. However, some attacks do not follow complete recovery, increasing the level of neurological disability (Stokes 2004). There are four accepted types of MS: benign, relapse remitting, secondary progressive and primary progressive (Figure 1). Benign is classified as one or two relapses that are separated by considerable time, where either full recovery or mild disability remains. Relapse remitting is defined by relapses of symptoms which appear to fade, or remit either partially or completely. At disease onset this is the most common type of MS, consisting of approximately 80% of MS diagnoses (Compston and Coles 2008). This remission phase does not occur in approximately 10% to 15% of people diagnosed with MS. However, it is estimated that 65% of those diagnosed with relapse remitting MS will eventually develop secondary progressive after 15 years (Multiple Sclerosis Society 2014). Primary

Progressive MS, as the name would suggest, is defined as the continued progression of the condition, in which symptoms gradually worsen over time. Secondary progressive MS follows a similar pattern to that of primary MS; however, deteriorations occur without evidence of exacerbations.

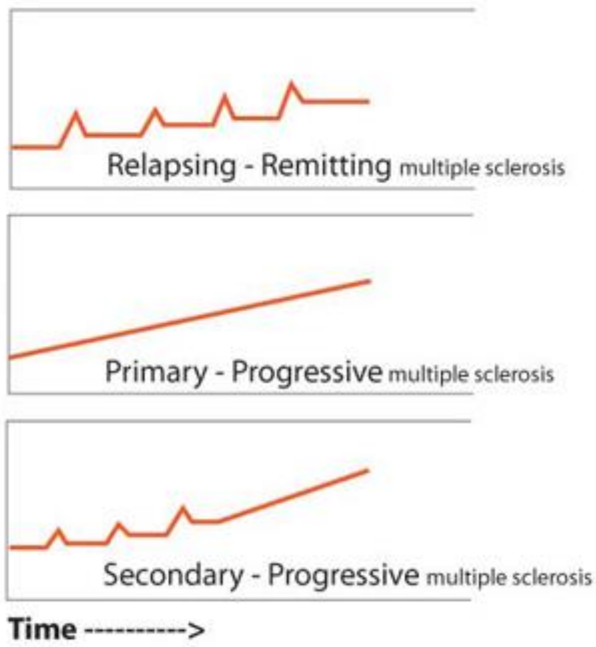

Figure 1 Graphical representation of the different types of Multiple Sclerosis compared to the level of disability over time

2.2.1 Epidemiology (patterns, causes, and effects)

In Europe and North America the prevalence of MS is estimated to be 1:800 people, with an annual incidence of 2–10:100,000, making MS the most common cause of neurological disability in young adults (Sloka *et al* 2005). The National MS Society states that 200 people are diagnosed weekly in America alone (Kennedy *et al* 2009). At present, a definitive aetiology of MS remains unclear. However, research suggests that it may be due to a combination of genetic, infectious, autoimmune and/or environmental factors (White and Dressendorfer

2004). As illustrated in Figure 2, environmental studies suggest that the incidence of MS is much less common in people living near the equator, in addition to an increase in prevalence when moving both north and south of the equator (Alonso and Hernán 2008), with a higher occurrence in northern Europe (World Health Organisation [WHO] 2008).

MS is twice as common among women as it is in men, with 10% to 15% of people diagnosed also having a relative with MS (Stokes 2004). MS is considered a lifelong condition, with an average age of diagnosis of 30 years (Milo and Kahana 2010). While not classified as a fatal illness, it is reported to reduce life expectancy by approximately 10 years (Brønnum-Hansen *et al* 2004). However, over the course of the disease, death is attributed to MS in two-thirds of cases, and related to secondary factors such as increased risks of infection from the skin, chest and bladder (Compston and Coles 2008).

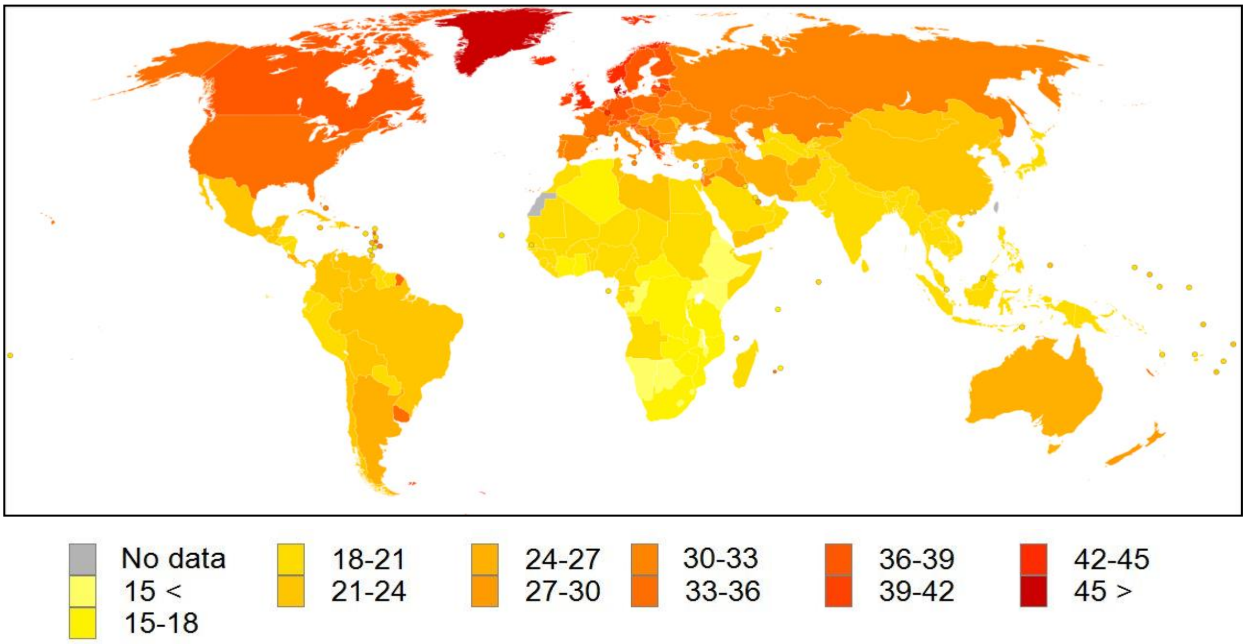

Figure 2 Age-standardised disability-adjusted life year rates of MS by country (per 100,000 inhabitants). Source: WHO (2008). The global burden of disease: 2004 update, Geneva. Created by Lokal_Profil (2010), WikiCommins.com

2.2.2 Treatment Types

Disease-Modifying Medications

There are a number of medications to treat the disease and symptoms of MS. Disease-modify agents such as Avonex®, Rebif® and Novantrone are just a few used in an attempt to manage or reduce the rate of disease progression. As with a majority of medications, there are side effects that may influence the quality of life of the individual. These may cause liver toxicity, decreased white blood cell and platelet counts, and worsening of thyroid disease, seizures, or depression. Currently, medications that offer a clinically meaningful effect on the level of physical ability and the effects of the condition do not exist. Therefore, the importance of physical treatments through rehabilitation and exercise are paramount in optimising physical function of those with MS.

Physiotherapy Rehabilitation Theory

With regards to the treatment of MS, or to rephrase, the treatment of disabilities seen in those with MS, physiotherapy is aimed towards reducing the level of impairment in an attempt to improve functional ability, but is unlikely to modify the progression of the disease (Stokes 2004). Therefore, one of the primary aims of rehabilitation is to increase activity, participation and independence levels (Langdon and Thompson 1999). In general, physiotherapy treatment methods are based on a singular, or combination of two underlying principles: the Bobath concept and the motor re-learning programme. In summary, the Bobath concept is focused more towards manual manipulation or facilitation of normal movement (Lennon and Ashburn 2000). The motor re-learning programme differs in that it is focused on strength training and skill acquisition of movements that are critical to everyday activity, meaning the therapist adopts a less manual role (Stokes 2004). At present there is little evidence to support the superiority of any one approach (Ashburn *et al* 1993), or any specific exercise intervention/programme (Rietberg *et al* 2004) in the treatment of MS. Despite the method chosen by the therapist, there is a strong emphasis on exercise as a means of maintaining both function and skill. Moreover, Strokes (2004) defines the primary aims of physiotherapy as: 1) maintain and increase range of movement; 2) encourage postural control; 3) prevent contractures; and 4) maintain and encourage weight-bearing.

In meeting these aims, exercise prescription is based on a balance between activity and energy conservation; a consequence of extremes of physical activity may result in exacerbations of symptoms and fatigue (Gallien *et al* 2007; Sutherland and Andersen 2001). Yet, there is one key requirement for all means of treatment discussed so far, and that is the need for a physiotherapist. Physiotherapists play a key role in the prescription of exercise for people with MS; however, considering that the life expectancy for people with MS is only marginally reduced, the variations of exercises that are not only effective, but accepted and engaging are currently limited.

2.2.3 Exercise and Multiple Sclerosis

Physical activity and exercise are essential in maintaining/improving health through lowering the risk of cardiovascular disease, diabetes, obesity, cancer and musculoskeletal conditions (Fletcher *et al* 1996), irrespective of neurological condition. Moreover, research specific to MS suggests that chronic disuse of muscles leads to exacerbations of fatigability, de-conditioning, and muscle weakness (Lenman *et al* 1989). Furthermore, people with MS participate in significantly less physical activity than non-MS sedentary individuals (Ng and Kent-Braun 1997). This highlights the secondary health considerations that have the potential to further reduce physical health and quality of life in people with MS.

According to the National Institute for Clinical Excellence (NICE) guidelines for MS management, aerobic exercise is beneficial in the treatment of symptoms of fatigue, weakness, reduced cardio-respiratory fitness, and muscular pain (NICE 2014). White and Dressendorfer (2004) make recommendations for exercise in people with MS using modifications of the American College of Sports Medicine (ACSM) (ACSM 2000) guidelines, suggesting cardio-respiratory training 2-3 sessions per week, at an intensity of either 64-75% of peak heart rate, 50-70% peak VO_2, or a rating of perceived exertion of 11-14. However, impaired balance and gait, estimated to affect approximately 75% and 85% of people with MS, respectively (Martyn 2005; Scheinberg *et al* 1980), can notably hamper the opportunity for meaningful exercise.

2.2.4 Balance and Gait in Multiple Sclerosis

Postural balance is defined as the ability to maintain the centre of gravity over the base of support (Bronstein *et al* 2004). *Static balance* is the ability to maintain a base of support with minimal movement, and *dynamic balance* the ability to perform a task while maintaining a stable position (Winter 1990). *Postural control* is defined as the act of maintaining or restoring a state of balance during any posture or activity (Pollock *et al* 2000). The consequences of reduced or poor balance are clear. Balance-related problems/deficiencies which result in an injurious fall cost the NHS more than £2 billion per year (Tian *et al* 2013). To the individual these problems can lead to a loss of confidence, dependence and an inability to maintain a safe environment (Askham *et al* 1991).

The ability to maintain postural control is a major requirement in common motor skills (Burke-Doe *et al* 2008). There are several factors that may place people with MS at high risk of injury due to falls. The symptoms of MS are many and varied between individuals, but often include impairments to balance and/or gait, vision, and cognitive functions. All of which are known risk factors for injurious falls among disabled and non-disabled older adults (Peterson *et al* 2008). As a consequence of the neurological condition, people with MS may present with disorders of strength (Ponichtera *et al* 1992), sensation, co-ordination, postural control and gait (Ng and Kent-Braun 1997). This, in turn, may lead to a varied and progressive degree of limitation in functioning in daily life (Rietberg *et al* 2004) and an increased prevalence of injury through falls (Cattaneo *et al* 2002).

The risk of fracture from falls in people with MS is 2- to 3.4-times higher than in non-MS healthy individuals (Shabas and Weinreb 2000). More recently, an MS survey conducted in 2011 reported that of the 265 respondents, 58.2% reported one or more falls in the previous six months, of which 58.5% resulted in injury (Matsuda *et al* 2011). Furthermore, this same study reported a significant association between falls and decreased balance (Matsuda *et al* 2011). Therefore, the need to maintain or increase postural control in people with MS is paramount in not only reducing the opportunity for injurious falls, but to positively affect general health. Clinicians and exercise specialists often prescribe balance specific exercises in an attempt to treat the effects of the condition through maintaining or increasing the opportunity for meaningful physical activity.

2.3 Physiological process of postural control

Postural control is a complex motor skill, based on the interaction of multiple sensorimotor processes (Horak and Macpherson 1996) and the result of two main factors: postural orientation and postural equilibrium (Horak 2006). These are defined as the active task of body alignment and tone with respect to external and internal stimuli (e.g. gravity, supporting surfaces, visual feedback and internal references), and the coordination of sensorimotor strategies during both self-initiated and external triggers of postural sway, respectively (Horak 2006).

It is well supported that postural sway is the result of a combination of visual, somatosensory, and vestibular systems; however, little is known as to how these systems are combined to produce postural control in changing environments (Peterka 2002). The somatosensory system provides information regarding the external environment through physical touch (i.e. contact with the skin), in additional to feedback about our physical position in space (e.g. proprioception). Proprioceptors, located in the skeletal muscle, tendons, joints, ligaments and connective tissue, provide constant feedback of body position through the CNS (Marieb and Hoehn 2007). Lastly, the vestibular system provides linear and angular information orientation (Winter 1995). However, importantly, in people with MS such sensory systems are often compromised.

2.4 Balance, gait performance and health

An increased occurrence of falls is not considered a normal part of the ageing process (Anson and Jeka 2010). However, it is accepted that as a result of the effects of ageing, specifically in later years, individuals will suffer from mild and multiple impairments, such as sensory loss, orthopaedic constraints and diminished cognitive function (Horak, 2006).

Understanding how the CNS allows for the regulation of postural control during activities such as quiet standing, walking and environment interaction is important. Through this we are able to better understand and identify the specific systems that contribute to postural control. Individuals who are limited in terms of their visual, somatosensory, and/or vestibular systems may find postural control more difficult in certain situations. In addition to the natural ageing process, this may be due to physical injury, or compromise of the CNS (i.e. a neurological condition). It is important to highlight, however, that impairment to one of these systems will not necessarily translate into spontaneous balance disturbances. For example, a loss of sensory stimulation, to the feet for example, may be compensated by greater reliance of visual input; which is estimated to account for approximately 80% of sensory perception in the organisation of locomotion (Friedrich *et al* 2008). However, if visual information were also lost balance disturbances would become more apparent.

As mentioned, the weighting of such sensory systems remains unclear. The results of a linear sensory integration model in healthy adults during stance on a firm surface estimated that postural control is based on a 10% dependence on visual feedback, 20% on vestibular information, and 70% on somatosensory information (Peterka, 2002). However, when the environment is changed to an unstable one, such as through ambulation, there is an alteration in sensory weighting towards greater dependency on vestibular and visual systems (Peterka 2002). This ability to re-weight sensory information of the CNS allows for the body to compensate, to change, and therefore limit the disturbance of balance control (Winter 1995). However, the ability for re-weighting sensory information is often compromised for people with MS as the CNS is either permanently damaged, or under constant assault. This limits the use of such vital sensory information in the organisation of balance and gait.

2.5 Pain and Function

Pain may be defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage (Merskey and Bogduk 1994). Pain may also be described by its duration since onset. Acute pain is a short-term pain of less than 12-weeks (British Pain Society 2010). Chronic pain is considered to be a continuous, long-term pain of more than 12-weeks, or of longer duration than expected based on the healing process (British Pain Society 2010). The definition of pain specific to MS is more complex due to the nature of the disease, where episodes of relapse and remission are common. Acute pain may be associated with active inflammatory processes and related to bouts of relapse. Chronic pain, however, may result from the MS pathology, in addition to the many associated symptoms; which suggests pain can be central and/or peripheral in nature.

Acute and chronic pain is recognised as affecting quality of life, activities of daily living and functional ability in people with MS (Svendsen *et al* 2003). Estimations of the prevalence of pain are varied throughout the literature. Clifford and Trotter (1984), through a review of 317 MS patients, reported a pain prevalence of 29%. Solaro *et al* (2004), through in a multicentre evaluation of 1,672 MS patients, reported that 43% were found to be experiencing pain. Warnell (1991), through a descriptive study of 364 patients, reported that 64% had experienced pain at some time during their disease, with 40% of those experiencing pain since diagnosis. Reporting the highest incidence of MS related pain, Stenager *et al* (1995) observed 49 MS patients with acute and chronic pain from the time of assessment, documenting a 35% prevalence of pain, which increased to 78% over a five year period. However, this high prevalence is not consistent with studies of larger sample sizes.

2.6 The International Classification of Functioning, Disability and Health

There are many national and international guidelines for the assessment and measurement of impairments specific to those with MS. Consequently, there are no clear recommendations regarding which instrument to use in the assessment of symptoms, limiting factors in participation, health service delivery, and policy and management (Khan and Pallant 2007). The International Classification of Functioning, Disability and Health – or more commonly known as ICF - is a framework developed by the WHO (WHO 2001). The ICF provides a globally-agreed-upon framework for the classification and recording of problems faced by patients, and therefore, a tailored therapeutic intervention which is not solely focused on physical disability. The ICF is based on a bio-psychosocial model in which functioning and disability are considered as multi-dimensional units that comprise of three levels: Body Function and Structures, Activities and Participation, and Personal and Environmental factors (Figure 3). In 2011, both a comprehensive and brief core set of categories, based on the ICF, were developed specific to MS (Coenen *et al* 2011).

As this PhD thesis is based on the administration of a physical intervention, and the chosen outcomes designed to quantify physical and psychological impairments specific to MS, the individual outcome measures (introduced in Chapter 4, page 103) are linked to these core sets in acknowledgment of the ICF categories. These categories have been informed by the original ICF guideline (WHO 2002; Figure 3) and the core set specific to MS (Coenen *et al* 2011; Figure 4). In brief, these include the assessment of balance and gait (ICF domain: Body Function and Structure), and the aspects of functioning using the World Health Organisation Disability Assessment Schedule 2.0 (WHODAS 2.0) questionnaire (introduced in section 4.8 WHODAS 2.0, page 131). This questionnaire is based on the very concepts of the ICF (ICF domain: Activity and Participation) (Figure 4).

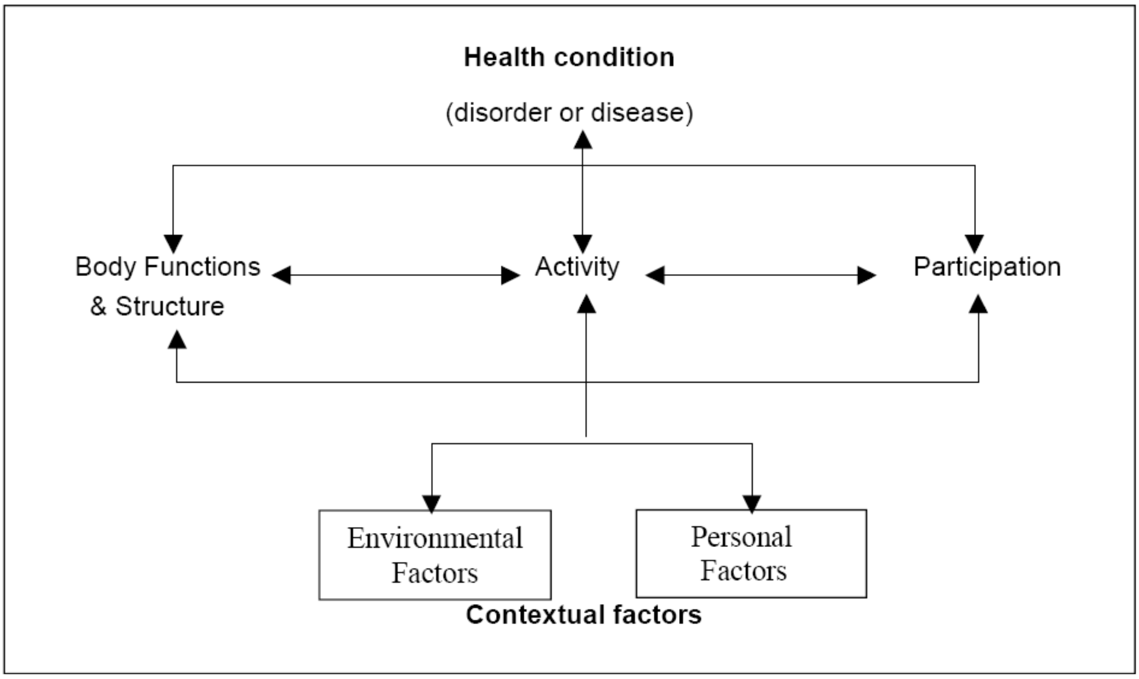

Figure 3 The bio-psychosocial perspective of the International Classification of Function Disability and Health (ICF) (WHO 2002)

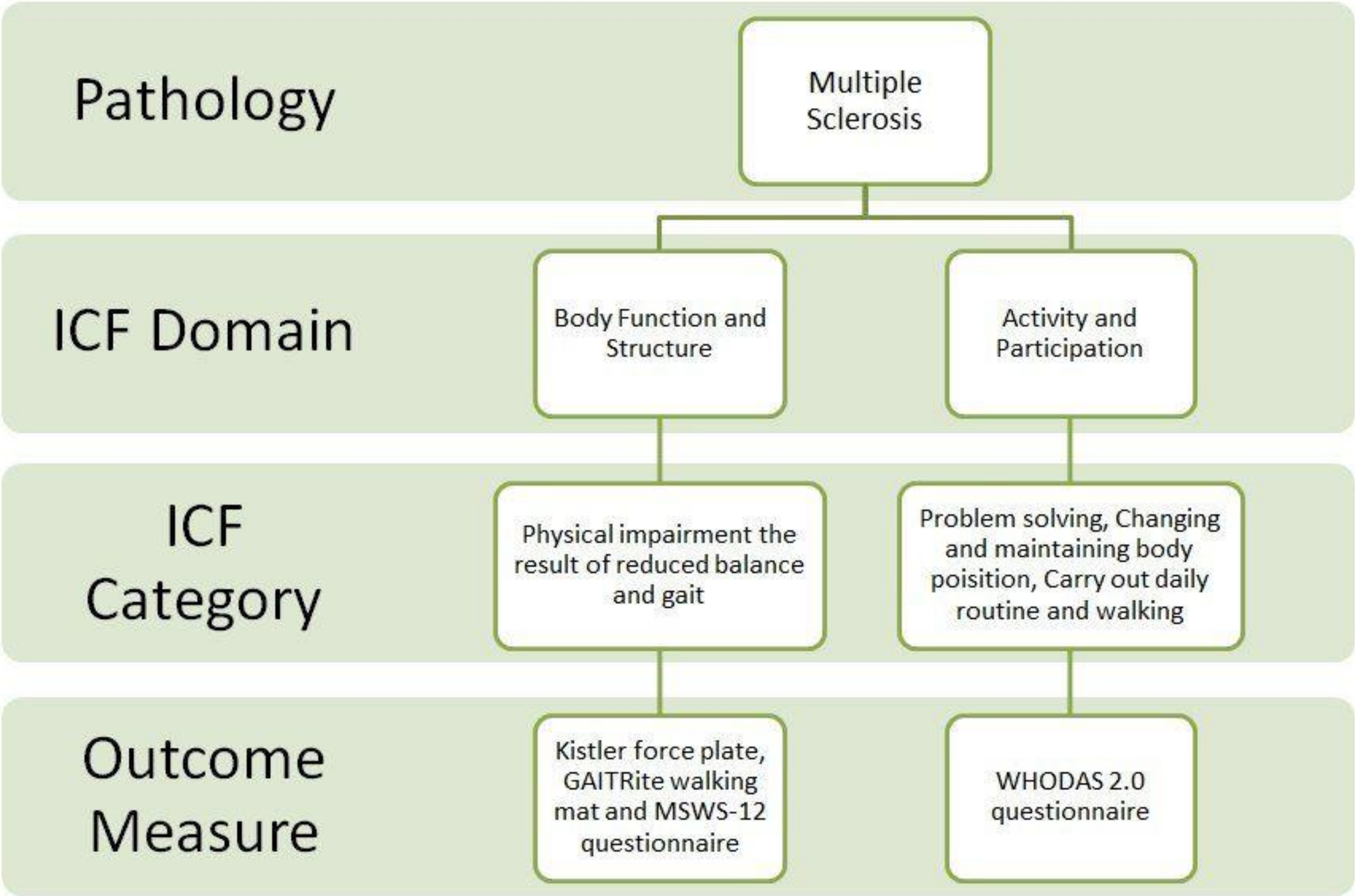

Figure 4 International Classification of Functioning domains with corresponding outcome measures, specific to MS

2.7 Virtual Reality and Exergaming Technology

Virtual reality can be defined as the use of interactive simulations created with computer hardware and software, to present users with opportunities to engage in environments that appear to be and feel similar to real world objects and events (Weiss *et al* 2004). A ‘virtual reality-based intervention’ can be administered through any kind of computer game or virtual reality where the participant can interact with virtual objects through physical movement (Sandlund *et al* 2009). Exergaming is where this same technology is used, but with a specific focus on balance, strength, cardiovascular or flexibility training (Oh and Yang 2010), based on the concepts of gameplay.

There are many types of virtual reality and exergaming systems; these can generally be categorised as either purpose-designed for clinical use or as commercially available systems, i.e., off-the-shelf consoles. Those which are purpose-designed are intended to facilitate specific therapeutic goals, and more recently, can be combined with force-platforms or walking machines. Such systems require a computer programmer who can create the custom virtual-interactive environment – such as the Interactive Rehabilitation and Exercise system (IREX™) and the Gait Real-time Analysis Interactive Lab system (GRAIL™). These systems would fall within the category of virtual reality technology due to their immersive properties. Although commercially available systems - such as the Microsoft Kinect™ and the Nintendo Wii Fit™ and Wii Fit™ balance board - are not customisable to the same degree, they are easily obtainable physical-gaming systems. Conversely, these systems would fall within the category of exergaming.

An important contrast between these systems is cost. A purpose-made system can range between thousands or into the millions of pounds (IREX™ and GRAIL™, respectively); the Microsoft Kinect™ and Nintendo Wii Fit™ are priced, as of 2013, at £277 and £230, respectively. Moreover, commercial systems often have the benefit of being easy-to-use and transportable, unlike the much larger purpose-made systems; however, do lack the ability to provide clinical information specific to function which can be obtained from more expensive stationary systems.

2.7.1 Virtual Reality Applications

The term ‘virtual reality’ was used in 1989 by Jaron Lanier. However, it is common for Ivan Sutherland to be cited as the first author who wrote about an ‘illusion generated by a computer’ in 1965 (Riva 1999). A ‘virtual environment’ may be defined as a computer-generated simulation of a real world setting, which may be experienced by a user (Holden 2005). Schultheis and Rizzo (2001, p298) describe virtual reality as:

> “… *an advanced form of human-computer interface that allows the user to interact with and become immersed in a computer generated environment*”.

This second definition provides a greater interpretation of the potential of virtual reality through emphasising characteristics such as *interaction*, *immersion,* and *computer-generated environment*.

The applications of virtual reality have extended from and into a number of fields to facilitate the training of aviation and military, industrial machinery operation, as well as medical techniques (Holden, 2005). Also, such technological developments are becoming more recognised in the clinical community as a potential treatment modality (Rand *et al* 2004), despite its original design as a means of entertainment and gaming (Weiss *et al* 2004). Virtual reality has been used in the clinical assessment of patients in areas of cogitative function (Grealy *et al* 1999), meal preparation (Zhang *et al* 2003), and spatial memory (Wilson *et al* 1996). It has also been used clinically for the training of reaching movements (Piron *et al* 2001), gait (Rose *et al* 1996), hand strength and range of movement (Jack *et al* 2001) and postural control (Thornton *et al* 2005).

2.7.2 Video Capture Technology vs Head Mounted Displays

Virtual reality environments, including those provided through exergaming technology, may be experienced through two technological forms: static video capture technology (VCT) or dynamic head mounted display (HMD). In 2002, VCT was estimated to account for 50% of the virtual-based health care applications in medicine, and HMD much less, approximately <10% (Riva 2002). In brief, VCT systems normally use a stationary camera and appropriate software to track the movement of a subject in a single plane, without the need for joint specific markers (Weiss *et al* 2004). An advantage of this method is that the patient can see themselves in real time, without the need to wear special apparatus (Rand *et al* 2004). This encourages the use of active movement and reduces the likelihood of experiencing side-effects (Weiss *et al* 2003; Rand *et al* 2004). VCT have the additional advantage of collaborative viewing and offer an attractive financial option through having multiple uses other than just being a dedicated virtual reality display (Sharples *et al* 2008). HMD, based on a combination of audio and visual stimuli, have been used with neurological conditions such as Parkinson's disease to offer visual cues that overlap with the real world to aid in movement initiation and gait (Jack *et al* 2001).

As mentioned, like many interventions this technology is not without the potential for side-effects. There are a number of studies which report the presence of what has been termed '*cyber-sickness*'. Cyber-sickness presents with three major symptoms: nausea, oculomotor discomfort, and disorientation (Kennedy *et al* 1993). More specifically, symptoms can include eyestrain, blurred vision, headaches, vertigo, imbalance, nausea and vomiting, and are believed to occur as a result of conflicts between visual, vestibular and proprioceptive information (Sato *et al* 2012). Through a comparison of different virtual reality displays, Sharples *et al* (2008) reported that 60-70% of participants experienced an increase in cybersickness after virtual reality exposure; with HMD accounting for significantly greater symptoms (e.g. nausea, oculomotor and disorientation) than in desktop and reality theatre-based technologies. However, more recently, Laver *et al* (2012) conducted a Cochrane Review of 19 trials to evaluate the effects of virtual reality and exergaming technology in stroke, and reported that the effects of cyber-sickness symptoms were in fact rare. Despite that HMD systems were not used in this thesis, as this technology is now becoming more common with the release of the oculus rift virtual reality HMD, this section provides a comparison of both types of systems and an indication of a possible shift in technology.

2.7.3 Purpose-designed Interactive Technology – Virtual Rehabilitation

There a number of non-commercial virtual reality systems available. Some of which have been designed solely for the clinical setting, such as the IREX™. Using this technology, a clinician may tailor the virtual environment to stimulate a detailed movement response in an attempt to address a specific limitation or requirement of treatment (Schultheis and Rizzo, 2001), within a controlled, objective and safe environment (Weiss *et al* 2004). This specific system is based on VCT where the participant's image is captured using a green screen and displayed on a computer monitor or television (Figure 5). This allows the participant to see and interact with a superimposed virtual environment. This technology is an evolution of systems often used in television weather reports where the presenter is displayed in front of a weather map (Sveistrup *et al* 2003) (Figure 6).

Figure 5 The IREX™ system gameplay – Soccer (GestureTek™ Health 2008)

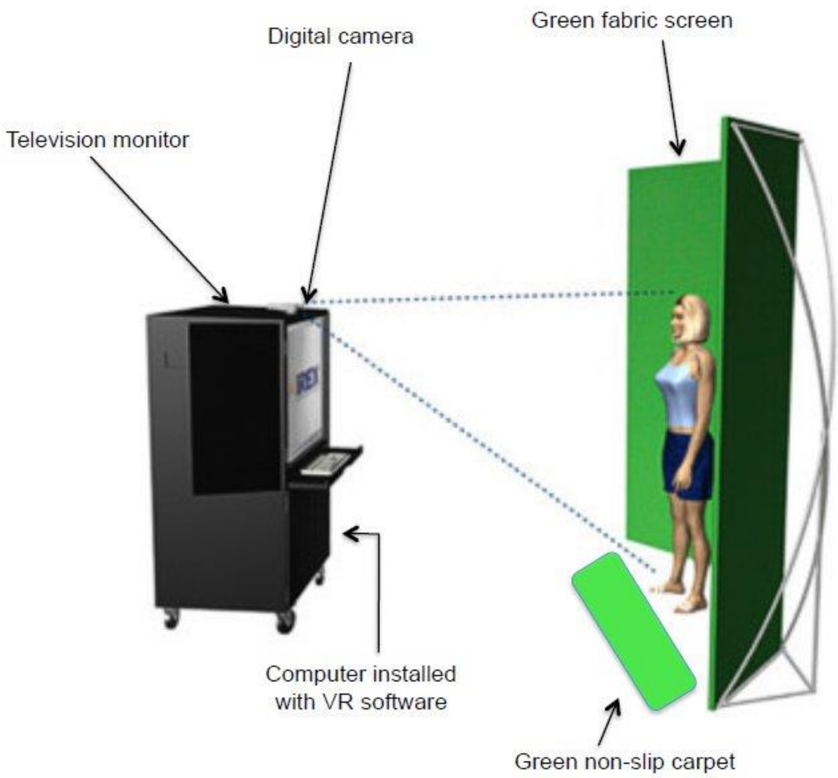

Figure 6 The IREX™ system – Setup (GestureTek™ Health 2008)

2.7.4 Commercial Interactive Gaming Technology – Exergaming

Over the years there have been a number of different commercially-available exergaming systems. Arguably, the first systems were designed more towards gameplay interaction as opposed to encouraging meaningful physical activity. However, despite this, therapists and researchers noted the potential of this technology as a physical intervention, which may have led manufactures towards this more therapeutic technology development through exergaming. These systems are briefly introduced, and in order of their release to the commercial market.

2.7.5 Sony PlayStation™ 2 EyeToy™

One of the first forms of commercially-available exergaming systems was the Sony PlayStation™ 2 EyeToy™ (Figure 7), released in 2003. This system incorporated a small video camera, comparable to a web camera, which allowed the video image of a user to interact with the gaming environment and observed on a standard television screen (Figure 8). Gameplay, undertaken in either standing or sitting, was limited to upper body movement. Despite this limitation, the EyeToy™ was one of the most common technology platforms to play exergames (Plow *et al* (2011), followed by the Nintendo Wii™.

Figure 7 Sony Playstation 2 EyeToy™

Figure 8 Playstation 2 EyeToy™ gameplay, as seen from the perspective of the user. (Picture by Dave Pape; released under a Creative Commons License.)

2.7.6 Nintendo Wii™ And Wii Fit™

In December 2006, and based on a greater emphasis of combining exercise with interactive gaming, Nintendo™ released their newest console, the Nintendo Wii™ (Figure 9). While other manufactures were competing to produce the most powerful and technologically advanced games console, Nintendo™ focused on the development of a new means of interactive gameplay. This system is based on the use of a wireless controller that incorporates three accelerometers and an infra-red sensor to record and interact with a selected game (Newbon 2006). To highlight the popularity of the Nintendo Wii™, based on current figures, 101.06 million units have been sold worldwide (Nintendo™ 2014a).

In December 2007, Nintendo™ released an additional games package called the 'Wii Fit™', offering a new form of gameplay interaction via body movement, or more accurately, weight distribution (Figure 10). This game currently ranks as the 5th best-selling video game for the Wii™, selling 22.67 million units (Nintendo™ 2014b). A comparable Wii™ game (Wii™ Sports), based on the same principles of gameplay interaction, is ranked as the 2nd besting selling game of all time, selling 82.54 million units (Nintendo™ 2014b). This establishes the popularity of this means of technology, taking into consideration it was only released in 2006. This popularity may be due to the differences in gameplay, where unlike the Sony EyeToy™, the user interacts with the gaming environment via movement of the game's controller and the Wii Fit™ balance board, and is represented by a preselected virtual character or *avatar* (Figure 11).

Figure 9 Nintendo Wii Fit™ Console

Figure 10 Nintendo Wii Fit™ Balance Board

Figure 11 Nintendo Wii™ gameplay with use of the Wii Fit™ Balance Board

2.7.7 Microsoft Xbox™ 360 – Kinect™

More recently, VCT systems, much like the PlayStation EyeToy™, are becoming increasingly popular through the development of greater immersive and interactive technologies like the Microsoft Xbox *Kinect*™ (Figure 12). The Kinect™, released in November 2010, is an add-on peripheral for the Xbox™ console. Using comparable technology to that of the IREX™ system, the Kinect™ enables the user to control and interact with the game without the need of a controller; but instead with physical video-captured movement and spoken commands (Figure 13).

Figure 12 Microsoft Xbox 360™ - Kinect™

A note to the reader: as this gaming system was released towards to the middle of the PhD thesis there was limited research as to its potential application as a therapeutic intervention. However, having undertaken an assessment of the available games and gameplay, it was noted that while entertaining and enjoyable, the Kinect™ games were extremely energetic and physically demanding. Therefore, at this time, it was felt that this technology would not be appropriate as a therapeutic intervention for people with MS.

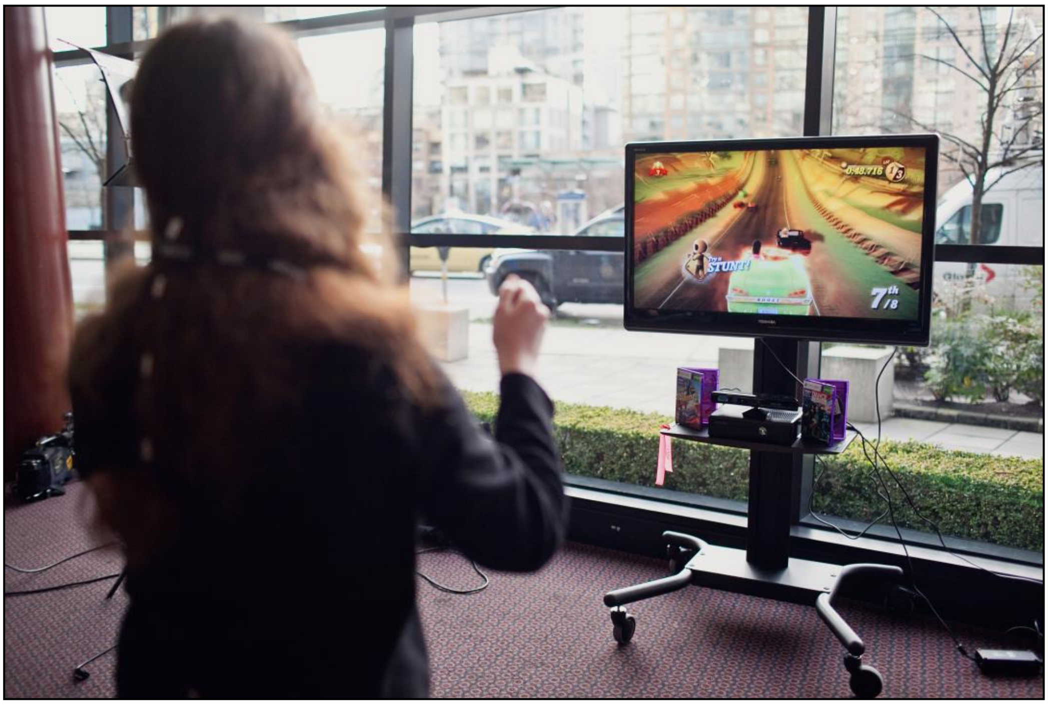

Figure 13 Xbox™ and Kinect™ gameplay (Picture by Vancouver Film School [http://www.flickr.com/photos/vancouverfilmschool/]; released under a Creative Commons License.)

2.7.8 Why Exergaming?

In the developed world the trend of both sedentary work and leisure has led to increased risks of associated chronic disease conditions, such as obesity (Salmon *et al* 2006), type II diabetes (Venables and Jeukendrup 2009), cardiovascular disease and some cancers (Friedenreich and Orenstein 2002; Nelson *et al* 2007). This sedentary lifestyle is, in part, a result of modern conveniences. Even though the beneficial effects of exercise are well documented, the perennial problem of motivation and concordance endures. Unfortunately, those with neurological conditions, such as MS, are just as susceptible to such negative health concerns, if not more vulnerable due to MS-related postural and gait instability, and MS-related fatigue and pain – serving to limit the potential for meaningful physical activity.

The sedentary activity of watching television has long been a common pastime; which only increased with the development of traditional games consoles and video games (Siegel *et al* 2009). Moreover, such gameplay is no longer restricted to children or adolescents. The British Broadcasting Corporation (BBC) surveyed almost 3,500 people across the UK, showing that 59% of 6 to 65 year olds in the UK were 'gamers', with the total number estimated to be 26.5 million (BBC 2005). Also, the average age of a UK gamer was 28 years, and just over half (51%) aged between 36 to 50 years, highlighting the opportunity and acceptance for gameplay in older groups (BBC 2005). In terms of the potential for traditional gaming to positively affect health, research would suggest that gaming using a hand-held controller or keyboard is comparable to the activity of watching a DVD (Straker and Abbott 2007). However, as stated, traditional gaming possesses some potentially important properties: enjoyment, acceptance and engagement – which, combined with a physical intervention, has the potential to benefit health through exergaming technology.

Exergaming is a new and promising option whereby a negative contributory factor may be transformed into part of the solution. As stated, the Wii Fit™ and balance board currently ranks as the 5th best-selling video game for Nintendo™ and the 'Wii Sports™' game the 2nd bestselling game of all time. As such, there is clear approval of activity-orientated gameplay. Specifically, such technologies have been used to assist in physical rehabilitation (Rose *et al* 1996; Piron *et al* 2001; Thornton *et al* 2005), psychological functioning (Wilson *et al* 1996; Grealy *et al* 1999) and therapeutic exercise prescription (Weiss *et al* 2004; Deutsch *et al* 2008; Brosnan 2009).

Exergaming technology has been shown to lead to greater exercise enjoyment, as well as enhanced exercise adherence (Warburton *et al* 2005; Rhodes *et al* 2008). Moreover, such interactive gameplay has also demonstrated immersive properties; to the point of reducing perceptions and intensity of effort during physical exercise (De Bourdeaudhuij *et al* 2002; Yamashita *et al* 2006). From the view of exercise prescription in sedentary or neurological groups, there are clear advantages to such immersive properties acting to distract from the intensity of exercise, whereby encouraging higher levels of intensity. However, despite the popularity of these systems, investigatory research remains limited. This is perhaps, in part, due to the nature of such continually developing technology and in keeping with 'Moore's Law', which states that the number of transistors in a dense integrated circuit doubles approximately every two years, allowing for the exponential growth in computing technology (Schaller 1997). Also, in the current literature there are mixed findings as to the effects of exergaming technology due to employment of limited research designs, small sample sizes, and the combination of multiple simultaneous interventions.

2.8 An Introduction To Exergaming Literature In General

The section will provide a general introduction and brief review of the current non-MS research undertaken in exergaming in general. Also, the psychometric outcome measures of user-acceptance and flow state will also be introduced, in addition to their applications in previous exergaming research. This will be followed by a systematic literature review specific to MS exergaming research (Chapter 3, page 81).

2.8.1 Exergaming literature in healthy participants

Having first conducted a literature search for non-MS exergaming studies (methods comparable to those of Chapter 3), several papers were found. In summary, a majority of these were conducted through single case studies and pilot trials, using small sample sizes, and reported with mixed results. Again, given the scarcity of published research, irrespective of clinical group, confirms this as a relatively new field within the health care setting.

A number of exergaming studies have recruited participants recovering from stroke. Flynn *et al* (2007), reporting the results from a single post-stroke participant, investigated the feasibility of using the Sony PlayStation™ 2 games console. Exergaming was completed over 20 one-hour sessions using the PlayStation 2 EyeToy™, encouraging target-based motion, dynamic balance and motor planning. The authors reported that although the subject was at a high functional level post-stroke, minor beneficial changes were found in clinical assessments of BBS, Dynamic gait index and TUG. The authors concluded exergaming to be a feasible adjunct to standard therapy. In review of this paper it must be highlighted that as a singular case study it is unclear as to the true cause of said improvements - these may have occurred as a result of the exergaming intervention, or simply a result of increased physical activity.

Brosnan (2009) investigated the Nintendo Wii™ with two acute stroke subjects. Comparisons were made with a single chronic stroke subject. The two intervention subjects completed four, 45-minute sessions using the Wii™, playing games such as tennis, bowling, and boxing. Brosnan (2009) reported finding increases in shoulder range of movement, as well as questionnaire measures (Fulg-Meyer Upper Extremity Sensory and Motor assessment, and the Stroke Impact Scale). A critique specific to this paper is its title, which refers to the subject's as acute stroke patients; however, the participants were reported as being of two and five years post-stroke. This would place the participants' within the category of at least intermediate, if not chronic stages of recovery; as defined by Stokes (2004). Therefore, the authors may have missed an unidentified strength of their findings – as a majority of post-stroke improvements occur during the early stages of recovery (Skilbeck *et al* 1983), typically during the first 3-6 months. Consequently, any improvements identified 2-5 years post-stroke are likely to be the results of the noted interventions, or, an increase in physical activity in general.

Kim *et al* (2009) investigated 24 chronic stroke patients, all undertaking conventional physical therapy four sessions per week, for four-weeks, each lasting 40 minutes. Half of these also completed 30 minutes of exergaming each session using the IREX™ system. Significant improvements were reported in BBS and dynamic balance angles using a force platform, in both anterior-posterior [AP] and medial-lateral [ML] sway, than in the control group. Significant improvements were also observed in gait velocity, modified motor assessment scale scores, cadence, step time, step length and stride length. Again, this study highlights the possibilities of exergaming with stroke patients when combined with conventional therapy. And, with such a design, the aforementioned critique should be considered; are these improvements the result of the exergaming intervention, or the additional 30 minutes of exercise therapy per session, equating to a supplementary 2 hours per week (8 hours total).

Research has also been undertaken in other clinical groups. In a case study of a 13 year old with Cerebral Palsy, Deutsch *et al* (2008) studied the effects of the Wii™ combined with traditional therapy, and reported improvements in postural control, CoP sway, weight distribution, in addition to overall mobility. The results of this study are promising, indicating positive improvement in the selected outcomes. With regards to the functional outcomes, client mobility also improved (through walking distance progressions from 4.6m to 45.7m, to 76.2m at follow-up). This demonstrates a considerable improvement to mobility. However, it was noted that additional treatments were undertaken, which included both physiotherapy and occupational therapy.

The studies by Flynn *et al* (2007), Brosnan (2009) and Deutsch *et al* (2008) present a number of limitations. The recruitment of small sample sizes impedes the generalisation of its results, and therefore, the external validity of the findings. In both the Brosnan (2009) and Deutsch *et al* (2008) research, it was also noted that the participants underwent additional therapies and studies, which may be considered as a confounding variable. Also, Flynn *et al* (2007) does not comment on any attempt to control external variables. However, despite these limitations, these papers provide justification for further research.

There have also been a number of studies in healthy or non-clinical participants. The most recent of these was by Bateni (2012) who recruited 17 older participants (aged 53 to 91 years), allocated to either physical therapy, Wii Fit™ training, or combination of the two, three times a week, over a four-week period. Bateni (2012) did not employ inferential statistics; however, did report finding no changes to balance (assessed through the BBS) in any participants. Conversely, Nitz *et al* (2010) studied ten women (aged 30 to 58 years) undertaking 30 minutes of Wii Fit™ balance training, twice-weekly, for ten-weeks, and reported significant improvements in balance and lower limb muscle strength. Brumels *et al* (2008) conducted a comparison of efficacy between traditional and exergaming balance programs in 28 participants (aged 18 to 24 years), allocated to either a control (no intervention), traditional therapy, or one of two exergaming groups (Nintendo Wii™

and Dance Dance Revolution™[1] [DDR] platform). Sessions were held three times a week, over a four-week period and lasted around 15 minutes per session. Significant improvements were found in both groups for postural sway (force plate), and only the traditional therapy group for the Star Excursion Balance Test (SEBT). Moreover, significance was approached or met through a questionnaire of perceived difficulty and enjoyment, finding that exergaming was less strenuous (DDR™, $p = 0.07$, Wii Fit™, $p = 0.01$) and more enjoyable (DDR™, $p = 0.01$, Wii Fit™, $p = 0.01$) than traditional therapy.

This paper highlights the benefits of an exergaming balance intervention over that of traditional exercises in terms of effectiveness, enjoyment and perceived difficulty. This indicates the potential for exergaming to increase exercise concordance; as previous research has shown concordance to any exercise programme is a common problem, as many people lack sufficient motivation to complete a given programme (Campbell *et al* 2001; Middleton 2004).

To present a balanced and fair reflection of the current literature, and to highlight the potential negative aspects of this technology, there are a number of papers that comment on the occurrence of injury with use of the Nintendo Wii™. Harrison (2009), through a letter to the Emergency Medicine Journal, comments on an increase in patients presenting with acute muscular unilateral shoulder pain. It is reported that this acute pain occurred after playing the Nintendo Wii™ using Wii controllers. It was observed by Dr Harrison that the Wii Sports™ games, specifically Wii Boxing, seem to be quite strenuous, even to generally fit

[1] The DDR is played by applying body weight in a sequence as it is displayed on the TV via the games console, offering both visual and audio feedback.

populations. Injuries related to the Wii™ through overuse or repetitive movements have coined the terms "*Wii-shoulder*", "*Wii-itis*" and "*Nintendinitis*" (Sparks *et al* 2009; Rubin 2010). Interestingly, these injuries occurred in cases where the Wii Fit™ is used independently, as a home-based intervention, and without the support of a healthcare professional. This may suggest that such technology, when applied as a therapeutic intervention, should be supervised in order to prevent such injuries – acting as justification for the continued role of the physiotherapist.

The above research offers insight into the different applications of exergaming technology with a variety of participant types. These primarily highlight the positive effects in terms of physical ability, with improvements documented in gait speed, gait endurance, and balance. A majority of the existing literature is based on different neurological groups such as acute and chronic stroke, cerebral palsy, as well as those without clinical pathology. However, to date, there are no systematic reviews of exergaming technology for people with MS; which would provide context to the current research, and the findings of this PhD thesis.

2.9.2 Exergaming literature and user-acceptance

The need to understand why and how individuals come to use and accept information technology has been long established (Venkatesh *et al* 2007). To determine technology acceptance, and therefore user-acceptance and behavioural intention to use the technology, Venkatesh *et al* (2003) conducted a review and empirical comparison of eight competing acceptance models: the Theory of

Reasoned Action (Ajzen and Fishbein 1980), Technology Acceptance Model (Davis 1989), Motivational Model (Davis *et al* 1992), Theory of Planned Behaviour (Ajzen 1991), combined Technology Acceptance Model and Theory Of Planned Behaviour (Taylor and Todd 1995), Model of PC Utilization (Thompson *et al* 1991), Innovation Diffusion Theory (Moore and Benbasat 1991), and the Social Cognitive Theory (Bandura 1986; Compeau and Higgins 1995), to develop the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire for informative technology systems (Venkatesh *et al* 2003).

According to the UTAUT model, four constructs play a role as direct predictors of behavioural intention to use the technology under study. As indicated in Figure 14, the UTAUT model also includes four variables (gender, age, experience with the technology and voluntariness of use) that moderate the relationship between the four main constructs and the behavioural intention and use behaviour (Venkatesh *et al* 2003). These four UTAUT main predictors of technology acceptance are defined as:

1. Performance Expectancy - the degree to which the user feels that the system will improve performance

2. Effort Expectancy - degree of ease associated with the use of the system

3. Social Influence - the degree to which those important to the user believe they should use the system

4. Facilitating Conditions - the degree to which the user believes that there is support for using that system

(Venkatesh *et al* 2003)

The first construct, *Performance Expectancy*, is considered the strongest predictor of intention; however, its effects on intention are likely to be moderated by the demographic factors of gender and age, such that the effect will be stronger for younger men (Venkatesh *et al* 2003). Both *Effort Expectancy* and *Social Influence* are positively related to behaviour intention to use technologies; however, conversely, this effect is stronger for older women with limited experience (Venkatesh *et al* 2003). Lastly, *Facilitating Conditions* has been shown to have a positive effect on actual use, which is stronger for older workers with high experience (Venkatesh *et al* 2003). A search of the literature revealed that there are currently no published investigations to explore user-acceptance using the UTAUT model and exergaming technology in people with MS. As such, the measurement of user-acceptance in people with MS will provide new information specific to exergaming in general (healthy sedentarty users) and from a clinical group (those with MS).

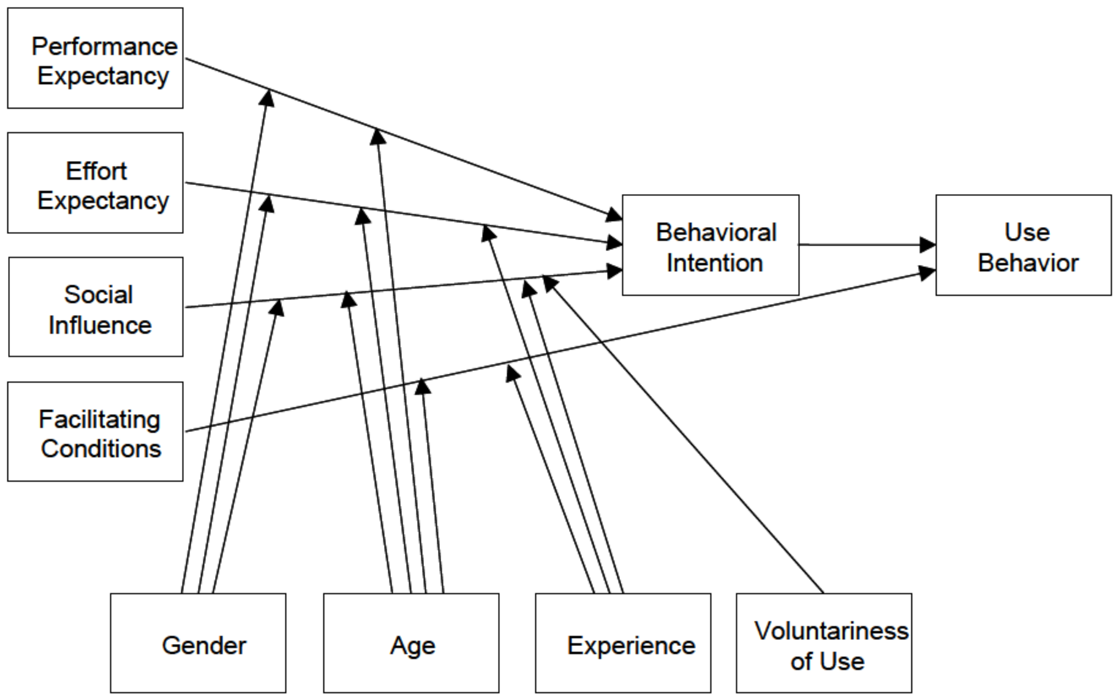

Figure 14 Unified Theory of Acceptance and Use of Technology model

2.9.3 Exergaming literature and flow experience

Csikszentmihalyi, the founder of flow theory, refers to flow state as pure engagement in an activity, with high enjoyment (Csikszentmihalyi 1990), and has investigated the occurrence of flow through a range of activities including rock climbing, dancing, chess, music and sporting activities (Weinberg and Gould 2011). The concept of flow is related to a person's overall wellbeing, considered a state of optimal human experience (Seligman 2011), and linked to high levels of performance (Jackson and Eklund 2002). As greater attained flow is an intrinsically motivating optimal state, people will want to repeat the activity (Csikszentmihalyi 1990), which should improve exercise concordance. Flow can be experienced through any number of activities. Even daily activities such as browsing the Internet or watching television can encourage flow experience;

however, flow is often related to more interactive activities as opposed to more passive ones (Csikszentmihalyi 1990).

The principles of flow have been adapted by Jackson and Marsh to produce the Flow State Scale (FSS) questionnaire for use in sport and physical activity (Jackson and Marsh 1996). The FSS is based on nine subscales:

1. *Autotelic Experience* - the activity is intrinsically rewarding and undertaken for its own sake

2. *Clear Goals* - clear idea of what needs to be accomplished

3. *Challenge-Skill Balance* - balance between the challenge of the activity and personal skills

4. *Concentration on the Task at Hand* - complete focused on the task

5. *Paradox of Control* - a belief of being in complete control of own actions, without any conscious or exertive effort at the task

6. *Unambiguous Feedback* - clear and immediate feedback

7. *Action-Awareness Merging* - involvement in the task; actions become automatic

8. *Transformation of Time* - altered perception of time; either speeding up or down

9. *Loss of Self-Consciousness* - no concerns with appearance; focused only the activity

Flow plays an important role in understanding engagement and positive experiences in the context of gaming (Nah *et al* 2014) as commercial games are often designed using these very concepts (Chen 2007; Nacke and Lindley 2008). Modern computer games are able to provide constant feedback and clear goals, in addition to automatically adapting to the skill of the player, creating a balance between the challenge of the task and the ability of the player (Bressler and Bodzin 2013; Fang *et al* 2013). When a gamer attains flow they experience a high level of engagement and involvement, in addition to an altered perception of time. In the attainment of flow state, comparable to expressions of feeling ‘in the zone’, it is important that there is a balance between the skill/ability of the individual and the challenge/difficulty of the situation. If a task is too easy the individual will lose interest and become board; if it is too hard the individual will present with increased stress and anxiety (Figure 15).

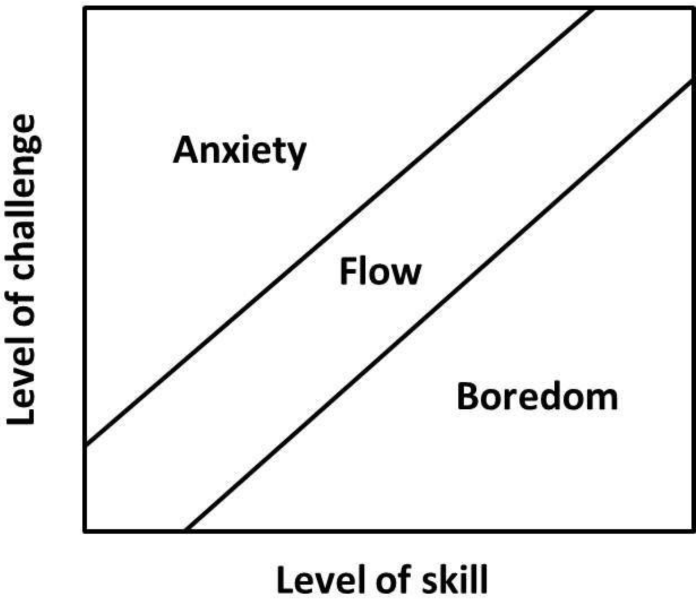

Figure 15 Flow state in work and gaming (Csiksentmihalyi 1975)

Much of the previous research into flow experience has been undertaken in traditional sporting activities (Jackson 1995; Bakker *et al* 2011) and even sports combined with external factors such as music (Pates *et al* 2003). However, a search of the literature revealed that there are currently no published investigations to explore the relationship between flow state and exergaming technology in people with MS, and only one study with a clinical group. As such, the measurement of flow state in people with MS will provide new information specific to exergaming and a clinical group.

At present there is only one study to examine the presence of flow in exergaming technology in healthy users, highlighting this as a new and limited area of research. Thin *et al* (2011) investigated 14 young adults, who completed a programme consisting of exergaming (6 games for 6 minutes each) and traditional cycling, across three sessions, using the PlayStation 2™ EyeToy™ and the

Nintendo Wii Fit™. The authors reported significantly higher flow state scores for the subscales Challenge-Skill Balance, Action-Awareness Merging, and Loss of Self-Consciousness in the exergaming systems than in normal exercise; scores found to be comparable to normative traditional sporting activities. However, unfortunately, the authors do not provide a reference for these normative values, or the specific FSS scores of their participants. Therefore, an accurate comparison of these findings with comparable research or those of this thesis is not possible.

Currently, there is only one study to examine the effects of an exergaming system in terms of flow experience with a clinical group. Galna *et al* (2014) investigated the Microsoft Kinect™ with nine Parkinson's disease subjects. Participants played a selected game for approximately 30 minutes, following which they were asked to complete a number of questionnaires, including the FSS. Reporting the descriptive statistics only, given the small sample size, the authors found high scores for the subscales Concentration on the Task at Hand, Loss of Self-Consciousness, Clear Goals, and Autotelic Experience, and concluded that flow was achieved in Parkinson's disease participants. As noted by the authors, this research was limited through the employment of a small sample, and only a single clinical group; therefore, inferential analysis and comparisons with traditional exercise interventions are not possible.

It would appear that the current literature has focused on flow attainment during either traditional physical activity, or computer/online gaming (non-exergaming), but not the two combined (exergaming). In finding only two previous investigations of flow experience in exergaming technology there is a clear need for further research in both healthy and clinical groups. Traditional video games appear to offer a highly engaging experience (Koster 2013); however, knowledge of these effects when combined with exercise is currently limited. Therefore, measuring flow may provide insightful information on the effects of exergaming technology, and potentially address the long known problem of exercise concordance.

CHAPTER 3: SYSTEMATIC LITERATURE REVIEW

3.1 Systematic Review of the literature

Systematic reviews provide the highest level of scientific evidence for interventions and are therefore considered an important source of information for evidence-based medicine (Greenhalgh 2010). Khan *et al* (2003) defines a systematic review as the identification of relevant studies, appraisal of quality, and summary of results based on a scientific methodology. Given the current lack of evidence to support or refute the use of exergaming technology as a means of physical exercise specific to balance training, a systematic review of the literature was undertaken.

3.2 Aims

The aims of this were: 1) identify the range of current literature specific to MS-based exergaming research and balance training; and 2) provide a critical evaluation of said research.

3.3 Methods

Based on the primary aim, this section will report the search strategy, assessment of methodological quality, data extraction and results. Following which, the second aim will be reported. This section will conclude with a summary of the current literature specific to exergaming.

3.4 Search Strategy

This review is reported, where appropriate, in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Liberati *et al* 2009). A well-framed, focused research question can comprise of three or four elements, and is based on a standard framework (Flemming 1998). This framework is used to formulated and identify the Population of interest (P), the Intervention (I), the Comparative intervention (C), if any, and the Outcomes (O) (PICO). The PICO framework provides structure when conducting a systematic literature search and is used for questions specific to therapeutic interventions (Khan *et al* 2003). Given the scarcity of current research, the PIO framework was used, as the addition of a comparative intervention may exclude papers of interest. Using this framework the following focused question was developed:

> *Does exergaming (I) have an effect on balance (O) in people with Multiple Sclerosis (P).*

The databases CINAHL[2] (1981 to October 2013), AMED[3] (1995 to October 2013), MEDLINE[4] (1946 to October 2013), EMBASE[5] (1947 to October 2013), PEDro[6] (1929 to October 2013), PsycINFO[7] (1880 to October 2013) and Cochrane Library Register of Controlled Trials[8] (1972 to October 2013) were searched. Based on the first set of aims, the following keywords and comparable synonyms were

[2] www.cinahl.com
[3] www.ebscohost.com/corporate-research/amed
[4] www.nlm.nih.gov/bsd/pmresources.html
[5] www.elsevier.com/online-tools/embase
[6] www.pedro.org.au
[7] www.apa.org/pubs/databases/psycinfo/index.aspx
[8] www.thecochranelibrary.com

searched: multiple sclerosis (P), exergaming (I) and postural control (O). These were combined using the Boolean operators ‘OR’ and ‘AND’. The operator ‘OR’ is used to look for articles that include *any* of the identified keywords, while the operator ‘AND’ is used to look for articles that include *all* the identified keywords (Cronin *et al* 2008). The full search strategy is provided in Table 1, and was used by the author (JR) for the indicated databases. As the PEDro and Cochrane library databases do not facilitate use of the PIO framework, only the main search terms were used. No limits were placed on the search at this time; however, all papers were required to meet the inclusion and exclusion criteria.

3.5 Inclusion and Exclusion Criteria

Studies must have used an exergaming or virtual reality-based intervention with people with MS. ‘Exergame’ was defined as: a combination of exertion and video games play, aimed towards balance (the primary focus of this review and thesis), strength or flexibility training (Oh and Yang 2010). Exergaming was defined as playing exergames or any other video games to promote physical activity (Oh and Yang 2010). Virtual reality-based interventions were defined as any kind of computer game or virtual reality technique where the participant could interact with virtual objects through physical movement (Sandlund *et al* 2009). As mentioned, the primary interest was research which employed balance specific outcomes. Secondary interests were compliance, enjoyment, and adverse events. No restrictions with regards to study design or sample size were considered. Studies were excluded if they used non-MS participants, children, were conference proceedings or abstracts, or were not available in the English language.

Table 1 Keywords used and the number of papers identified from the indicated databases: A systematic review

Search ID	Search Terms	Results						
		CINAHL	AMED	MEDLINE	EMBASE	PsycINFO	PEDro	Cochrane
S1	multiple sclerosis*	12,258	1,551	54,389	82	9467	-	-
S2	MS	12,160	4,569	406,411	258,844	25,193	-	-
S3 (P)	S1 OR S2	20,079	5,471	437,353	307,297	28,731	218	235
S4	exergaming*	24	4	50	60	21	-	-
S5	virtual reality	2,427	249	4311	9,842	4974	-	-
S6	virtual rehabilitation	134	46	239	75	175	-	-
S7	active video games	30	6	54	50	35	-	-
S8	Wii	250	53	326	499	132	-	-
S9	Wii fit	63	13	57	1,118	27	-	-
S10	Nintendo	135	39	206	327	127	-	-
S11 (I)	S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10	2,695	297	4760	10,402	5190	28	4
S12	postural control*	1,262	715	3509	3,943	1146	-	-
S13	balance	24,920	4,467	163,147	216,408	28385	-	-
S14	falls	15,740	2,758	39,625	36,706	25530	-	-
S15 (O)	S12 OR S13 OR S14	38,623	6,835	200,564	251,341	53467	355	331
S16	S3 AND S11 AND S15	8	1	11	23	2	3	0

[a] Grey highlight indicates the total number of hits for the PIO elements of the search.
[b] * = key terms used to identify PIO elements for the PEDro and Cochrane databases

3.6 Methodological Quality

Studies were assessed for methodological quality using the McMaster Critical Review Form for Quantitative Studies (Law *et al* 2011, Figure 16). This tool was used as it allows for the assessment of differing methodological designs – which were anticipated given the novel nature of research specific to exergaming. The McMaster Critical Review tool comprises 15 items; 14 of which are assessed through an indication of ‘yes’, ‘no’, ‘not addressed’ or ‘not applicable’. The remaining item is the identification of the study design. Each of the studies identified was assessed according to the McMaster item requirements. For each item marked as ‘yes’, a score of 1 was awarded. If inadequately addressed, or considered to be lacking in detail, it was awarded half a mark (0.5); if completely overlooked it was given a marked of ‘no’, and thus received a 0 score. ‘Not applicable’ responses were omitted from the total possible score. The total number of points received by a study (raw score), out of a maximum of 14, was then calculated and reported as a percentage.

3.7 Data Extraction

Relevant information was extracted from the identified papers by the author of this PhD thesis. Data included: author(s), sample size, sample population, intervention, outcome measures, reported significance, and key findings (Table 2).

Critical Review Form – Quantitative Studies
©Law, M., Stewart, D., Pollock, N., Letts, L. Bosch, J., & Westmorland, M.
McMaster University

Instructions: Use tab or arrow keys to move between fields, mouse or spacebar to check/uncheck boxes.

CITATION	Provide the full citation for this article in APA format:
1. STUDY PURPOSE Was the purpose stated clearly? ☐ Yes ☐ No	Outline the purpose of the study. How does the study apply to your research question?
2. LITERATURE Was relevant background literature reviewed? ☐ Yes ☐ No	Describe the justification of the need for this study:
3. DESIGN ☐ Randomized (RCT) ☐ cohort ☐ single case design ☐ before and after ☐ case-control ☐ cross-sectional ☐ case study	Describe the study design. Was the design appropriate for the study question? (e.g., for knowledge level about this issue, outcomes, ethical issues, etc.): Specify any biases that may have been operating and the direction of their influence on the results:
SAMPLE 4a. N = Was the sample described in detail? ☐ Yes ☐ No 4b. Was sample size justified? ☐ Yes ☐ No ☐ N/A	Sampling (who; characteristics; how many; how was sampling done?) If more than one group, was there similarity between the groups?: Describe ethics procedures. Was informed consent obtained?:

<table>
<tr><td rowspan="2">OUTCOMES

5a. Were the outcome measures reliable?
☐ Yes
☐ No
☐ Not addressed

5b. Were the outcome measures valid?
☐ Yes
☐ No
☐ Not addressed</td><td colspan="2">Specify the frequency of outcome measurement (i.e., pre, post, follow-up):</td></tr>
<tr><td>Outcome areas:</td><td>List measures used.:</td></tr>
<tr><td>INTERVENTION

6a. Intervention was described in detail?
☐ Yes
☐ No
☐ Not addressed

6b. Contamination was avoided?
☐ Yes
☐ No
☐ Not addressed
☐ N/A

6c. Cointervention was avoided?
☐ Yes
☐ No
☐ Not addressed
☐ N/A</td><td colspan="2">Provide a short description of the intervention (focus, who delivered it, how often, setting). Could the intervention be replicated in practice?</td></tr>
<tr><td>RESULTS

7a. Results were reported in terms of statistical significance?
☐ Yes
☐ No
☐ N/A
☐ Not addressed

7b. Were the analysis method(s) appropriate?
☐ Yes
☐ No
☐ Not addressed</td><td colspan="2">What were the results? Were they statistically significant (i.e., $p < 0.05$)? If not statistically significant, was study big enough to show an important difference if it should occur? If there were multiple outcomes, was that taken into account for the statistical analysis?</td></tr>
</table>

7c. Clinical importance was reported? ☐ Yes ☐ No ☐ Not addressed	What was the clinical importance of the results? Were differences between groups clinically meaningful? (if applicable)
7d. Drop-outs were reported? ☐ Yes ☐ No	Did any participants drop out from the study? Why? (Were reasons given and were drop-outs handled appropriately? Was intention-to-treat acknowledged?)
8. CONCLUSIONS AND IMPLICATIONS Conclusions were appropriate given study methods and results ☐ Yes ☐ No	What did the study conclude? What are the implications of these results for practice? What were the main limitations or biases in the study?

Figure 16 Example of McMaster Critical Review form

Table 2 Systematic Review Data Extraction

Authors	**n**	**Population** Mean (SD)	**Intervention**	**Outcome**
Plow and Finlayson (2011)	30	Age 43.2 (9.3) years; 23 females	Wii Fit: 3pw, 14w (baseline control)	Physical Activity and Disability Survey; Modified Fatigue Impact Scale (MFIS); 36-item Short Form Health Status Survey; Timed Up and Go (TUG) test; the Equiscale Balance test; 3-minute stepping test; Balance Evaluation Systems Test; and YMCA Fitness Testing.
Kalron and Frid (2012)	32	Age 43.6 (SE 1.9); 19 females, 13 males	Wii Fit: 30-mins of Wii-Tennis	Balance: Functional Reach Test and Four Square Test (FSST) (pre vs post assessment)
Prosperini *et al* (2013)	36	Age: grp 1 35.3 (8.6) grp 2 37.1 (8.8); women: 25, men: 11	Wii: 12w home-based, followed by 12w no-intervention (randomised)	Force platform–based measures of static standing balance; FSST; 25-Foot Walking Test (25-FWT), and the 29-item MS Impact Scale (MSIS-29).
Fulk (2005)	1	Age:48 years; female	Physical Therapy and IREX: 2pw, 12w (BWS/TM system)	Gait speed; Gate endurance: 6-minute walk test; Balance: BBS, Activities-Specific Balance Confidence (ABC) scale, NeuroCom SMART Balance Master (posturography); MFIS
Nilsagård *et al* (2013)	84 (4 lost to FU)	Age: grp 1: 50; grp 2: 49.4; males, 20; females 64.	Wii: 2pw, 6-7w, supervised 30-min ps (total 12 sessions)	Primary: TUG Secondary; TUG-cognitive; FSST; 25-FWT; the Dynamic Gait Index (DGI); the 12-item MS Walking Scale (MSWS-12); the ABC; and the Timed Chair Stand test.

Abbreviations: pw, per week; ps, per session; w, week(s) (total); grp, group; BWS/TM, Body weight system/treadmill

Table 2 Systematic Review Data Extraction, continued

Authors	Sign	Finding
Plow and Finlayson (2011)	Physical activity significantly improved at week 7 only (P > 0.05) compared with the baseline control period. Sign improvement in: Maximum number of push-ups (p = 0.01); Timed number of steps (p = 0.005); Balance: Eyes open, one foot, firm surface, s (p = 0.009); Eyes closed one foot, firm surface, s (p = 0.01)	Physical assessments indicated that people with MS may be able to improve their fitness levels by using Wii Fit™.
Kalron and Frid (2012)	Significant improvements for both balance tests	Exergaming had an immediate effect on balance following a single session. Related to simultaneous auditory and visual feedback. Exergaming recommended for MS patients
Prosperini *et al* (2013)	WBBS was effective in ameliorating force platform measures (F = 4.61, P =0.02), FSST (F = 3.75, P = 0.03), 25-FWT (F = 3.34, P = 0.05), and MSIS-29 (F = 4.28, P= 0.02).	No sig. diff over-time. However, sig. diff. between groups. These findings indicate significant between-group differences over time favours WBBS training in static and dynamic balance, walking speed, and QoL
Fulk (2005)	n/a	The client demonstrated improvements in gait speed, gait endurance, and balance post-intervention and maintained the improvements at a 2-month follow up.
Nilsagård *et al* (2013)	Significant improvement in all measures of the Wii Fit™ group, with the exception for walking speed and balance confidence. Significant improvement in FSST and DGI only. However, there were no significant differences between the intervention and control group.	In comparison with no intervention, a programme of supervised balance exercise using Nintendo Wii Fit™ did not render statistically significant differences.

Table 2 Systematic Review Data Extraction, continued

Authors	n	Population Mean (SD)	Intervention	Outcome
Brichetto *et al* (2013)	36	Age, Wii group: 40.7; control: 43.2 ys	Wii vs Control: 3 x 60-min pw, 4w (12 total)	Berg Balance Scale (BBS), MFIS, and sway area under conditions of opened and closed eyes.
Aiello *et al* (2012)	10	Age: 40.6; 9 females, 1 male	X-SENS (virtual environment) with treadmill: 2pw; 45 mins ps, 6w (12 total)	Six minute walk test (6MWT), TUG, FSST, the “10 meter test” and the BBS. Gait performance using a six camera stereophotogrammetric system (Vicon T20) and the Davis marker set with two embedded force platforms.
Gutiérrez *et al* (2013)	50	Age exp: 39yr, Con: 42yr; Gender: 25f, 22m.	Xbox 360 vs Physo: Xbox, 4pw, 20-min ps, 10w; Physio, 2pw, 40-min ps, 10w	Dynamic posturography; BBS; Tinettti

Abbreviations: pw, per week; ps, per session; w, week(s) (total); BWS/TM, Body weight system/treadmill

Table 2 Systematic Review Data Extraction, continued

Authors	Sign	Finding
Brichetto *et al* (2013)	BBS showed a statistically significant improvement (from 49.6 to 54.6 points, $p < 0.05$) in the Wii group.	Interactive visual-feedback exercises such as Wii could be more effective than the current standard protocol in improving balance disorders in MS.
Aiello *et al* (2012)	No statistics reported. Distance walked over 6minutes improved (endurance) at T1 and T2. Improvement in gait and balance, with a decrease of fall risk.	All improvements gained were stable after three months (control group is needed). Virtual reality system and the results are very encouraging.
Gutiérrez *et al* (2013)	Sign between-group post-treatment differences in the composite equilibrium score, BBS and Tinetti scales in the experimental group.	A virtual reality program enables anticipatory postural control and response mechanisms, which might serve as a successful therapeutic alternative

3.8 Results

A search of the noted databases identified a total of 1,374,276 papers. These were processed using the Boolean operators ‘OR’ and ‘AND’ to detect 48 pieces of literature. Of these, eight were found to be specific to MS and exergaming. The remaining were either duplications, non-research based, or not specific to the search aims.

3.9 Methodological Quality Scores

The included studies were generally of moderate methodological quality. The McMaster Critical Appraisal Tool raw scores varied from 4.5 to 13, out of a possible 14, and percentages from 38% to 93% (mean 67%). A summary of the critical appraisal scores, specific to each question, is provided through Table 3. Of the eight studies, two were Randomised Controlled Trials (RCTs), one Quasi-Experimental study, one cross-over study, one longitudinal trial, one cohort study, and two case studies. Common aspects affecting the studies’ quality included not providing justification or estimation of required sample size, and limited reporting of reliability and validity of identified outcome measures. Of those studies where participant drop-outs were identified, limited demographic or follow-up information was provided, as well as limited reporting of intention-to-treat analysis.

Table 3 A summary of the critical appraisal scores

Author(s)	**Items**															**Score**		
	1	2	3	4a	4b	5a	5b	6a	6b	6c	7a	7b	7c	7d	8	Raw	Out of	%
Nilsagård *et al* (2013)	1	1	RCT	1	1	1	1	1	1	0	1	1	1	1	1	13	14	93%
Prosperini *et al* (2013)	1	1	CO	1	0	1	1	1	0	1	1	1	1	1	1	12	14	86%
Plow and Finlayson (2011)	1	1	LT	1	0	1	1	1	n/a	0	1	1	1	1	1	11	13	85%
Kalron and Frid (2012)	1	1	QE	1	0	0	0	1	n/a	n/a	1	1	1	1	1	9	12	75%
Gutiérrez *et al* (2013)	1	1	CH	1	0	0.5	1	1	0	0	1	1	0	0.5	1	9	14	64%
Brichetto *et al* (2013)	1	1	RCT	1	0	0	0	0.5	0	0	1	1	0	1	1	7.5	14	54%
Fulk (2005)	1	1	CS	1	0	0.5	0.5	0.5	n/a	0	0	0	0.5	1	0	6	13	46%
Aiello *et al* (2012)	1	0.5	CS	0	0	0	0	0	n/a	n/a	0	1	0	1	1	4.5	12	38%

[a] Study design: RCT, Randomised Controlled Trial; CH, Cohort Study; LT, Longitudinal; QE, Quasi-Experimental; CO, Crossover; CS, Case study

[b] McMaster Items: 1. Study Purpose; Item 2. Literature; Item 3. Design; Item 4a. N; Item 4b. N justified; Item 5a. Outcomes Reliable; Item 5b. Outcomes Valid; Item 6a. Detail; Item 6b. Contamination; Item 6c. Cointervention; Item 7a-d. Results; Item 8. Conclusions.

3.10 Summaries of MS Exergaming research

The mean age of MS participants was 43 years (SD 4), and ranged from 35 to 50 years. The total combined number of males and females recruited through all eight studies were 81 males and 235 females. Intervention durations ranged from a single 30-minute session (Kalron and Frid 2012) to 14-weeks (three sessions per week) (Plow and Finlayson 2011). The number of sessions per week ranged from two (Fulk 2005; Aiello *et al* 2012; Nilsagård *et al* 2013) to four (Gutiérrez *et al* 2013). Adverse events were reported in two papers (Prosperini *et al* 2013; Plow and Finlayson 2011), involving a total of six participants. Injuries consisted of knee and low back pain, and related to one participant leaving the study (Prosperini *et al* 2013).

One high quality (13/14; 93%) RCT investigated the effects of a Nintendo Wii Fit™ balance exercise programme on balance function and walking ability in people with MS (Nilsagård *et al* 2013). The primary outcome was the Timed Up and Go (TUG) test. The authors reported statistically significant within-group improvements in the exergaming group for TUG ($p = 0.02$), $TUG^{Cognitive}$ ($p < 0.01$), Four Square Step ($p < 0.01$), Dynamic Gait Index ($p < 0.01$), Activities-specific Balance Confidence ($p = 0.02$), and MSWS-12 ($p = 0.01$). The non-exercise group showed statistically significant improvements for the Four Square Step Test ($p = 0.01$), and the Dynamic Gait Index ($p < 0.01$) only. No significant differences were reported between-groups. Overall, despite finding no significant differences between the two groups, a programme of supervised balance exercises using the Nintendo Wii Fit™ presented significant within-group improvements and moderate effect sizes for several measures of balance performance. However, it should be acknowledged that improvements were also reported in the control group.

One high quality (12/14; 86%) crossover study evaluated the effectiveness of home-based rehabilitation on balance using the Nintendo Wii™ and Wii Fit™ balance board in people with MS (Prosperini *et al* 2013). Primary outcomes were the mean difference (compared with baseline) in force platform measures (reported as the sum of displacement of the centre of pressure velocity [CoP velocity] [in mm]), Functional Reach Test and Four Square Test (FSST), 25-Foot Walking Test (25-FWT), and the 29-item MS Impact Scale. No significant within-group differences were found. However, there were statistically significant between-group differences, favouring the Wii Fit™ group, for: force platform measures (p = 0.02), FSST (p = 0.02), 25-FWT (p = 0.04), and the MSIS-29 (p = 0.02). This indicates the positive effects of Wii Fit™ training on static and dynamic balance, walking speed, and quality of life. However, Prosperini *et al* (2013) note the limitation of not having a washout period; whereby one treatment may alter the effects of subsequent treatments (Sibbald and Roberts 1998). Also, there were five adverse events attributable to the Wii Fit™ (knee or low back pain), from which one participant left the study. Overall, moderate effects were seen through the improvement of balance, walking speed and quality of life outcomes as a result of the supervised balance exercises. However, this paper also reports the potential for injury through exergaming technology.

One high quality (11/13; 85%) longitudinal pilot study investigated the potential of Nintendo Wii Fit™ to increase physical activity behaviour and health among people with MS (Plow and Finlayson 2011). The primary outcomes were the Physical Activity and Disability Survey, Modified Fatigue Impact Scale, and the 36-item Short Form Health Status Survey. Secondary outcomes were mobility (TUG test), balance (the Equiscale Balance test), strength (the 3-minute stepping test), and weight. Results from the questionnaires indicated that physical activity had significantly improved at week 7, but at week 14 levels declined and these differences were no longer significant compared to the control period. Physical assessments indicated that balance and strength significantly improved at week 7. Also, the authors reported the occurrence of one adverse event (repetitive knee injury). Overall, physical assessments indicated that people with MS may be able to improve their fitness levels by using Wii Fit™, and despite the adverse event, the Wii Fit™ was considered safe for home use for those with minimal balance and mobility problems.

One moderate-to-high quality (9/12; 75%) quasi-experimental study aimed to evaluate balance in moderately impaired MS participants following a single session of Wii™ training (Kalron and Frid 2012). The primary outcomes were the measures of balance using the Functional Reach Test and the FSST. The authors reported significant improvements in both balance tests following a single intervention. It was concluded that there were immediate beneficial effects on balance following a single session; results potentially attributed to simultaneous auditory and visual feedback, reinforcing multi-sensory integration. Based on these findings, Kalron and Frid (2012) support the use of exergaming technology with MS patients with impaired balance.

One moderate quality (9/14; 64%) investigation examined the effects of exergaming in people with MS in terms of balance and postural control (Gutiérrez *et al* 2013). Telerehabilitation was administered using the Microsoft Xbox 360™, and monitored by the authors via videoconference. Comparisons were made with a physiotherapy group. The outcome measures were posturography, BBS, and the Tinetti balance assessment tool. The authors reported significant between-group post-treatment differences in the composite equilibrium score ($p < 0.001$), BBS ($p < 0.001$) and Tinetti scale ($p < 0.001$) in the experimental group. It was concluded that telerehabilitation might offer an important alternative to standard treatments in people with MS who present with poor mobility and/or restrictive geographical access.

One low-to-moderate quality (7.5/14; 54%) pilot study investigated the effectiveness using the Wii™ balance board compared to traditional rehabilitation strategies in improving balance in people with MS (Brichetto *et al* 2013). The primary outcome measure was the BBS. Secondary outcomes measures were the Modified Fatigue Impact Scale and the stabilometric platform (postural sway, reported in mm^2). The authors found significant improvements in BBS scores ($p < 0.05$) in the Wii™ group when compared to control. It was concluded that both interventions demonstrated excellent compliance. However, those in the Wii™ group demonstrated greater improvement in BBS scores and eyes-open and eyes-closed stabilometry than in the control-group. These positive findings differ from those of the most comparable study by Nilsagård *et al* (2013), which showed that when compared to no-intervention, no statistically significant differences were found. This may be the result of differing methodological procedures and outcomes; however, consideration should also be given to the differences in methodological quality scores.

One low quality (6/13; 46%) case study investigated the effectiveness of virtual rehabilitation on balance, mobility and endurance in a single MS participant (Fulk 2005). Given the nature of the study design, a number of clinical outcomes were employed such as the 6-minute walk test, BBS, Activities-Specific Balance Confidence scale, the Modified Fatigue Impact Scale, in addition to the laboratory based measure of posturography. The author also administered a number of intervention types: a treadmill with a body weight support system, a home exercise programme, and virtual rehabilitation exercises using the IREX™ system. The interventions were undertaken two days a week, over a 12-week period. In total, the participant completed 19 locomotor and 13 IREX™ sessions, in addition to a home exercise programme. By study completion the author reported a 21% improvement in gait speed and a 25% improvement in endurance; which were maintained at post-intervention and 2-month follow up.

Fulk (2005) highlights the treatment variety that is available to those with balance and gait disturbances; however, due to the combination of three different interventions it is impossible to identify the effectiveness for any single treatment. This type of treatment programme may also be considered as a limitation when highlighting its practicality in a clinical setting; such a rehabilitation programme required three trainers to facilitate gait re-education, a body weight support system, an appropriate treadmill, in addition to the IREX™ system. Therefore, the likelihood of reproducing this type of rehabilitation programme as a standard practice would be costly in a real world scenario.

A second low quality (4.5/12; 38%) case study evaluated virtual reality environments using inertial sensors (X-SENS) and a treadmill in gait training with ten individuals with MS (Aiello *et al* 2012). The outcome measures were comparable to those of Fulk (2005), and included the 6-minute walk test, the TUG test, FSST, the 10 metre test, and the BBS. As the study is reported through a supplementary format the reporting of the specific findings is limited; reflected through the critical appraisal score. The authors reported finding improvements in most motor functions, specific to the 6-minute walk and the TUG tests. These were maintained at a three month follow-up. The authors conclude that the group responded positively to the intervention and that the results are encouraging to those who intend to use this technology in people with MS.

3.11 Discussion

The aims of this systematic review were to identify literature specific to MS-based exergaming and balance training. These were critiqued using a standardised critical analysis framework for consistency of analysis across the identified papers, and reported in a similar manner to other published systematic reviews. Considering no limits were placed in terms of research design, only eight papers were identified. Five studies employed the Nintendo Wii Fit™ as an exercise intervention for people with MS (Plow and Finlayson 2011; Kalron and Frid 2012; Brichetto *et al* 2013; Nilsagård *et al* 2013; Prosperini *et al* 2013). The remaining studies employed different technologies: the IREX™ system (Fulk 2005), the X-SENS (a virtual environment) (Aiello *et al* 2012), and the Microsoft Xbox™ system (Gutiérrez *et al* 2013). These exergaming systems may be subcategorised as either commercially available (the Nintendo Wii Fit™ and the Microsoft Xbox™), requiring no computer programming knowledge, or purpose-designed virtual reality systems (the IREX™ and X-SENS), which are generally not commercially or clinically available due to the advanced technical knowledge required and high cost.

This systematic literature review found that there is limited, but moderate evidence supporting the application of exergaming technology in people with MS. Of these, and upon review of the concepts of internal and external validity and reliability, only one was of high quality (Nilsagård *et al* 2013). Half of the research scored between 38% to 64% on the McMasters framework. The small number of papers identified is perhaps a reflection on the relatively recent development of such technology, and therefore justification for further research. Of the existing research, a limitation, irrespective of the clinical focus, is the variety of outcome measures, and the differing durations and frequencies of interventions. Also, a common limitation is the application of multiple co-interventions; serving to mask the true effects of any one intervention. Given the above findings, it is reasonable to question the application of exergaming technology for people with MS at this time; however, this also provides a clear justification for continued research, the potential for positive health-related changes in people with MS, and the undertaking of this PhD thesis.

3.12 Summary

In MS, traditional methods of physical rehabilitation have been shown to improve disability, as well as having a positive impact on mental state through improved quality of life (Solari *et al* 1999). There is potential for this to also be true for exergaming technology; something which may be identified through continued research. Moreover, as demonstrated through the introduced literature, there is a clear need for further randomised controlled trials due to the contrasts in findings. To date, no published trials have used 3 arms to compare exergaming against traditional balance exercises and a no-intervention control group. Also a limitation in some studies is the primary use of clinical outcome measures; which are prone to ceiling effects (Jarnlo 2003). In addition to the physiological benefits of exergaming technology, exergaming may be a familiar and attractive environment to exercise. This may improve initial motivation and, through better acceptance and engagement, help with long term concordance.

CHAPTER 4: AIMS OF THE THESIS AND REVIEW OF THE MEASUREMENT TECHNIQUES

4.1 Aims of the Thesis

At present, and demonstrated through the above literature review, there is limited evidence to support or refute the applications of exergaming technology when used in a clinical setting, and specifically for the application of balance training. Through an exploratory trial in healthy sedentary participants (study 1), the current thesis will investigate the effects of exergaming on balance performance following a short-term intervention (primary aim). It will also establish if this technology is accepted and allows for flow to be experienced (a state of engagement) (secondary aim).

Through a definitive RCT (study 2), and based on the findings of the initial study, the thesis will investigate the effects of exergaming on balance performance and gait following a short-term intervention (primary aim) in people with MS. It will also establish if this technology is accepted, and allows for flow to be experienced (a state of engagement) in its users. Additionally, due to the employment of a clinical sample, changes in self-perceived walking ability, and limitations in activity and participation will be assessed (secondary aim).

4.1.1 Research Question

There are two research questions for each study of the current thesis:

Study 1:

- Does exergaming technology affect standing balance (postural sway) in healthy sedentary individuals?

- What are the effects of exergaming technology on user-acceptance and flow experience in healthy sedentary individuals?

Study 2:

- Does exergaming technology affect standing balance (postural sway) and walking ability (gait analysis) in people with MS?

- What are the effects of exergaming technology on user-acceptance, flow experience, self-perceived walking ability, and limitations in activity and participation in people with MS?

4.1.2 Specific Objectives

Over two studies, one with healthy sedentary and one with MS participants, this thesis explores the effects of a four-week balance-orientated exercise programme through the observation of AP and ML standard deviation (SD), AP and ML range, CoP velocity, and gait. This thesis also explores these effects through quantitative psychological questionnaires of both user-acceptance and flow experience.

Specifically, the two studies of the current thesis are as follows:

> *Study 1: The effect of a four-week exergaming programme on postural sway, user-acceptance, and flow experience in healthy sedentary individuals*

Study 1 will compare two exergaming platforms, one purpose-designed for clinical use (IREX™) and one commercially available system (Wii Fit™), to identify the effects of a four-week exergaming programme in terms of postural sway, user-acceptance and flow experience. These last two psychological measures are chosen to establish the acceptance of this technology, as an indicator of user-intention, as well as flow experience, as a measure of engagement during its use.

> *Study 2: The effect of a four-week exergaming programme on postural sway, gait, user-acceptance, flow experience, self-perceived limitations in activity and participation, and walking ability in people diagnosed with MS.*

Study 2 will employ the same outcome measures to the first, with the addition of gait analysis, and two self-completion questionnaires to provide a measure of self-perceived walking ability, and activity limitations and participation restrictions. This study will also recruit from a clinical population: participants diagnosed with the neurological condition of MS; a condition known to affect balance performance, gait, as well as well-being. In this second study comparisons will be made between the Nintendo Wii Fit™, matched traditional physiotherapy-based balance exercises (recommended by NICE guidelines, and standard practice in the management of MS), and a control group (no intervention).

4.1.3 Hypotheses

These will be reported specific to the chosen outcome measures, and identified for each study of the PhD thesis.

4.1.4 Experimental Hypotheses

Based on the findings of previous research, current literature, and clinical knowledge, a two-tailed (non-directional) experimental hypothesis was chosen for both studies:

Postural Sway:

> *There will be significant differences between- or within-group when comparing two exergaming platforms in healthy sedentary participants (study 1); or, comparing exergaming and traditional balance training in MS participants (study 2), in terms of measures of postural sway.*

Gait (study 2):

> *There will be significant differences between- or within-group when comparing exergaming and traditional balance training in MS participants in terms of gait (study 2).*

User-acceptance:

There will be significant differences between- or within-group when comparing two exergaming platforms in healthy sedentary participants (study 1); or, comparing exergaming and traditional balance training in MS participants (study 2), in terms of user-acceptance.

Flow Experience:

There will be significant differences between- or within-group when comparing two exergaming platforms in healthy sedentary participants (study 1); or, comparing exergaming and traditional balance training in MS participants (study 2), in terms of flow experience.

There are also additional non-directional hypotheses specific to study 2:

Walking ability:

There will be significant differences between- or within-group when comparing exergaming and traditional balance training in MS participants in terms of measures of self-reported walking ability.

Activity limitations and participation restrictions:

There will be significant differences between- or within-group when comparing exergaming and traditional balance training in MS participants in terms of measures of perceived activity limitations and participation restrictions.

4.2 Introduction: Review of The Measurement Techniques

This chapter will introduce, review and rationalise the techniques employed in the current study. The physiological measures using the force platform and GAITRite™, as well as the psychological measures of user-acceptance and flow experience will be presented. Comparable assessment outcome measures commonly used in the clinical setting will also be introduced, and, where appropriate, compared with the chosen measures of this thesis to provide additional context to the reader. Also, where applicable, these will be linked to the International Classification of Functioning, Disability and Health (ICF) domains specific to Multiple Sclerosis (MS). This chapter will conclude with a description of participant selection over the two studies of the PhD thesis, and the choices of exergaming interventions.

4.3 Measurement of balance and postural control

The assessment of balance can be an informative method for those working in neurological fields, as well as clinicians in general. The measurement of balance performance is often undertaken to assess an individual's ability to maintain appropriate posture during functional movement, in addition to the assessment of the physiological processes of postural control (as described in Chapter 2). The specific methods employed to quantify balance performance can vary greatly between clinicians and pathology. Moreover, it is supported that there is no singular tool that can evaluate all aspects of balance control (Horak 1997).

In the clinical setting there are a number of balance measures which may be employed to quantify the level of balance disturbance, and predict the likelihood of a fall, such as the Timed Up and Go Test (TUG) (Shumway-Cook *et al* 2000), Tinetti Performance-Oriented Mobility Assessment (Tinetti *et al* 1988; Thapa *et al* 1996) and the Berg Balance Scale (BBS) (Thorbahn and Newton 1996; Shumway-Cook *et al* 1997). In laboratory based research, posturography is a popular measure of balance performance using a force platform. These have been used in the quantitative analysis of postural control since the 1970s (Palmieri *et al* 2002).

4.3.1 Clinical Versus Laboratory Measures

There has been extensive research into the validity and reliability of clinical measures of balance. A brief overview of this research will be provided to inform the reader of the many options of balance assessment, and to justify the chosen method of posturography. The BBS consists of a 14-item functional activities task, and has excellent intra-rater and inter-rater reliability (r = 0.91) (Berg *et al* 1992), as well as concurrent validity by its correlation with other balance tests: the Tinetti Balance and Gait Assessment (r = 0.91) (Tinetti *et al* 1986), and the TUG (r = 0.76) (Podsiadlo and Richardson 1991). The Tinetti Balance and Gait Assessment is a 14-item balance and 10-item gait test, and has good inter-rater reliability and sensitivity (Topper *et al* 1993; Maki *et al* 1994). The TUG (Podsiadlo and Richardson 1991) is performed by recording the time to rise from a chair, walk 3 m, turn around, walk back, and sit down. It has the ability to accurately identify most fallers and non-fallers among the elderly with a sensitivity and specificity of 87% (Shumway-Cook *et al* 2000). Two reach tests - the Functional and Lateral

Reach Tests - measure the maximal anterior and lateral reach beyond the arm's length while in a stance position, and have high test-retest reliability (r = 0.92 and r = 0.99, respectively) (Duncan *et al* 1990; Brauer *et al* 1999).

In the measurement of gait, the Dynamic gait index is an 8-item assessment of the observation of limitation during specific tasks to identify the patient's ability to respond to changing task demands during walking. The Dynamic gait index has good inter-rater and intra-rater reliability in MS patients (McConvey and Bennett 2005). The 12-item multiple sclerosis walking scale (MSWS-12) (Hobart *et al* 2003) is a disease-specific self-report measure of walking ability, with answers provided using a Likert scale. It has good internal consistency, high reliability and validity, and good generalisability (McGuigan and Hutchinson 2004; Motl and Snook 2008).

Despite the popularity of clinical outcome measures, based on their relative ease and cost effectiveness, the specificity and ability to predict falls, and therefore balance performance at a quantitative level is limited. Specifically, the BBS, Tinetti Balance and Gait Assessment, TUG and Dynamic gait index lack the ability to identify minor balance disturbances at the early stages of balance regression in active individuals, and therefore, are prone to creating a ceiling effect (Jarnlo 2003). The Functional and Lateral Reach Tests are also limited through only assessing one singular task and vulnerable to user compensatory strategies to gain additional reach at the scapular-shoulder complex (Jonsson *et al* 2003). However, the MS-specific MSWS-12 questionnaire is more resistant, but not immune, to floor and ceiling effects (Bethoux and Bennett 2011).

To determine the accuracy of such clinical tests, Boulgarides *et al* (2003) compared five clinical balance tests (BBS, Dynamic gait index, TUG, Modified Clinical Test for Sensory Interaction on Balance, and 100% Limits of Stability Test), in the predication of falls in 99 adults (aged 65 to 90 years), categorised as active and independent. Using logistic regression only two models were found to predict falls; however, these only predicted three subjects who were at risk. Therefore, Boulgarides *et al* (2003) concluded that the five clinical tests did not predict falls in a sample of community-dwelling older adults. Again, these findings may be explained by the presence of a ceiling effect in clinical outcome measures.

Cattaneo *et al* (2007), investigating the effects of traditional balance retraining in 44 MS participants, reported BBS and Dynamic Gait Index test scores close to the maximum; advocating that balance measures through posturography may have provided a more accurate evaluation of balance. Similarly, Karst *et al* (2005) compared laboratory-based measures of postural sway with the BBS in MS participants with minimal or no balance deficits. These authors reported that according to the BBS, MS participants had minimal to no balance deficits; however, centre of pressure (CoP) measures (to be discussed in Chapter 4.4, page 112) obtained through posturography identified clear differences compared to healthy adults.

Posturography allows for the linear, objective, and reliable measurement of balance. Laboratory-based balance measures using force platforms provide quantitative valid information in the identification of poor postural control, and an increased likelihood of falls in both known-fallers and non-fallers (Pajala *et al*

2008). Brauer *et al* (2000) compared various laboratory measures (CoP measures using a force plate) and clinical tests in an attempt to prospectively predict fallers in community-dwelling elderly women. The authors concluded that clinical tests were unable to predict fallers; however, a combination of the laboratory measures was able to predict 77% of falls. Thus, quantitative laboratory-based measures may be more appropriate in detecting minor balance disturbances at the early stages of balance regression. However, such measures require additional technical knowledge, time to assess and equipment – which are often not available within the clinical setting.

In the current PhD thesis, the measurement of postural control was not undertaken with the aims of predicting falls in MS participants, but to quantify any change in balance performance. Nevertheless, literature purports that improvements in postural control are related to a reduced likelihood of future falls. An advantage of using a force platform is that it is possible to obtain directional and velocity specific information during static and dynamic tasks, during eyes open and closed, and therefore assess the physiological influences of postural control. The application of force platforms in the measurement of postural control will be introduced through the following sections.

4.4 Postural Stability

In undertaking activities of daily living the ability to maintain an upright posture, through keeping the centre of gravity within the base of support, is imperative; this is the definition of postural control. When reviewing the quality of this ability the term *Postural Sway* is often used, defined as the body's ability to move in the medial-lateral (ML) and anterior-posterior (AP) directions; the magnitude or velocity of which is a measure of balance performance. Falls in MS are considered to be the result of increased postural sway (Shafizadeh *et al* 2012), and associated with a reduced ability to control movement towards the boundaries of stability and slowed responses to postural disturbances (Cameron and Lord 2010).

4.4.1 Dual-Tasking and Balance Performance

Despite the cognitive element of balance performance not being assessed through this PhD thesis, it is important to acknowledge that this is integral to balance performance and, therefore, the concept of dual-tasking will be introduced. The ability to maintain an upright standing position is based on the physiological processes of postural control, combined with the cognitive focus towards a task. In the assessment of balance, dual-tasking is where the individual is asked to complete a mental or physical activity (for example, mental problem solving or upper limb task) during standing. It is generally accepted that the addition of dual-tasking has a negative effect on balance, as a result of dividing the central processing capacity which subsequently increases the risk of falls (Woollacott and Shumway-Cook 2002). It has been reported that as a result of dual-tasking (through calculation tasks) in older women (aged over 75 years), the risk of a fall increased 2.4-fold; assessed using a force platform, which identified increased sway in the ML direction (Bergland and Wyller 2004). However, balance training can incorporate dual-tasking in an attempt increase the ability for balance and cognitive function and therefore reduce the likelihood of falls. Dual-tasking may also assist in improving postural control in people with MS (Cameron and Lord, 2010), something exergaming is able to offer through facilitating engaging, interactive and enjoyable game-play.

4.5 Introduction To Force Platforms

As a quantitative objective tool, force platforms have been used since the 1970s (Palmieri *et al* 2002) and are considered the gold standard measure of postural control (Nichols *et al* 1995). The force platform is a highly sensitive measure of balance and able to differentiate between young, middle-aged, and older individuals (Era and Heikkinen 1985). A force platform allows for the measurement of changes in postural control by recording the ground-reaction force project by the individual standing on it (Browne and O'Hare 2000). A force plate consists of four force sensors (load cell or piezoelectric) positioned at each corner. These measure three force components: Fx, Fy and Fz (x, y, and z corresponding to ML, AP, and vertical directions, respectively) (Figure 17).

The centre of mass (CoM) is the centre of the total body mass, calculated through the weighted average of the CoM of each body segment (Shumway-Cook and Woollacott 2007). The centre of gravity (CoG) is the vertical projection of CoM onto the ground. The base of support (BoS) is the area of the body that is in contact with the support surface (typically the ground). One of the most commonly reported measures of postural control is the CoP. The CoP is the point location of the vertical ground action force which represents the weighted average of all the pressure over a contact surface area (Winter 1995). The location of the CoP is determined by the relative vertical forces, as recorded at each sensor (Figure 17, labelled 1-4). The CoP velocity is the total distance covered by CoP (total sway path) divided by the set sampling rate during the assessment of postural control (Simoneau *et al* 2008).

Figure 17 Kistler force platform with four force sensors, and the directional axes of measurement

4.5.1 Kistler Force Platform Sampling Rate

In the recording of postural sway it is important to select an appropriate sampling rate. If it is too low, the true peaks and valleys (observed through the wave form) will be clipped; if it is too high, there will be an increase in errors due to the integration process (Caldwell *et al* 2004). There are currently no guidelines which recommend a universal sampling rate; however, between 500-2000 Hz is reported within the research, and 1000 Hz is a common choice (Bartlett 2007; Payton and Bartlett 2007) and reported in comparable research (Brauer *et al* 2000; Karst *et al* 2005; Rome *et al* 2009; Hatton *et al* 2012). In the current thesis sway data will be recorded at 1000 Hz, and this raw data filtered using a low-pass filter at 10 Hz.

4.5.2 Centre of Pressure as a Representation of Postural Stability

Where balance is reduced, and therefore the boundaries of postural control are unclear, individuals typically exhibit increased postural sway, interpreted as ‘scanning’ the limits of said boundaries (Mochizuki *et al* 2006). Assessment of the CoP path during standing and functional movements provides a means for assessing postural control in response to internally-generated perturbations specific to functional activity (Karst *et al* 2005). Therefore, where postural sway increases, this represents a decrease in postural control. This can be the result of ankle injury, increased age (due to somatosensory function deterioration [Priplata *et al* 2003]) or a compromise of neuromuscular systems; such as in people with MS.

4.5.3 Postural Sway Parameters

A force plate can also provide directional specific information. These are reported as the amplitude of movements in the AP and ML directions when in quiet standing (Shumway-Cook and Woollacott 1995). The magnitude of CoP path movement, reported as range, standard deviation and velocity provides a reliable measure of balance ability (Le Clair and Riach 1996). In the current thesis, these will be reported during bipedal (BP) and unipedal (UP) standing.

4.5.4 AP and ML range

The CoP range (in AP and ML directions) indicate the minimum and maximal deviation (in mm) of the CoP displacement, and represent a global measure of the estimated overall postural performance (Figure 18, page 119). Increases in postural sway in AP and ML directions are associated with increased likelihood of falls (Sosnoff *et al* 2011). However, there is some debate of the direction (AP or ML) where balance disturbances are most common. To a degree, the direction of sway is related to the anatomical structure responsible for maintaining an upright position. In the ankle joint, larger sway is seen in the AP direction; in the CoP velocity, larger sway is seen in the ML direction (Mochizuki *et al* 2006).

A number of studies advocate that increased age corresponds with increases in sway amplitude in the ML direction, and is an independent and significant predictor of falls (Lord *et al* 1993; Maki *et al* 1994). Specific to those with MS, Porosińska *et al* (2010) reported that an increased risk of falls is related to increased postural sway velocity and length of mean sway, which is most pronounced in the ML direction. Conversely, comparing fallers with non-fallers, Maki *et al* (1994) reported that AP sway amplitude was higher in fallers; however, ML CoP movement was the strongest predictor of falls between groups. Since increases in postural sway in both directions appear to be associated with increased likelihood of falls (Palmieri *et al* 2002; Sosnoff *et al* 2011), for this PhD thesis a decrease in postural sway in either direction will be considered as an improvement in postural control and interpreted accordingly.

4.5.5 AP and ML standard deviation

The standard deviation (SD) is the dispersion of the CoP displacement from the mean position over the time of the recorded measurement, and specific to either the AP or ML direction. In healthy adults, Le Clair and Riach (1996) assessed the reliability of force platforms reporting the parameters of AP and ML SD, noting that AP and ML SD increase with time. Conversely, AP and ML SD have also been shown to decrease as a result of longer durations; hypothesised to be the result of the participant becoming accustomed to the task of maintaining postural control (Riach and Starkes 1994). Despite some debate, the use of AP and ML SD, as well as CoP measures, provide valuable information in assessing participants who present with minimal balance disturbances (Palmieri *et al* 2002).

4.5.6 CoP velocity

The CoP velocity (measured in mms−1) represents the total distance covered by the CoP (total sway path) divided by the duration of the sampled period (Figure 18, page 119). CoP velocity is considered to be a strong indication of the amount of activity required to maintain stability in an upright standing position (Geurts *et al* 1993). As such, increases in CoP velocity are also typically considered to be an indication of poor balance (Era *et al* 1996; Thapa *et al* 1996). Conversely, a decrease in CoP velocity is in indication of balance improvement. CoP velocity is a standard method of assessing postural control (Hunter and Hoffman 2001) and has demonstrated good reliability for between sessions during double limb stance (R = 0.84) (Le Clair and Riach 1996). Also, an increased risk of falls is related to increased postural sway velocity, which is most pronounced in the ML direction in those with MS (Porosińska *et al* 2010). Prosperini and Pozzilli (2013), using multivariate logistic regression in people with MS, calculated that for each 10mm increase in CoP path the risk of being classified as a faller also increases by 8%.

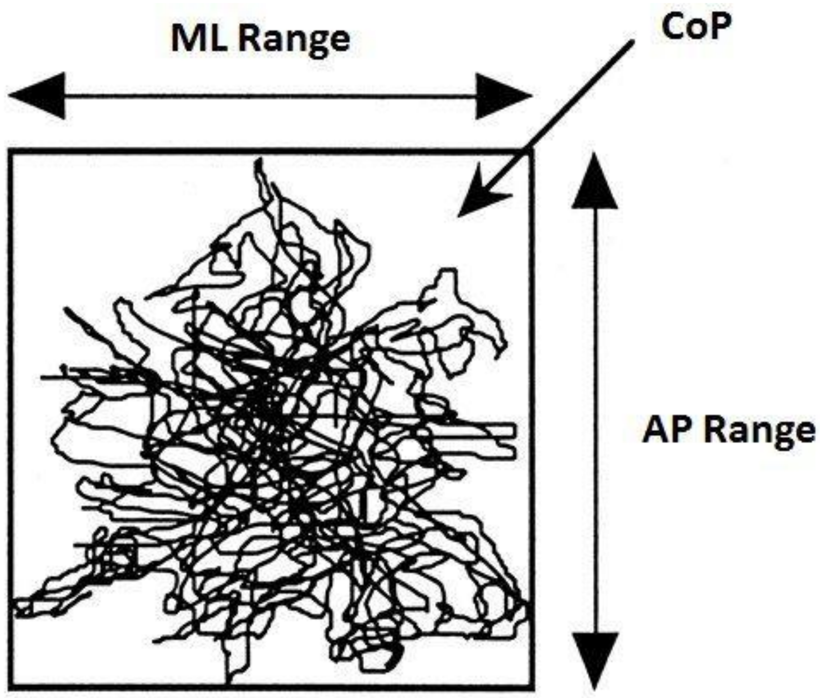

Figure 18 Visual representation of CoP path, and directional specific Range (anterior-posterior [AP] and medial--lateral [ML]) variables during standing balance

4.5.7 Factors Affecting Force Platform Data

There are a number of factors which can affect the reliability and validity of the force platform in the measurement of postural control. These will be introduced and acknowledged accordingly.

4.5.8 Number of measurement repetitions

There is some debate regarding the number of trials needed to establish a measure of reliability of postural control using a force platform. The limitations of a single measure are generally accepted – a single measure may skew the true measure of postural control through recording a fall or momentary loss of balance, and therefore reducing accuracy. Lafond *et al* (2004) found that two trials were enough to obtain a reliable measure of postural control. Conversely, Corriveau *et al* (2000) through investigating the intrasession reliability of CoP measures, recommended the recording of four repetitions. Pinsault and Vuillerme (2009) demonstrated that three 30 second trial recordings are sufficient to ensure excellent test–retest reliability in healthy participants (intraclass correlation coefficient [ICC] = 0.82). Based on previous studies, three trials of 30 seconds are consistent with comparable research, and will be used in this the PhD thesis.

4.5.9 Testing Duration

Similarly, there is no single agreed duration through which balance should be assessed. However, 30 seconds is reported as sufficient to assess adults and elderly populations (Le Clair and Riach 1996). Pinsault and Vuillerme (2009) demonstrated that a 30 second testing duration, recorded over 3 trials provided excellent test–retest reliability (ICC = 0.82). However, longer periods, such as 1-2 minutes may be too long for clinical populations like MS, which may lead to increased fatigue, a worsening of postural control, and limiting the ability to interpret any data. A testing duration of 30 seconds is comparable to previous research in both elderly-fallers (Jarnlo 2003; Hatton *et al* 2012) and people with MS (Brichetto *et al* 2013; Prosperini *et al* 2013), and will be used in the PhD thesis.

4.5.10 Foot positioning

When in an upright standing position, the base of support corresponds to a polygon determined by the lateral boarders of the feet. Alterations of foot position and orientation can have an effect on postural sway (Kirby *et al* 1987), and as such, the need to standardise foot placement is very important in the assessment of postural control (Chiari *et al* 2002). For example, a widening of the stance will have an effect of increasing the BoS and improving postural control. While the directional nature of this effect is unclear, it is agreed that changes will occur in AP and/or ML directions.

Therefore, the need to standardise foot position between testing is acknowledged. To achieve this, a procedure reported by Hatton *et al* (2009) (adapted from Buckley *et al* 2005) can be used where each participant stands on a piece of paper cut to the dimension of the force plate, adopting their normal preferred stance. This allows for a trace of the feet to be made; to be used for each test of postural stability and ensuring foot placement standardisation. This procedure will be employed in the PhD thesis.

4.5.11 ICF domain: Force platform

The assessment for postural stability sits within the ICF domain of Body Functions and Structures, and is specific to vestibular and proprioceptive function (Coenen *et al* 2011). It also sits within the domain of Activity and Participation, and is specific to changing and maintaining body position (Coenen *et al* 2011).

4.6 Temporal Spatial parameters of gait: GAITRite™

The characteristics of abnormal gait patterns assessed using quantitative measures, with large sample sizes, is currently limited in people with MS (Givon *et* *al* 2009). In the assessment of gait there are a number of clinical outcome measures used to quantify mobility, such as the TUG, the Timed 25 Foot Walk, the Six-Minute Walk Test and the MS specific 12-item Multiple Sclerosis Walking Scale (MSWS-12). However, as mentioned, these can be affected by a ceiling effect, and therefore have limited ability to detect small changes. However, the quantitative GAITRite™ system is sensitive enough to highlight compromised gait patterns in those with MS who present with very low levels of disability and of relatively short disease duration (Givon *et al* 2009). Previous (non-exergaming) studies have reported reduced stride length, velocity, and a prolonged double support phase in people with MS (Rodgers *et al* 1999; Givon *et al* 2009). Givon *et al* (2009) found significantly lower mean velocity, cadence, step length and Functional Ambulation Profile (FAP) scores, as well as significantly higher step time and base-of-support in MS participants compared to able-bodied healthy subjects. Also, people with MS may present with a wide-based gait and a deteriorating balance when changing direction (Tesio 2010).

The GAITRite™ is a walking mat consisting of computerised sensors, available in a variety of lengths (4.3 m to 7.9 m) and arranged in a grid-like pattern to identify footfall contacts (Givon *et al* 2009) (Figure 19). Gait measurements comprise: velocity, FAP, cadence, step length, stride length and heel-to-heel base of support, and are obtained using GAITRite™ software (CIR Systems, Inc., Havertown, PA 19083, USA). Participants can be assessed either barefoot or in their own shoes, in addition to with or without a walking aid. In the current thesis, the following GAITRite™ parameters were selected as they are commonly reported in comparable research: Velocity, Cadence, FAP score, Step Length (right and left), Stride length (right and left) and Heel-Heel support (right and left). A description of each parameter has been provided through Table 4.

For additional information and interpretation of the above parameters, the FAP scoring system integrates time and distance parameters to provide a numerical representation of gait ability and performance in adults (Nelson *et al* 2002). The FAP scoring system is based on the work of Nelson *et al* (2002) using healthy adults and the linear relationship of step length/leg length ratio to step time when velocity is "normalized" to leg length; providing a scoring system which ranges from 95 to 100 points in the healthy adult population.

Figure 19 GAITRite walking mat

Table 4 GAITRite™ system parameters and description

Variable	Description
Velocity (cm.s−1)	Obtained after dividing the Distance Travelled by the Ambulation time. It is expressed in centimetres per second (cm.s−1)
Cadence (steps/min)	Number of steps per minute
Functional Amb. Profile (FAP)	A numerical value of gait impairment based on selected temporal and spatial markers of gait
Step Length (Right and Left Foot) (cm)	Measured along the length of the walkway, from the heel centre of the current footprint to the heel centre of the previous footprint on the opposite foot.
Stride Length (Right and Left Foot) (cm)	Measured on the line of progression between the heel points of two consecutive footprints of the same foot (left to left, right to right)
HH Base Support (Right and Left Foot) (cm)	It is the vertical distance from heel centre of one footprint to the line of progression formed by two footprints of the opposite foot.

4.6.1 Validity and reliability

The GAITRite™ has high reliability in older adults (Menz *et al* 2004) and high concurrent validity compared with video-based motion analysis systems for spatial and temporal parameters of gait (Bilney *et al* 2003). The validity of the FAP score is well documented, with values of 0.90–0.97 for test–retest reliability and 0.95–1.00 for inter-rater reliability (McDonough *et al* 2001; Bilney *et al* 2003).

4.6.2 ICF domain: GAITRite™

Temporal spatial gait analysis through the GAITRite™ system will allow for information particular to the ICF components of Body functions and Structures, and specific to: Gait pattern functions, and Structure of the lower extremity. The GAITRite™ system will also provide data on the Activities and Participation component; namely, Walking and Moving around (Coenen *et al* 2011).

4.7 Psychometrics

In addition to providing an alternative means of exercise, there are also psychological benefits of exergaming technology. Studies have reported that exergaming is perceived as significantly less strenuous and more enjoyable than traditional therapy (Brumels *et al* 2008), in addition to positively affecting self-esteem, mood and motivation (Staiano and Calvert 2011). Exergaming may also be more acceptable and engaging than traditional means of exercise (Warburton *et al* 2007) - which may positively affect exercise uptake and concordance. The psychological concepts of user-acceptance (Venkatesh *et al* 2003) and flow experience (Jackson and Marsh 1996) are important to these aspects of therapeutic exercise prescription. Both of these are used in the assessment of exergaming technology, and will now be introduced.

4.7.1 Technology acceptance

To determine technology acceptance, and therefore user-acceptance and behavioural intention, Venkatesh *et al* (2003) created one unified model that integrated eight previous models for technology acceptance to develop the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire for informative technology systems.

Based on the UTAUT model, four constructs play a role as direct predictors of behavioural intention. As noted in Figure 14, page 75, the UTAUT model also includes four variables (gender, age, experience with the technology and voluntariness of use) that moderate the relationship between the four main constructs and behavioural intention and use behaviour (Venkatesh *et al* 2003). These four UTAUT main predictors of technology acceptance are defined as:

1. *Performance Expectancy* - the degree to which the user feels that the system will improve performance

2. *Effort Expectancy* - degree of ease associated with the use of the system

3. *Social Influence* - the degree to which those important to the user believe they should use the system

4. *Facilitating Conditions* - the degree to which the user believes that there is support for using that system

(Venkatesh *et al* 2003)

The first construct, *Performance Expectancy*, is considered the strongest predictor of intention; however, its effects on intention are likely to be moderated by the demographic factors of gender and age, such that the effect will be stronger for younger men (Venkatesh *et al* 2003). Both *Effort Expectancy* and *Social Influence* are positively related to behaviour intention to use technologies; however, conversely, this effect is stronger for older women with limited experience (Venkatesh *et al* 2003). Lastly, *Facilitating Conditions* has been shown to have a positive effect on actual use, which is stronger for older workers with high experience (Venkatesh *et al* 2003).

4.7.2 Validity and reliability

Venkatesh *et al* (2003), investigating the validity and reliability of the UTAUT model, reported that all psychometrically measured constructs in the UTAUT were reliable, with internal consistency levels 0.70 or higher. Furthermore, the UTAUT was found to be a more accurate predictor of technology acceptance, surpassing all previous acceptance models, and able to account for 70% of the total variance in usage intention (adjusted R^2) (Venkatesh *et al* 2003). To assess the applicability of the UTAUT model in playing online games through mobile phones, Chen *et al* (2011) reported reliability coefficients ranging from 0.90 (Facilitating Conditions) to 0.95 (Behavioural Intention), far exceeding the standard cut-off of 0.70. It was also reported that the UTAUT demonstrated acceptable convergent and discriminate validity, therefore, assuring construct validity (Chen *et al* 2011).

At present, and to the author's knowledge, there are no published studies to use the UTAUT questionnaire with exergaming technology and a clinical population. If exergaming technology is to be used as a therapeutic intervention, irrespective of its effectiveness, it must be accepted by the intended users. Therefore, the UTAUT questionnaire will be used to assess the user-acceptance, and its penultimate outcome variable behavioural intention, to use exergaming technology first with healthy sedentary individuals, and then with the clinical population of people with MS.

4.7.3 ICF domain: UTAUT

As the UTAUT is a measure of technology acceptance and therefore behavioural intention, it does not relate to the stated ICF components of Body Function and

Structures, Activities and Participation, or Personal and Environmental. However, as mentioned above, it will provide valuable information on the acceptance of exergaming technology.

4.7.4 Flow State

The concept of flow experience is related to a person's overall wellbeing, considered a state of optimal human experience (Seligman 2011), and linked to high levels of performance (Jackson and Eklund 2002). Flow is considered a state of pure engagement in an activity, linked to high enjoyment, and an intrinsically motivating optimal state (Csikszentmihalyi 1990). In the attainment of flow state, comparable to expressions of feeling 'in the zone', it is important that there is a balance between the skill/ability of the individual and the challenge/difficulty of the situation. If a task is too easy the individual will lose interest and become board; if it is too hard the individual will present with increased stress and anxiety (Figure 15, page 78). Flow plays an important role in understanding engagement and positive experiences in the context of gaming (Nah *et al* 2014), as commercial games are often designed using the very concepts of flow state (Chen 2007; Nacke and Lindley 2008). As a reminder, the principles of flow, as measured using the Flow State Scale (FSS) questionnaire for use in sport and physical activity (Jackson and Marsh 1996), are based on nine subscales:

1. *Autotelic Experience* - the activity is intrinsically rewarding and undertaken for its own sake

2. *Clear Goals* - clear idea of what needs to be accomplished

3. *Challenge-Skill Balance* - balance between the challenge of the activity and personal skills

4. *Concentration on the Task at Hand* - complete focused on the task

5. *Paradox of Control* - a belief of being in complete control of own actions, without any conscious or exertive effort at the task

6. *Unambiguous Feedback* - clear and immediate feedback

7. *Action-Awareness Merging* - involvement in the task; actions become automatic

8. *Transformation of Time* - altered perception of time; either speeding up or down

9. *Loss of Self-Consciousness* - no concerns with appearance; focused only the activity

.

4.7.5 Validity and reliability

The FSS has been used in a number of sports-based studies, and shown high internal consistency with alpha ranging from 0.72-0.91 (Jackson and Roberts 1992), 0.79 to 0.86 (Jackson and Marsh 1996), and 0.91 (Bakker *et al* 2011).

4.7.6 ICF domain: FSS

As the FSS is a measure of flow experience, it does not relate to ICF components of Body Function and Structures, Activities and Participation, or Personal and Environmental. However, as mentioned above, it will provide valuable information on the engagement properties in exergaming technology and attainment of the motivational optimal state of flow.

4.8 12-item Multiple Sclerosis Walking Scale (MSWS-12)

The MSWS-12 questionnaire (Hobart *et al* 2003) is a 12-item, disease-specific self-reported measure of walking ability, using a 5-point Likert scale, from 1 (Not at all) to 5 (Extremely). Completion of the questionnaire is based on the user rating the extent of their ability to walk and perform activities while standing during the previous two-weeks. Scores on the 12-items are summed and transformed to a 0-100 scale.

4.8.1 Validity and reliability

The MSWS-12 questionnaire has undergone extensive testing with regards to its psychometric properties, and as such, as a secondary outcome measure, validity and reliability will not be tested within this thesis. Previous research has demonstrated good internal consistency, high reliability and validity, and good generalizability (McGuigan and Hutchinson 2004; Motl and Snook 2008). Specifically, this questionnaire has excellent internal consistency (Cronbach's α = 0.97) and high reliability and validity (ICC = 0.96) (Graham and Hughes 2006), as well as good generalizability (Motl and Snook 2008). Higher scores are an indication of a greater impact of MS on walking ability, and range from 0 (no disability) to 100 (extreme disability) (Hobart *et al* 2003). The MS-specific MSWS-12 questionnaire is more resistant, but not immune, to floor and ceiling effects than comparable outcome measures (Bethoux and Bennett 2011).

4.8.2 ICF domain: MSWS-12

The MSWS-12 questionnaire will allow for information particular to the ICF components of Body functions and Structures, and specific to: Gait pattern functions, and Structure of the lower extremity, as well as the Activities and Participation component; namely, Walking and Moving around (Coenen *et al* 2011). Unlike physical measures of walking analysis, the MSWS-12, being a self-perceived measure of walking ability, may offer insight into walking ability in everyday life and therefore the effects of the intervention on activities of daily living.

4.9 WHODAS 2.0

The World Health Organisation Disability Assessment Schedule 2.0 (WHODAS 2.0) questionnaire is a measure of the aspects of functioning, and based on the concepts of the ICF (World Health Organisation [WHO] 2001). The WHODAS 2.0 is considered more holistic in its approach of the assessment of impairments and disabilities than more traditional assessments based on activities-of-daily-living scales (Schlote *et al* 2009). The WHODAS 2.0 is a self-report questionnaire that assesses activity limitations and participation restrictions (i.e. disability), irrespective of medical diagnosis. The WHODAS 2.0 was developed to assess difficulties due to health conditions including diseases, illnesses or injuries, mental or emotional problems, and problems with alcohol or drugs (Andrews *et al* 2009). It is a practical, generic assessment instrument that can measure health and disability at population level, or in clinical practice, to capture the level of functioning through six domains of life:

1. *Cognition* - understanding and communicating
2. *Mobility* - moving and getting around
3. *Self-care* - attending to hygiene, dressing, eating and staying alone
4. *Getting along* - interacting with other people
5. *Life activities* - domestic responsibilities, leisure, work and school
6. *Participation* - joining in community activities, participating in society.

(Üstün 2010)

The 12-item version measures the two most significant elements from the 36-item questionnaire, to measure all six elements of the ICF domain: 'Activities and Participation' (*Understanding and communicating*, items 3 and 6; *Getting around*, items 1 and 7; *Self-care*, items 8 and 9; *Getting along with people*, items 10 and 11; *Life activities*, items 2 and 12; and, *Participation in society*, items 4 and 5) (Luciano *et al* 2010). For each question the participant is asked to rate the magnitude of the disability from the previous 30 days, selecting either: *None* (indicating no difficulty), *Mild*, *Moderate*, *Severe* or *Extreme/cannot*.

4.9.1 Validity and reliability

The WHODAS 2.0 has undergone extensive testing in countries across the world with regards to its psychometric properties, and as such, as a secondary outcome measure, validity and reliability will not be tested within this thesis. Previous authors have established good reliability and item-response characteristics, and a sturdy factor structure that remains consistent across cultures and different types of patient populations. Specifically, the WHODAS 2.0 has high internal consistency (Cronbach's $\alpha = 0.86$), a stable factor structure, and high test-retest reliability (ICC = 0.98) (Üstün 2010).

4.9.2 ICF domain: WHODAS 2.0

The six domains reflect two dimensions of the ICF model: Activity limitations (understanding and communicating; getting around; and self-care) and Participation (getting along with others; life activities; and participation in society) (WHO 2010).

4.10 Summary

To gain the most insight into the effects of exergaming technology in terms of balance performance and gait, physical assessments should evaluate how balance strategies change under difference conditions (Horak 1997). Based on the strengths and weaknesses of clinical and laboratory outcome measures, a combination of both will be the most revealing in terms of balance performance; therefore, the application of both laboratory based (Kistler™ force plate and

GAITRite™) and clinical (MSWS-12 and WHODAS 2.0) measures will be employed in this PhD thesis in the assessment of a clinical group.

An important consideration in the prescription of new technologies is user-acceptance (to be quantified using the UTAUT questionnaire) and user-engagement (to be quantified using the FSS questionnaire); both will be addressed in the research presented in this PhD thesis. Irrespective of the effectiveness of an intervention, if it is not accepted by the intended user(s) there is little worth in validating it as an alternative intervention. Furthermore, to better understand the components of user-engagement during physical activity, and therefore intrinsic motivation, flow experience may offer insight into exercise concordance. Also, in the assessment of clinical populations, a MS-specific assessment of walking ability (using the MSWS-12 questionnaire), in addition to a more patient-centred assessment of exergaming technology (using the WHODAS 2.0 questionnaire) – specific to the domains of health and disability at a population level – will offer additional insight into the effectiveness of exergaming technology.

CHAPTER 5: METHODOLOGY FOR THE EFFECTS OF EXERGAMING IN HEALTHY SEDENTARY PARTICIPANTS

5.1 Introduction

The current chapter will describe the methods and procedures implemented during an investigation of the effect of exergaming on postural sway, user-acceptance and flow experience in healthy sedentary young adults recruited through study 1 of this thesis.

5.2 Aims

Through this exploratory trial the following primary aims are introduced:

To compare the effects of a four-week virtual reality/exergaming programme with healthy-sedentary participants in terms of postural sway, user-acceptance and flow experience between the:

a. Interactive Rehabilitation and Exercise system (IREX™)
b. Nintendo Wii Fit™ system

5.3 Study Design

An experimental pre- post-intervention randomised design was used. Participant randomisation was employed in an attempt to control confounding variables, selection bias and, with a large enough sample, baseline differences. Moreover, randomisation should ensure that any observable differences between the groups at post-intervention are most likely the result of manipulation of the independent variable, as opposed to other external factors (Lancaster and Titman 2011). Based on a framework for design and evaluation of complex interventions to improve health, this exploratory research was a phase II trial, and aimed to establish the acceptability and feasibility of the interventions (Campbell *et al* 2000; Medical Research Council 2000), using two groups and two factors:

Group 1 – Virtual rehabilitation using the IREX™ system

Group 2 – Exergaming using the Wii Fit™ system

Factor 1 - between-group, exercise group with two levels – IREX™ and Wii Fit™

Factor 2 - within-group, time with two levels - start (pre-intervention) and end (post-intervention)

5.4 Ethical Approval

Ethical approval was granted by the Teesside University School of Health and Social Care Research Ethics and Governance Committee in December 2009 (Appendix 2, page 327). Verbal and written informed consent (Appendix 3, page 329) was obtained having reviewed of the participant information sheet (Appendix 4, page 330) and screened both inclusion and exclusion criteria (described in section 5.6).

5.5 Recruitment, Sampling Method and Sample Size Estimation

Non-probability convenience sampling using poster advertisement, face-to-face contact and University email (Teesside University Outlook) was used to recruit participants (Appendix 5, page 335). Only email lists readily available to the

Teesside University Outlook account holders were used, in accordance with the 'Teesside University Notes for Guidance for Good Conduct in the Use of the Internet for Research'. In addition, posters were placed on designated Teesside University notice boards (Appendix 6, page 336). In the event of a 'serious adverse event' or 'suspected unexpected serious adverse reaction', all such occurrences will be reported immediately to the PhD supervisors and the study sponsor (Teesside University) using standardised documentation (Appendix 7, page 337). Using the program G*Power Version 3.1.9.2 (Faul *et al* 2007), a power analysis was conducted for a two-group comparison to detect a large effect (f = 0.40) for the postural sway outcome measure and 0.80 power using analysis of variance, calculating a sample size of 26 per group (52 total). To adjust for a dropout rate of 20%, the total required sample size was 64. Within the final four weeks of the study no new participants had volunteered to take part, and restricted by time, data collection ended before the stipulated target of 64 participants was achieved.

5.6 Participants, Inclusion and Exclusion Criteria

A sample of 33 participants (25 females, 8 males; mean age 28 years, Standard Deviation [SD] 8; mean height 1.71cm, SD 0.11; mean weight 63.85kg, SD 13.30) were recruited from staff and students of Teesside University. Inclusion criteria were: aged 18-65 years, leading a predominantly sedentary life style (defined as undertaking less than 30 minutes of moderate exercise most weeks [ACSM 2005]). Exclusion criteria were: any condition or injury which would contraindicate participation in the exercise programme and physical activity, acute/sub-acute musculoskeletal injury (within the previous 12-weeks, since occurrence), and inability to comprehend and write English.

5.7 Research Environment

All data collection and interventions took place at the School of Health and Social Care Physiotherapy Research Laboratory, Constantine Building, Teesside University.

5.8 Instrumentation and outcomes measures

5.8.1 Kistler force platform

Postural sway data were obtained from a Kistler™ Force plate (Model 9286AA, Kistler, Alton, UK) - W 40 × L 60 × H 3.5 cm - with a sampling rate of 1000 Hz. Balance outcomes were the centre of pressure velocity (CoP, mm.sec^{-1}), and the range and SD of the excursions in the anterior-posterior (AP) and medial-lateral (ML) directions (AP range, AP SD, ML range, ML SD respectively, all mm) during bipedal (BP) and unipedal (UP) standing with eyes open.

5.9 Psychometrics

Quantitative measures of psychological social-cognition variables were recorded through self-completion paper-based questionnaires. These will provide insight into the effects of exergaming technology with regards to user-acceptance and flow experience following a four-week intervention. The first questionnaire was recorded to measure user-acceptance and exercise behaviour using the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire (Venkatesh et al 2003) (Appendix 8, page 339). Attitude towards exercise behaviour was measured using the Flow State Scale (FSS) questionnaire (Jackson and Marsh 1996) (Appendix 9, page 347).

5.9.1 Technological Acceptance Questionnaire

The UTAUT questionnaire contains 22 items related to the behaviour of exercise across six subscales. Four of the six scales are considered direct predictors of behavioural intention (to use the technology): *Performance Expectancy* (PE; the degree to which the user feels that the system will improve performance), *Effort Expectancy* (EE; the system's ease-of-use), *Social Influences* (SI; the degree to which those important to the user believe they should use the system) and *Facilitating Conditions* (FC; the degree to which the user believes that there is support for using that system). The remaining subscales are: *Self-Efficacy* (SE; the degree to which a person is confident of using the system) and *Behavioural Intention* (BI; the degree to which a person has intention to use the system) (Venkatesh *et al* 2003).

5.9.2 Flow State Scale Questionnaire

Flow state is an optimal human experience which can occur during any activity, is linked to a person's overall wellbeing and often referred to as a state of pure engagement (Seligman 2011), and related to high enjoyment and concordance (Csikszentmihalyi 1990). The principles of flow were adapted to produce the FSS for use in sport and physical activity to identify and understand the nature of the experience in these environments (Jackson and Marsh 1996). The FSS is based on nine subscales: *Autotelic Experience* (AE; the activity is intrinsically rewarding and undertaken for its own sake), *Clear Goals* (CG; clear idea of what needs to be accomplished), *Challenge-Skill Balance* (CB; balance between the challenge of the activity and personal skills), *Concentration-On-Task* (CT; complete focused on the task), *Paradox Of Control* (PC; clear feeling of control), *Unambiguous Feedback* (UF; clear and immediate feedback), *Action-Awareness Merging* (AM; involvement in the task; actions become automatic), *Transformation of Time* (TT; altered perception of time; either speeding up or down), and *Loss of Self-Consciousness* (LS; no concerns with appearance; focused only on the activity).

5.10 Participant Positioning

5.10.1 Foot positioning and foot templates

Foot position was not standardised. However, all participants were given the same instructions regarding foot placement. Participants were asked to place their feet in a position that felt natural, at approximately hip width (Mochizuki *et al* 2006), and equidistant to the borders of the force plate; this was visually checked by the researcher (JR) during each recording. All participants were asked to stand on the force platform having removed both shoes and socks.

5.10.2 Upper limbs

Instruction to reduce the variability of upper body movement was given. All participants were asked to stand relaxed, as quietly as possible, with their eyes open, and their arms positioned at their sides; comparable to previous research (Hatton *et al* 2009; Mochizuki *et al* 2006).

5.10.3 Head orientation

In an attempt to control for head position during quite standing, participants were instructed to stand looking directly forwards and to focus on a visual target (round black marker, 100mm in diameter) positioned on a board 3m from the force platform (see Figure 20). As reported by previous authors, this visual target was adjusted to the eye level of each participant and placed at a height equal to eye level and adjusting for the depth of the force platform (350mm) (Rome and Brown 2004; Wilson *et al* 2008; Hatton *et al* 2009; Rome *et al* 2009).

5.10.4 Seating specifications

Participants were seated on a hydraulic plinth, adjusted to allow for sitting with the knees at 90°. For this, the height of the plinth was measured using a tape measure from the force platform to the upper surface of the plinth, and adjusted to each participant’s knee height, comparable to previous research (Hatton *et al* 2009).

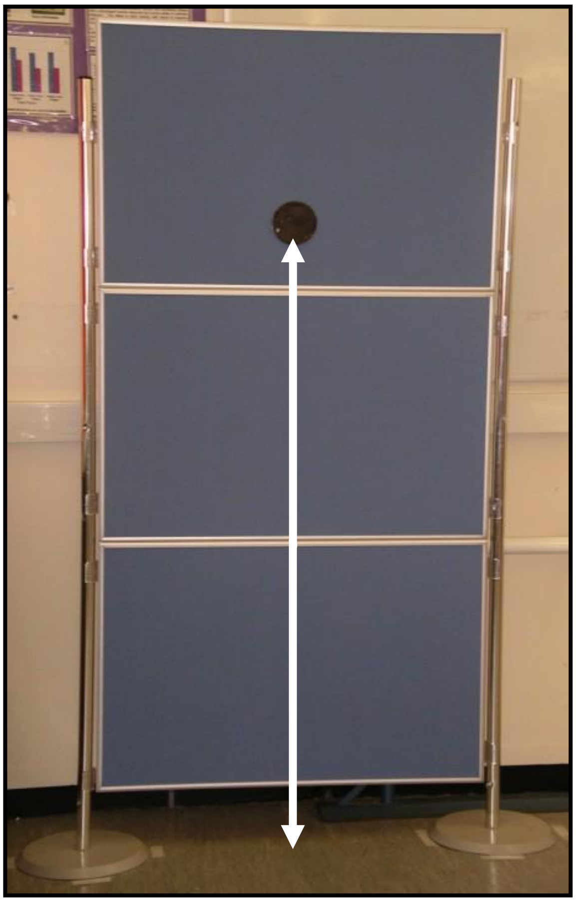

Figure 20 Visual marker mounted at participants eye level and placed in front of Kistler™ force plate

5.10.5 Exergaming Systems

The Interactive Rehabilitation and Exercise system (IREX™) (*http://www.gesturetekhealth.com*) uses gesture-recognition technology to allow the user to interact with a game in real time, using their own body movements, and viewing their *own* image projected into a virtual environment (see Figure 21). The second system, the Nintendo Wii Fit™ (Nintendo Wii™, Nintendo™ Co Ltd, Minami-ku Kyoto, Japan), uses a central game console, connected to a television. Navigation is via a handheld control pad (see Figure 22) and the distribution of weight while standing on the Wii Fit™ balance board (length 511mm, width

316mm and height 53.6mm), which controls an *avatar* in the gaming environment (see Figure 23). For both platforms, the games environment and images were displayed on a 37 inch widescreen Plasma television (Hanspree, Type T73B, Greyenstraat 65, Netherlands).

Figure 21 Gameplay using the IREX™ system

Figure 22 Gameplay using the Nintendo Wii Fit™ and Wii Fit™ handheld controllers

Figure 23 Gameplay using the Nintendo Wii Fit™ and Wii Fit™ board

5.11 Procedures

5.11.1 Clothing

All participants were asked to wear appropriate clothing for physical activity for both pre- and post-intervention data collection, and the exercise interventions, having removed all footwear, socks and tights/stockings.

5.11.2 Quiet standing balance

For the collection of postural sway data, participants were asked to stand on the Kistler™ force plate with their eyes open (looking at a black circle placed at eye level, 3 m from the centre of the force plate) and to remain as relaxed as possible. Standing balance was recorded once the participant was correctly orientated with regards to foot and upper body position. At this point, recording was triggered using the Kistler force platform. Participants stood for 30 seconds, three times, with 15 seconds between each, then, after a two-minute break, three times for 15 seconds on only their dominant leg (preferred kicking leg).

5.11.3 Group randomisation

Once baseline balance data were collected, participants were randomised to either the IREX™ or Wii Fit™ group using cards randomly generated to treatment allocations, concealed in opaque envelopes.

5.11.4 Intervention

The first training session was undertaken immediately after group allocation. During this initial session the researcher (JR) explained the procedures and demonstrated the movements required for each game, answering any questions offered by the participant. The IREX™ games were matched with the Wii™ games in terms of their physical demands: the first four focused on balance training (1-4) and the remainder (5-8) on general physical activity (see Table 5; images of gameplay provided through Appendix 10, page 351). Participants allocated to the Nintendo Wii™ and Wii Fit™ system were asked to play four balance orientated games (1-4), and four games based on general physical activity exercises (5-8) (see Table 6; images of gameplay provided through Appendix 11, page 354). This required the participant to stand on the Wii Fit™ balance board. The system creates a cartoon like avatar on the screen which the participant controls and moves by varying their weight distribution on the board. No additional equipment is required.

Participants played all of the eight games allocated to their group. The four balance games were repeated three times (with a one-minute break between each) and the four general physical activity games were completed only once (also with a one-minute break between each). Each game initially lasted for approximately one to two minutes. Each session lasted for 30-40 minutes, and was conducted on a one-to-one basis under the supervision of the primary researcher (JR). Both groups completed a total of 12 sessions, three times a week for four-weeks. For those allocated to the IREX™, all participants began at an intensity setting of 3 (minimum of 1 to maximum of 10) and progressed at the participants request through subsequent sessions. For Wii Fit™, there were only two settings, and all participants began at *Normal* and increased to *Advanced* upon request. Having completed the four-week programme each participant repeated the measures recorded at baseline at a final appointment, within five days of the final exergaming session.

Table 5 IREX™ Games - Study 1 Healthy sedentary participants

No.	Exergame - IREX™	Duration
1	**Formula Racing** *Driving a F1 car around a track through body position. Encouraging postural/dynamic mobility through shifting of weight in a standing position.*	1min x3
2	**Snowboard** *Snowboarding around a course in which directions is controlled through moving forwards and back when standing side-on to the TV. Encouraging mobility and balance.*	1min x3
3	**Soccer** *As a soccer goalie, the participant must move his or her body in order to block as many balls as possible from entering into the soccer net. Encouraging full body movement and dynamic stability.*	1min x3
4	**Conveyor** *The subject moves boxes from one conveyor belt to the other. Encouraging postural stability and trunk mobility through rotation.*	1min x3
5	**Step ups/Forwards step up/ up and over** *Completed with use of a step up box. The subject copies a virtual instructor in completing the exercise. Encouraging dynamic stability and strength. This game has a 3 minute allocation as it is a combination of steps, forward steps and stepping up and over*	3min
6	**Hip abduction** *Simple hip mobility exercise undertaken with the subject in standing. One leg supports the body while the other is moved to the side. Encouraging postural stability and strength.*	1min
7	**Lunges** *The participant steps one leg forward and into a lunge position flexing the forward knee while maintaining an erect torso. Encouraging postural/dynamic stability and strength.*	1min
8	**Squat** *The participant should stand with both feet less than a shoulder width apart and flex at the hip and knee while maintaining an erect torso. Encouraging postural stability and strength.*	1min

Table 6 Wii Fit™ Games - Study 1 Healthy sedentary participants

No.	Exergame - Wii Fit™	Duration
1	**Ski Slalom (Balance Games)** *Ski down the mountain slope and try to navigate through the flags. The goal is to slide down the mountain around the flags. Encouraging static mobility.*	1min x3
2	**Snowboard slalom (Balance Games)** *Realigning the board sideways and standing on it like a snowboard. Same purpose as Ski Slalom*	1min x3
3	**Soccer heading (Balance Games)** *Teammates will take turns kicking soccer balls, soccer shoes, or panda heads at you. Points are scored by heading the soccer ball. To interact with the avatar body weight in shifted left/right. (Point: you do not actually have to make a heading motion)*	1min x3
4	**Torso Twists (Strength Training)** *Virtual demonstration and instruction of standing trunk rotations while maintaining postural stability.*	1min x3
5	**Basic Step (Aerobics Training)** *Combination of step up exercises undertaking to a musical beat. Movements are made forwards, right and left of the Wii Fit™ board.*	3min
6	**Sideways Leg Lift (Strength Training)** *As IREX™ - Virtual demonstration and instruction of leg Abduction while standing on the Wii Fit™ board*	1min
7	**Lunges (Strength Training)** *As IREX™ - Virtual demonstration and instruction of a simple lunge exercise*	1min
8	**Rowing Squat (Strength Training)** *As IREX™ - Virtual demonstration and instruction of a simple squat exercise*	1min

5.11.5 Technological Acceptance and Flow State Scale Questionnaires

At the end of the first session participants completed the UTAUT and FSS questionnaires, and were reminded to provide an answer based on their initial opinion at that point in time (not a predicted opinion having completed the four-week intervention). This was to ensure that comparisons could be made over time.

5.11.6 Data Processing and Extraction

Postural sway data obtained from the Kistler™ Force plate (Model 9286AA, Kistler, alton, UK) – W 40 x L 60 x H3.5 cm - with a sampling rate of 1000 Hz. The CoP AP and ML range and SD (mm) were calculated automatically using the force platform Bioware software package. CoP velocity ($mm.sec^{-1}$) were calculated using previous methods (Raymakers *et al* 2005) after low-pass filtering of the raw data at 10Hz.

5.11.7 Statistical Analysis

Data were analysed with Statistical Package for the Social Sciences Version 18 for Windows (SPSS™, Chicago, IL, USA) *as randomised,* following intention-to-treat principles. Intention-to-treat dictates that all participants that are randomised are included in the final analysis, regardless of withdrawal or becoming lost to follow-up (Montedori *et al* 2011). To account for any differences between the groups at baseline, separate analyses of covariance (ANCOVA) were conducted for each outcome measure to identify post-intervention between-group differences, using the pre-intervention values as a covariate. In addition, within-group differences over-time (pre- to post-intervention) were investigated with paired *t*-tests. Based on the lack of comparative research, through this exploratory analyses there was greater concern with first identifying the presence of an effect, which could be tested further in subsequent studies (and hence avoiding Type II errors is considered more important than making Type I errors [Armstrong 2014]). Therefore, Bonferroni corrections were not used, as this would significantly reduce the power of analyses and increase the probability of Type II errors (Perneger 1998; Armstrong 2014). All analysis used a significance level of 0.05. Effect sizes based on a difference in mean scores were expressed as Cohen's *d,* and values of 0.2, 0.5, and 0.8 used to interpret the effect sizes as small, moderate, and large, respectively (Cohen 1988). The reporting of effect sizes allows for additional interpretation, beyond the simple provision of *p* values, to establish the magnitude of the difference using a standardized measure. In an exploratory analysis, multiple regression was used to investigate influences on future use of the platforms for exercise, where the UTAUT subscale of BI was used as the dependent variable and the other subscales as predictors.

5.11.8 Further analysis using Magnitude Based Inferences

Clinical research data is commonly analysed using traditional statistical probability (*p*-values); however, this can limit the clinicians' ability to interpret said data in aid of clinical decision making (Page 2014). One method for interpreting statistical significance is to use the 'minimal clinically important difference', the 'minimally clinically important change, or the 'smallest worthwhile change'. These provide the clinician with a means of quantifying the magnitude or importance of a statistical effect (Copay *et al* 2007) for clinical interpretation.

The concept of Magnitude Based Inferences (MBI) allows for further interpretation of inferential statistics, beyond the traditional method of null-hypothesis significance testing, especially in the finding of non-significance. Where traditional interpretation is solely based on the findings of significance (where $p \leq 0.05$) or non-significance (where $p > 0.05$), MBI allows for exploration beyond this arbitrary threshold using the concept of smallest worthwhile change value and confidence intervals.

Using an Excel spreadsheet by Hopkins (2007), quantitative inferences about the true (population) values of the effect of exergaming on postural sway were calculated by converting the *P* values into 90% confidence intervals for, and inferences about, the true value of the effect statistic. An effect was deemed unclear if its confidence interval overlapped the thresholds for substantiveness; that is, if the effect could be substantially positive and negative, or beneficial and harmful (Batterham and Hopkins 2006). This approach divides the effect into likelihoods of benefit, triviality, and harm[9] by dividing the range of substantial values into more finely graded magnitudes. These, combined with relevant qualitative descriptors, were used to interpret outcomes with regards to the likelihood of benefit as follows: <1%, almost certainly not; 1–5%, *very unlikely*; 5–25%, *unlikely or probably not*; 25–75%, *possibly or may be*; 75–95%, *likely or probably*; 95–99%, *very likely*; >99%, *almost certainly* (Hopkins *et al* 2009).

[9] The descriptor of 'harm(ful)' does not infer actual physical harm; only that the outcome variable may have a negative effect on balance performance.

The concept of smallest worthwhile change is not a new one, and can be considered a means of justifying the cost, risk, and inconvenience of an intervention (Ferreira *et al* 2012). However, establishing the smallest worthwhile change using posturography, in clinical groups, is currently lacking. In fact, there are no standards for calculating clinically important changes in outcomes (Page 2014). This can make clinical interpretation of such measures difficult. In the only study to report on such, Šarabon *et al* (2010), with the aim of determining the reliability of a new portable balance measurement system (comparable to a force plate), used a statistical model reported by Hopkins (2000) to establish the smallest worthwhile change. Šarabon et al (2010), based on the findings of Orr *et al* (2006) and Paterno *et al* (2004), suggested that a change in balance ability of around 10% would be practically meaningful. Despite this figure appearing liberal, where the smallest worthwhile change for athletes may be as small as 0.5% (Flyger 2009), and not derived from a clinical population, it does provide a conservative point of reference which errs on the side of caution in terms of clinical interpretation. Therefore, to make such inferences, the smallest worthwhile change in balance performance was assumed to be a reduction or increase of 10%.

5.11.9 Within-Session Reliability

The reliability of the physiological outcome measures were assessed using a 2-way fixed Intraclass Correlation Coefficient (ICC), to establish the test-retest reliability, and using the three data collection trials[10] (Weir 2005). ICC is a measure of the between-subject variance versus total variance. ICC close to or approaching

[10] E.g. where balance was recorded over three trials to calculate an average and used for statistical inferences

1.0 are an indication of little variance between each measure (e.g. postural sway: reliability across the three measurement trials), and a measure of consistency between the comparable variables (Field 2009). Interpretation is based on the thresholds reported by Cicchetti and Sparrow (1981)[11].

To assess the ability of the psychological questionnaire subscales to measure the noted dimensions consistently, internal consistency - the extent to which all items measure the same concept (Tavakol and Dennick 2011) - of the UTAUT and FSS will be established using Cronbach's coefficient (α). Cronbach's α is the most widely used objective measure of reliability, reflects the average inter-correlation among all of the items, and is considered to demonstrate acceptable reliability when ranging between 0.70-0.80 (Field 2009; Tavakol and Dennick 2011).

[11] ICC can be interpreted as follows: 0-0.2 indicates poor agreement; 0.3-0.4 indicates fair agreement; 0.5-0.6 indicates moderate agreement; 0.7-0.8 indicates strong agreement; and > 0.8 indicates almost perfect agreement.

CHAPTER 6: RESULTS FOR THE EFFECTS OF EXERGAMING IN HEALTHY SEDENTARY PARTICIPANTS

6.1 Introduction

This chapter will present the results of exergaming on postural sway parameters during bipedal (BP) and unipedal (UP) quiet standing balance, recorded over 30 seconds (BP) and 15 seconds (UP), in healthy sedentary adults. The results of the psychological measures of user-acceptance and flow experience will also be reported. This chapter will present descriptive statistics such as mean, standard deviation (SD), intraclass correlations coefficients (ICCs), 95% confidence intervals and effect size.

6.2 Healthy sedentary Subjects

A convenience sample of 37 healthy sedentary adult participants was recruited from a population of university staff and students; of these, 33 met the inclusion criteria. Sixteen participants were randomly allocated to the Interactive Rehabilitation and Exercise system (IREX™) group (mean age 29 years, SD 9) and 17 to the Nintendo Wii Fit™ (mean age 27 years, SD 7). Four participants withdrew from the study at week three due to increased work commitments, as documented in the Consolidated Standards of Reporting Trials (CONSORT) flow diagram (see Figure 24). No adverse event were observed or reported.

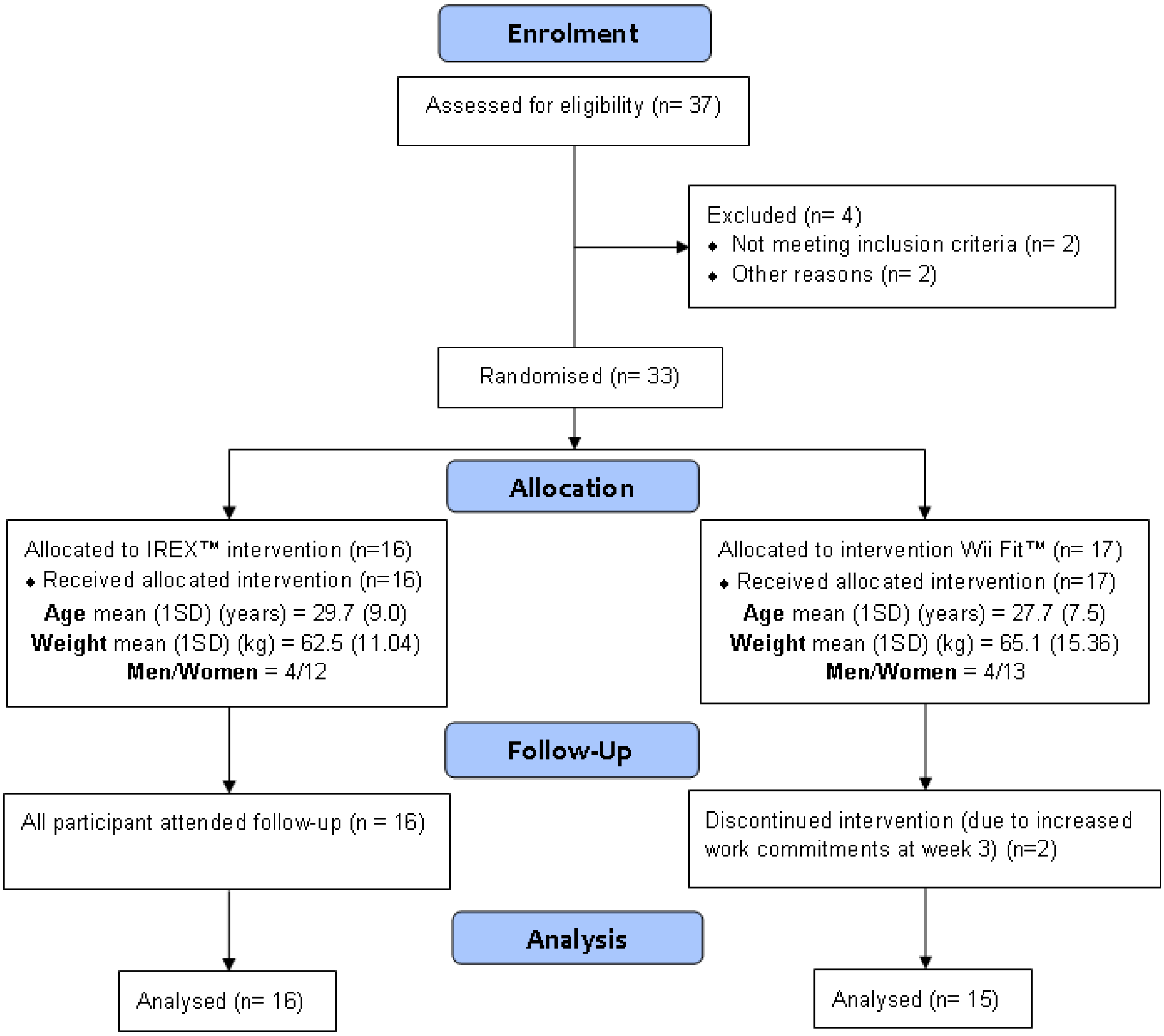

Figure 24 CONSORT flow diagram for healthy sedentary adults recruitment

6.3 Postural Sway and Exergaming in Healthy sedentary Adults

6.3.1 Reliability of Postural Sway

All ICCs[12] were found to be greater than 0.2 - the threshold for poor agreement - and ranged from fair (ICC ≥ 0.3) to almost perfect reliability (ICC ≥ 0.9) (Table 7).

Table 7 Intraclass Correlation Coefficient for postural sway data at pre- and post-intervention

	Pre-intervention: Bipedal			**Pre-intervention: Unipedal**		
Variable	Intraclass Correlation	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Intraclass Correlation	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
COP	**0.90**	0.83	0.95	**0.70**	0.52	0.83
AP SD	**0.41**	0.20	0.62	**0.30**	0.06	0.53
AP Range	**0.44**	0.23	0.64	**0.31**	0.05	0.53
ML SD	**0.67**	0.49	0.80	**0.51**	0.29	0.70
ML Range	**0.75**	0.60	0.86	**0.55**	0.34	0.74
	Post-intervention: Bipedal			**Post-intervention: Unipedal**		
Variable	Intraclass Correlation	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Intraclass Correlation	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
COP	**0.80**	0.76	0.98	**0.78**	0.64	0.88
AP SD	**0.36**	0.13	0.60	**0.39**	0.16	0.61
AP Range	**0.37**	0.14	0.60	**0.43**	0.20	0.64
ML SD	**0.34**	0.11	0.58	**0.51**	0.26	0.70
ML Range	**0.49**	0.27	0.70	**0.52**	0.31	0.71

[12] ICC can be interpreted as follows: 0-0.2 indicates poor agreement; 0.3-0.4 indicates fair agreement; 0.5-0.6 indicates moderate agreement; 0.7-0.8 indicates strong agreement; and > 0.8 indicates almost perfect agreement (Cicchetti & Sparrow, 1981).

6.3.2 Postural Sway during Quiet Standing in healthy sedentary participants

The non-adjusted descriptive statistics of postural sway, as recorded both pre- and post-intervention using the Kistler Force platform, are shown in Table 8.

6.3.3 Postural Sway Results: Between-Groups Post-Intervention Differences

The analysis of covariance (ANCOVA) indicated significant baseline (covariate) effects for all postural sway measures ($p < 0.05$), with the exception of UP anterior-posterior (AP) standard deviation (SD) and UP AP range. For the effect of group, the ANCOVA identified no significant post-intervention between-groups differences for any of the measures of postural sway (see Table 9).

6.3.4 Postural Sway Results: Within-Group Change Over-Time

There were general improvements in all balance outcomes (through a reduction in balance measures), with the exception of UP AP SD in the Wii Fit™ group. Of these, paired *t*-tests identified significant improvements over-time for the IREX™ group in four of the UP measures (UP AP range, t [13] = 2.21, p = 0.05, d = 0.6; UP medial-lateral [ML] range, t [13] = 1.37, p = 0.04, d = 0.7; UP ML SD, t [13] = 2.68, p = 0.02, d = 0.7; and UP centre of pressure (CoP) Velocity, t [13] = 3.87, p = 0.002, d = 1.1) (see Table 9). For the Wii Fit™ group significant improvements were found in two of the UP measures and one of the BP measures (BP ML Range, t [16] = 2.2, p = 0.05, d = 0.5; UP ML range, t [16] = 2.4, p = 0.03, d = 0.6; and UP CoP, t [16] = 2.2, p = 0.01, d = 0.7).

Table 8 Descriptive statistics of pre- and post-programme values (mean, SD) for force-plate measures: anterior-posterior (AP) and medial-lateral (ML) SD and range (mm), and Centre of Pressure velocity (CoP) (mm.sec-1) during bipedal and unipedal standing

		Pre-Programme		Post-Programme	
		IREX™	Wii Fit™	IREX™	Wii Fit™
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Bipedal	AP SD	3.9 (1.1)	4.4 (1.4)	3.9 (1.3)	4.2 (1.5)
	AP Range	19.8 (5.0)	20.5 (5.4)	19.2 (6.2)	19.7 (6.2)
	ML SD	2.4 (1.6)	2.7 (1.5)	2.0 (0.9)	2.3 (1.1)
	ML Range	14.5 (8.7)	14.2 (6.4)	11.2 (4.6)	11.8 (4.6)
	COP Velocity	26.0 (7.1)	21.0 (4.3)	23.5 (4.0)	20.7 (3.8)
Unipedal	AP SD	8.3 (2.3)	6.6 (1.6)	6.9 (2.1)	6.9 (1.8)
	AP Range	40.5 (13.5)	30.0 (8.5)	30.9 (7.3)	32.3 (8.0)
	ML SD	6.1 (1.9)	5.3 (1.3)	4.9 (0.8)	5.1 (1.3)
	ML Range	28.2 (5.9)	27.0 (5.9)	24.1 (4.0)	25.0 (5.8)
	COP Velocity	50.6 (14.8)	43.1 (7.6)	40.3 (7.2)	39.6 (7.8)

Table 9 Force plate balance measures: between-group (group effect – ANCOVA) and within-subject (time effect – paired t-test) mean diff (95% Confidence Interval [CI]) for force-plate measures: anterior-posterior (AP) and medial-lateral (ML), SD and range (mm), and Centre of Pressure velocity (CoP Velocity) (mm.sec-1) during bipedal and unipedal standing

		Adjusted post-intervention difference between groups (ANCOVA)			Within-group change over time (paired t-test)					
					IREX™			Wii™		
		Mean diff. (95% CI)	*P*	*d*	Mean (95% CI) diff	*P*	*d*	Mean (95% CI) diff	*P*	*d*
Bipedal	**AP SD**	-0.1 (-0.9 to 1.0)	.91	0.0	-0.0 (-0.6 to 0.6)	.92	0.0	-0.2 (-1.0 to 0.6)	.65	0.1
	AP Range	-0.2 (-4.3 to 4.0)	.93	0.0	-0.6 (-4.1 to 2.9)	.71	0.1	-0.8 (-3.8 to 2.3)	.61	0.1
	ML SD	-0.2 (-0.9 to 0.5)	.66	0.2	-0.4 (-1.4 to 0.6)	.38	0.2	-0.5 (-1.1 to 0.1)	.10	0.4
	ML Range	-0.6 (-3.7 to 2.5)	.68	0.2	-3.3 (-8.4 to 1.9)	.19	0.4	-2.4 (-4.8 to -0.0)	.05*	0.5
	COP Velocity	0.2 (-1.9 to 2.3)	.84	0.0	-2.5 (-5.5 to 0.5)	.10	0.5	-0.3 (-1.3 to 0.7)	.50	0.2
Unipedal	**AP SD**	-0.1 (-1.7 to 1.5)	.91	0.0	-1.3 (-3.3 to 0.7)	.17	0.4	0.4 (-0.7 to 1.4)	.49	0.2
	AP Range	-2.2 (-8.5 to 4.1)	.48	0.3	-9.7 (-19.2 to -0.1)	.05*	0.6	-0.7 (-5.5 to 4.1)	.80	0.1
	ML SD	-0.6 (-1.3 to 0.1)	.10	0.7	-1.3 (-2.3 to -0.2)	.02*	0.7	-0.2 (-0.6 to 0.3)	.77	0.2
	ML Range	-1.5 (-4.6 to 1.6)	.32	0.4	-4.4 (-7.9 to -0.3)	.04*	0.7	-2.0 (-3.8 to -0.3)	.03*	0.6
	COP Velocity	-3.1 (-7.1 to 1.0)	.13	0.7	-10.3 (-16.1 to -4.5)	.001*	1.1	-3.6 (-6.3 to -0.9)	.01*	0.7

[a] * = Significance at the $p < .05$ level

[b] *P* = P value; *d* = Cohen's *d*

6.3.5 Magnitude Based Inferences: Postural Sway In Healthy Sedentary Adults

Magnitude-based inferences (MBI) indicated the overall positive effects of the IREX™ on postural sway measures, with the likelihood of benefit ranging from 82.4% to 99.8%. Where traditional null-hypothesis significance testing indicated a significant improvement in postural sway, MBI indicated a likelihood of benefit of 96% and 96.8% for UP AP range and UP ML range, respectively. The MBI Excel spreadsheet provided qualitative descriptors which further expressed these findings as "*very likely beneficial, very likely unlikely harmful*" for these balance measures (see Table 10). It is important to note that MBI also suggests the likelihood of benefit where non-significance was found using null-hypothesis significance testing, for the following variables: BP CoP velocity, UP AP SD, and BP ML SD (see Table 10). The variable BP ML SD was considered non-significant according to null-hypothesis significance testing, and MBI indicating the likely outcome as *Trivial* (MBI estimated likelihood of benefit = 41.3%) or *Harmful* (MBI estimated likelihood of benefit = 53.4%).

For the Wii Fit™ group, where traditional null-hypothesis significance testing indicated a significant improvement in postural sway, MBI indicated a likelihood of benefit of 95.6%, 97.5% and 99.1% for BP ML range, UP ML range and UP CoP velocity, respectively (see Table 11). Similarly, where non-significance was found using null-hypothesis significance testing, MBI reports the likelihood of benefit in BP ML SD (MBI estimated likelihood of benefit = 91.7%). For the Wii Fit™ group, the remaining variables are considered as unclear, suggesting more data is needed, or that the likely outcome is *Trivial* or possibly *Harmful*.

Table 10 Qualitative inferences using MBI about the effects of exergaming on postural sway performance, expressed as beneficial, trivial, and harmful (as a percentage), in the IREX™ group

		Percentage Chance			Conclusion
		Beneficial	**Trivial**	**Harmful**	
Bipedal	**AP SD**	45.8	0.3	53.8	Unclear
	AP Range	34.1	2.8	63.1	Unclear
	ML SD	5.4	41.3	**53.4**	Poss. harmful, unlikely beneficial, don't use
	ML Range	**82.4**	12.9	4.7	Likely beneficial, very unlikely harmful, use
	CoP Velocity	**91.9**	5.1	3	Likely beneficial, very unlikely harmful, use
Unipedal	**AP SD**	**85.2**	10.2	4.6	Likely beneficial, very unlikely harmful. Use
	AP Range*	**96.0**	2.4	1.6	Very likely beneficial, very unlikely harmful, use
	ML SD*	**98.4**	1.0	0.6	Very likely beneficial, very unlikely harmful, use
	ML Range*	**96.8**	1.9	1.3	Very likely beneficial, very unlikely harmful, use
	CoP Velocity*	**99.8**	0.1	0.1	Most likely beneficial, most unlikely harmful, use

* Significance through traditional null-hypothesis significance testing using the *p* value

a. The Percentage Chance descriptor - 'Harmful' - does not infer actual physical harm; only that the outcome variable may have a negative effect on balance performance.

Table 11 Qualitative inferences using MBI about the effects of exergaming on postural sway performance, expressed as beneficial, trivial, and harmful (as a percentage), in the Wii™ group.

		Percentage chance			Conclusion
		Beneficial	**Trivial**	**Harmful**	
Bipedal	**AP SD**	30.5	4	65.6	Unclear
	AP Range	28	5	66.9	Unclear
	ML SD	**91.7**	5.4	2.9	Likely beneficial, very unlikely harmful, use.
	ML Range*	**95.6**	2.6	1.5	Very likely beneficial, very unlikely harmful, use
	CoP Velocity	20.1	10.4	**69.5**	Poss. harmful; unlikely beneficial.
Unipedal	**AP SD**	19.9	11.39	69.4	Poss. harmful, unlikely beneficial, don't use
	AP Range	37.6	1.8	60.6	Unclear
	ML SD	9.9	26.6	**63.5**	Poss. harmful, unlikely beneficial, don't use
	ML Range*	**97.5**	1.6	0.9	Very likely beneficial, very unlikely harmful, use
	CoP Velocity*	**99.1**	0.6	0.3	Very likely beneficial

* Significance through traditional null-hypothesis significance testing using the *p* value

a. The Percentage Chance descriptor - 'Harmful' - does not infer actual physical harm; only that the outcome variable may have a negative effect on balance performance.

6.4 UTAUT Of Exergaming In Healthy Young Adults

The non-adjusted descriptive statistics for the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire, recorded both pre- and post-intervention, are shown in Table 12.

6.4.1 Reliability of the UTAUT questionnaire

A reliability analysis was also undertaken for the UTAUT questionnaire. All ICCs[13] were found to be greater than 0.2 - the threshold for poor agreement - and ranged from fair (ICC ≥ 0.3) to almost perfect reliability (ICC ≥ 0.9) (Table 13). Therefore, the UTAUT questionnaire is deemed a reliable means of quantifying user-acceptance in healthy sedentary adults. The questionnaire was also assessed using a Cronbach's α for pre- and post-intervention scores (Table 14). Reliability was assumed at the > 0.70 level. All UTAUT subscales achieved levels above 0.70.

Table 12 Descriptive statistics of pre- and post-programme values (mean, SD) for UTAUT questionnaire for each subscale

Subscale	Pre-intervention		Post-intervention	
	IREX™	Wii™	IREX™	Wii™
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Performance Expectancy	4.8 (1.4)	5.2 (1.2)	5.4 (1)	5.7 (1.1)
Effort Expectancy	5.5 (0.8)	5.6 (1.4)	6.1 (1.1)	5.9(1.7)
Social Influences	4.7 (1)	4.9 (1)	5.4 (0.9)	5.3 (1.2)
Facility Conditions	5.5 (1)	5.6 (1.6)	5.9 (0.8)	5.6 (1.4)
Self-efficacy	5.2 (1.3)	5 (1.5)	5.7 (1.5)	5.4 (1.7)
Behavioural Intention	5.3 (1.3)	5.5 (1.8)	5.6 (1.3)	5.3 (1.9)

[13] ICC can be interpreted as follows: 0-0.2 indicates poor agreement; 0.3-0.4 indicates fair agreement; 0.5-0.6 indicates moderate agreement; 0.7-0.8 indicates strong agreement; and > 0.8 indicates almost perfect agreement (Cicchetti & Sparrow, 1981).

Table 13 Results of the Intraclass Correlation Coefficient

Subscale	Pre-intervention			Post-intervention		
	Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
Performance Expectancy	**0.70**	0.55	0.82	**0.58**	0.41	0.73
Effort Expectancy	**0.50**	0.32	0.67	**0.82**	0.71	0.89
Social Influence	**0.35**	0.20	0.50	**0.36**	0.17	0.54
Facility Conditions	**0.42**	0.20	0.62	**0.60**	0.41	0.76
Self-efficacy	**0.40**	0.23	0.59	**0.75**	0.63	0.85
Behavioural Intention to Use	**0.93**	0.88	0.96	**0.89**	0.81	0.94

Table 14 Results of the Reliability assessment – Cronbach's α

Subscale	**Pre-intervention**	**Post-intervention**
Performance Expectancy	0.90	0.85
Effort Expectancy	0.80	0.95
Social Influence	0.71	0.68
Facility Conditions	0.68	0.82
Self-efficacy	0.73	0.92
Behavioural Intention to Use	0.98	0.96

6.4.2 UTAUT Results: Between-Groups Post-Intervention Differences

The ANCOVA indicated significant baseline (covariate) effects on all UTAUT subscales ($p < 0.05$), with the exception of *Facilitating Conditions* (FC). For the effect of group, the ANCOVA identified no significant between-group post-intervention differences for any of the subscales (see Table 15). This would suggest that the two interventions are comparable in terms of user-acceptance in healthy sedentary adults completing a four-week exergaming intervention.

6.4.3 UTAUT Results: Within-Group Change Over-Time

There were general improvements in all UTAUT subscales (through an increase in acceptance scores); with the exception of *Behavioural Intention* (BI) in the Wii Fit™ group. Paired *t*-tests identified significant improvements for three subscales for the IREX™ group: *Performance Expectancy* (PE) ($t_{[15]} = -3.0$, $p < 0.01$, $d = 0.7$), *Effort Expectancy* (EE) ($t_{[15]} = -3.2$, $p < 0.01$, $d = 0.8$), and *Social Influences* (SI) ($t_{[15]} = -4.9$, $p < 0.01$, $d = 1.2$), with effect sizes ranging from small to large (see Table 15). For the Wii Fit™ Group, there were significant improvements for two of the subscales: PE ($t_{[16]} = -2.8$, $p < 0.01$, $d = 0.7$) and SI ($t_{[16]} = -2.4$, $p < 0.05$, $d = 0.6$), with large effect sizes. These findings indicate that users' acceptance of both platforms improved with use.

Table 15 Summary statistics for pre- and post-programme values (mean, SD), within-subject (time effect) and between-subject (group effect – adjusted for baseline differences ANCOVA) (mean, 95% CI) for the UTAUT questionnaire

Subscale	Adjusted post-intervention difference between groups (ANCOVA)			Within-group change over time (paired t-test) IREX™			Wii™		
	Mean diff. (95% CI)	*P*	*d*	Mean (95% CI) diff	*P*	*d*	Mean (95% CI) diff	*P*	*d*
Performance Expectancy	-0.04 (0.2, -0.5 to 0.4)	.85	0.0	0.6 (0.2 to 1.0)*	.01	0.7	0.5 (0.1 to 0.8)*	.01	0.7
Effort Expectancy	0.3 (0.3, -0.3 to 0.9)	.36	0.4	0.6 (0.2 to 1.0)*	.01	0.8	0.3 (-0.2 to 0.8)	.23	0.3
Social Influence	0.3 (0.2, -0.2 to 0.8)	.19	0.5	0.7 (0.4 to 1.1)*	.001	1.2	0.4 (0.04 to 0.8)*	.03	0.6
Facility Conditions	0.3 (0.4, -0.5 to 1.1)	.48	0.3	0.3 (-0.2 to 0.8)	.17	0.4	0.04 (-0.3 to 0.4)	.81	0.1
Self-efficacy	0.1 (0.4, -0.7 to 0.9)	.72	0.0	0.5 (-0.1 to 1.1)	.11	0.4	0.4 (-0.2 to 0.9)	.17	0.4
Behavioural Intention to Use	0.4 (0.3, -0.2 to 1.0)	.15	0.6	0.3 (-0.2 to 0.7)	.19	0.3	-0.2 (-0.6 to 0.3)	.45	0.2

[a] * = Significance at the $p < .05$ level

[b] *P* = P value; *d* = Cohen's *d*

6.4.4 Technological Acceptance Regression Analysis

Using standard multiple regression analysis to predict BI, a significant model emerged for pre-intervention measures ($F_{[3,32]} = 5.6$, $p < 0.01$). The subscale FC was found to be a significant predictor at baseline. The pre-intervention R^2 statistic indicated that this model accounted for 30% of the total variance in the prediction of BI. A significant model was also found for post-intervention measures ($F_{[3,32]} = 4.7$, $p < 0.05$), where both FC and PE were significant predictors of BI (Table 16) and accounted for 26% of the total variance. Based on this model, there is a large proportion of the total variance (74%) unaccounted for in healthy sedentary adults.

Table 16 Multiple Regression for the modified technological acceptance questionnaire

Predictors	Pre-Intervention			Post-intervention		
	B	SE B	β	B	SE B	β
Constant	-0.01	1.45		-0.28	1.57	
PE	0.27	0.21	0.22	0.60	0.28	0.39**
FC	0.71	0.26	0.44*	0.63	0.28	0.45**
EE	0.12	0.24	0.08	-0.20	0.25	-0.18
R^2	0.36			0.33		
Adjusted R^2	0.30			0.26		

Note: * p < 0.01, ** p < 0.05

6.5 FSS Of Exergaming In Healthy Young Adults

The non-adjusted descriptive statistics for the Flow State Scale (FSS) questionnaire, recorded both pre- and post-intervention, are shown in Table 17.

Table 17 Descriptive statistics of pre- and post-programme values (mean, SD) for FSS questionnaire for each subscale

Subscale	Pre-Programme		Post-Programme	
	IREX™	Wii Fit™	IREX™	Wii Fit™
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Autotelic Experience	3.7 (0.8)	3.9 (1.0)	4.1 (0.9)	4.2 (1.1)
Clear Goals	4.0 (0.8)	4.0 (0.9)	4.5 (0.6)	4.3 (0.9)
Challenge-Skill Balance	3.8 (0.8)	3.6 (0.7)	4.4 (0.7)	4.0 (0.8)
Concentration of Task	4.1 (0.7)	4.1 (1.0)	4.5 (0.6)	4.3 (0.7)
Paradox of Control	3.5 (1.0)	3.5 (1.0)	4.2 (0.7)	3.9 (1.0)
Unambiguous Feedback	3.7 (0.7)	3.7 (0.9)	4.3 (0.8)	4.0 (1.0)
Action-Awareness Merging	3.1 (0.6)	2.9 (0.9)	3.8 (0.7)	3.4 (0.9)
Transformation of Time	2.9 (1.0)	2.6 (1.4)	3.4 (1.1)	3.0 (1.4)
Loss of Self-Consciousness	4.0 (0.6)	3.9 (1.1)	4.3 (1.0)	4.1 (1.0)

6.5.1 Reliability of the FSS questionnaire

A reliability analysis was also undertaken for the FSS questionnaire. All ICCs[14] were found to be greater than 0.2 - the threshold for poor agreement - and ranged from fair (ICC ≥ 0.4) to almost perfect reliability (ICC ≥ 0.9) (Table 18). Therefore, the FSS questionnaire is a reliable means of quantifying flow experience in healthy sedentary adults. The questionnaire was also assessed using a Cronbach's α for pre- and post-intervention scores. Reliability was assumed at the > 0.70 level. All FSS subscales achieved levels above 0.70 (Table 19).

[14] ICC can be interpreted as follows: 0-0.2 indicates poor agreement; 0.3-0.4 indicates fair agreement; 0.5-0.6 indicates moderate agreement; 0.7-0.8 indicates strong agreement; and > 0.8 indicates almost perfect agreement (Cicchetti & Sparrow, 1981).

Table 18 Results of the Intraclass Correlation Coefficient

Subscale	Pre-intervention			Post-intervention		
	Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
Autotelic Experience	**0.69**	0.54	0.81	**0.82**	0.72	0.90
Clear Goals	**0.65**	0.50	0.79	**0.71**	0.57	0.83
Challenge-Skill Balance	**0.47**	0.30	0.65	**0.61**	0.44	0.76
Concentration on task	**0.49**	0.32	0.67	**0.77**	0.65	0.87
Paradox of Control	**0.76**	0.64	0.86	**0.85**	0.75	0.91
Unambiguous Feedback	**0.58**	0.42	0.74	**0.87**	0.78	0.93
Action-Awareness Merging	**0.43**	0.26	0.62	**0.72**	0.57	0.83
Transformation of Time	**0.74**	0.61	0.85	**0.70**	0.55	0.82
Loss of Self-Consciousness	**0.72**	0.59	0.83	**0.87**	0.79	0.93

Table 19 Results of the Reliability assessment – Cronbach's α

Subscale	**Pre-Intervention**	**Post-Intervention**
Autotelic Experience	0.90	0.90
Clear Goals	0.88	0.91
Challenge-Skill Balance	0.78	0.86
Concentration on task	0.79	0.93
Paradox of Control	0.93	0.90
Unambiguous Feedback	0.85	0.90
Action-Awareness Merging	0.75	0.91
Transformation of Time	0.92	0.90
Loss of Self-Consciousness	0.91	0.90

6.5.2 FSS Results: Between-Groups Post-Intervention Differences

The ANCOVA indicated significant baseline (covariate) effects on all UTAUT subscales ($p < 0.05$). For the effect of group, the ANCOVA identified no significant between-group post-intervention differences for any of the subscales (see Table

20). These findings suggest that the two interventions are comparable in terms of flow state experience in healthy sedentary adults completing a four-week exergaming intervention.

6.5.3 FSS Results: Within-Group Change Over-Time

There were general improvements in all FSS subscales (through an increase in flow state scores) in both groups. Paired *t*-tests identified that these were significant for eight out of nine subscales for the IREX™ group: *Autotelic Experience* (AE) ($t_{[13]} = 3.1$, $p = 0.01$, $d = 0.8$), *Clear Goals* (CG) ($t_{[13]} = 2.8$, $p = 0.01$, $d = 0.8$), *Challenge-Skill Balance* (CB) ($t_{[13]} = 3.2$, $p < 0.01$, $d = 0.9$), C*oncentration-On-Task* (CT) ($t_{[13]} = 2.8$, $p = 0.02$, $d = 0.7$), *Paradox Of Control* (PC) ($t_{[13]} = 3.4$, $p < 0.01$, $d = 0.9$), *Unambiguous Feedback* (UF) ($t_{[13]} = 3.3$, $p = 0.01$, $d = 0.9$), *Action-Awareness Merging* (AM) ($t_{[13]} = 3.8$, $p < 0.01$, $d = 1.0$) and *Transformation of Time* (TT) ($t_{[13]} = 2.4$, $p = 0.03$, $d = 0.6$), with effect sizes ranging from moderate to large (see Table 20). Paired *t*-tests also identified significant improvements for five of the subscales in the Wii Fit™ Group: CG ($t_{[16]} = 5.1$, $p < 0.01$, $d = 1.2$), CB ($t_{[16]} = 2.6$, $p = 0.02$, $d = 0.6$), PC ($t_{[16]} = 2.7$, $p = 0.02$, $d = 0.7$), UF ($t_{[16]} = 2.7$, $p = 0.02$, $d = 0.6$) and AM ($t_{[16]} = 2.1$, $p = 0.05$, $d = 0.5$), with effect sizes ranging from moderate to large (see Table 20). These findings indicate that both exergaming interventions are comparable, and encourage increased flow state over-time.

Table 20 FSS questionnaire: Summary statistics for pre- and post-programme values (mean, SD), within-subject (time effect) and between-subject (group effect – adjusted for baseline differences ANCOVA) (mean, 95% CI)

Subscale	Adjusted post-intervention difference between groups (ANCOVA)			Within-group change over time: IREX™			Within-group change over time: Wii Fit™		
	Mean diff (95% CI)	*P*	*d*	Mean diff (95% CI)	*P*	*d*	Mean diff (95% CI)	*P*	*d*
Autotelic Experience	-0.1 (-0.5 to 0.3)	.56	0.2	0.4 (0.1 to 0.6)	.01*	0.8	0.3 (0.0 to 0.1)	.07	0.5
Clear Goals	-0.1 (-0.4 to 0.2)	.46	0.2	0.5 (0.1 to 0.9)	.01*	0.8	0.4 (0.2 to 0.5)	≤.01*	1.2
Challenge-Skill Balance	-0.3 (-0.8 to 0.1)	.14	0.7	0.6 (0.2 to 1.0)	.01*	0.9	0.4 (0.1 to 0.6)	.02*	0.6
Concentration of Task	-0.3 (-0.6 to 0.1)	.21	0.7	0.5 (0.1 to 0.9)	.02*	0.7	0.2 (-0.2 to 0.6)	.26	0.3
Paradox of Control	-0.3 (-0.8 to 0.1)	.15	0.7	0.7 (0.3 to 1.2)	≤.01*	0.9	0.4 (0.1 to 0.7)	.02*	0.7
Unambiguous Feedback	-0.3 (-0.7 to 0.2)	.27	0.4	0.6 (0.2 to 1.0)	.01*	0.9	0.4 (0.1 to 0.7)	.02*	0.6
Action-Awareness Merging	-0.2 (-0.8 to 0.4)	.44	0.2	0.6 (0.3 to 1.0)	≤.01*	1.0	0.5 (0.0 to 1.0)	.05*	0.5
Transformation of Time	-0.3 (-0.9 to 0.4)	.42	1.0	0.6 (0.1 to 1.1)	.03*	0.6	0.4 (0.0 to 0.8)	.07	0.5
Loss of Self-Consciousness	-0.1 (-0.6 to 0.5)	.76	0.2	0.3 (0.3 to 0.9)	.31	0.3	0.2 (0.0 to 0.5)	.08	0.5

[a] * = Significance at the $p < .05$ level

[b] *P* = P value; *d* = Cohen's *d*

CHAPTER 7: DISCUSSION OF THE EFFECTS OF EXERGAMING IN HEALTHY SEDENTARY PARTICIPANTS

7.1 Introduction

This chapter will discuss the results from the first study undertaken comparing two exergaming systems with healthy sedentary adults, whilst referring to previous literature surrounding the topic of exergaming, postural sway, user-acceptance and flow state experience.

7.2 Postural Sway and Exergaming in Healthy sedentary Adults

Through the quantitative assessment of balance using postural sway, a general observation of the direction of between-group scores (i.e. positive or negative) suggested that postural sway measures were better in the Interactive Rehabilitation and Exercise system (IREX™) group, with the exception of bipedal (BP) centre of pressure (CoP) velocity. However, with acknowledgment of marked differences between the groups at baseline, a between-group analysis revealed no significant post-intervention differences between the IREX™ and the Wii Fit™ following a four-week intervention. Therefore, in the absence of significance between these exergaming systems we can postulate that both offer comparative effects in terms of balance.

A within-group analysis revealed significant improvement over-time for both exergaming systems. For the benefit of the reader, and to provide some measure of context and contrast (statistical and clinical), in addition to reporting statistical significance, differences will also be contextualised through reporting the percentage change scores; where the smallest worthwhile change in postural sway is 10% (Šarabon *et al* 2010).

For the IREX™ group, four of the five unipedal (UP) balance variables were found to have significantly improved over-time (where improvement is considered to be a decrease in the balance measure), which ranged from 15% to 24% (see Table 9). In the Wii Fit™ group, only two of the five UP measures were found to have significantly improved, improvements ranging from 7% to 8% (see Table 9). This would suggest that the IREX™ system not only showed a greater number of within-group effects (which are perhaps more clinically relevant), but also across a greater number of balance variables. Clearly, and with consideration to finding no significant post-intervention between-group differences, the IREX™ appears to demonstrate the potential for greater general improvements to postural sway (four out of five vs. two out of five UP variables); changes which may have established a significant between-group difference with a longer intervention period and/or a larger sample size.

Given the nature of the chosen sample, namely healthy but sedentary adults, improvement in BP balance variables were not necessarily expected. However, interestingly, there was a significant (and clinically meaningful) change in BP medial-lateral (ML) range in the Wii Fit™ group, with a 17% pre- to post-intervention improvement; surpassing the smallest worthwhile change of 10%. This finding was unexpected in these healthy sedentary participants as there was no reason to assume limitations to BP postural sway in this sample, as BP balance is common practice in activities of daily living. The reason for this finding remains unclear, but could lie in the movement pattern encouraged through the Wii™ system. What could be argued as a limitation of the Wii Fit™, through movements which are restricted to the Wii Fit™ balance board, may be the reason for the unexpected improvement to BP ML range. Many of the Wii Fit™ games are based on the controlled, purposeful movement through the ML range. Therefore, with such specific balance training in the frontal plane, the possibility of improvements is potentially increased than in balance exercises which are less specific.

Due to the paucity of published work in this area, comparisons with previous exergaming research are limited. However, in terms of improvements to balance performance, the findings of this thesis are consistent with the studies already introduced where balance was improved in healthy participants (Brumels *et al* 2008) and specifically were improvements to UP postural stability were found (Nitz *et al* 2010).

In the only study to compare two exergaming technologies, as well as traditional therapy and a control with healthy participants, Brumels *et al* (2008) reported significantly improved balance in two exergaming systems (over traditional exercises) for the average deviation of the CoP in the AP plane. While these findings support the use of exergaming technology in improving balance in healthy participants, the differences in our findings with regards to ML and AP improvements are unclear. This may be due to the differences in age, intervention duration or the selection of games oriented towards challenging balance in the AP direction. Nitz *et al* (2010) reported significant improvements in UP balance and lower limb muscle strength following a ten-week Wii Fit™ training programme in healthy women (aged 30-50 years). However, a limitation of this research is the lack of a control group and therefore the contributory cause of these changes cannot be proven (Mayer 2004). However, such studies have served to inform future research.

In the current study, the IREX™ group demonstrated a greater number of within-group improvements. This could be due to the physical demands of the two exergaming platforms, and again due to the nature of the participants – being healthy sedentary. As mentioned, in the Wii Fit™ platform movements are limited to the Wii Fit™ balance board, and physical interactions based on the distribution of weight. This compared to the IREX™, which allows for dynamic full-body movements, with no such spatial restriction. Even though the intensity of the exercises were not recorded, through subjective observation and clinical knowledge of exercise prescription as a physiotherapist, the exercises of the IREX™ platform appeared to be more physically demanding through full-body interaction. On this basis, it may be hypothesised that as the participants were healthy sedentary individuals (with no clinical condition to diminish postural sway), prescribed balance exercises would have to challenge individuals beyond their normal abilities for improvements to be made; indicating that the IREX™ may offer a greater challenge to postural systems.

Unipedal standing is considered to be a dynamic task, and requires greater recruitment and control of muscles and greater integration of visual, vestibular and other sensory feedback systems to achieve the finer control required to maintain equilibrium. Previous studies have shown that most falls occur during dynamic tasks (Speechley and Tinetti 1991), so these results would support the assertion that the beneficial impact of the IREX™ platform was occurring in measures where greater clinical benefit may accrue.

The aims of this study were to explore the potential of exergaming through assessment of postural sway following a four-week intervention. To the knowledge of the author, this is the first study to compare an exergaming platform purpose-designed for clinical application – the IREX™ - with one designed for home recreational use – the Wii Fit™. These findings offer an important insight into the potential benefits of exergaming technology when used as a balance training tool, and further the evidence base for its application in the clinical setting. Despite the current lack of research, and the limitations of previous research methodology, from the results of this thesis we can infer these findings to be a positive effect with some confidence, as reductions in measures of postural sway are considered to be indicators of reduced effort and therefore improved stability (Speechley and Tinetti 1991). In finding that both exergaming systems were comparable in terms of their effects on postural sway, the question of user-acceptance and flow experience may offer additional insight as to which system is more accepted and engaging to the users.

7.3 Technology Acceptance and Exergaming in Healthy sedentary Adults

The question of user-acceptance is important in the development of new technology, and even more so when technology is combined with an exercise modality, as motivation to exercise is often lacking (Campbell *et al* 2001; Middleton 2004). Therefore, a union of exercise prescription and current technologies may provide an answer to the long-established problem of concordance.

Both exergaming systems had moderate-to-high scores at baseline, which suggests that new users are accepting of both exergaming systems at first use. Assessment of the direction of the between-group scores (i.e. positive or negative) found that the Unified Theory of Acceptance and Use of Technology (UTAUT) post-intervention scores were generally higher in the IREX™ group. The only exception to this was for the subscale *Performance Expectancy* (PE) in the Wii Fit™ group, which was marginally higher. However, a between-group analysis revealed no significant differences between the IREX™ and the Wii Fit™ following a four-week intervention.

In the absence of significance, a general assessment of these findings noted that those allocated to the IREX™ system reported higher (but not significantly so) scores for ease-of-use (subscale *Effort Expectancy*; EE), social acceptance (subscale *Social Influences*; SI), support (subscale *Facilitating Conditions* [FC]), confidence (subscale Self-Efficacy; SE), and intention use the system (subscale *Behavioural Intention* [BI]). However, the Wii Fit™ group were found to have (marginally) greater confidence that the system would improve performance (subscale PE). Yet, in the absence of between-group significance, combined with small effect sizes, we can conclude that both demonstrated moderate-to-high user-acceptance, and offer comparative effects in terms of technology acceptance, and therefore BI.

With consideration to the reported differences between these exergaming systems, a finding of no significant between-group differences in terms of user-acceptance was unexpected. Based on the commercial design of the Wii™, and the priorities of the respective systems, higher acceptance scores were expected in those using the Wii Fit™. Specifically, the Wii Fit™ is firstly a games console, designed to encourage user enjoyment and motivational gameplay. Conversely, the IREX™ system is firstly an exercise/rehabilitation system, where user enjoyment and motivational gameplay are secondary factors.

Despite moderate-to-high scores at baseline, a within-group analysis using paired *t*-tests found these score significantly increased over time for three subscales in the IREX™ group (subscales PE, EE and SI), and two in the Wii Fit™ group (subscales PE and SI). Significant increases in within-group scores for the subscales PE and SI suggest that users believed the system to be effective in improving balance (subscale PE), and that people important to the user also believe they should use the system (subscale SI). Furthermore, the degree of ease associated with the IREX™ system significantly improved with continued use (subscale EE). These findings are positive for both exergaming systems as PE is the strongest predictor of intention to use the technology (Venkatesh *et al* 2003). Therefore, in healthy sedentary users, both would likely be accepted as a means of balance training.

Through the findings of the current study the benefit of exergaming technology to encourage user-intention is acknowledged, suggesting that acceptance increases with exposure, and the potential for high concordance as a consequence of high technology acceptance. Incidentally, the only subscale to decrease (non-significantly) over-time was BI in the Wii Fit™ group. Again, as a general observation, due to these participants being healthy sedentary, combined with the lower physical challenge offered by the Wii Fit™, may explain why BI decreased over the course of the intervention.

A multiple regression analysis showed that PE and FC were significant predictors of BI by study completion; however, this model only accounted for 26% of the total variation observed in BI to accept exergaming technology. Finding a significant prediction model would suggest that these subscales are of importance in the use of exergaming technology, and should be considered when prescribing such an intervention. Moreover, we can infer that increases in the subscales PE and FC will cause a positive change in BI. The results would also suggest the usefulness of using the technology acceptance model for exergaming research, and acknowledge the importance of people's perceptions of exergaming when used as a means of balance training in healthy sedentary adults.

Through the findings of the current study the benefit of exergaming technology in encouraging user-intention is acknowledged, and indicates the potential for higher concordance as a consequence of high technology acceptance. Based on these findings, the idea that exergaming technology may have a beneficial influence on exercise concordance is supported through descriptive statistics and significant improvements over time. However, further investigations over a prolonged period are needed to establish long-term acceptance.

7.4 Flow Experience and Exergaming in Healthy sedentary Adults

Both exergaming systems had moderate-to-high flow state scores at baseline, which suggests that new users are susceptive to flow properties at first use. Observation of the direction of between-group scores (i.e. positive or negative) found that Flow State Scale (FSS) post-intervention scores were marginally higher in the IREX™ group. However, a between-group analysis revealed no significant post-intervention differences between the IREX™ and the Wii Fit™. Similar to the results reported for user-acceptance, a finding of no significant between-group differences was unexpected. Again, based on the commercial design of the Wii Fit™, it would be logical to assume higher acceptance scores in this system. Specifically, commercial games, like those of the Wii Fit™, are designed using the very concepts of flow state as a means of encouraging continued gameplay (Chen 2007; Nacke and Lindley 2008).

This finding may be explained through both interventions facilitating exercise and physical activity. Sport is closely linked to the feeling of being ‘in the zone’ and represents an optimal state of intrinsic motivation, which is one of the key descriptors of flow experience (Thin *et al* 2011). Therefore, due to these games being linked to physical activity the opportunity for flow experience is constant where there is a balance between the person’s skill and the challenge of the exercise. This would suggest that there is a natural link between exergaming technology and the attainment of flow – irrespective of whether or not the concepts have been used in its game design. Essentially, the act of physical exercise may provide the opportunity for flow experience, irrespective of the intervention type. This is an important finding when comparing the two systems, and suggests the versatility of flow attainment in the presence of physical activity. However, despite this, there are well established issues with traditional exercise prescription and the non-compliance of home exercises (Campbell *et al* 2001; Middleton 2004), suggesting that comparisons between traditional and exergaming interventions are needed.

Moderate-to-high FSS scores at baseline, combined with the general improvement of all subscales over-time, suggest that flow experience increases with use in both platforms. A within-group analysis using paired *t*-tests found that all subscales had significantly improved, with moderate to large effect sizes for the IREX™ group, bar the subscale *Loss of Self-Consciousness* (LS) (p = 0.31). Also, five of the nine subscales (*Clear Goals* [CG], *Challenge-Skill Balance* [CB], *Paradox Of Control* [PC], *Unambiguous Feedback* [UF], and *Action-Awareness Merging* [AM]) significantly increased over time for Wii Fit™ group. The remaining subscales (*Autotelic Experience* [AE], *Transformation of Time* [TT] and LS) were found to be approaching significance with moderate effect sizes (AE: p = 0.07, d = 0.50; TT: p = 0.07, d = 0.50; LS: p = 0.08, d = 0.50).

These improvements over the course of the intervention suggest that participants in both groups found the allocated system intrinsically rewarding (subscale AE), with clear direction (subscale CG), balanced in terms of difficulty and skill (subscale Challenge-Skill Balance), with high attainable focus (subscale C*oncentration-On-Task* [CT]), a feeling of control (subscale PC), clear immediate feedback (subscale Unambiguous Feedback), automatic movements (subscale AM), an altered perception of time (subscale Transformation of Time), and a diminished concern of self-appearance (subscale Loss of Self-Consciousness).

Similar to the UTAUT questionnaire, the levels of improvement were greater – but not significantly so - in the IREX™ group, and theoretically for the same reason: due to the potential for higher physical intensities of the IREX™ system. The attainment of flow state is dependent on a balance between the skill/ability of the individual and the challenge/difficulty of the situation (Csikszentmihalyi 1990). If a task is too easy, the individual will lose interest and become bored; if it is too hard, the individual will present with increased stress and anxiety. Based on the opportunity for greater physical exertion with healthy sedentary participants, it could be argued there is greater opportunity for flow state. Moreover, at the time of the study, the IREX™ was a unique exergaming system; one which the participants would not have experienced before. Based on the novelty of such an exergaming system there may have been greater opportunity for flow attainment. In comparable studies using healthy volunteers, the effects of exergaming and flow are overall positive. Thin *et al* (2011) reported significantly higher flow state scores for the subscales CB, AM and LS in exergaming systems (the Sony PlayStation™ 2 and Nintendo Wii™ console) than in normal exercise; scores found to be comparable to traditional sporting activities.

Similar contrasts can be made using the findings of the current study. Comparison of mean flow scores found in the current thesis with those of published normative values (Jackson *et al* 2001; flow scores: AE 3.48, CG 4.14, CB 3.76, CT 3.66, PC 3.50, UF 3.62, AM 3.11, TT 2.82, and LS 3.48) for sports (n = 236; orienteering, surf lifesaving and road cycling) noted higher scores in all nine flow state subscales in both the IREX™ and Wii Fit™ users. This comparison offers support for exergaming technology through higher flow state scores than in traditional sporting activities. Furthermore, Lai *et al* (2012), reporting the findings of a survey, identified a positive correlation indicating that with higher ‘frequency of use’ and ‘longer use’ of exergaming technology the incidence of flow state and enjoyment is increased, a finding also demonstrated through the results of this four-week study. These are positive results, and suggest that exergaming technology has the potential to meet, or surpass, the opportunity for flow experience than in traditional sporting activities. However, further research is needed to compare exergaming to traditional balance interventions.

These findings support the hypothesis that flow experience increases over-time, with no significant difference between the exergaming systems. With consideration to the clinical implications of these findings, previous studies have shown that concordance to any exercise programme is a common problem, as people lack sufficient motivation to complete any given programme (Campbell *et al* 2001; Middleton 2004). However, the presence of flow is positively correlated with higher levels of performance and motivation (Csikszentmihalyi *et al* 2005). In fact, the balance between the ‘challenge of the task’ and the ‘skill need for completion’ facilitates the attainment of the flow state, and is widely accepted as a motivator for continued use (Csikszentmihalyi 2000). Overall, in terms of exercise concordance, the attainment of flow is a valuable asset in the prescription of exercise and one which should be investigated further with in clinical populations.

7.5 Summary of the Effects of Exergaming in Healthy sedentary Adults

There is growing evidence for the use of exergaming technology. These findings support the use of two systems – one purpose designed for rehabilitation and one commercially available, designed for gameplay. The data gathered through this exploratory trial indicated that both systems are comparable in terms of their effect of postural sway, facilitating significant improvements over-time and either towards, or surpassing, the smallest worthwhile change.

Similarly, a comparison of the users’-acceptance and flow experience found no significant differences between exergaming platforms, with significant improvements in both over-time. This suggests both systems are accepted and facilitate the attainment of flow experience in healthy sedentary users. Moreover, the results of an exploratory regression analyses indicate that FC and PE are significant predictors of BI to use this technology. These may be important factors in addressing the problem of exercise concordance and should be considered when using this technology as an exercise or rehabilitation tool. Through this study there is evidence to support the use of this technology in healthy sedentary adults; however, investigations into the effects of exergaming technology in clinical populations are still lacking.

7.6 Healthy sedentary research: informing clinical investigations

Investigating novel and new concepts using healthy participants plays an important role in exploratory research (Shamoo and Resnik 2006). Research using healthy participants is primarily designed to develop new knowledge, and does not make claims of direct benefit to study participants. Such studies can be very informative of the effects of an intervention. However, there are also a number of benefits through the recruitment of non-clinical participants to studies with a clinical diagnosis.

Compared to clinical groups, healthy participants are often easier to find, more robust, free of medications, more likely to respond uniformly and better at completing long and complex trials (Association of the British Pharmaceutical Industry 2007). Therefore, any findings from this group are likely to represent the effects of the intervention, and not the additional medications or therapies that would need to be considered when interpreting the results from clinical participants (Cohen and Posner 2000). When conducted as part of a larger study (as in the case of this thesis), they provide an opportunity to assess feasibility, refine methodological techniques and outcome measures, and reduce the number of unanticipated problems in aid of future research with clinical participants (Leon *et al* 2011). The above noted benefits of this investigation with healthy participants provided new knowledge to the effects of an exergaming intervention, in addition to an opportunity to practice, refine and justify mythological protocols for the second study with the clinical group of interest – people with MS.

For interpretation of the balance measures with regards to the magnitude of change in postural sway, improvements ranged from 15% to 24% in the IREX group and from 7% to 8% in the Wii Fit™ group, having completed a four week intervention. As there were no significant post-intervention differences between the groups, a decision of which system to use can be based on other factors such as cost, acceptance and engagement. These are interesting findings, as with a non-clinical sample, with no perceived balance deficiencies, significant improvements were seen with a relatively short intervention. This finding justifies the use of the

Wii Fit™ as a tool to aid in balance training; however, the effects in clinical populations remain unclear.

7.8 Limitations in the investigation of Exergaming in Healthy sedentary Adults

This primary investigation into the effects of two exergaming systems with healthy sedentary adults is not without limitation. These will be acknowledged with considerations to this initial study being an exploratory trial, aimed to increase current knowledge, and to develop and refine a second clinical investigation.

Through the recruitment of healthy sedentary individuals, with no physical condition that would limit postural sway (except for being a non-exerciser), it could be argued that these findings are not indicative of clinical populations. However, as measures of postural stability improved over a relatively short four-week intervention, it is plausible that improvements could be achieved in those of diminished balance, whom have a greater potential for improvement. An additional limitation would be the lack of a control group to address the effect of time. However, such studies often provide direction for future research (Mayer 2004); this study was undertaken to first establish any effects of exergaming as a basis for future research. Finally, limited statistical power in the present study may have played a role in limiting the significance of some of the statistical comparisons as a result of the modest sample size (n = 33). As indicated, the calculated sample size was not achieved. However, a post-hoc power analysis based on the same parameters revealed that a sample of 33 provided a reasonable statistical power of 0.61. As this was an exploratory trial, and through limited comparable research in the field, these findings provide needed evidence in the effects of exergaming technology; and guidance for the second study of this PhD thesis.

7.9 Clinical Summary

This first study provides needed evidence in the effects of exergaming technology when used as a means of balance training. To aid clinical decision making with regards to the application of exergaming technology, this first study with health-sedentary users' found that a purpose-designed virtual reality system is as effective as a commercial, off-the-shelf, exergaming system in improving balance, and is equally accepted and engaging. Therefore, for the therapist and patient, the Nintendo Wii Fit™ is an affordable and effective alternative to the more costly system. Such technology could be used by the therapists to provide needed variety to traditional balance training regimes, offering increased enjoyment, interaction, and concordance. For the patient, this technology could also be used independently and reduce reliance on the therapist to provide motivation.

CHAPTER 8: METHODOLOGY FOR THE EFFECTS OF EXERGAMING IN MULTIPLE SCLEROSIS PARTICIPANTS

8.1 Introduction

Based on the current but limited research, combined with the findings of the first study of the PhD thesis, there is good reason to hypothesise that exergaming has the potential to benefit individuals with a neurological condition. In brief, previous studies have employed exergaming technology in clinical settings for those with stroke (Brosnan 2009), cerebral palsy (Deutsch *et al* 2008), as well as with healthy subjects (White *et al* 2011). However, there is limited research into the effects of this technology in people with Multiple Sclerosis (MS).

Many people with MS have difficulty in walking and moving due to reduced balance and coordination, as well as difficulties with muscular control and pain (Miltenburger and Kobelt 2002; Svendsen *et al* 2003; Forbes *et al* 2006). These can be primary factors in the restriction of physical activity and negatively impact on the quality of life. However, a possible contributory cause of these problems can be the result of physical deconditioning and/or exercise avoidance, as exercise by traditional methods may be too demanding or inaccessible to people with MS (Sutherland and Andersen 2001). Even though the beneficial effects of exercise are well documented, the perennial problem of motivation and concordance endures.

Compared to other more established fields of scientific investigation, there has been very little published research on the effects of using exergaming technology as a balance training tool, as identified through the reported systematic literature review (Chapter 3, page 81). Through the prescription of exergaming technology this second study will attempt to provide information to address some of the issues of exercise in people with MS. The current chapter will describe the methods and procedures implemented during the second study of the PhD thesis, aimed to establish the effects of exergaming on postural sway, gait, user-acceptance, flow experience, and general health in participants diagnosed with MS. Full details of the instrumentation, participant preparation and testing procedures are provided through Chapter 5, page 135. Therefore, this chapter will report only the additional methodological instrumentation and procedures used in this second investigation specific to people with MS.

8.2 Aims

Based on the findings of previous research, and of study 1, the following primary aims are introduced:

> To compare the effects of a four-week exergaming programme with MS participants in terms of postural sway, gait, user-acceptance and flow experience between:
>
> c. Exergaming (using the Nintendo Wii Fit™ system)
>
> d. Traditional, matched balance training
>
> e. A control (receiving no-intervention)

Secondary aims were:

> To compare the effects of a four-week exergaming programme with MS participants in terms of 1) self-reported walking ability, and 2) perceived activity limitations and participation restrictions, between the above listed groups.

8.3 Study Design

Randomised Controlled Trials (RCTs) are considered highly reliable in the hierarchy of research designs, and offer one of the strongest scientific designs for establishing the effect of an intervention (Jun *et al* 2010). Randomisation of participants into experimental groups ensures any observable differences between the intervention and control groups are most likely the results of manipulation of the independent variable, as opposed to other external factors (i.e. confounding variables, selection bias and baseline differences) (Akobeng 2005; Lancaster and Titman 2011). Based on a framework for design and evaluation of complex interventions to improve health, this definitive RCT was a phase III trial, and aimed to compare a fully defined intervention with an appropriate alternative (Campbell *et al* 2000; Medical Research Council 2000). This second study employed the design of a RCT, using three groups and two factors:

> Group 1 - Exergaming with the Nintendo Wii Fit™ system
> Group 2 - Matched traditional balance training
> Group 3 - Control group (no intervention[15])

[15] This study would recruit participants who were not currently receiving physiotherapy. Therefore, treatment was not withheld for those allocated to the control group.

Factor 1 - between-group, exercise group with three levels – Nintendo Wii™, traditional balance training and control groups

Factor 2 - within-group, time with two levels - start (pre-intervention) and end (post-intervention)

8.4 Ethics Approval

Ethical approval was granted by Teesside University (Appendix 12, page 357) and the National Research Ethics Service (Appendix 13, page 359); permission was given by the South Tees Hospital NHS Foundation Trust R&D Dept. (Appendix 14, page 360), and registered through the International Standard Randomised Controlled Trial Number Register (ISRCTN13924231). Verbal and written informed consent was obtained (Appendix 15, page 361); having reviewed of the participant information sheet (Appendix 16, page 363) and screened for both inclusion and exclusion criteria (section 8.6).

8.5 Recruitment, Sampling Method and Sample Size Estimation

Convenience sampling techniques were used to recruit MS participants. Participants were referred by a senior MS physiotherapist at James Cook University Hospital, and through the Middlesbrough MS therapy centre (non-NHS, Skippers Lane, Middlesbrough). Those participants recruited were also encouraged to refer any friends or colleagues which met the inclusion and exclusion criteria; which were confirmed by the author. In addition, posters were placed on designated hospital and therapy centre notice boards (Appendix 17, page 369). In the event of a 'serious adverse event' or 'suspected unexpected serious adverse reaction', all such occurrences will be reported immediately to the PhD supervisors and the study sponsor (Teesside University) using standardised documentation (Appendix 7, page 337). This study ran between October 2011 and April 2012. A power analysis was conducted with the program G*Power Version 3.1.9.2 (Faul *et al* 2007) for a three-group comparison using analysis of variance to detect a large effect (f = 0.40) for postural sway outcome measure and 0.80 power; the results showed the required total sample size was 22 per group (66 total). To adjust for a dropout rate of 20%, the total required sample size was 78.

8.6 Participants, Inclusion and Exclusion Criteria

Sixty-four participants were assessed for eligibility. Eight were excluded due to not meeting the inclusion criteria. Fifty-six (38 females, 18 males; mean age 52 years, SD 5.8, Table 21) were randomly allocated to either: exergaming with the Nintendo Wii Fit™ (n = 20), traditional balance training (n = 18), or no intervention (control) (n = 18). Inclusion criteria were: Men and women aged between 18-65 years, with a clinical diagnosis of MS, self-reported ability to walk 100 meters with or without resting with the use of one stick or crutch (equivalent to an Expanded Disability Status Scale [EDSS] (Kurtzke 1983) score of 6.0) (Appendix 18, page 370), and able to read and comprehend written and spoken English. Exclusion criteria were: acute exacerbation and/or relapse of MS symptoms within the last three months, diagnoses of any other condition affecting the central nervous system, any musculoskeletal injury, or receiving physical therapy.

Table 21 Descriptive statistics for the MS participant demographics

	Wii Fit™ Mean (SD)	Traditional Balance Training Mean (SD)	Control Mean (SD)
Age (y)	52.6 (6.1)	53.9 (6.5)	51.9 (4.67)
Weight (kg)	77.7 (17.6)	80.2 (14.5)	84.3 (25.9)
Height (cm)	169.4 (10.0)	165.1 (10.1)	156.4 (31.4)
Gender (f/m)	14/6	12/7	12/5

8.7 Research Environment

Outcome measures were recorded in the Teesside Centre for Rehabilitation Sciences (TCRS, James Cook University Hospital, Middlesbrough, UK), and interventions undertaken in either the TCRS or the Middlesbrough MS Therapy Centre (non-NHS).

8.8 Instrumentation specific to study 2

8.8.1 GAITRite™ Temporal and spatial parameters

The GAITRite™ is a 4.6 m walking mat consisting of computerised sensors, arranged in a grid-like pattern to identify footfall contacts (Givon *et al* 2009). Gait measurements comprised: velocity, Functional Ambulation Profile (FAP), cadence, step length, stride length and heel-to-heel base of support, and were obtained using GAITRite™ software (CIR Systems, Inc., Havertown, PA 19083, USA). All participants walked barefoot along the mat three times, at a self-selected speed. The average of these measures were calculated and used for statistical analysis.

8.8.2 Data Processing and Extraction

GAITRite™ measures were extracted and relevant parameters saved through the dedicated GAITRite™ software (CIR Systems – Version 3.8). Where required, the software's 'Foot Fall Editor' was applied to erase the recording of a walking stick or errors in foot placement (errors in the GAITRite™ system recording or footfalls outside the area of measurement) to ensure only participants' foot falls were analysed.

8.9 Psychometrics

Quantitative measures of psychological social-cognition variables were recorded through self-completion paper-based questionnaires. In addition to those used/reported in study 1, self-reported measures of MS-specific walking ability, and perceived participant health status, function and disability were recorded. These questionnaires will be briefly reintroduced for the benefit of the reader.

8.9.1 UTAUT Questionnaire

To determine user-acceptance, and therefore behavioural Intention, the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire was used, and adapted for exergaming specificity (Appendix 19, page 371).

8.9.2 Flow State Scale Questionnaire

To determine flow experience, and therefore the potential to improve exercise concordance, the Flow State Scale (FSS) was used (Appendix 20, page 377).

8.9.3 MSWS-12 Questionnaire

The 12-item Multiple Sclerosis Walking Scale (MSWS-12) (Appendix 22, page 383) is a self-reported measure of walking quality (Hobart *et al* 2003), scored on a 1 to 5 scale (1 = *Not at all*; 5 = *Extremely*). Upon completion, a total score is generated and reported on a 0 to 100 scale by subtracting the minimum score possible (12) from the patient's score, dividing by the maximum score (60), and multiplying the result by 100. High scores indicate a greater impact on walking (Hobart *et al* 2003).

8.9.4 WHODAS 2.0 Questionnaire

The 12-item interviewer-administered version of the World Health Organisation Disability Assessment Schedule 2.0 (12-item WHODAS 2.0; World Health Oganisation 2000) (Appendix 21, page 381) is designed to assess the activity limitations and participation restrictions experienced by an individual, irrespective of medical diagnosis. This questionnaire allows for the measurement of disability with acknowledgment of six International Classification of Functioning, Disability and Health (ICF) domains: Understanding and Communicating, Getting Around, Self-Care, Getting Along With People, Life Activities, and Participation In Society (Luciano *et al* 2010). For each question the participant is asked to rate their magnitude of the disability from the previous 30 days, selecting to report either: *None* (indicating no difficulty), *Mild*, *Moderate*, *Severe* or *Extreme/cannot*.

8.9.5 Technological Acceptance and Flow State Scale Questionnaires

The MSWS-12 and WHODAS 2.0 were completed at the start and at the end of the study, and were reminded to answer these questionnaires based on their opinion at that point in time (not a predicted opinion having completed the four-week intervention). This was to ensure that comparisons could be made over time.

8.10 Participant Positioning

8.10.1 Foot positioning and foot templates

To standardise participant foot position for within- and between-session testing, a foot-position template using a trace of the participant’s foot position while in natural standing was made for each participant (Hatton *et al* 2009). This was drawn directly onto trace paper, which had been cut to the exact measurement of the force plate (Figure 25, page 198). All participants were given the same instruction for foot placement: to place their feet in a position that felt natural, at approximately hip width (Mochizuki *et al* 2006), and equidistant to the borders of the force plate. This was visually checked by the researcher (JR) during each recording. All participants were asked to stand on the force platform having removed both shoes and socks.

8.10.2 Upper limbs

To reduce the variability of upper body movement, participants were asked to place their hands on their hips during balance testing. All participants were instructed to stand relaxed, as quietly as possible, with their eyes open (Hatton *et al* 2009; Mochizuki *et al* 2006).

Figure 25 Example of Force Plate foot-position template

8.11 Exergaming System

The Nintendo Wii Fit™ (Nintendo Wii™, Nintendo™ Co Ltd, Minami-ku Kyoto, Japan) uses a central game console, connected to a television. Navigation is via the handheld control pad and physical whole body movements through standing on the Wii Fit™ balance board (length 511mm, width 316mm and height 53.6mm) (Figure 26). These movements control an avatar in the gaming environment. The games environment and images were displayed on a 37 inch widescreen Plasma screen (Hanspree, Type T73B, Greyenstraat 65, Netherlands) (Figure 27).

Figure 26 Nintendo Wii™ Balance Board

Figure 27 Gameplay using the Nintendo Wii Fit™ and Wii Fit™ board

8.12 Procedures

8.12.1 Group randomisation and Intervention

Each participant was randomly allocated to one of the groups' once written informed consent, demographic information and baseline outcome data had been collected. Participants were allocated using block randomisation (blocks of 6) into one of the three groups using an online computer generated sequence created prior to participant recruitment (Urbaniak and Plous 2013). A follow-up appointment for four-weeks was arranged for those allocated to the control group (no intervention). Both intervention groups were then introduced to the allocated programme, undertaking each of the programme-specific exercises, following which they were asked to complete the UTAUT and FSS questionnaires, as well as the MSWS-12 and WHODAS 2.0 questionnaires. Once completed, appointments for four-weeks of twice-weekly 40-60 minute exercise sessions were arranged at the participant's convenience, at either the TCRS (James Cook University Hospital) or the Middlesbrough MS Therapy Centre (non-NHS). All exercise sessions were completed on a one-to-one basis and under the supervision of the primary researcher (JR, a UK qualified physiotherapist).

8.13 Exergame And Matched Traditional Exercises

Bespoke exercise programmes were developed for the study. The American College of Sports Medicine (ACSM) state that balance training is one of the least well defined exercise modalities (ACSM 2010). Given the lack of standardised balance training programmes/prescription, combined with the variability of fitness levels in this population, there is no universal exercise training programme (ACSM 2009). As such, balance training can include any activity which stresses balance to elicit adaptations in the control of posture and equilibrium (ACSM 2010).

Balance training exercises using the Wii Fit™ were categorised using the pre-established Wii Fit™ descriptions (Nintendo™ 2011); these being Balance Games, Aerobic Games, and Muscle Workouts. For those in the Wii Fit™ group, the exercise programme consisted of the following games: Soccer Heading, Ski Slalom, Table Tilt, Tightrope Walk, Rhythm Boxing, Basic Step, and Hula Hoop (an example of Wii Fit™ gameplay can be seen through Figure 28; and the full programme through Appendix 22, page 384). These were each completed three times per sessions. The games Torso Twist and Rowing Squats were completed only once per session. For the Wii Fit™ system, there were two difficulty settings; participants began at *Normal* and increased to *Advanced* upon request.

To design a comparable balance training programme, these games were assessed in terms of their gross movement patterns and tailored to replicate the actions and demands of the Wii Fit™, based on common stressors of postural control[16] (ACSM 2010), to isolate any effects due to the intervention type. For example, the Wii Fit™ game *Tightrope Walk* was mirrored by the traditional balance training group by having the participant walk along a marked straight-line, heel to toe (a common balance training exercise). The selected Wii Fit™ games and comparable matched traditional balance exercises are listed through Figure 29. Having completed the four-week programme the participant repeated the baseline measures (postural sway, gait and questionnaires) within five days of their final exercise session. Those in the control group returned after four-weeks to repeat these same measures, with the exception of the intervention specific questionnaires.

[16] Narrowing the base of support, perturbation of the group support, decrease in proprioception sensation, diminished or misleading visual inputs and disturbed vestibular system input.

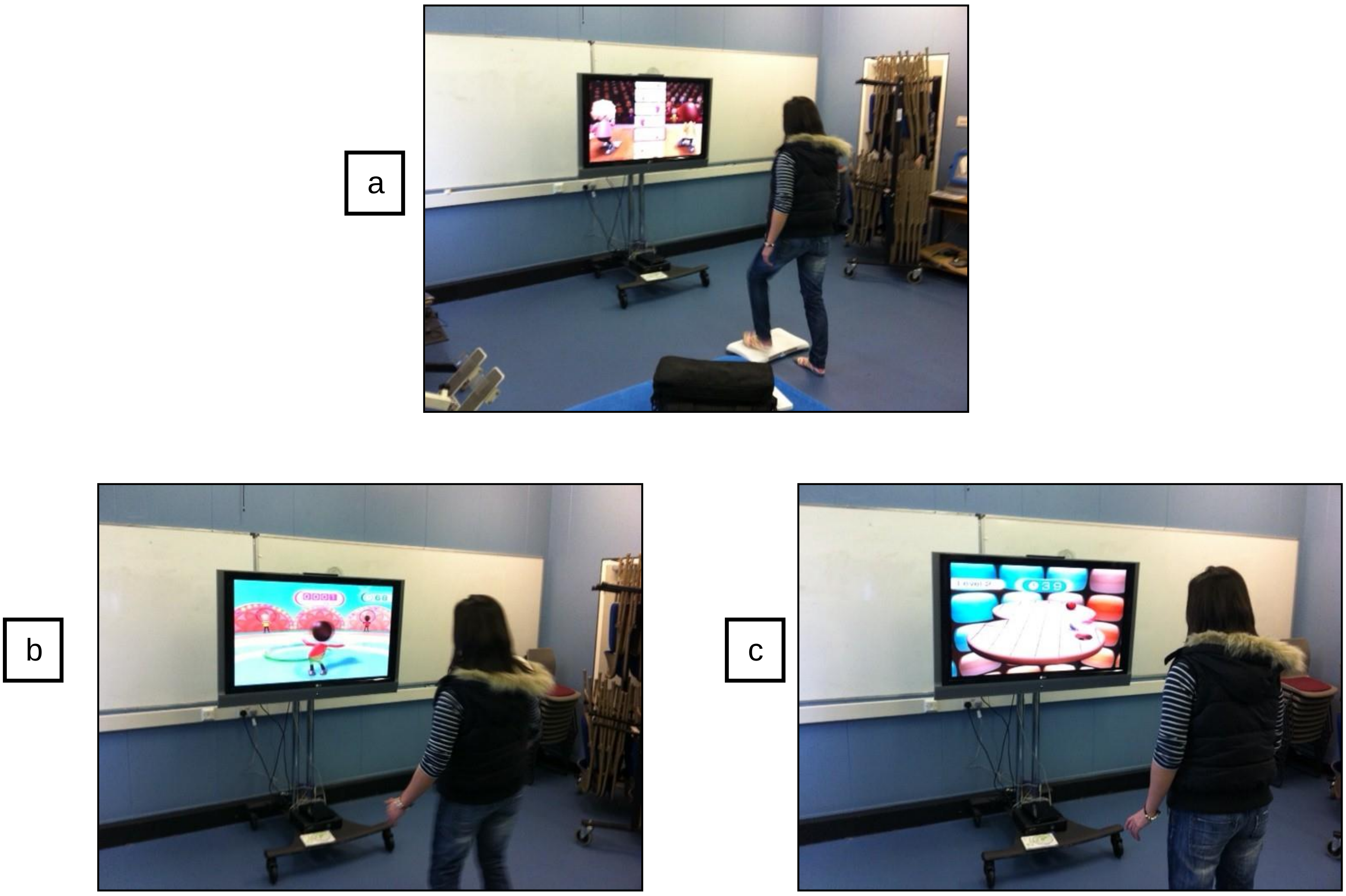

Figure 28 Wii Fit™ balance games: (a) Step Up Class, (b) Hula Hoop and (c) Table Tilt

Nintendo Wii Fit™ Group	Traditional Balance training Group	
Balance Games (Menu)	**Balance Game Equivalent**	**Frequency**
Heading (soccer) (Balance board).	Wall Taps (reaching for number placed on a wall).	3 times per session
Ski Slalom (Balance board).	Standing with feet together; resistance to perturbation.	3 times per session
Table Tilt (Balance board).	Wobble board (small inflatable).	3 times per session
Tight Rope (Balance board).	Straight line walking; heel to toe.	3 times per session
Aerobic Workouts (Menu)	**Aerobic Workout Equivalent**	
Boxing (Handheld controllers).	Basic (non-impact) shadow boxing.	3 times per session
Step Ups Class (Balance board).	Step ups.	3 times per session
Hula Hoop (Balance board).	Standing hip rotations.	3 times per session
Muscle Workouts (Menu)	**Muscle Workouts Equivalent**	
Torso Twists (Balance board).	Torso twists.	1 per session
Rowing Squats (Balance board).	Mini squats.	1 per session

Note: Two sessions per week, for four weeks. Total approximate duration per session: 40-60 minutes (inclusive of rest periods when required).

Figure 29 Wii Fit™ and matched traditional balance exercises: description and frequency

8.14 Statistical Analysis

Data were analysed with Statistical Package for the Social Sciences Version 20 for Windows (SPSS™, Chicago, IL, USA). Data from all participants who were randomly assigned (following the recording of baseline outcome measures) were analysed using intention-to-treat principles according to their randomised allocation (Montedori *et al* 2011), using complete case analysis (Heritier *et al* 2003; Allison 2012). Intention-to-treat analysis maintains the advantages of random allocation, which may be lost if subjects are excluded from analysis (Sibbald and Roland 1998).

To account for any differences between the groups at baseline, separate analyses of covariance (ANCOVA) were conducted to identify between-group post-intervention differences, using the pre-intervention values and age as a covariate, and group and gender as fixed factors. The use of the ANCOVA is considered to be common practice in the analysis of RCT data, adjusting for baseline outcome values and increasing statistical power compared to standard ANOVA (Van Breukelen 2006; Blance *et al* 2007). Within-group differences for each group over-time (from pre- to post-intervention) were investigated with paired *t*-tests. Through this analysis, Bonferroni corrections were not used, as this would significantly reduce the power of analyses and increase the probability of Type II errors (Rothman 1990; Perneger 1998; Armstrong 2014). In this analysis there was greater concern with identifying novel relations specific to the reported data (and hence avoiding Type II errors is considered more important than making Type I errors).

All analysis used a significance level of 0.05. Effect sizes were interpreted using Cohen's *d* (Cohen 1988)[17], and allowed for interpretation beyond the *p* value. In an exploratory analysis, multiple regression was used to investigate influences on future use of the platforms for exercise. The UTAUT subscale of BI was used as the dependent variable and the other subscales as predictors.

8.14.1 Further analysis using Magnitude Based Inferences

As a reminder for the reader, and due to the unique nature of the method, this will be briefly reintroduced. The concept of Magnitude Based Inferences (MBI) allows for further interpretation of inferential statistics, beyond the traditional method of null-hypothesis significance testing, especially in the finding of non-significance. MBI allows for exploration beyond the arbitrary threshold of 0.05, and based on the concepts of smallest worthwhile change. As established through previous research, the smallest worthwhile change in balance performance was considered to be a reduction of 10% (Šarabon *et al* 2010). This method is described in greater detail in Chapter 5.11.8, page 150.

[17] Based on 0.2, 0.5, and 0.8 considered as small, moderate, and large, respectively.

CHAPTER 9: RESULTS FOR THE EFFECTS OF EXERGAMING IN MULTIPLE SCLEROSIS PARTICIPANTS

9.1 Introduction

This chapter will present the results for a four-week exergaming programme on postural sway parameters during bipedal (BP) and unipedal (UP) quiet standing balance, recorded over 30 seconds (BP) and 15 seconds (UP), in addition to the temporal and spatial parameter of gait in Multiple Sclerosis (MS) participants. The results of the psychological measures of user-acceptance and flow experience will be reported. Secondary measures of MS-specific walking ability (using the MSWS-12 questionnaire), and activity limitations and participation restrictions (using the World Health Organisation Disability Assessment Schedule [WHODAS 2.0]), will be reported to provide information specific to the clinical sample recruited. This chapter will present descriptive statistics such as mean, standard deviation (SD), intraclass correlations coefficients (ICCs), 95% confidence intervals and effect sizes.

9.2 Multiple Sclerosis Subjects

Based on the design of a randomised controlled trial, a non-probability sample of 64 MS participants were assessed for eligibility. Eight were excluded due to not meeting the inclusion criteria. Fifty-six were randomly allocated to either: exergaming with the Nintendo Wii Fit™ (n = 20), traditional balance training (n = 18), or no intervention (control) (n = 18) (Figure 30). Five of the randomised participants had withdrawn from the study before start of the intervention. By study completion, an additional five participants had been lost to follow-up due to suspected MS remission, hospitalisation (not related to the study) or family-matters. No adverse event were observed or reported. Using complete case analysis, statistical analysis was based on n = 20 for Wii Fit™ group; n = 15 for the traditional balance training group; and, n = 11 for the no intervention group. Within the final four-weeks of the study no new participants had volunteered to take part. As this research was part of a PhD thesis, and restricted by time, data collection ended before the stipulated target of 66 participants was achieved.

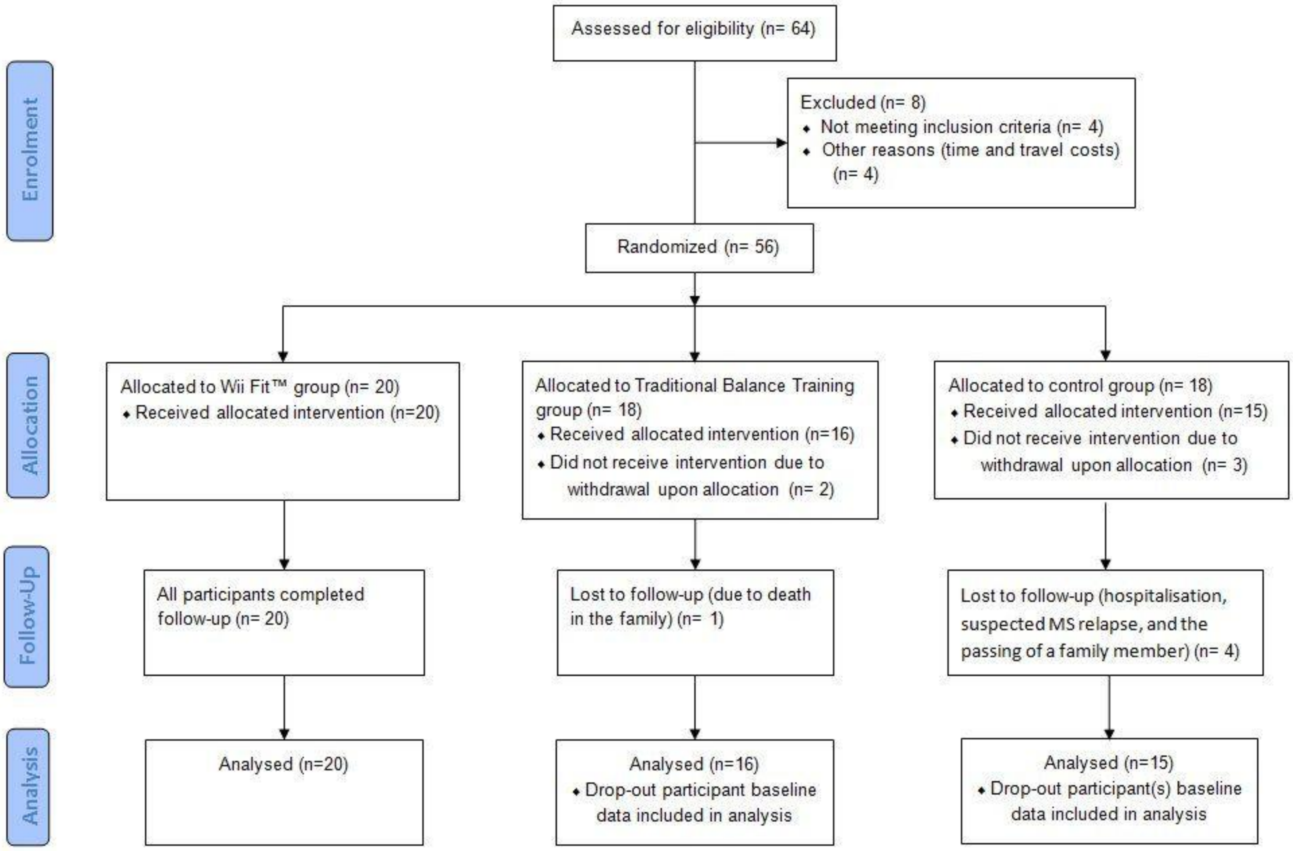

Figure 30 CONSORT flow diagram illustrating a participant entering the study. The final number of participants analysed is based on the principle of complete case analysis and intention-to-treat principles9.3 Postural Sway and Exergaming in people with Multiple Sclerosis

9.3.1 Reliability of Postural Sway

All ICCs[18] were found to be greater than 0.2 - the threshold for poor agreement - and ranged from fair (ICC ≥ 0.3) to almost perfect reliability (ICC ≥ 0.8) (Table 22).

Table 22 Intraclass Correlation Coefficient for postural sway data at pre- and post-intervention

	Pre-intervention: Bipedal			Pre-intervention: Unipedal		
Variable	Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
COP	**0.99**	0.98	0.99	**0.96**	0.94	0.98
AP (SD)	**0.59**	0.42	0.73	**0.48**	0.30	0.65
AP (Range)	**0.66**	0.50	0.78	**0.48**	0.30	0.65
ML (SD)	**0.35**	0.16	0.54	**0.36**	0.18	0.57
ML (Range)	**0.33**	0.14	0.53	**0.35**	0.15	0.55
	Post-intervention: Bipedal			**Post-intervention: Unipedal**		
Variable	Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
COP	**0.99**	0.96	1.00	**0.99**	0.94	0.98
AP (SD)	**0.91**	0.84	0.95	**0.87**	0.77	0.93
AP (Range	**0.95**	0.91	0.97	**0.88**	0.79	0.94
ML (SD)	**0.91**	0.85	0.95	**0.89**	0.81	0.94
ML (Range)	**0.90**	0.84	0.94	**0.81**	0.67	0.90

9.3.2 Postural Sway during Quiet Standing in Multiple Sclerosis participants

The non-adjusted descriptive statistics for postural sway, as measured both pre- and post-intervention using the Kistler™ force platform, are shown in Table 23.

[18] ICC can be interpreted as follows: 0-0.2 indicates poor agreement; 0.3-0.4 indicates fair agreement; 0.5-0.6 indicates moderate agreement; 0.7-0.8 indicates strong agreement; and > 0.8 indicates almost perfect agreement (Cicchetti & Sparrow, 1981).

9.3.3. Postural sway results: between-groups post-intervention differences

The analysis of covariance (ANCOVA) indicated significant baseline (covariate) effects for all postural sway measures (p < 0.05); however, there were no significant age (covariate) effects (p > 0.05). The ANCOVA revealed a significant main effect of group for BP anterior-posterior (AP) range ($F_{[2, 40]}$ = 4.1, p = 0.02, d = 0.91), medial-lateral (ML) range ($F_{[2, 40]}$ = 5.9, p = 0.001, d = 1.09), and centre of pressure (CoP) velocity ($F_{[2, 40]}$ = 4.7, p = 0.01, d = 0.97). Pairwise comparisons identified greater improvement in balance scores in all three measures in the Wii Fit™ group when compared to control group, and in BP AP and ML range in traditional balance training group when compared to the control group (Table 24). Also, a comparison between the Wii Fit™ and the control group noted that UP CoP velocity was found to be approaching significance, with a large effect size, in favour of the Wii Fit™ group (p = 0.07, effect size d = 0.95). However, no significant differences were found between the two intervention groups. There were no statistically significant between-group differences for any of the remaining postural sway measures.

9.3.4 Postural sway results: within-group change over-time

Paired t-tests identified significant improvements (through reduced balance scores) over-time for the Wii Fit™ group in four of the BP measures (CoP velocity, $t_{[19]}$ = 2.1, p = 0.05, d = 0.5; AP SD, $t_{[19]}$ =2.3, p = 0.03, d = 0.5; AP Range, $t_{[19]}$ = 3.8, p = 0.001, d = 0.9; and ML Range, $t_{[19]}$ = 2.2, p = 0.04, d = 0.5), as well as one of the UP measures (CoP, $t_{[18]}$ = 2.2, p = 0.04, d = 0.5). In the traditional balance training group, significant improvements were found in only two of the BP measures (AP range, $t_{[14]} = 2.8$, $p = 0.01$, $d = 0.8$; and ML range, $t_{[14]} = 2.1$, $p = 0.05$, $d = 0.6$). For the control group, there was no significant change (Table 24).

Table 23 Descriptive statistics of pre- and post-programme values (non-adjusted mean, SD) for force-plate measures: anterior-posterior (AP) and medial-lateral (ML) SD and range (mm), and Centre of Pressure velocity (CoP) (mm.sec-1) during bipedal and unipedal standing

			Pre-Programme			Post-Programme	
		Wii Fit™	**Traditional BT**	**Control**	**Wii Fit™**	**Traditional BT**	**Control**
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Force Plate — **Bipedal**	**AP SD** (mm)	9.3 (5.7)	9.5 (4.1)	7.5 (2.8)	8.1 (4.8)	10.5 (9.6)	10.7 (7.0)
	AP Range (mm)	45.7 (24.3)	47.3 (18.4)	40.1 (15.1)	37.9 (20.7)	39.0 (17.1)	47.2 (19.1)
	ML SD (mm)	5.0 (4.1)	5.3 (3.3)	3.6 (0.8)	4.9 (4.3)	5.0 (3.7)	6.0 (4.4)
	ML Range (mm)	29.3 (27.5)	33.8 (21.3)	23.6 (8.5)	26.1 (26.5)	24.3 (14.1)	34.1 (19.5)
	COP Velocity (cm.s−1)	18.5 (4.5)	17.7 (3.4)	19.3 (4.9)	18.0 (4.1)	17.6 (3.7)	20.1 (4.7)
Unipedal	**AP SD** (mm)	11.1 (3.7)	10.7 (4.1)	10.0 (4.1)	10.0 (4.0)	10.6 (4.5)	12.7 (5.7)
	AP Range (mm)	53.9 (20.0)	53.8 (19.8)	51.9 (22.0)	48.3 (19.7)	50.9 (19.4)	63.2 (28.6)
	ML SD (mm)	7.4 (4.4)	7.2 (2.6)	6.6 (3.6)	6.7 (3.1)	6.7 (2.5)	7.3 (3.5)
	ML Range (mm)	33.7 (19.2)	32.8 (10.7)	32.5 (15.4)	31.9 (14.2)	32.0 (12.7)	39.6 (22.1)
	COP Velocity (cm.s−1)	19.4 (4.0)	18.8 (3.1)	19.7 (4.8)	18.7 (3.4)	18.4 (3.5)	20.1 (4.5)

[a] BT= balance training

Table 24 Force plate balance measures: between-group (group effect – ANCOVA) and within-subject (time effect – paired t-test) mean diff (95% Confidence Interval [CI]) for force-plate measures: anterior-posterior (AP) and medial-lateral (ML), SD and range (mm), and Centre of Pressure velocity (CoP V Velocity) (mm.sec-1) during bipedal and unipedal standing

		Adjusted post-intervention difference between groups (ANCOVA)									Within-group change over time (paired t-test)					
		Wii Fit™ - Control			Traditional BT - Control			Wii Fit™ - Traditional BT			Wii Fit™		Traditional BT		Control	
		Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	Mean diff. (95% CI)	*P*	Mean diff. (95% CI)	*P*
Bipedal	**AP SD**	-4.1 (-10.1 to 2.0)	.30	0.65	-2.0 (-8.4 to 4.4)	1	0.32	-2.0 (-7.5 to 3.4)	1	0.32	-1.2 (-2.3 to -0.1)	.03*	1.0 (-3.6 to 5.6)	.65	3.1 (-2.5 to 8.8)	.24
	AP Range	-13.0 (-25.7 to -0.3)	.04*	0.97	-14.2 (-27.7 to -0.6)	.04*	1.05	-1.1 (-10.4 to 12.7)	1	0.09	-7.8 (-12.1 to -3.5)	.001*	-10.3 (-17.7 to -2.8)	.01*	7.1 (-8.0 to 22.2)	.32
	ML SD	-2.2 (-5.5 to 1.2)	.33	0.62	-2.4 (-5.9 to 1.2)	.31	0.68	0.2 (-2.8 to 3.2)	1	0.06	-0.1 (-0.7 to 0.5)	.70	-0.4 (-2.9 to 2.2)	.75	2.4 (-0.7 to 5.6)	.11
	ML Range	-12.4 (-24.6 to -0.3)	.04*	0.96	-17.7 (-30.7 to -4.7)	.01*	1.37	5.3 (-5.8 to 16.3)	.72	0.41	-3.2 (-6.2 to -0.2)	.04*	-9.4 (-18.9 to -0.01)	.05*	10.5 (-0.7 to 21.7)	.06
	COP Velocity	-1.4 (-2.6 to -0.3)	.01*	1.15	-1.1 (-2.3 to 0.2)	.12	0.85	-0.4 (-1.5 to 0.7)	1	0.30	-0.6 (-1.1 to -0.01)	.05*	-0.1 (-0.4 to 0.3)	.60	0.8 (-0.5 to 2.1)	.21
Unipedal	**AP SD**	-3.3 (-7.7 to 1.0)	.18	0.78	-2.5 (-7.0 to 2.0)	.51	0.59	-0.8 (-4.5 to 2.9)	1	0.19	-1.1 (-2.8 to 0.5)	.17	-0.1 (-3.2 to 2.9)	.93	2.7 (-0.9 to 6.4)	.12
	AP Range	-15.8 (-36.2 to 4.6)	.18	0.79	-13.0 (-34.2 to 8.3)	.40	0.65	-2.8 (-20.2 to 14.6)	1	0.14	-5.7 (-13.6 to 2.3)	.15	-2.8(-17.2 to 11.5)	.68	11.3 (-8.8 to 31.4)	.23
	ML SD	-1.0 (-3.2 to 1.2)	.75	0.48	-0.9 (-3.2 to 1.4)	1	0.41	-0.2 (-2.0 to 1.7)	1	0.07	-0.7 (-2.1 to 0.7)	.33	-0.4 (-1.8 to 1.0)	.52	0.7 (-0.7 to 2.2)	.29
	ML Range	-8.4 (-20.8 to 3.9)	.29	0.69	-7.6 (-20.5 to 5.3)	.44	0.62	-0.8 (-11.4 to 9.7)	1	0.07	-1.8 (-8.5 to 4.8)	.57	-0.7 (-7.6 to 6.1)	.82	7.1 (-2.5 to 16.7)	.13
	COP Velocity	-1.2 (-2.4 to 0.1)	.07	0.95	-0.8 (-2.2 to 0.5)	.33	0.69	-0.3 (-1.4 to 0.8)	1	0.25	-0.7 (-1.5 to -0.04)	.04*	-0.4 (-0.9 to 0.2)	.21	0.4 (-0.5 to 1.2)	.33

[a] * = Significance at the p <.05 level

[b] P= P value

[c] BT = balance training

9.4 Magnitude Based Inferences: Postural Sway in People with Multiple Sclerosis.

As per the data analysis in the first study, further inferences with regards to the statistical findings, expressed through the reported *P* values, and based on the concept of the 'smallest worthwhile change' to determine the practical significance of the interventions (Hopkins 2007) are provided. To reiterate, this principle is based on the *P* value converted into 90% confidence intervals for, and inferences about, the true value of the effect statistic. This approach divides the effect into likelihoods of benefit, triviality, and harm[19] by dividing the range of substantial values into more finely graded magnitudes.

Magnitude-based inferences (MBI) indicated the overall positive effects of the Wii Fit™ on postural sway measures, with the likelihood of benefit ranging from 26.7% to 99.9%. Where traditional null-hypothesis significance testing indicated a significant improvement in postural sway, MBI indicated a likelihood of benefit of over 95% for the variables BP and UP CoP, BP AP SD, BP and UP AP range, and BP ML Range (Table 25). The MBI Excel spreadsheet provided qualitative descriptors which further expressed these findings as "*very likely beneficial, very unlikely harmful*" for these balance measures (Table 25). It is important to note that MBI also suggested the likelihood of benefit where non-significance was found according to null-hypothesis significance testing for the variables UP AP SD (MBI estimated likelihood of benefit = 82.4%) and UP AP range (MBI estimated likelihood of benefit = 83.9%) (Table 26)

[19] The descriptor of 'harm(ful)' does not infer actual physical harm; only that the outcome variable may have a negative effect on balance performance.

For the traditional balance training group, where traditional null-hypothesis significance testing indicated a significant improvement in postural sway, MBI indicated a likelihood of benefit of 99.2% and 95.9% for BP AP range, BP ML range, respectively (see Table 26). Similarly, where non-significance was found using null-hypothesis significance testing, MBI also reported the likelihood of benefit in UP CoP (MBI estimated likelihood of benefit = 84.9%). The remaining variables were considered as unclear, suggesting more data is needed.

Table 25 Qualitative inferences using quantitative data and MBI for the effects of exergaming on postural sway performance expressed (as a percentage) as beneficial, trivial, and harmful, in the Wii Fit™ group

		Percentage chance			Conclusion
		Beneficial	Trivial	Harmful	
Bipedal	**AP SD***	**97.4**	1.7	0.9	Very likely beneficial, very unlikely harmful, use
	AP Range*	**99.9**	0.1	0.0	Most likely beneficial, most unlikely harmful, use
	ML SD	33.5	3.0	63.5	Unclear, get more data
	ML Range*	**96.6**	2.2	1.2	Very likely beneficial, very unlikely harmful, use
	CoP Velocity*	**95.8**	2.7	1.5	Very likely beneficial, very unlikely harmful, use
Unipedal	**AP SD**	**82.4**	12.4	5.3	Likely beneficial, very unlikely harmful, use.
	AP Range	**83.9**	10.2	5.9	Likely beneficial, very unlikely harmful, use.
	ML SD	0.0	**100**	0.0	Most unlikely harmful, most unlikely beneficial
	ML Range	26.7	6.7	66.5	Unclear, get more data
	CoP Velocity*	**96.6**	2.2	1.2	Very likely beneficial, very unlikely harmful, use

* Significance through traditional null-hypothesis significance testing using the *p* value

a. The Percentage Chance descriptor - ‘Harmful’ - does not infer actual physical harm; only but that the outcome variable may have a negative effect on balance performance.

Table 26 Qualitative inferences using quantitative and data MBI for the effects of matched traditional balance training on postural sway performance expressed (as a percentage) as beneficial, trivial, and harmful, in the traditional balance training group

		Percentage chance			Conclusion
		Beneficial	Trivial	Harmful	
Bipedal	**AP SD**	33.1	3.9	63	Unclear; get more data
	AP Range*	**99.2**	0.5	0.3	Very likely beneficial, most unlikely harmful, use.
	ML SD	39.2	1.5	59.2	Unclear; get more data
	ML Range*	**95.9**	2.6	1.5	Very likely beneficial, very unlikely harmful, use
	CoP Velocity	26.7	6.7	66.5	Unclear; get more data
Unipedal	**AP SD**	44.8	0.4	54.8	Unclear; get more data
	AP Range	33.5	3.0	63.5	Unclear; get more data
	ML SD	19.8	11.2	**69**	Possibly harmful, unlikely beneficial
	ML Range	40.5	1	58.5	Unclear; get more data
	CoP Velocity	**84.9**	8.7	6.4	Likely beneficial, very unlikely harmful, use.

* Significance through traditional null-hypothesis significance testing using the *p* value

a. The Percentage Chance descriptor - ‘Harmful’ - does not infer actual physical harm; only that the outcome variable may have a negative effect on balance performance.

9.5 Spatiotemporal parameters of gait in Multiple Sclerosis participants

The non-adjusted descriptive statistics of gait, recorded both pre- and post-intervention using the GAITRite™ walkway, are shown in Table 27.

9.5.1 GAITRite™ Temporal and Spatial Parameters Results: Between-Groups Post-Intervention Differences

The ANCOVA indicated significant baseline (covariate) effects for all gait measures ($p < 0.05$); however, there were no significant age (covariate) effects ($p > 0.05$). The ANCOVA revealed no significant between-group post-intervention differences in any of the gait outcome measures (Table 28). However, both Step Length (right foot) and Stride Length (left foot) were found to be approaching significance with moderate effect sizes (p = 0.07, effect size d = 0.72 and p = 0.08, effect size d = 0.72, respectively) between the Wii Fit™ and traditional balance training group. Given the magnitude of the effect sizes and near significance we can tentatively suggest that these may have become significant given a larger sample size, and in favour of the Wii Fit™ group.

9.5.2 GAITRite™ Temporal and Spatial Parameters Results: Within-Group Change Over-Time

Paired t-tests identified significant improvements over-time in the Wii Fit™ group for velocity (t $[_{15}]$ = 3.0, p = 0.01, d = 0.76), cadence (t $[_{15}]$ = 2.3, p = 0.03, d = 0.59), Functional Ambulation Profile (FAP) (t $[_{15}]$ = 4.8, p < 0.001, d = 1.22), Step Length (Left Foot) (t $[_{15}]$ = 2.5, p = 0.02, d = 0.63), Step Length (Right Foot) (t $[_{15}]$ = 3.1, p = 0.01, d = 0.77), Stride Length (Left Foot) (t $[_{15}]$ = 3.1, p = 0.01, d = 0.78), and Stride Length (Right Foot) (t $[_{15}]$ = 3.0, p = 0.01, d = 0.76). The remaining measures (heel-to-heel base of support, left and right) were found to be non-significant (Table 28). For the traditional balance training group there was no significant change over-time; however, heel-to-heel base of support (left) was found to be approaching significance (t $[_{11}]$ = 2.0, p = 0.07, d = 0.58) (Table 28). Interestingly, there were also significant improvements in the control group in two of the variables: Step Length (Right Foot) (t $[_{7}]$ = 2.7, p = 0.03, d = 0.95) and heel-to-heel base of support (right) (t $[_{7}]$ = 2.3, p = 0.05, d = 0.82) (Table 28).

Table 27 GAITRite™: Descriptive statistics (non-adjusted) of pre- and post-programme values (mean, SD)

	Pre-Programme			Post-Programme		
	Wii Fit™	**Traditional BT**	**Control**	**Wii Fit™**	**Traditional BT**	**Control**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Velocity (cm.s−1)	64.7 (28.9)	76.0 (20.9)	65.5 (24.9)	76.6 (27.1)	80.1 (23.9)	76.6 (36.5)
Cadence (steps/min)	85.0 (20.1)	92.0 (7.1)	86.6 (11.6)	90.1 (16.9)	96.5 (9.5)	90.2 (16.7)
Functional Amb. Profile	69.9 (15.6)	73.1 (15.9)	72.3 (16.0)	78.3 (12.1)	77.4 (16.0)	72.7 (17.7)
Step Length (Left Foot) (cm)	43.2 (12.0)	49.6 (10.9)	45.1 (12.1)	48.6 (11.3)	49.8 (11.5)	49.0 (16.6)
Step Length (Right Foot) (cm)	45.1 (11.4)	48.6 (11.5)	44.4 (13.1)	50.7 (9.5)	48.7 (11.2)	49.2 (15.1)
Stride Length (Left Foot) (cm)	88.1 (22.7)	98.7 (22.6)	89.4 (24.4)	99.4 (20.4)	99.0 (22.6)	98.4 (31.0)
Stride Length (Right Foot) (cm)	88.5 (23.2)	98.2 (21.8)	90.4 (24.6)	100.1 (20.4)	99.6 (22.6)	98.2 (30.6)
HH Base Support (Left Foot) (cm)	14.1 (5.2)	12.1 (4.6)	18.1 (4.1)	14.1 (6.0)	14.0 (4.3)	16.9 (5.7)
HH Base Support (Right Foot) (cm)	14.1 (5.8)	12.6 (4.2)	18.1 (4.1)	14.0 (6.2)	14.0 (4.6)	16.7 (5.5)

a BT= balance training

Table 28 Gait measures: Between-group (group effect – ANCOVA) and within-group (time effect – paired t-test) mean diff (95% CI)

	Adjusted post-intervention difference between groups (ANCOVA)									Within-group change over time (paired t-test)					
	Wii Fit™ - Control			Traditional BT - Control			Wii Fit™ - Traditional BT			Wii Fit™		Traditional BT		Control	
	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	Mean diff. (95% CI)	*P*	Mean diff. (95% CI)	*P*
Velocity (cm.s−1)	1.2 (-13.0 to 15.3)	.87	0.07	-5.8 (-21.1 to 9.4)	.44	0.37	7.0 (-5.8 to 19.8)	.27	0.44	11.8 (3.5 to 20.2)	.01*	4.1 (-5.9 to 14.1)	.39	11.1 (-0.9 to 23.2)	.06
Cadence (steps/min)	0.9 (-6.5 to 8.4)	.80	0.11	1.6 (-6.4 to 9.6)	.68	0.19	-0.7 (-7.4 to 6.0)	.84	0.08	5.1 (0.5 to 9.7)	.03*	4.5 (-1.7 to 10.7)	.14	3.6 (-1.6 to 8.7)	.15
Functional Amb. Profile	7.5 (-1.4 to 16.5)	.13	0.96	4.1 (-5.3 to 13.4)	.84	0.52	3.4 (-4.1 to 11.0)	.78	0.44	8.4 (4.8 to 12.1)	<.001*	4.3 (-3.1 to 11.7)	.22	0.4 (-1.3 to 2.2)	.57
Step Length (Left Foot) (cm)	2.1 (-4.5 to 8.6)	.53	0.28	-2.9 (-9.9 to 4.2)	.41	0.39	4.9 (-1.1 to 10.9)	.10	0.67	5.5 (0.8 to 10.1)	.02*	0.2 (-4.3 to 4.6)	.94	3.9 (-1.2 to 9.0)	.11
Step Length (Right Foot) (cm)	1.2 (-4.6 to 7.1)	.68	0.18	-3.5 (-9.8 to 2.8)	.26	0.53	4.7 (-0.5 to 10.0)	.07	0.72	5.6 (1.7 to 9.5)	.01*	0.2 (-4.3 to 4.6)	.94	4.8 (0.6 to 9.1)	.03*
Stride Length (Left Foot) (cm)	3.0 (-9.2 to 15.2)	.62	0.22	-6.8 (-19.9 to 6.3)	.30	0.50	9.8 (-1.2 to 20.9)	.08	0.72	11.4 (3.6 to 19.2)	.01*	0.3 (-8.7 to 9.4)	.94	8.9 (-0.7 to 18.6)	.06
Stride Length (Right Foot) (cm)	4.5 (-7.4 to 16.5)	.45	0.33	-4.3 (-17.2 to 8.5)	.50	0.32	8.8 (-2.0 to 19.7)	.11	0.65	11.5 (3.4 to 19.6)	.01*	1.3 (-7.5 to 10.2)	.75	7.7 (-1.1 to 16.5)	.08
HH Base Support (Left Foot) (cm)	0.7 (-2.3 to 3.7)	.63	0.23	2.4 (-1.0 to 5.7)	.16	0.75	-1.7 (-4.2 to 0.9)	.20	0.53	-0.04 (-1.8 to 1.8)	.96	1.9 (-0.2 to 4.1)	.07	-1.2 (-3.0 to 0.6)	.17
HH Base Support (Right Foot) (cm)	1.0 (-2.0 to 4.0)	.52	0.30	2.2 (-1.1 to 5.4)	.19	0.68	-1.2 (-3.8 to 1.4)	.35	0.37	-0.1 (-2.3 to 2.0)	.90	1.4 (-0.4 to 3.2)	.11	-1.5 (-3.1 to 0.03)	.05*

[a] * = Significance at the p <.05 level

[b] P = P value

[c] BT = balance training

9.6 UTAUT Questionnaire and Exergaming in people with Multiple Sclerosis

9.6.1 Reliability of UTAUT Questionnaire

For the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire, reliability was assessed using ICCs and Cronbach's α statistics. All ICCs[20] were found to be greater than 0.2 - the threshold for poor agreement - and ranged from fair (ICC ≥ 0.4) to almost perfect reliability (ICC ≥ 0.8) (Table 29). The questionnaire was also assessed using Cronbach's α for pre- and post-intervention scores; where reliability was assumed at the > 0.70 level (Table 30). Therefore, the UTAUT questionnaire is deemed a reliable means of quantifying user-acceptance in people with MS.

Table 29 Results of the Intraclass Correlation Coefficient

Subscale	Pre-intervention			Post-intervention		
	Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
Performance Expectancy	**0.74**	0.61	0.84	**0.81**	0.72	0.89
Effort Expectancy	**0.77**	0.66	0.86	**0.84**	0.75	0.91
Social Influence	**0.55**	0.39	0.71	**0.41**	0.24	0.59
Facility Conditions	**0.68**	0.52	0.81	**0.63**	0.46	0.77
Self-efficacy	**0.55**	0.38	0.7	**0.53**	0.37	0.69
Behavioural Intention to Use	**0.91**	0.85	0.95	**0.99**	0.98	0.99

[20] ICC can be interpreted as follows: 0-0.2 indicates poor agreement; 0.3-0.4 indicates fair agreement; 0.5-0.6 indicates moderate agreement; 0.7-0.8 indicates strong agreement; and > 0.8 indicates almost perfect agreement (Cicchetti & Sparrow, 1981).

Table 30 Results of the Reliability assessment – Cronbach's α

Subscale	Pre-intervention	Post-intervention
Performance Expectancy	0.92	0.95
Effort Expectancy	0.93	0.95
Social Influence	0.83	0.74
Facility Conditions	0.87	0.84
Self-efficacy	0.83	0.81
Behavioural Intention to Use	0.97	0.99

9.6.2 UTAUT Questionnaire in MS participants

The non-adjusted descriptive statistics for the UTAUT questionnaire, as measured both pre- and post-intervention, are shown in Table 31.

Table 31 Descriptive statistics from the Unified Theory of Acceptance and Use of Technology questionnaire

Subscale	Pre-Programme		Post-Programme	
	Wii Fit™	Traditional BT	Wii Fit™	Traditional BT
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Performance Expectancy	4.9 (1.3)	4.7 (1.4)	6.2 (0.7)	5.5 (1.1)
Effort Expectancy	4.7 (1.3)	5.2 (1.1)	6.2 (0.8)	5.6 (1.1)
Social Influences	5.2 (1.1)	5.6 (1.0)	6.1 (0.8)	6.1 (1.0)
Facility Conditions	4.5 (1.7)	5.6 (0.8)	5.9 (1.2)	6.1 (0.8)
Self-efficacy	5.1 (1.1)	5.4 (1.3)	6.0 (0.8)	5.9 (1.1)
Behavioural Intention	5.6 (1.3)	5.9 (0.8)	6.5 (1.1)	6.2 (0.7)

9.6.3 UTAUT Questionnaire results: between-groups post-intervention differences

Pre-intervention scores for the UTAUT were high in both intervention groups indicating moderate-to-high acceptance. An ANCOVA indicated significant baseline (covariate) effects for FC and SE subscales only ($p < 0.05$); however, there were no significant age (covariate) effects ($p > 0.05$). The ANCOVA found no significant between-group post-intervention differences (Table 32). However, differences in two subscales were found to be approaching significance with moderate effect sizes: *Performance Expectancy* (PE) ($p = 0.08$, effect size $d = 0.67$) and *Effort Expectancy* (EE) ($p = 0.09$, effect size, $d = 0.66$). Given the magnitude of the effect sizes and near significance we can tentatively suggest that these may have become significant given a larger sample size, and in favour of the Wii Fit™ group.

9.6.4 UTAUT Questionnaire results: within-group change over-time

Paired samples *t*-tests identified significant improvements over-time for all of the UTAUT subscales in the Wii Fit™ group: PE ($t_{[19]} = 3.9$, $p = 0.001$, $d = 0.87$), EE ($t_{[19]} = 4.5$, $p = 0.0003$, $d = 1.00$), *Social Influences* (SI) ($t_{[19]} = 3.2$, $p = 0.005$, $d = 0.72$), *Facilitating Conditions* (FC) ($t_{[19]} = 3.9$, $p = 0.001$, $d = 0.88$), *Self-Efficacy* (SE) ($t_{[19]} = 3.5$, $p = 0.002$, $d = 0.79$), and *Behavioural Intention* (BI) ($t_{[19]} = 2.4$, $p = 0.03$, $d = 0.54$) (Table 32). Also, significant improvements over-time were found in all UTAUT subscales for the traditional balance training group: PE ($t_{[14]} = 3.0$, $p = 0.01$, $d = 0.77$), SI ($t_{[14]} = 2.2$, $p = 0.04$, $d = 0.58$), FC ($t_{[14]} = 4.0$, $p = 0.001$, $d = 1.02$), SE ($t_{[14]} = 5.5$, $p = 0.0001$, $d = 1.41$), with the exception of EE ($t_{[14]} = 1.5$, $p = 0.15$, $d = 0.39$) and BI ($t_{[14]} = 2.0$, $p = 0.06$, $d = 0.53$) (Table 32).

Table 32 Unified Theory of Acceptance and Use of Technology questionnaire: Between-group[21] (group effect – ANCOVA) and within-group (time effect – paired *t*-test) mean difference (95% CI)

Subscale	Adjusted difference between groups post-intervention Wii Fit™ - Traditional BT			Within-group change over time					
				Wii Fit™			Traditional BT		
	Mean diff (95% CI)	*P*	*d*	Mean diff (95% CI)	*P*	*d*	Mean diff (95% CI)	*P*	*d*
Performance Expectancy	0.6 (-0.1 to 1.3)	.08	0.67	1.4 (0.6 to 2.1)	<.001*	0.9	0.8 (0.2 to 1.3)	.01*	0.8
Effort Expectancy	0.6 (-0.1 to 1.3)	.09	0.66	1.5 (0.8 to 2.2)	<.001*	1.0	0.4 (-0.2 to 1.0)	.15	0.4
Social Influences	-0.04 (-0.7 to 0.6)	.90	0.05	0.9 (0.3 to 1.4)	.01*	0.7	0.5 (0.02 to 1.0)	.04*	0.6
Facility Conditions	0.3 (-0.5 to 1.0)	.46	0.29	1.4 (0.7 to 2.1)	.001*	0.9	0.6 (0.3 to 0.9)	.001*	1.0
Self-efficacy	0.2 (-0.4 to 0.7)	.51	0.25	0.9 (0.4 to 1.5)	.01*	0.8	0.5 (0.3 to 0.7)	<.001*	1.4
Behavioural Intention	0.4 (-0.3 to 1.1)	.29	0.40	0.9 (0.1 to 1.6)	.03*	0.5	0.3 (-0.02 to 0.7)	.06	0.5

[a] * = Significance at the p <.05 level

[b] P= P value

[c] BT = balance training

[21] As the UTAUT questionnaire was completed to assess the user-acceptance of an intervention, the control group is not included within this analysis.

9.6.5 Technological Acceptance Regression Analysis

To further explore the relationship between subscales, a mean-centred regression analysis was undertaken to reduce multicollinearity - where two or more predictor variables or interaction terms are highly related (Clark-Carter 2010) - using direct predictors of BI (PE, EE, SI and FC, age, group and gender) combining both intervention groups, for pre- and post-intervention scores (Table 33). A significant model emerged for pre-intervention BI ($F_{[7,35]} = 2.3$, $p = 0.05$). Observation of the R^2 statistic found that this model accounted for 37% of the total variance. Assessment of individual pre-intervention covariates found that only EE ($t_{[35]} = 2.9$, $p = 0.01$) and SI ($t_{[35]} = 2.5$, $p = 0.02$) were significant predictors of BI. A regression analysis which included pre-intervention interaction terms found an R^2 change of 0.37, indicating a 37% increase and accounting for a total 74% of the total variance; however, this model was found to be non-significant.

Undertaking the above analysis with post-intervention data found this regression model was no longer significant ($F_{[7,35]} = 0.6$, $p = 0.78$), as were individual post-intervention covariates; and through observation of the R^2 statistic accounted for only 12% of the total variance (Table 33). Regression analysis to include post-intervention interaction terms found an R^2 change of 0.40, indicating a 40% increase, and accounting for a total 52% of the total variance; however, this was also found to be non-significant.

Table 33 Multiple-regression analysis of the modified Technology Acceptance model

	Pre-intervention		**Post-intervention**	
	D only β	D + I β	D only β	D + I β
R^2	*0.37	0.86	0.12	0.52
Adjusted R^2	0.21	0.74	-0.97	-0.3
R^2 Change	0.37	0.3	0.12	0.4
Performance Expectancy	-0.33	3.83	-0.07	-9.94
Effect Expectancy	**0.49	-1.84	0.28	9.22
Social Influence	*0.69	3.51	0.14	7.85
Facilitating Conditions	-0.21	-0.25	-0.02	-0.26
Age (AGE)	0.00	-0.11	0.03	0.30
Gender (GDR)	0.08	0.96	0.01	2.39
Intervention (Int)	-0.12	1.32	-0.24	1.33
PE x GDR		-0.72		-1.52
EE x GDR		0.58		1.3
FC x GDR		0.77		-1.18
SI x GDR		-1.03		0.97
PE x AGE		-0.02		0.22
EE x AGE		0.01		-0.18
FC x AGE		-0.01		0.01
SI x AGE		-0.04		-0.17
PE x Int		-1.42		-0.09
EE x Int		1.08		-0.34
SI x Int		0.21		0.13
FCx Int		-0.47		0.67
AGE x GDR		0.08		-0.03
AGE x Int		0.02		-0.14
Gender x Int		-0.64		-1.45

[a] D only: Direct effects only; D + I: Direct effects and Interaction terms; Greyed out cells are not applicable for specific column.

[b] * $p < 0.05$; ** $p < 0.01$

9.7 Flow State Of Exergaming In People with MS

9.7.1 Reliability of Flow State Scale

For the FSS questionnaire, reliability was assessed using ICCs and Cronbach's α statistics. All ICCs[22] were found to be greater than 0.2 - the threshold for poor agreement - and ranged from fair (ICC ≥ 0.3) to almost perfect reliability (ICC ≥ 0.8) (Table 34). Therefore, the FSS questionnaire is deemed a reliable means of assessing flow experience in people with MS. The questionnaire was also assessed using Cronbach's α for pre- and post-intervention scores; where reliability was assumed at the > 0.70 level. High reliability was found through all subscales of the FSS questionnaire (Table 35).

[22] ICC can be interpreted as follows: 0-0.2 indicates poor agreement; 0.3-0.4 indicates fair agreement; 0.5-0.6 indicates moderate agreement; 0.7-0.8 indicates strong agreement; and > 0.8 indicates almost perfect agreement (Cicchetti & Sparrow, 1981).

Table 34 Results of the Flow State Scale (Intraclass Correlation Coefficient)

Subscale	Pre-intervention			Post-intervention		
	Intraclass Correlation	95% Confidence Interval		Intraclass Correlation	95% Confidence Interval	
		Lower Bound	Upper Bound		Lower Bound	Upper Bound
Autotelic Experience	**0.74**	0.51	0.84	**0.74**	0.61	0.84
Clear Goals	**0.74**	0.62	0.84	**0.83**	0.74	0.90
Challenge-Skill Balance	**0.58**	0.42	0.73	**0.30**	0.13	0.48
Concentration on task	**0.61**	0.45	0.75	**0.59**	0.43	0.73
Paradox of Control	**0.81**	0.71	0.89	**0.71**	0.57	0.82
Unambiguous Feedback	**0.76**	0.65	0.86	**0.78**	0.68	0.87
Action-Awareness Merging	**0.68**	0.55	0.80	**0.67**	0.53	0.79
Transformation of Time	**0.54**	0.38	0.70	**0.80**	0.70	0.88
Loss of Self-Consciousness	**0.76**	0.66	0.87	**0.80**	0.70	0.88

Table 35 Results of the Reliability assessment, MS – Cronbach's α

Subscale	**Pre-Intervention**	**Post-Intervention**
Autotelic Experience	0.92	0.92
Clear Goals	0.92	0.95
Challenge-Skill Balance	0.85	0.62
Concentration on task	0.86	0.85
Paradox of Control	0.95	0.91
Unambiguous Feedback	0.93	0.94
Action-Awareness Merging	0.90	0.89
Transformation of Time	0.82	0.94
Loss of Self-Consciousness	0.93	0.94

9.7.2 Flow State Scale questionnaire in MS participants

The non-adjusted descriptive statistics for the FSS questionnaire, as measured both pre- and post-intervention, are shown in Table 36.

Table 36 Descriptive statistics from the Flow State Scale questionnaire

Subscale	Pre-Programme		Post-Programme	
	Wii Fit™	Trad	Wii Fit™	Trad
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Autotelic Experience	4.2 (0.8)	3.9 (0.8)	4.6 (0.56)	4.1 (0.8)
Clear Goals	3.5 (0.8)	3.9 (0.8)	4.3 (0.6)	4.0 (0.8)
Challenge-Skill Balance	3.3 (0.8)	3.7 (0.9)	3.9 (0.5)	4.2 (0.7)
Concentration of Task	3.9 (0.9)	3.8 (0.7)	4.4 (0.7)	3.9 (0.8)
Paradox of Control	3.0 (0.9)	3.6 (1.1)	3.8 (0.7)	3.9 (0.8)
Unambiguous Feedback	3.2 (0.9)	3.7 (1.1)	4.2 (0.7)	3.9 (1.2)
Action-Awareness Merging	2.8 (0.9)	3.1 (0.8)	3.9 (0.9)	3.3 (0.7)
Transformation of Time	3.3 (0.7)	2.2 (0.8)	4.1 (0.9)	2.2 (0.9)
Loss of Self-Consciousness	3.9 (0.9)	4.3 (0.8)	4.3 (0.7)	4.3 (0.9)

9.7.3 Flow State Scale in MS participants: between-groups post-intervention differences

Similarly, pre-intervention scores for the FSS questionnaire were high in both intervention groups, indicating moderate-to-high flow experience at the first session. An ANCOVA indicated significant baseline (covariate) effects for all FSS subscales ($p < 0.05$) with the exception of AM; however, there were no significant age (covariate) effects ($p > 0.05$). An ANCOVA revealed a significant main effect of group for the subscales *Clear Goals* (CG) ($F_{[1, 30]} = 4.0$, $p = 0.05$, $d = 0.74$), C*oncentration-On-Task* (CT) ($F_{[1, 30]} = 5.1$, $p = 0.03$, $d = 0.84$), *Unambiguous Feedback* (UF) ($F_{[1, 30]} = 2.3$, $p = 0.04$, $d = 0.77$), *Action-Awareness Merging* (AM) ($F_{[1, 30]} = 5.1$, $p = 0.03$, $d = 0.84$) and *Transformation of Time* (TT) ($F_{[1, 30]} = 14.3$,

p = 0.001, d = 1.37). Pairwise comparisons indicated scores were statistically significantly higher in the Wii Fit™ group for CG, CT, UF, AM and TT (Table 37). No significant differences were found between the remaining subscales. However, the difference in *Autotelic Experience* (AE) was found to be approaching significance, with a moderate effect size (p = 0.08 and d = 0.66). Therefore, as a general observation, we can tentatively suggest that there may have been a significant finding given a larger sample size, and in favour of the Wii Fit™ group.

9.7.4 Flow State Scale in MS participants: within-group change over-time

Paired samples t-tests identified significant improvements over-time for all questionnaire subscales in the Wii Fit™ group: AE ($t_{[19]}$ = 2.5, p = 0.02, d = 0.56), CG ($t_{[19]}$ = 3.9, p = 0.001, d = 0.87), *Challenge-Skill Balance* (CB) ($t_{[19]}$ = 2.9, p = 0.001, d = 0.66), CT ($t_{[19]}$ = 2.6, p = 0.02, d = 0.59), *Paradox Of Control* (PC) ($t_{[19]}$ = 4.4, p = 0.0003, d = 0.98), UF ($t_{[19]}$ = 4.2, p = 0.0005, d = 0.95), AA ($t_{[19]}$ = 3.6, p = 0.002, d = 0.82), TT ($t_{[19]}$ = 4.5, p = 0.0002, d = 1.02), and *Loss of Self-Consciousness* (LS) ($t_{[19]}$ = 2.4, p = 0.03, d = 0.53) (Table 37). In the traditional balance training group significant improvements over-time were found in three subscales: CB ($t_{[14]}$ = 2.8, p = 0.01, d = 0.72), PC ($t_{[14]}$ = 2.4, p = 0.03, d = 0.61), and UF ($t_{[14]}$ = 3.0, p = 0.01, d = 0.76) only (Table 37).

Table 37 Flow State Scale questionnaire: Between-group[23] (group effect – ANCOVA) and within-group (time effect – paired *t*-test) mean difference (95% CI)

Subscale	Adjusted post-intervention difference between groups (ANCOVA) Wii Fit™ - Traditional BT			Within-group change over time (paired t-test) Wii Fit™			Traditional BT		
	Mean diff (95% CI)		*d*	Mean diff (95% CI)	*P*	*d*	Mean diff (95% CI)	*P*	*d*
Autotelic Experience	0.4 (0.01 to 0.7)	.08	0.66	0.4 (0.1 to 0.7)	.02*	.56	0.2 (-0.1 to 0.5)	.14	0.4
Clear Goals	0.5 (-0.01 to 0.9)	.05*	0.71	0.9 (0.4 to 1.3)	.001*	.87	0.2 (-0.1 to 0.4)	.18	0.4
Challenge-Skill Balance	-0.2 (-0.5 to 0.2)	.35	0.33	0.6 (0.2 to 1)	.01*	.66	0.5 (0.1 to 0.8)	.01*	0.7
Concentration of Task	0.4 (0.04 to 0.8)	.03*	0.78	0.5 (0.1 to 0.8)	.02*	.59	0.1 (-0.01 to 0.2)	.08	0.5
Paradox of Control	0.3 (-0.1 to 0.7)	.17	0.51	0.9 (0.5 to 1.3)	.001*	.98	0.3 (0.02 to 0.5)	.03*	0.6
Unambiguous Feedback	0.5 (0.02 to 1.1)	.04*	0.74	1.0 (0.5 to 1.4)	.001*	.95	0.3 (0.1 to 0.4)	.01*	0.8
Action-Awareness Merging	0.6 (0.06 to 1.2)	.03*	0.78	1.1 (0.5 to 1.7)	.01*	.85	0.3 (-0.03 to 0.5)	.08	0.5
Transformation of Time	1.2 (0.5 to 1.7)	.001*	1.71	0.9 (0.5 to 1.1)	.001*	1.02	-0.1 (-0.1 to 0.3)	.51	0.2
Loss of Self-Consciousness	0.2 (-0.2 to 0.6)	.23	0.43	0.4 (0.1 to 0.8)	.03*	.53	0.1 (-0.1 to 0.2)	.45	0.2

[a] * = Significance at the p <.05 level

[b] P= P value

[c] BT = balance training

[23] As the FSS questionnaire was completed to assess the engagement of the intervention(s), the control group is not included within this analysis.

9.8 MSWS-12 Questionnaire

9.8.1 MSWS-12 Questionnaire in people with MS

For the benefit of the reader, the descriptive statistics for each individual question, 1-12, are provided through Appendix 24, page 387. The summed mean (SD) MSWS-12 scores are shown in Table 38, and were used for inferential statistical analysis. Higher scores are an indication of a greater impact of MS on walking ability, and range from 0 (no disability) to 100 (extreme disability) (Hobart *et al* 2003).

9.8.2 MSWS-12 Questionnaire: between-groups post-intervention differences

The ANCOVA indicated a significant baseline (covariate) effect ($p < 0.05$); however, there was no significant age (covariate) effect ($p > 0.05$). An ANCOVA identified a moderate-high effect size of group that did not reach significance at the 0.05 level ($F_{[2,\ 40]} = 2.6$, $p = 0.09$, $d = 0.74$). However, pairwise comparisons identified a significantly lower post-intervention score in traditional balance training group than in the control group, with a *p* value of 0.03 and a large effect size ($d = 0.89$) (Table 39). This finding will be considered as a general observation, and tentatively suggests that there may have been a significant finding for this subscale given a larger sample size. Differences between the remaining groups were non-significant.

9.8.3 MSWS-12 Questionnaire: within-group change over-time

Paired *t*-tests identified significant improvements over-time (through a reduction in MSWS-12 scores) for the Wii Fit™ group ($t_{[19]} = 2.2$, $p = 0.04$, $d = 0.50$) and the traditional balance training group ($t_{[14]} = 2.2$, $p = 0.05$, $d = 0.56$). There was no significant difference found in the control; however, it was noted that MSWS-12 scores has increased (mean increase: 3.8) over the four-week period (Table 39).

Table 38 MSWS-12: Descriptive statistics, summed mean (SD) scores

	Pre-Programme			**Post-Programme**		
	Wii Fit™	**Trad**	**Control**	**Wii Fit™**	**Trad**	**Control**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
MSWS-12 score	64.5 (17.5)	58.4 (16.2)	56.8 (20.7)	59.0 (16.5)	52.3 (16.2)	60.6 (22.4)

Table 39 MSWS-12 Questionnaire: Between-group (group effect – ANCOVA) and within-group (time effect – paired *t*-test) mean difference (95% CI)

	Adjusted post-intervention difference between groups (ANCOVA)									**Within-group change over time (paired t-test)**								
	Wii Fit™ - Control			**Traditional BT - Control**			**Wii Fit™ - Traditional BT**			**Wii Fit™**			**Traditional BT**			**Control**		
	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*
MSWS-12 Scores	-7.3 (-15.9 to 1.4)	.10	0.65	-9.96 (-18.9 to -0.97)	.03*	0.89	2.7 (-5.1 to 10.5)	.49	0.24	-5.6 (-10.8 to -0.3)	.04*	.50	-6.1 (-12.1 to -0.4)	.05*	.56	3.8 (-5.9 to 13.5)	.40	.27

[a] * = Significance at the p <.05 level

[b] P = P value

[c] BT = balance training

9.9 WHODAS 2.0 Questionnaire

9.9.1 WHODAS 2.0 Questionnaire in MS participants

For the benefit and interest of the reader the descriptive statistics for each individual question, 1-12, are provided through Appendix 25, page 388. Inferential statistical analyses are conducted using the standard simple-summed scores, as described by Üstün (2010); these are provided through through Table 40. For interpretation, the sum score for global disability ranges from 0 (no disability) to 48 (complete disability).

9.9.2 WHODAS 2.0 Questionnaire: between-groups post-intervention differences

An ANCOVA indicated a significant baseline (covariate) effect for WHODAS summed score ($p < 0.05$); however, there were no significant age (covariate) effect ($p > 0.05$). An ANCOVA revealed a significant main effect of group ($F_{[2, 39]} = 19.4$, $p = 0.001$, $d = 2.0$). Pairwise comparisons identified significantly lower post-intervention scores in both the Wii Fit™ and traditional balance training groups than in the control group (Table 41). However, there was no significant post-intervention difference between the Wii Fit™ and traditional balance training group.

9.9.3 WHODAS 2.0 Questionnaire: within-group change over-time

The paired *t*-tests using the summed scores identified a significant improvement over-time for both the Wii Fit™ group (t [19] = 11.0, $p < 0.0001$, $d = 2.46$), and the traditional balance training group (t [13] = 12.3, $p < 0.0001$, $d = 3.30$) (Table 41). Conversely, there was also a small (but non-significant) increase in the WHODAS score for the control group.

Table 40 Descriptive statistics: Summed mean scores at pre- and post-intervention for the WHODAS 2.0 questionnaire

	Pre-Programme			Post-Programme		
	Wii Fit™	**Trad**	**Control**	**Wii Fit™**	**Trad**	**Control**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
WHODAS Score	25.0 (4.7)	24.1 (7.2)	15.6 (7.9)	13.7 (4.7)	14.4 (7.6)	15.8 (8.0)

Table 41 WHODAS 2.0 Questionnaire: Between-group (group effect – ANCOVA) and within-group (time effect – paired *t*-test) mean difference (95% CI)

	Adjusted post-intervention difference between groups (ANCOVA)									Within-group change over time (paired t-test)								
	Wii Fit™ - Control			Traditional BT - Control			Wii Fit™ - Traditional BT			Wii Fit™			Traditional BT			Control		
Item	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*
WHODAS Score	-10.2 (-13.5 to -6.8)	<.001*	2.74	-8.7 (-12.2 to -5.2)	<.001*	2.35	-1.5 (-4.1 to 1.1)	.26	0.40	-11.3 (-13.5 to -9.2)	<.001*	2.46	-9.7 (-11.4 to -8.0)	<.001*	3.30	0.2 (-1.4 to 1.7)	.80	0.1

[a] * = Significance at the p <.05 level

[b] P= P value

[c] BT = balance training

9.9.4 WHODAS 2.0 Questionnaire: Domains

For additional interpretation of the WHODAS 2.0 questionnaire, raw scores for individual questions may be combined to represent the six domains of the International Classification of Functioning, Disability and Health (ICF) model. As a reminder for the reader, these are: Domain 1: *Cognition – understanding and communicating*; Domain 2. *Mobility – moving and getting around*; Domain 3: *Self-care – attending to one's hygiene, dressing, eating and staying alone*; Domain 4: *Getting along – interacting with other people*; Domain 5: *Life activities – domestic responsibilities, leisure, work and school*; and Domain 6: *Participation – joining in community activities, participating in society* (WHODAS 2010). Higher scores are an indication of poorer health related outcomes. Descriptive statistics are shown in Table 42.

9.9.5 WHODAS 2.0 Questionnaire Domains: between-groups post-intervention differences

The ANCOVA indicated significant baseline (covariate) effects for all WHODAS 2.0 domains ($p < 0.05$); however, there were no significant age (covariate) effects ($p > 0.05$). An ANCOVA revealed a significant main effect of group for Cognition ($F_{[2, 39]} = 5.4$, $p = 0.01$, $d = 1.06$), Mobility ($F_{[2, 39]} = 7.1$, $p = 0.002$, $d = 1.21$), Self-care ($F_{[2, 39]} = 4.8$, $p = 0.01$, $d = 1.00$), Getting along with people ($F_{[2, 39]} = 4.98$, $p = 0.01$, $d = 1.00$), Life activities ($F_{[2, 39]} = 11.1$, $p < 0.001$, $d = 1.50$) and Participation in society ($F_{[2, 39]} = 8.8$, $p = 0.001$, $d = 1.34$). Pairwise comparisons showed significantly lower post-intervention scores in all 6 domains in Wii Fit™ group than in the control. Significantly lower post-intervention scores were also found in the traditional balance training group than in the control group in all but one domain (Self-care). However, there were no significant differences between the Wii Fit™ and traditional balance training group (Table 43).

9.9.6 WHODAS 2.0 Questionnaire: within-group change over-time

Paired *t*-tests using the domain specific scores identified significant reductions in all domains for the Wii Fit™ group: Cognition ($t_{[19]} = 7.8$, $p < 0.0001$, $d = 1.74$), Mobility ($t_{[19]} = 3.6$, $p = 0.002$, $d = 0.81$), Self-care ($t_{[19]} = 6.4$, $p < 0.0001$, $d = 1.44$), Getting along with people ($t_{[19]} = 8.5$, $p < 0.0001$, $d = 1.91$), Life activities ($t_{[19]} = 8.4$, $p < 0.0001$, $d = 1.89$), and Participation in society ($t_{[19]} = 7.4$, $p < 0.0001$, $d = 1.65$). Significant reductions were also found in all domains for the traditional balance training group: Cognition ($t_{[13]} = 4.6$, $p = 0.001$, $d = 1.22$), Mobility ($t_{[13]} = 5.7$, $p < 0.0001$, $d = 1.52$), Self-care ($t_{[19]} = 8.3$, $p < 0.0001$, $d = 2.2$), Getting along with people ($t_{[13]} = 15.7$, $p < 0.0001$, $d = 4.19$), Life activities ($t_{[13]} = 9.6$, $p < 0.0001$, $d = 2.55$), and Participation in society ($t_{[13]} = 4.7$, $p = 0.0004$, $d = 1.25$). Conversely, in the control group there was a significant increase (indicating a negative health related outcome) in one of the domains: Mobility ($t_{[10]} = 2.7$, $p = 0.02$, $d = 0.80$); the remaining domains were non-significant (Table 43).

Table 42 WHODAS 2.0 questionnaire: Domain specific content, raw means standard deviations (SD) scores at pre- and post-intervention

	Pre-intervention						Post-intervention					
	Wii Fit™		**Traditional BT**		**Control**		**Wii Fit™**		**Traditional BT**		**Control**	
WHODAS Domains	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Domain 1: Cognition	3.8	1.07	3.4	1.40	2.0	2.10	1.7	0.93	1.9	1.90	2.0	1.79
Domain 2: Mobility	6.5	1.43	6.4	1.87	4.9	1.30	5.2	1.70	4.8	1.63	5.6	1.80
Domain 3: Self-care	2.9	1.12	2.5	0.94	1.2	1.47	0.7	0.92	0.7	1.27	0.8	0.98
Domain 4: Getting along with people	3.7	1.31	3.6	1.55	1.8	1.40	1.3	0.97	1.9	1.73	1.7	1.62
Domain 5: Life activities	4.4	0.88	4.4	1.83	3.6	1.75	2.8	1.16	2.6	1.69	3.4	2.06
Domain 6: Participation in society	3.8	1.47	3.7	1.27	2.1	1.58	2.1	1.41	2.4	1.95	2.3	1.56

Table 43 WHODAS 2.0 Questionnaire Domains: Between-group (group effect – ANCOVA) and within-group (time effect – paired *t*-test) mean difference (95% CI)

	Adjusted post-intervention difference between groups (ANCOVA)									**Within-group change over time (paired t-test)**								
	Wii Fit™ - Control			**Traditional BT - Control**			**Wii Fit™ - Traditional BT**			**Wii Fit™**			**Traditional BT**			**Control**		
WHODAS Domains	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*	Mean diff. (95% CI)	*P*	*d*
Domain 1: Cognition	-1.6 (-2.5 to -0.6)	.002*	1.40	-1.1 (-2.1 to -0.1)	.04*	0.95	-0.5 (-1.3 to 0.3)	.20	0.46	-2.1 (-2.7 to -1.5)	<.001*	1.74	-1.5 (-2.2 to -0.8)	.001*	1.22	0.0 (-0.7 to 0.7)	1.0	0.00
Domain 2: Mobility	-1.6 (-2.7 to -0.6)	.004*	1.26	-2.3 (-3.1 to -0.9)	.001*	1.58	0.4 (-0.5 to 1.3)	.37	0.31	-1.3 (-2.0 to -0.5)	.002*	0.81	-1.6 (-2.3 to -1.0)	<.001*	1.52	0.7 (0.1 to 1.3)	.02*	0.80
Domain 3: Self-care	-1.4 (-2.4 to -0.5)	.01*	1.28	-0.7 (-1.8 to 0.3)	.18	0.63	-0.7 (-1.5 to 0.1)	.07	0.65	-2.4 (-3.2 to -1.6)	<.001*	1.44	-1.6 (-2.1 to -1.2)	<.001*	2.21	-0.1 (-0.6 to 0.4)	.68	0.13
Domain 4: Getting along with people	-1.1 (-1.8 to -0.4)	.003*	1.41	-0.8 (-1.5 to -0.1)	.02*	1.07	-0.3 (-0.8 to 0.3)	.35	0.34	-2.2 (-2.7 to -1.7)	<.001*	1.91	-1.8 (-2.0 to -1.5)	<.001*	4.19	-0.4 (-0.8 to 0.1)	.10	0.54
Domain 5: Life activities	-1.4 (-2.0 to -0.7)	<.001*	1.61	-1.5 (-2.2 to -0.8)	<.001*	1.78	-0.2 (-0.5 to 0.7)	.62	0.17	-1.7 (-2.1 to -1.2)	<.001*	1.89	-1.8 (-2.2 to -1.4)	<.001*	2.55	-0.3 (-0.9 to 0.3)	.34	0.30
Domain 6: Participation in society	-1.8 (-2.6 to -0.9)	<.001*	1.77	-1.4 (-2.3 to -0.5)	.003*	1.43	-0.3 (-1.0 to 0.4)	.33	0.34	-1.7 (-2.2 to -1.2)	<.001*	1.65	-1.4 (-2.0 to -0.7)	<.001*	1.25	0.2 (-0.2 to 0.6)	.34	0.30

[a] * = Significance at the p <.05 level

[b] P = P value

[c] BT = balance training

CHAPTER 10: DISCUSSION OF THE EFFECTS OF EXERGAMING IN PEOPLE WITH MULTIPLE SCLEROSIS

10.1 Introduction

This chapter will discuss the experimental results from the second study, undertaken in people with Multiple Sclerosis (MS), comparing the Nintendo Wii Fit™ with matched traditional balance training and a control group. As the research topic of exergaming is relatively new, contrasts with previous research are difficult. However, where possible, comparisons have been made with previous literature surrounding the topic of exergaming, postural sway, user-acceptance and flow experience. Secondary outcomes – the self-reported walking ability, and perceived activity and participation restrictions (based on the International Classification of Functioning, Disability and Health [ICF] domains) - will also be discussed and, where possible, with relation to normative values and comparable research.

10.2 Postural Sway and Exergaming in people with Multiple Sclerosis

The findings of the current study with regards to balance improvements are consistent with previous RCTs (Brichetto *et al* 2013; Nilsagård *et al* 2013). However, this is the first RCT to use three arms to compare exergaming with traditional balance training and a control group. As such, these findings provide novel evidence in this area.

A between-group analysis revealed no significant differences between the two intervention groups. However, a number of postural sway measures were significantly lower in these intervention groups (indicative of better postural sway) than in those of the control group.

This contrasts with Nilsagård *et al* (2013) who found both Wii Fit™ and control groups improved with no between group differences, and Brichetto *et al* (2013) who reported benefit from using the Wii Fit™, but not from traditional balance exercises. These results are a positive finding for exergaming in that they indicate that the Wii Fit™ is comparable to matched traditional balance training as a means of improving postural sway in people with MS, and offers significant improvements over no intervention.

Despite finding that both interventions improved balance when compared to the control group, no significant differences were found between the Wii Fit™ and traditional balance training. This is a positive finding for exergaming, as it suggests that the Wii Fit™ is comparable to traditional balance training as a means of improving balance in people with MS. These findings support previous research which indicates the positive effect of exergaming technology. Brumels *et al* (2008) reported significantly greater improvement of postural sway measures in two exergaming groups (Nintendo Wii™ and Dance Dance Revolution™) than in traditional balance training. The current study has been unable to demonstrate the superiority of one intervention over another; however, differences between these findings may be due to a number of factors: participants in the Brumels *et al* (2008) study were non-clinical, aged 18 to 24 years, and consequently able to exercise at higher intensities. However, despite these differences, the available evidence supports the potential for improved balance through the use of exergaming technology in people with MS.

A within-group analysis revealed significant improvement over-time for both intervention groups. For the benefit of the reader, and to provide some measure of context and contrast (statistical and clinical), in addition to reporting statistical significance, differences will also be contextualised through reporting the percentage change scores. Based on the findings of previous studies, the smallest worthwhile change in postural sway is considered to be a 10% (Šarabon *et al* 2010).

Having completed a four-week programme, postural sway had significantly improved (through a reduction in sway measures) in bipedal (BP) and unipedal (UP) measures in the Wii Fit™ group; improvements ranging from 3% (BP centre of pressure [CoP] velocity) to 17% (BP AP Range). This can be considered a positive effect, as reductions in postural sway measures are indicators of reduced effort, and therefore improved stability (Rogers *et al* 2001); and, in some variables, surpassing the smallest worthwhile change of 10%. Prosperini *et al* (2013) also reported improvements following a home-based Wii Fit™ programme in people with MS, which ranged from 15% to 17%. However, their programme was completed over a 12-week period. This contrast between studies not only indicates the potential for meaningful improvements with this technology in people with MS, but also establishes a time frame through which improvements are probable - from four to 12 weeks. This offers valuable information for those wishing to employ a similar intervention with regards to exercise duration, with improvements occurring earlier than Prosperini *et al* (2013) findings suggest.

Falls in MS are considered to be linked with increased postural sway (Shafizadeh *et al* 2012), and associated with a reduced ability to control movement towards the boundaries of stability, and slowed responses to postural disturbances (Cameron and Lord 2010). Using posturography, Porosiñska *et al* (2010) reported that an increased risk of falls is related to an increased postural sway velocity and length of mean sway, which is most pronounced in the medial-lateral (ML) direction in those with MS. Contrariwise, other authors report that increases in postural sway in both directions are associated with increased likelihood of falls (Sosnoff *et al* 2011). Through the current study, reductions in postural sway measures in both ML and anterior-posterior (AP) directions were found; we can infer this to be an encouraging finding.

From a clinical context, the results of a recent multivariate logistic regression found that that for each 10mm increase in CoP path values, there is an 8%-increased risk of being classified as a faller in people with MS (Prosperini and Pozzilli 2013). In the current study, for those in the Wii Fit™ group, a (mean) reduction of 7.8mm and 3.2mm were observed in the AP and ML range, respectively. These findings indicate the potential for meaningful reductions in postural sway which, based on the findings of Prosperini and Pozzilli (2013), may equate to a reduced risk of falls - an effect seen over a relatively short four-week intervention.

Based on the current but limited research, combined with the data gathered, the effects of exergaming technology on postural sway in people with MS are promising. Having established the benefits of exergaming in the improvement of postural sway, two important questions remain – is this technology accepted, and is flow achieved in people with MS.

10.3 Magnitude Based Inferences Interpretation

The concept of Magnitude Based Inferences (MBI) allowed of further interpretation of these findings. Traditional null-hypothesis significance testing indicated significant improvements over-time for four of the BP and one in the UP measures of postural sway in the Wii Fit™ group. This was supported through MBI with the estimated likelihood of benefit ranging from 95.8% to 99.9% for these variables. However, MBI also suggested likely benefit in two additional UP postural sway variables (AP SD and AP range) where non-significance was found. The combination of these two methods of analysis (null-hypothesis significance testing and MBI) suggests the overall positive effects of balance training using the Wii Fit™ in people with MS.

For the traditional balance training group these results were not so clear. Traditional null-hypothesis significance testing indicated a significant improvement in only two of the BP postural sway measures (and MBI, the likelihood of beneficial change above 90%). However, the likelihood of beneficial effects across all variables ranged from 19.8% to 99.2%, with a majority of the MBI (six out of 10) needing more data, and the likely estimations of effect spread across beneficial, trivial and harmful descriptors.

10.4 Gait and Exergaming in people with Multiple Sclerosis

The characteristics of abnormal gait patterns assessed using quantitative measures, with large sample sizes, is currently limited in people with MS (Givon *et al* 2009). The GAITRite™ system is sensitive enough to highlight compromised gait patterns in those with MS who have a very low level of disability and relatively short disease duration (Givon *et al* 2009). Previous (non-exergaming) studies have reported reduced stride length, velocity, and prolonged double support phase in people with MS (Rodgers *et al* 1999; Sosnoff *et al* 2011). Also, Givon *et al* (2009) reported significantly lower mean velocity, cadence, step length and Functional Ambulation Profile (FAP) scores, as well as significantly higher step time and base-of-support in MS participants than in able-bodied subjects.

A between-group analysis found that there were no significant post-intervention differences between the intervention groups, or when compared to the control group. However, it did suggest (with p values approaching significance and medium-to-large effect sizes) the potential for differences between the Wii Fit™ and traditional balance training group for Step length (p = .07, d = 0.72) and Stride Length (p = 0.8, d = 0.72), in favour of the Wii Fit™ group. Therefore, these findings remain unclear, and should be pursued in future research. Given the complex nature of ambulation and gait, combined with the limited duration of the intervention, and that none of the exercises were specifically gait-oriented, a finding of no significant between-group differences is not unexpected. However, with some gait variables approaching significance there is clear justification for further research.

The results of a within-group analysis are interesting. In the Wii Fit™ group there were significant improvements in all spatial-temporal measurements with the exception of heel-to-heel base of support. In fact, those in the Wii Fit™ group demonstrated markedly improved gait velocity, exceeding the minimum clinically important change of 0.10 cm/s (Fritz and Lusardi 2009). Conversely, and for clinical context, this did not reach a walking speed considered standard for healthy adults (between 120 to 140 cm/sec) (Fritz and Lusardi 2009). However, and again for clarity, it should be noted that participants were instructed to self-select their preferred walking speed. A significant improvement was also found for FAP score, with a final score of 78 (SD 12); where scores between 95 to 100 are found in healthy adults (Nelson *et al* 2002).

Conversely, in the traditional balance training group there were some trends for improvements; however, none of these were significant. Unexpectedly, there were also improvements in the control group which also exceeded the minimum clinically important change for gait velocity. A finding of significant improvements over-time is a promising discovery for the Wii Fit™; however, notwithstanding these general improvements, the ANCOVA showed no significant differences between any of the groups. Therefore, these findings remain unclear and, in the case of the control group, may be attributed to a learning/Hawthorn effect or associated with behavioural measurement and participant characteristics (Waters *et al* 2012).

10.5 MSWS-12 and Exergaming in people with Multiple Sclerosis

Unlike physical assessments, as a self-perceived measure of walking ability, the 12-item Multiple Sclerosis Walking Scale (MSWS-12) offers information of user-mobility in everyday life and activities of daily living. For clinical context, through the completion of a four-week intervention scores were distinctly higher (reflecting poorer perceived walking ability) than normative MS data (normative MSWS-12 score: 28.2; mean age: 42 years), as well as healthy individuals (normative MSWS-12 score: 2.2; mean age: 40 years) (Goldman *et al* 2008). However, these normative scores are based on younger participants (by approximately 10 years).

A between-group analysis found no significant post-intervention difference between intervention groups, or when compared to control. However, unusually, pairwise comparisons quantified significantly lower post-intervention scores in the traditional balance training group than in the control group. Therefore, interpretations of these findings will be proposed as a general consideration, aimed to advise future research. Previous experience of traditional methods of balance training, and the presence of a physiotherapist may play an important role in the administration of an exercise modality, and its perceived effectiveness when compared to one led by a computer. Again, this would be an interesting consideration for further research.

A within-group analysis revealed significant improvements over-time in the Wii Fit™ group and the traditional balance training group; however, scores for the control group had (non-significantly) worsened. In a comparable MS study, Nilsagård *et al* (2013) also found significant improvements in MSWS-12 scores in participants using the Wii Fit™, reporting a reduction of 5.9, over a 6-7 week intervention. In the current study, the MSWS-12 scores for the Wii Fit™ and traditional balance training groups were found to have significantly reduced by similar amounts, 5.5 and 6.1, respectively. However, the control group were found to have marginally worsened by 3.8. In finding comparative changes to previous research, we can suggest that people with MS perceive improvements to walking ability earlier than Nilsagård *et al* (2013) findings would suggest.

Interpretation of these findings is difficult as, unfortunately, there are no known guidelines indicating the smallest worthwhile change for the MSWS-12 questionnaire. Therefore, the clinical significance of these findings is unclear. However, we can report in finding positive changes to perceived walking ability over this four-week intervention. Interestingly, only the traditional balance training group were found to have post-intervention scores significantly lower than those of the control, although the GAITRite™ system in fact showed greater gait improvements in the Wii Fit™ group. Again, this may offer further insight into the participants' perceptions of traditional balance training compared to an exergaming system.

10.6 WHODAS 2.0 and Exergaming in people with Multiple Sclerosis

In recognition of the International Classification of Functioning, Disability and Health (ICF) framework, the WHODAS 2.0 questionnaire can be used to provide a single score, or grouped scores to represent the six levels of functioning. The reported outcomes measures of this thesis have been linked (where appropriate) to the individual ICF domains (Body Function and Structure, and Activity and Participation) and ICF categories (e.g. reduced balance and gait, problem solving, changing and maintaining body position etc.) particular to people with MS. Specifically, the WHODAS 2.0 provides a measure of functioning and disability beyond the traditional assessment of physical function, taking into account environmental factors which make up the physical, social and attitudinal environment.

In the current thesis, scores found in this MS sample were distinctly higher (reflecting poorer perceived health status) than normative data from the general population of a comparable age (normative World Health Organisation Disability Assessment Schedule [WHODAS] score 3.2; aged 45-54), as well as those with chronic physical conditions (normative WHODAS score 5.9; aged 45-54) (Andrews *et al* 2009). In the current study, a between-group analysis found significantly lower post-intervention scores in both the Wii Fit™ group and traditional balance training groups than in the control. Moreover, there were no significant post-intervention differences between the intervention groups, suggesting that both facilitate positive changes to participant health status, function and disability following a four-week intervention.

A within-group analysis revealed significant improvements over-time in the Wii Fit™ group and the traditional balance training group; however, scores for the control group had worsened, but only very marginally. For the intervention groups, these reductions suggest a positive change in the participants' perceived quality of life having completed a relatively short intervention; improvements found to be significantly greater than no-intervention. However, in finding no significant difference between these intervention groups we can conclude that both have influenced a positive change. In terms of the clinical meaning of these changes, at present there is no globally agreed threshold to classify an individual with significant disability using the WHODAS 2.0. Andrews *et al* (2009) suggests that scores between 10–48 are in the top 10% of the population distribution, and are likely to have clinically significant disability; placing our participants within this category. However, following a four-week programme we can conclude both interventions have facilitated a significant improvement over no-intervention; improvements which warrant further investigation.

10.7 Technology Acceptance and Exergaming in people with Multiple Sclerosis

The question of user-acceptance is important in the development of new technology, and even more so when technology is combined with an exercise modality; as motivation to exercise is commonly lacking (Campbell *et al* 2001; Middleton 2004). To the knowledge of the author, this is the first study to investigate user-acceptance of exergaming technology using the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire in people with MS.

This research will offer insight into how people with MS accept and react to exergaming technology compared to traditional interventions.

High scores were found at baseline, which suggest high acceptance of both forms of balance training. A between-group analysis found no significant differences between the intervention groups. However, it did suggest (with *p* values approaching significance and medium effect sizes) the potential for differences in the subscales *Performance Expectancy* (PE) and *Effort Expectancy* (EE), with higher scores in the Wii Fit™ group.

In the absence of statistical significance, only a general observation of these results can be offered with the aim of guiding future research. With PE and EE approaching significance, would suggest that those in the exergaming group believed the Wii Fit™ to be more effective in improving balance (PE), and with a higher degree of ease associated with its use (EE). In the only comparable study, Theng *et al* (2009), using the Technology Acceptance Model (Davis 1989), established that the Nintendo Wii™ would likely be accepted by senior citizens if it was perceived as useful. In the current study, perceived usefulness, comparable to the UTAUT subscale PE (Davis 1989; Venkatesh *et al* 2003), was found to be approaching significance. Therefore, we can surmise that the Wii Fit™ would be accepted by MS users.

Despite high scores reported at baseline – suggesting high acceptance of both forms of balance training - a within-group analysis found these had significantly improve over-time in all subscales in the Wii Fit™ group. For the traditional balance training group, scores also significantly improved in all but two subscales (EE and Behavioural Intention [BI]). In finding such improvements over-time we can suggest that acceptance of exergaming technology increases with exposure, and is comparable to traditional balance training – the current standard in clinic and home exercises. Through the findings of the current study the benefit of exergaming technology in encouraging user-intention is acknowledged, and indicates the potential for higher concordance as a consequence of high user-acceptance.

A multiple regression analysis showed that EE and *Social Influences* (SI) were significant predictors of BI at pre-intervention; however, only accounted for 37% of the total variation observed in BI to accept exergaming technology. In finding a significant regression model, this would suggest that these two subscales are of importance in the use of exergaming technology, and should be considered when prescribing such an intervention. On the basis of the evidence currently available, it seems fair to suggest that the Wii Fit™ would likely be accepted as a means of balance training for people with MS, as PE is the strongest predictor of intention to use the technology (Venkatesh *et al* 2003). However, further investigations over a prolonged period are needed to establish long-term user-acceptance and exercise concordance.

10.8 Flow Experience and Exergaming in people with Multiple Sclerosis

In the current study, there were high scores at baseline for both intervention groups, suggesting that new users are responsive to flow state properties. A between-group analysis revealed significantly higher post-intervention scores in the Wii Fit™ group than in traditional balance training on five subscales. Furthermore, a within-group analysis found significant improvements in all subscales in those allocated to the Wii Fit™, compared to only three in the traditional balance training group.

This indicates that those in the Wii Fit™ group had significantly higher awareness of what needed to be accomplished (subscale *Clear Goals* [CG], p = 0.05), higher attainable focus (subscale C*oncentration-On-Task* [CT], p = 0.03) and clear immediate feedback (*Unambiguous Feedback*, p = 0.04). In addition, those in the Wii Fit™ group were able to achieve significantly higher levels of involvement in the task whereby movements seemed automatic (subscale *Action-awareness Merging* [AM], p = 0.03), in addition to an altered perception of time (subscale *Transformation of Time* [TT], p = 0.001). These last two subscales may contribute to an important psychological property of exergaming technology, and an advantage over traditional balance training methods – 'user-distraction' (Kato 2010).

Exergaming has produced some very positive findings as a result of distracting users from not only the duration of physical activity, but also the intensity. Warburton *et al* (2009) demonstrated that the addition of gaming technology to stationary cycling resulted in higher physiological metabolic requirements and without increasing perceived exertion than in non-exergaming intensity-matched cycling. This would suggest that the addition of gaming technology may distract from the perceived intensity of physical activity; therefore, encouraging higher/longer workloads – as confirmed through comparable non-exergaming studies (De Bourdeaudhuij *et al* 2002; Yamashita *et al* 2006). This hypothesis is also supported by Brumel *et al* (2008), who reported that exergaming was perceived as less difficult, more engaging and enjoyable than traditional balance training. Therefore, this indicates the presence of positive psychological factors beyond those of traditional balance training.

Furthermore, in the current study, subjective observations by the researcher (JR) found that many of the participants in the Wii Fit™ group reported sensations of altered time-perception, believing that only several minutes had passed by the end of the session. This is evidenced by the large between-group difference for the subscale TT (post-intervention difference = 1.2), small p value ($p = 0.001$) and a considerable effect size ($d = 1.71$). In fact, finding significantly higher flow scores in the Wii Fit™ group was not unexpected, as flow is widely accepted as one of the key reasons that people play games (Csikszentmihalyi 1990).

It is accepted that modern computer games are designed using the very concepts of flow state as a means of encouraging continued game play (Chen 2007; Nacke and Lindley 2008), and thus increasing flow experience and motivation to continue. A benefit of computer gaming technology, unlike traditional games or physical exercise, is that it can automatically adapt to the skill of the player, allowing for the opportunity for (the subscale) challenge-skill balance in flow attainment (Bressler and Bodzin 2013). Furthermore, games designers can tailor the gaming environment to optimise the opportunity for (the subscales) user-feedback and CG, needed for flow experience (Fang *et al* 2013). From a clinical perspective, there are clear advantages of an exercise modality which has flow 'built-in', since flow achievement is also strongly related to repeat activity and continued use (Csikszentmihalyi 1990; Jones 1998). Lai *et al* (2012), reporting the findings of a survey, identified a positive correlation indicating that with higher 'frequency of use' and 'longer use' of exergaming technology the incidence of flow state and enjoyment is increased; a finding also demonstrated through the results of this four-week study. Therefore, the Wii Fit™ has the potential to positively influence exercise concordance, and may offer an accepted alternative to traditional balance training, in which concordance is a problem (Campbell *et al* 2001; Middleton 2004). Yet despite the popularity of exergaming systems, there is currently limited information regarding the nature of the players' experiences (Thin *et al* 2011), and even less with clinical populations – information now provided through this study.

In one of the few comparable studies using healthy volunteers, the effects of exergaming and flow are positive overall. Thin *et al* (2011) reported significantly higher flow state scores for the subscales Challenge-Skill Balance (CB), AM, and Loss of Self-Consciousness in exergaming compared to normal exercise; scores found to be comparable to sporting activities and a finding consistent with those of this PhD thesis, study 1. Such contrasts can also be made with the second study in people with MS. Comparisons using the flow scores from this second study with published normative values (Jackson *et al* 2001) for sports (n = 236; orienteering, surf lifesaving and road cycling) found higher scores for all nine flow state subscales in those using the Wii Fit™, and all but three subscales (CG, AM, and TT) in the traditional balance training group.

Overall, these are positive findings, and again suggest that exergaming technology has the potential to meet, or surpass the opportunity for flow experience than traditional balance training and even traditional sporting activities in MS users.

10.9 Limitations of the study

Although this is a larger study compared to most in the specific area of exergaming and MS, it does appear to lack sufficient power to give fully definitive results for some of the comparisons. However, a post-hoc power analysis based on the same parameters revealed that a sample of 46 provided a reasonable statistical power of 0.65. As this research was conducted as part of the completion of a PhD, it was restricted by time, geographical area, staffing, and funds. This was the main limiting factor in participant recruitment, as all of the participants volunteered their time and the cost of travel. Compared to larger funded trials and published research, these limitations would not likely apply. Where the effect sizes were relatively large the design did show these to be statistically significant as planned. However, as indicated, there may have been some instances in which potentially significant differences were not highlighted as such. Where this may have been the case it has been emphasised that without verification from a larger analysis, any such observation should remain speculative.

For practical reasons, neither the participants nor the researcher were blinded and thus the results will contain a degree of bias. The interventions were matched in terms of gross movement pattern akin to traditional balance training exercises; however, these may have differed in terms of physical intensity. A comparable exercise programme to the Wii Fit™, which is matched in terms of intensity, may offer additional insight into the effects of such an intervention in people with MS. Future work should also include a follow-up to assess the duration of any effects, and could investigate the use of the Wii Fit™ without supervision.

10.10 Clinical Summary

This section will provide a clinically orientated summary, with the aim of guiding future use of, and evidence for, the application of exergaming technology in people with MS. This second study found that the Nintendo Wii Fit™ is as effective as traditional balance training in improving balance and gait, and is equally accepted. However, exergaming is superior in terms of flow experience and therefore user engagement. This is an important distinction when considering exercise concordance.

Balance improvements in the Wii Fit™ group ranged from 3% to 17% having completed a four week intervention. These are indicative of greater stability and control within the base of support. Previous literature also suggests these reductions are clinically suggestive of stability improvements and a move away from the limits of stability where a fall will occur. Prosperini *et al*., (2013) reported improvements ranging from 15% to 17% in people with MS completing a 12 week, home-based, Wii™ exercise programme. This offers valuable information for those wishing to employ a similar intervention with regards to exercise duration, with improvements occurring earlier than the findings of Prosperini *et al*., (2013) suggest. A recent study reported that for each 10mm increase in COP path values there is an 8%-increased risk of being classified as a faller in people with MS (Prosperini and Pozzilli 2013). Therefore, these findings indicate the potential for clinically meaningful changes in postural sway which may equate to a reduced risk of falls.

From a clinical perspective, there are clear advantages of an exercise modality which has flow 'built-in', since flow achievement is also strongly related to repeat activity and continued use (Csikszentmihalyi 1990; Jones 1998). Therefore, the Wii Fit™ has the potential to positively influence exercise concordance, and may offer an accepted alternative to traditional balance training, in which concordance is a problem (Campbell *et al* 2001; Middleton 2004).

10.11 Study Conclusions

Exergaming was found to be comparable to traditional balance training in terms of its effects on balance and gait, in addition to user-acceptance and self-perceived walking ability and health related outcomes. However, those using the Wii Fit™ demonstrated significantly higher flow state scores in five of the nine subscales, proposing that exergaming may be more intrinsically motivating than traditional balance training. Overall, this would suggest the Wii Fit™ to be an effective and attractive means of balance and gait training, with high acceptance and flow experience in people with MS, which may not only assist in exercise uptake, but also concordance. This research has added to the limited evidence base specific to the effects of exergaming technology in MS users, in addition to having been peer reviewed and published through the BMC Sports Science, Medicine and Rehabilitation journal (Appendix 1, page 315).

CHAPTER 11: GENERAL DISCUSSION AND CONCLUSIONS

11.1 Introduction

Through the completion of this thesis, new knowledge has been reported specific to the effects of two exergaming systems in healthy sedentary adults, and exergaming compared to matched traditional balance training in people with multiple sclerosis (MS). Furthermore, this thesis provides additional insight of exergaming technology in terms of the levels of user-acceptance (behavioural intention), flow experience, and health related outcomes. The completion of a four-week exergaming programme was related to improvements in postural sway, and higher levels of user-acceptance and flow experience. This chapter will provide a summary of these findings, discuss the limitations of the thesis, and provide potential direction for future research.

11.2 Aims of the thesis

This thesis was undertaken to explore the effects of two exergaming systems in terms of postural sway, user-acceptance, and flow experience in healthy sedentary adults. This study provided new knowledge from individuals who were free from clinical pathologies, medications or additional therapies, and therefore any effects were likely to be the result of the intervention (Cohen and Posner 2000). These findings, in addition to the published works of other authors, informed a second investigation aimed to establish the effects of exergaming compared to matched traditional balance training in people with MS in terms of postural sway, gait, user-acceptance, and flow experience; in addition to secondary health-related outcomes.

The thesis had two research questions for each study:

Study 1:

- Does exergaming technology affect standing balance (postural sway) in healthy sedentary individuals?

- What are the effects of exergaming technology on user-acceptance and flow experience in healthy sedentary individuals?

Study 2:

- Does exergaming technology affect standing balance (postural sway) and walking ability (gait) in people with MS?

- What are the effects of exergaming technology on user-acceptance, flow experience, self-perceived walking ability, and limitations in activity and participation in people with MS?

The conclusions of this investigation and recommendations from each study's findings will now be discussed.

11.3 Synthesis of findings

Having completed a systematic review of the literature, the need for further evidence was apparent. There were clear shortcomings of the previous research through the employment of limited research designs, multiple simultaneous therapies and the recruitment of small sample sizes. However, the current literature established the need for continued research, provided insight for future research, and highlighted this as an area of interest in the clinical field. At present there are only eight published studies, undertaken from 2005-2013, to investigate the effects of exergaming technology in people with MS. Clearly, this is a small number, justifying this as a new area of investigation and the need for continued research.

In determining the effects of exergaming on balance performance, many of the previous investigations quantified balance using clinical outcome measures. Admittedly, these methods are easy to administer, commonly used in the clinical setting and often require no additional financial costs. However, such clinical outcome measures are limited in their ability to detect small, but meaningful changes in balance performance due to ceiling effects. Therefore, there is a need for quantitative, reliable and accurate analyses of balance performance, and a clear gap of knowledge in this area.

Moreover, even if exergaming were found to be a highly effective intervention, the question of user-acceptance is often lacking in comparable research, the importance of which is underappreciated. This is apparent with current physical interventions, as many lack the motivation to exercise or complete prescribed exercises; even at the consequence of ill health. Therefore, there is a need for a means of exercise that is accepted, which may translate into exercise concordance. To the author’s knowledge, there is no previous literature on the assessment of user-acceptance specific to exergaming technology in clinical populations or in people with MS.

A third factor in exercise prescription is the lack of engagement into the activity (referred to as flow). While flow can be experience in any activity, its presence in rehabilitation-type exercise has not yet been established. Flow state is synonymous with pure engagement in an activity with high enjoyment and considered an intrinsically motivating optimal state (Csikszentmihalyi 1990). Therefore, a clinical intervention which, by design, facilitates flow state may also assist in exercise concordance. To the author’s knowledge, there is only one previous study to investigate flow and exergaming technology: a cohort study with 14 healthy-young subjects, reporting positive results of exergaming (Thin *et al* 2011). This again indicates the limited research in this field.

Lastly, as demonstrated through the introduced literature, there is a clear need for further randomised controlled trials (RCT) on exergaming for people with MS due to the employment of limited research designs. At present, no published trials have used three arms to compare exergaming against traditional balance exercises and also a no-intervention control group. Therefore, this PhD thesis is aimed to bridge the gap of knowledge in this area. This PhD thesis is the first to report the effects exergaming through the quantitative assessments of postural sway and gait, in addition to user-acceptance and flow experience, using the design of a RCT in people with MS. This thesis reports one of the largest sampled studies in the current literature. These results are complimented through the additional reporting of secondary clinical outcome measures of self-perceived walking ability, and aspects of functioning based on the concepts of the International Classification of Functioning, Disability and Health (ICF).

Therefore, this thesis provides novel evidence, addressing a number of important gaps in the current literature, which include the following:

1. The effect of two exergaming systems (the purpose-designed, virtual reality IREX™ system vs exergaming technology, Wii Fit™) on standing balance (postural sway), user-acceptance and flow experience in healthy sedentary individuals.

2. The effect of exergaming technology on balance (postural sway), walking ability (gait), user-acceptance, flow experience, self-perceived walking ability, and limitations in activity and participation in people with MS.

11.4 Postural Sway

Through a four-week exergaming programme using either the Interactive Rehabilitation and Exercise system (IREX™) system or the Wii Fit™ in healthy sedentary adults, this investigation found no significant post-intervention differences between the respective systems in terms of the effects on postural sway. This would suggest that both systems are comparable as means of training balance. However, both systems demonstrated significant improvements in postural sway measures.

In this first study, there were significant improvements for the IREX™ group in four postural sway measures: unipedal (UP) centre of pressure (CoP) velocity, anterior-posterior (AP) and medial-lateral (ML) range, and standard deviation (SD). For the Wii Fit™ group there were significant improvements in three of the postural sway measures: UP CoP velocity and ML range, in addition to bipedal (BP) ML range.

Through a second study comparing the Wii Fit™ to matched traditional balance training and a control group, this investigation found no significant post-intervention differences between the intervention groups. This would suggest that the Wii Fit™ is comparable to traditional balance training, with both interventions showing significant improvement compared to no-intervention (the control group). For the Wii Fit™ group there were significant improvements in five postural sway measures: BP and UP CoP velocity, BP AP and ML range, and AP SD. For the traditional balance training group there were significant improvements in two of the postural sway measures: BP ML and AP range.

An advantage of exergaming technology, one which has not been investigated within this PhD thesis, is the effect of visual feedback on balance training. Traditional balance training relies on somatosensory, vestibular and visual feedback, and as such, does not necessarily provide information as to the quality of the movement. Furthermore, as MS is a neurological condition, the ability to relay (afferent) information from these systems may be diminished. Unlike traditional balance training, in addition to these central feedback systems, the Wii Fit™ provides the user with constant audio and visual feedback specific to the actions of the game and the postural sway of the user. Therefore, the Wii Fit™ may be considered a sensory-rich environment (Esculier *et al* 2012), ideal for independent balance training. Prosperini *et al* (2013) purport that balance training with such feedback could improve postural sway and reduce the risk of falling in people with MS. However, to the author's knowledge, there are no published investigations to examine the accuracy of such sensory feedback provided through this technology. An additional consideration to this technology is the facilitation of dual-tasking - an attempt to combine and improve simultaneous balance and cognitive function – which may also assist in improving postural sway in people with MS (Cameron and Lord 2010), something that exergaming is able to offer through engaging, interactive and enjoyable game-play.

Overall, the effects of exergaming technology are promising when used as a means of balance training in healthy sedentary individuals, and in people with MS. These results would suggest that the exergaming Wii Fit™ is not only comparable to a purpose-designed virtual reality system (in healthy users), but also to traditional balance training (in MS users). Clinically these are interesting findings. Firstly, the purpose-designed IREX™ system currently costs $12,999, approximately £8,300 (Flaghouse 2014). The Nintendo Wii™ costs approximately £230. Therefore, with no significant post-intervention differences between these systems, the Wii Fit™ is an affordable option for the implementation of an exergaming intervention for the therapist *and* the user. Moreover, the IREX™

system is gradually becoming outdated, as evidenced by the release of the Microsoft Kinect™ system – developed using the same technology and game-play concepts.

Both interventions reported significant within-group improvements over-time, suggesting they are clinically effective. At present there is some debate in the literature regarding the importance of the direction of change in postural sway measures. As introduced and discussed through this thesis, there is evidence to support that increases in postural sway in either direction (AP and ML) are associated with increased likelihood of falls (Sosnoff *et al* 2011). This assumption formed the basis for interpretation of these findings, and suggests that exergaming technology is an effective means of balance training through improvements in both AP and ML postural sway, in addition to CoP velocity.

Based on the concept of ‘smallest worthwhile change’ - considered to be a 10% reduction in postural sway measures - in healthy sedentary adults the Wii Fit™ facilitated significance improvements which ranged from 7% to 8%; not quite reaching this established threshold. However, accounting for the nature of these participants (absent of clinical injury or pathology), such a finding is informative of the general effects of exergaming technology. Moreover, in people with MS, the Wii Fit™ facilitated significant improvements which ranged from 3% to 17% - some of these clearly exceeding the smallest worthwhile change. An additional clinical consideration of both studies is that despite a relatively short four-week intervention, changes to postural sway were found in both studies. Therefore, based on these findings, and those of the discussed authors, this thesis can conclude that the Wii Fit™ is an effective intervention in facilitating meaningful changes to balance for both healthy sedentary and MS users.

11.4.1 Postural Sway summary

Based on the findings of study 1 with healthy sedentary adults, this PhD thesis concludes the following:

- The IREX™ system and the Wii Fit™ are comparable as means of training balance, with no significant differences between the two.
- Both systems demonstrated significant improvements in postural sway measures, suggesting they are clinically effective.

Based on the findings of study 2 with people with MS, this PhD thesis concludes the following:

- The Wii Fit™ is comparable to matched traditional balance training, with no significance differences between the two.
- Both interventions showed significant improvement compared to no-intervention.
- Both systems demonstrated significant improvements in postural sway measures, suggesting they are clinically effective.

11.5 User-acceptance

Through a four-week exergaming programme using either the IREX™ system or the Wii Fit™ in healthy sedentary adults, this research found no significant post-intervention differences between the respective groups in terms of user-acceptance. This would suggest that both systems are accepted as a means of balance training in healthy sedentary users. Furthermore, high scores at baseline suggest that new users are open to the concept of exergaming technology at first use. For both groups there were significant improvements in the questionnaire subscales *Performance Expectancy* (PE) and *Social Influence* (SI), as well as *Effect Expectancy* for the IREX™ group only.

Through the second study comparing the Wii Fit™ to matched traditional balance training and a control group, this research found no significant differences between the intervention groups. This would suggest that the Wii Fit™ is comparable to traditional balance training in terms of user-acceptance. Also, high scores at baseline suggest that new users are open to the concept of exergaming technology at first use. Furthermore, user-acceptance was found to significantly increase with continued use for all subscales in the Wii Fit™ group.

This is the first study to report on the user-acceptance of exergaming technology for people with MS; therefore, comparisons with previous research are not possible. This PhD thesis provides new and insightful information on the psychological processes of user-acceptance of exergaming technology in a clinical population. The subscale PE, considered the strongest predictor of intention to use the technology (Venkatesh *et al* 2003), was found to significantly improve in both healthy sedentary and MS users. As indicated through study 1, a commercial exergaming system (Wii Fit™) is equally accepted as a means of balance training than one purpose-designed for rehabilitation (the IREX™ system). Again, this is an interesting consideration when taking into account the cost of the respective systems. Also, as indicated through study 2, the commercial exergaming system was equally accepted as traditional balance training – the standard modality of balance training and often prescribed by therapists. Therefore, this thesis can conclude that the Wii Fit™ is an accepted intervention when used as a means of balance training in both healthy sedentary and MS users.

11.5.1 User-acceptance summary

Based on the findings of study 1 with healthy sedentary adults, this PhD thesis concludes the following:

- The IREX™ system and the Wii Fit™ are comparable in terms of user-acceptance, with no significant differences between the two.
- Both systems demonstrated significant improvements in user-acceptance scores, suggesting acceptance increases with use.

Based on the findings of study 2 in people with MS, this PhD thesis concludes the following:

- The Wii Fit™ is comparable to traditional balance training in terms of user-acceptance, with no significant differences between the two.
- Both interventions showed significant improvement in user-acceptance.

- All user-acceptance subscales significantly increased in the Wii Fit™ group.
- Both systems demonstrated significant improvements in user-acceptance scores, suggesting acceptance increases with use.

11.6 Flow Experience

Through the first study of a four-week exergaming programme using either the IREX™ system or the Wii Fit™ in healthy sedentary adults, this research found no significant post-intervention differences between the Wii Fit™ or IREX™ group in terms of flow experience. This would suggest that both systems are equal in their facilitation of flow state in healthy sedentary users. Also, high scores at baseline suggest that new users are susceptible to flow at first use; with scores that improve with use.

Through the second study comparing the Wii Fit™ to matched traditional balance training and a control group, there were significantly higher scores in the Wii Fit™ group for the subscales: *Clear Goals* (CG), *Concentration on Task* (CT), *Unambiguous Feedback, Action-Awareness Merging*, and *Transformation of Time*. This would suggest an important advantage of exergaming technology over that of traditional balance training – the facilitation of flow state.

Finding greater flow state properties in a therapeutic exergaming intervention is potentially of great importance. In fact, the success of gaming technology as an adjunct to physical therapy is the result of increased engagement and motivation compared to the typically mundane and repetitive tasks associated with traditional physical therapy (Kato 2010). Moreover, as noted through comparisons with previous research, exergaming technology would appear to surpass flow state scores found in traditional sporting activities.

In terms of the clinical context for those with neurological conditions: MS is a lifelong neurological disease, through which physical activity and balance training is encouraged. To put this into perspective with regards to a balance training routine, the average life expectancy for a female in England and Wales is 82 years (Office of National Statistics 2013), and the average age of MS diagnosis is 30 years (Milo and Kahana 2010). While MS is not classified as a fatal illness, it is reported to reduce life expectancy by approximately 10 years (Brønnum-Hansen *et al* 2004). Therefore, a female aged 30 years with MS would be encouraged to undertake MS-related physical activity (exercise or rehabilitation) over a period of approximately 42 years. The likelihood of exercise adherence through traditional balance training, over this period of time, is questionable. Furthermore, it is well reported that adherence to any exercise programme is a common problem, as many lack sufficient motivation, irrespective of condition (Campbell *et al* 2001; Middleton 2004).

These findings may be explained through noting an important underlining benefit of exergaming technology. Unlike traditional physical exercise, exergaming can allow for the opportunity for (the subscale) challenge-skill balance in flow attainment by automatically adapting to the skill of the player (Bressler and Bodzin 2013), in addition to providing constant meaningful (subscale) user-feedback and (subscale) CG needed for flow experience (Fang *et al* 2013), as demonstrated through the significantly higher post-intervention scores in the Wii Fit™ group. Essentially, and of benefit to exercise prescription, flow state properties are built in to exergaming technology.

This is the first study to report on the flow experience of exergaming technology for people with MS; therefore, further comparisons with previous research, beyond those provided through the discussion sections, are not possible. This PhD thesis provides new and insightful information on the psychological properties of flow state in exergaming technology which may be used to guide further research. Based on the findings of this PhD thesis, we can conclude that exergaming facilitates flow state in healthy sedentary users and people with MS. As indicated through study 1, an ‘off the self’ exergaming system is comparable to a purpose-designed virtual reality rehabilitation system in healthy sedentary users. However, as indicated through study 2, the Wii Fit™ is superior to traditional balance training in terms of its facilitation of flow state in people with MS.

11.6.1 Flow State summary

Based on the findings of study 1 with healthy sedentary adults, this PhD thesis concludes the following:

- The IREX™ system and the Wii Fit™ are comparable in terms of flow experience, with no significant differences between the two.
- Both systems demonstrated significant improvements in flow scores, suggesting flow increases with use.

Based on the findings of study 2 with people with MS, this PhD thesis concludes the following:

- The Wii Fit™ demonstrated significantly higher post-intervention scores for the subscales: *Clear Goals, Concentration on Task, Unambiguous Feedback, Action-Awareness Merging,* and *Transformation of Time*.
- Suggesting the Wii Fit™ is superior to traditional balance training in terms of its facilitation of flow state.
- Both interventions showed significant improvement in flow experience.
- Flow experience increased in all subscales in the Wii Fit™ group.

11.7 Limitations of the research

The studies undertaken through this PhD thesis provide new and unique knowledge to the field of exergaming research in healthy sedentary adults and MS users. This thesis has a number of strengths; however, in recognition that all studies have limitations, these will be acknowledged and discussed with the aim of guiding future research, and to expand on the already reported limitations of each study.

As indicated, and a strength of this research, a power analysis was undertaken for each investigation to identify the number of participants required in order that the findings may be generalised to the population, and detect a clinically relevant treatment effect (Schulz and Grimes 2005). However, the planned sample sizes were not achieved in either study, potentially limiting the power to attain significant results (Altman 1980). In acknowledgment of this, and a further strength of this research**,** post-hoc power analyses were undertaken to inform the reader of the achieved power, and established that moderate statistical power was obtained with these smaller samples. Where the effect sizes were relatively large, the design showed these to be statistically significant as planned. However, as indicated, there may have been some instances in which potentially significant differences were not highlighted; findings which were reported as a general observation due to small, but non-significant, *p* values. Despite this limitation, comparisons with the current literature established that both studies are still among the highest sampled in the current exergaming literature. Moreover, through reporting the additional analyses of Magnitude Based Inferences, and the concept of smallest worthwhile change, clinical interpretations of such findings can be made beyond the arbitrary threshold of null-hypothesis significance testing.

An additional strength of this research was that both studies used random allocation to assign participants to an intervention (or control) to reduce the possibility of bias, and increase the reliability and generalisability of the findings (Brown *et al* 2003). Despite this, a potential limitation was the absence of blinding to participant allocation. The application of blinding within research can be used to prevent observer bias, contamination, and cointervention bias in allocated groups (Mayer 2004). However, blinding is difficult in studies of modalities such as procedures and devices, and was not possible in these participants given the nature of completing a physical intervention. Researcher blinding could have been employed, potentially increasing the internal validity of these findings; however, as a PhD thesis, the investigator (JR) was the sole researcher and responsible for administering the interventions.

Some consideration should also be given to participant attrition where individuals were lost to follow-up, and potentially diminishing the validity of these findings (Prasad 2014). However, participant dropouts are common in research and, in practice, a dropout rate of less than 20% is deemed acceptable (Mayer 2004). Both studies were within this threshold. Moreover, participant dropouts were acknowledged, the given reasons reported, and the results analysed using intention-to-treat principles and complete case analysis as a means of compensation and data transparency.

An additional consideration is that these findings are informative of the short-term effects of exergaming technology; therefore, any inferences are specific to this intervention period. However, these intervention durations are consistent with the current literature, appropriate to address the study aims, and within the time constraints of completing the PhD thesis.

The above limitations may be considered when critiquing these studies and their findings. However, taking into consideration the nature of this research, the lack of comparable research and the methodological rigor provided through the study design of a definitive randomised controlled trial, the strengths of these investigations far outweigh the limitations. Moreover, this research can be used to guide further investigations and inform clinical practice of the effects of exergaming technologies in healthy and MS users, in addition to provide useful input for future meta-analyses (Hopkins *et al* 2009).

11.8 Future direction for research

From the findings of this thesis, and those of comparable literature, there are clear points of future research in this field. As mentioned above, a limitation in this research is the administration of exergaming over a relatively short duration. The findings of this thesis indicate the potential for meaningful effects from only a four-week intervention; however, these effects may change with longer durations. This is of particular importance to clinical groups who are required to maintain physical activity to encourage continued health and independence. Based on the current findings of this PhD thesis, an extension of this research would be to investigate the long-term effects of exergaming technology, over a prolonged period – a point also expressed by other authors (Emery *et al* 2007). Given the complex nature of exercise motivation, qualitative research may offer additional insight into the specific barriers to, and facilitators of, the use of exergaming technology and reasons for increases in physical activity (Simon 2004). Therefore, a design which includes a qualitative element – such as one-to-one interviews or focus groups - may provide additional information specific to exercise concordance and user acceptance.

This combination of methods would provide evidence as to the lasting physiological effects of postural sway, and the psychological constructs of user-acceptance and flow (engagement), which are of particular interest with relation to concordance.

Much of the current literature has been completed through the administration of an exergaming intervention guided by the researcher or health care professional. Given the low cost of the Wii Fit™ system, a natural progression would be to investigate the independent use of this technology at home. Such a design would also account for the potential effects of the laboratory environment and the issues of observer bias. This would assist in the control of the Hawthorne effect and social desirability bias, through which participant's or researcher's reactions are potentially influenced by the environment, the observations of the researcher, or the behaviour congruity with social norms (Abbott and Sapsford 1998; Waters *et al* 2012).

Conversely, due to the design of exergaming technology, gaming experiences can also be shared. Previous (non-exergaming) interventions through traditional exercise have reported positive findings through community-based group exercise in people with MS (Learmonth *et al* 2012). In fact, the benefits of group exercises are many. The American College of Sports Medicine recommend exercise with a partner, as it can provide a safe environment, exercise variety, a social environment and motivation (Dolan 2008). Since exergaming systems can accommodate a number of simultaneous players, this may provide benefit through social support and interaction, competitive gameplay and shared enjoyment, all of which increase exercise adherence (Burke *et al* 2005). Moreover, since competition is synonymous with the attainment of flow, there is good reason to hypothesise that a community-based intervention would aid in exercise concordance. Playing against a human-controlled opponent has shown to give rise to higher levels of flow than playing against a computer-controlled opponent (Weibel *et al* 2008). Furthermore, this would encourage and enable the individual to manage their own condition, which research would suggest can result in greater activity levels and self-reported happiness (Rodin 1986).

To further explore the effects of exergaming technology compared to traditional exercise, a study of comparable exercises to the Wii Fit™ which are purposely matched in terms of intensity may offer insight into the physiological and psychological effects of such interventions. Lastly, with the release of newer exergaming and virtual reality systems, an assessment of this newer technology, such as the Microsoft Xbox Kinect™, may now be more appropriate for clinical groups and people with MS with the release of less physically demanding games.

11.9 Clinical Implications

Through undertaking a systematic review of the literature, a phase II exploratory investigation into the effects of exergaming technology with healthy-sedentary users, and a phase III definitive RCT with MS users, this body of work is not only unique, but addresses a clear gap in the knowledge base. This thesis is the first to make direct comparisons between exergaming technology, traditional balance exercises, and a control group. This thesis assessed the specific balance training exercises of the Nintendo Wii Fit™ to create a second comparable balance training programme, allowing for comparisons between the two. Unlike previous research, this training regime has been published in full, and could be used by a physiotherapist with their patients, or, by the patients themselves independent of a healthcare practitioner. This body of work could also be used to inform current clinical guidelines on MS management specific to balance training and exercise prescription.

This research advances our understanding of the effects of exergaming technology beyond any other currently published research through investigations of not only the physical effects, through balance assessment, but also the psychological effects, through user acceptance and engagement. To aid clinical decision making with regards to the options for balance training for people with MS, this research has found that exergaming technology is as effective as traditional balance training in facilitating improvements in balance and gait, and is equally accepted by users. However, it is superior in terms of user engagement, and therefore, could offer an effective alternative to traditional interventions in aid of concordance. Therefore, this body of work provides needed evidence to support the clinician in the application of exergaming technology.

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