Group exercise interventions improve balance, mobility and functional task performance in adults aged over 55 years

Vaughan Patrick Nicholson

Master of Physiotherapy Studies; Bachelor of Human Movement Science (ExSci) (Hons)

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ABSTRACT

The maintenance of balance, mobility and the ability to perform functional tasks are integral to healthy ageing and the maintenance of independence. Various exercise interventions are potentially capable of maintaining or improving balance, mobility and functional task performance but the effectiveness of many available exercise options are not yet known.

Exergaming (exercise based video games) and group exercise classes are exercise options that have the potential to improve balance, mobility and functional task performance in middle-aged and older adults. The use of exergaming equipment such as the Nintendo Wii is highly accessible, inexpensive and has been shown to help improve balance in older adults in supervised environments. The effectiveness and potential safety of unsupervised Nintendo Wii gaming in independent older adults is not yet well established.

Gym or fitness facility based activities are growing in popularity amongst middle-aged and older adults. The effectiveness of gym based activities such as traditional resistance training is well established but the effectiveness of pre-choreographed group fitness classes has been scarcely assessed. Two of the most popular group fitness classes available globally are BodyPump™ and BodyBalance®. BodyPump™ is a low-load high-repetition resistance training class while BodyBalance® incorporates elements of tai chi, yoga and Pilates. Both classes are available in several thousand fitness facilities globally so the potential reach of such classes is vast but the effectiveness of these classes has yet to be determined in middle-aged or older adults.

Three studies were designed to assess the effectiveness of three group exercise interventions on balance, mobility and functional task performance in adults aged over 55. Study one assessed the effectiveness of Nintendo Wii training in adults aged between 65 and 85 years. Older adults were recruited from local retirement villages and educational settings to participate in a six-week two-group repeated measures study. The Wii group (n = 19, 75 ± 6 yr) undertook 30 minutes of unsupervised Wii balance gaming, three times per week in their retirement village while the comparison group (n = 22, 74 ± 5 yr) continued with their usual activity. Participants’ balance and functional abilities were assessed pre- and post-intervention. Significant group-by-time interactions (p <0.05) were evident for the timed up
and go, left single leg balance, lateral reach (left and right) and gait speed in favour of the Wii group indicating an improvement in mobility and medio-lateral balance.

Study two assessed the effectiveness of BodyPump™ training in a randomised controlled trial. Sixty-eight apparently healthy, active adults aged over 55 years completed either 26 weeks of BodyPump™ training or served as control participants. The BodyPump™ group (n=32, age = 66 ± 4 years) trained twice per week for 26 weeks while the control group (n=36, age = 66 ± 5 years) continued with their normal activities. Balance, gait speed, leg-press and Smith-machine bench-press one repetition maximum (1RM), bone mineral density, body composition and self-reported health status were all assessed at baseline and follow-up. Significant group-by-time interactions in favour of the BodyPump™ group were found for single leg balance right (p = 0.006), normal gait speed (p = 0.028), leg-press 1RM (p = 0.007), Smith-machine bench-press 1RM (p = 0.001), and lumbar bone mineral density (p = 0.005). There were no group-by-time interactions for bone mineral density at the hip or total body, and no effect on body composition or health status measures. Three participants in the BodyPump™ group withdrew from training due to injury or fear of injury related to training.

Study three assessed the effectiveness of BodyBalance® training. Healthy, active adults aged 66 ± 5 years completed the randomised controlled trial. Balance, mobility, functional task performance, fear of falling and self-reported quality of life were assessed at baseline and after 12 weeks. Participants either undertook two sessions of BodyBalance® per week for 12 weeks (n = 15, age = 66 ± 5 years) or continued with their normal activities (n = 13, age = 66 ± 5 years). Significant group-by-time interactions were found for the timed up and go (p = 0.038), 30 second chair stand (p = 0.037) and medio-lateral centre of pressure range in narrow stance with eyes closed (p = 0.017). There were no significant effects on fear of falling or self-reported quality of life.

The combined results of all three studies indicated that balance training and low-load high-repetition resistance training can enhance certain aspects of balance, mobility and/or functional task performance in intervention group participants. In addition it was found that low-load high-repetition resistance training can improve maximal strength and maintain lumbar spine bone mineral density. Each intervention was well tolerated by the majority of participants.
The results of the studies indicate that even those middle-aged and older adults that do not have impaired balance or evident mobility limitations can benefit from various types of balance based exercise or high repetition resistance training suggesting that such training could be used as preventative interventions. More difficult balance assessment tasks may be required to better determine the effect of such training in such a high functioning population.
DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made. I certify that the material contained within this thesis has not been submitted for a degree at this or any other university.

Name: Vaughan Patrick Nicholson

Signature:

Date:
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Thank you to all the research participants that took part in the many hours of testing and training associated with this thesis. The research projects would not have been possible without your enthusiasm, commitment and curiosity.

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Abbreviations

1RM One-repetition maximum
ABS Australian Bureau of Statistics
BMD Bone mineral density
BMI Body mass index
COG Centre of gravity
COP Centre of pressure
CSEC Comfortable stance eyes closed
CSEO Comfortable stance eyes open
df Degrees of freedom
DXA Dual-energy X-ray absorptiometry
FFM Fat-free mass
GLM General linear model
IconFES Iconographical falls efficacy scale
IHRSA International Health, Racquet and Sportsclub Association
LMI Les Mills International
n Number
NSEC Narrow stance eyes closed
NSEO Narrow stance eyes open
PACES Physical activity enjoyment scale
® Registered trademark
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## Units of measurement

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<td>g</td>
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<td>g/cm²</td>
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LIST OF ORIGINAL PUBLICATIONS

Journal publications arising from this thesis

(Thesis chapter 3)

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Conference Publications

Nicholson, V.P., McKean, M., Burkett, B. (2013) Six weeks of unsupervised WiiFit game play improves balance and gait speed in independent older adults aged 65–84 years. *Journal of Science and Medicine in Sport*, 16 (6), e53

Winner Best New Investigator Physical Activity and Health Promotion at the 2013 Asics Conference of Science and Medicine in Sport. Phuket, Thailand.
CHAPTER 1: INTRODUCTION

1.1 Background

As a practicing physiotherapist I assess, diagnose and manage various injuries, conditions and ailments. The cause of these injuries, conditions and ailments are many and varied and may be linked to an acute incident, habitual postures, degenerative changes, or a multitude of other scenarios. Part of my role as a physiotherapist, and the role of many allied health professionals, is to safely guide clients back into appropriate physical activity, whether it is back into a walking program, spin class, gym program or elite level sport. An area that has always intrigued (and baffled) me and many of my colleagues is the lack of information regarding the effectiveness and potential safety of many physical activity or exercise programs widely available to people of all ages and various levels of physical ability. Several times a week clients will ask me whether they can return to BodyPump or BodyBalance or Boot camp or (insert any other poorly researched but popular activity here). My decision is largely based on the client’s pain/injury/condition and a knowledge of the basic movement patterns associated with the activity they are returning to. To help make my decision easier I would like to know:

Does activity “a,b or c” achieve what is required for that client? Does the activity achieve what the client thinks it does or should? Is that activity safe for them?

These simple questions are at the heart of why I have undertaken the research presented in this thesis by publication. A less personal and more theoretical background to the thesis follows.
Australia, like most nations has an ageing population (UN, 2002). Ageing is associated with deterioration in a number of physical characteristics such as balance (Era et al., 2006), mobility (Bohannon, 1997), muscular strength (Hughes et al., 2001) and body composition (Janssen, Heymsfield, Wang, & Ross, 2000; Warming, Hassager, & Christiansen, 2002). Many of these changes are evident by middle-age and are compounded by reductions in physical activity (Bleicher et al., 2011; Callahan et al., 2014; LaCroix et al., 1993; Nitz, Stock, & Khan, 2013). The terms middle-aged and older adult will be used throughout this thesis to describe those aged 55 to 64 years and those aged 65 years and over, respectively (ABS, 2013b; AIHW, 2005).

Deficits in physical characteristics such as balance and mobility are associated with a number of negative outcomes such as falls (Lord & Clark, 1996), physical disability (Buchner & De Lateur, 1991), mortality (Cooper et al., 2014), fractures (Cummings et al., 1993) and their associated health care costs. For example, the total health care cost attributable to fall related injury in Australia will exceed $1.3 billion dollars per annum by 2051 (Moller, 2003). Fortunately, undertaking various forms of exercise including resistance training (Bolam, van Uffelen, & Taaffe, 2013; Liu & Latham, 2009) and specific forms of balance training (Howe et al., 2011; Robertson & Gillespie, 2013) are able to delay or reverse the deterioration in many of these physical characteristics and prevent associated consequences.

Despite the benefits of such exercise, most older adults do not undertake enough physical activity or specific exercise (ABS, 2013a) to combat many of these age-related changes. Interestingly, recent trends indicate that of those older adults that do exercise, a growing number are beginning to undertake gym based activities (Merom, Cosgrove, Venugopal, & Bauman, 2012). Furthermore, according to the International Health, Racquet and Sportsclub association, the over 55 age group account for the fastest growing segment of new gym memberships (IHRSA, 2011). In Australian’s aged over 55 years, participation in fitness centre or gym based activities is second only to walking in terms of sport and physical recreation participation (ABS, 2013c).

With a growing number of older adults taking part in gym based activities it is worth exploring the apparent effectiveness of such activities. Certain gym based activities such as traditional resistance training have been thoroughly assessed in terms of their effectiveness in older adults (Kosek et al., 2006; Liu & Latham, 2009; Rabelo et al., 2011) and it is well established that appropriate resistance training interventions are successful at improving
characteristics such as balance (Holviala et al., 2014; Orr et al., 2006), strength (Fiatarone et al., 1990; Hagerman et al., 2000), body composition (Hunter et al., 2001; Maddalozzo & Snow, 2000) and bone mineral density in middle-aged and older adults (Bemben & Bemben, 2011; Kerr et al., 2001).

Other gym based activities that require less stringent supervision such as group fitness classes have not been subject to the same research scrutiny despite their popularity. A wide range of group fitness classes are available in Australia and throughout the world. Many of these group fitness classes are now pre-choreographed to allow for uniformity between facilities and across countries. The largest producer of pre-choreographed group fitness classes is Les Mills International (LMI) and their classes are now available in over 15,000 fitness facilities globally (LMI, 2013). Despite the reach of these classes there has been scarce peer-reviewed research into their effectiveness, particularly in older adults. Most of the research assessing pre-choreographed group fitness classes has been conducted on young adults (Gottschall, Jones, Mills, & Hastings, 2013; Greco et al., 2011; Harvey, Burkett, & McKeans, 2014; Khan, Marlow, & Head, 2008). Two of the most popular classes available from Les Mills International are BodyPump™ and BodyBalance®. To date, there has not been any published research assessing the effectiveness or safety of BodyPump™ or BodyBalance® in adults aged over 55 years where the potential benefit of such classes may be greatest due to the aforementioned age-related changes in characteristics such as balance and mobility.

BodyPump™ is a low-load high-repetition resistance training class with barbells that is available in over 15,000 facilities globally and is reportedly attended by millions of people per week (LMI, 2013). There is growing interest into the effects of low-load resistance training protocols using moderate to high-repetitions (Burd et al., 2010; Mitchell et al., 2012; Ogasawara, Loenneke, Thiebaud, & Abe, 2013; Van Roie et al., 2013) but there has been very limited peer-reviewed research into BodyPump™ despite its popularity. Other low-load resistance training programs have been successful at improving balance, functional task performance, strength and bone mineral density in middle-aged and older adults (Bemben & Bemben, 2011; Orr et al., 2006; Van Roie et al., 2013) but the effect of low-load training with high (over 60) repetitions is not yet known. The results reported from previous low-load training interventions suggest that the training stimulus provided by BodyPump™ has the potential to influence balance performance, strength and potentially bone mineral density but
to date there have been no longitudinal BodyPump™ training studies conducted on middle-aged or older adults.

BodyBalance® is a pre-choreographed class that incorporates elements of tai chi, yoga and Pilates (LMI, 2014). Twelve to 16 weeks of Tai chi, yoga and Pilates have all been found to have positive impacts on clinical and laboratory based balance performance in older adults (Bird & Fell, 2014; Tiedemann, O’Rourke, Sesto, & Sherrington, 2013; Voukelatos, Cumming, Lord, & Rissel, 2007) so participation in BodyBalance® may provide a further alternative for improving balance in middle-aged and older adults. There have been no peer reviewed studies assessing the effect of BodyBalance® on measures of balance. One study reported positive effects on strength, flexibility, body composition and anxiety after 12 weeks of BodyBalance® training in young and middle-aged adults (Khan et al., 2008) while more recently BodyBalance® was included as one aspect of a group fitness program in young adults but the assessment of balance was not performed (Gottschall et al., 2013).

Another activity that is growing in terms of its accessibility and exposure is active video gaming. Active video gaming consoles include the Nintendo Wii, Microsoft Xbox 360 and the Sony Playstation 3. The purpose of active video gaming consoles and their games is to use body or hand movements to control game play. For example, the Nintendo Wii balance board (WBB) detects changes in centre of pressure movements and changes in these movements dictate the movement of the on-screen character while the Xbox 360 can be equipped with a motion sensor to control on-screen characters. Currently, the Nintendo Wii is the highest selling of the active gaming consoles with over 100 million units sold world-wide (Nintendo, 2014). In part due to the popularity and accessibility of active video games, there has been an expansion of research into the effects of such gaming on a number of physical characteristics. The Nintendo Wii in particular has been the subject of many studies in various populations including children (Jelsma, Geuze, Mombarg, & Smits-Engelsman, 2014; Sheehan & Katz, 2012), patients with neurological conditions (Esculier et al., 2012; Nilsagård, Forsberg, & von Koch, 2013), older adults with a history of falls (Bateni, 2012; Griffin et al., 2012) and healthy older adults (Bieryla & Dold, 2013; Jorgensen et al., 2013). Of particular note is that Nintendo Wii game play appears to improve clinical measures of balance within a matter of weeks in healthy older adults (Bieryla & Dold, 2013; Rendon et al., 2012;
Toullette, Tourse, & Olivier, 2012). The effect of such training on laboratory based balance measures are not yet established but it appears that clinical balance measures are more likely to improve than laboratory measures according to the scant evidence currently available (Jorgensen et al., 2013; Pluchino et al., 2012).

Although these findings are promising, the majority of Wii based interventions in older adults have been closely supervised, when in the community older adults are more likely to play the Wii without supervision in their own home (Jorgensen et al., 2013). There is a paucity of literature examining the effectiveness and apparent safety of unsupervised Wii game play in healthy older adults. Only two published studies have examined unsupervised Wii based training in healthy older adults (Agmon et al., 2011; Pluchino et al., 2012). Both studies reported improvements in balance although the study by Agmon and colleagues (2011) assessed older adults with impaired balance and the study by Pluchino and associates (2012) did not include a control group for comparison. As such, the effect of unsupervised Wii based training in healthy older adults without established balance deficits compared to a control (non-training) group have yet to be established.

In summary, older adults are subject to a number of age-related changes that can have negative impacts on their everyday lives. Many of these changes are responsive to appropriate exercise, of which, there are a growing number of choices available to adults of all ages. It is prudent to determine the effectiveness of widely available exercise programs that may provide health benefits to older adults and therefore promote healthy ageing. As adults over 55 years are more likely to undertake gym based activities and potentially take part in group fitness classes, the appropriateness of such classes should be examined. In addition, active video gaming is now more accessible in the community and early reports suggest that it may have the potential to improve balance in older adults. The use of active video gaming technology such as the Nintendo Wii may also represent an enjoyable and motivating low-intensity exercise option for older adults.

1.2 Context

The major focus of the thesis was to determine the effect of different exercise interventions on balance performance in middle-aged and older adults. Balance (Nnodim et al., 2006; Tsang & Hui-Chan, 2004) and resistance training (Granacher et al., 2009;
interventions of relatively short durations have been successful at improving certain aspects of balance performance in middle-aged and older adults. The extent of improvement in balance performance following both balance and resistance training depends on a number of factors including the duration and frequency of the intervention, the ability of the participants and the balance assessment measures used (Howe et al., 2011; Orr, Raymond, & Fiatarone Singh, 2008). More substantial improvements are likely to occur in functional or clinical balance assessment tasks compared to static laboratory based assessments such as posturography (Howe et al., 2011). The majority of balance and resistance training programs that have provided improvements to balance performance have also used highly supervised protocols. Research attention should be given to training interventions that can be undertaken with minimal or no supervision, are easily accessible, are inexpensive and do not rely on repeated assessment to determine training intensity. If such training alternatives can provide tangible improvements in desired outcomes while providing a safe training environment, it is more likely that the results of such training are representative of what can be achieved in a non-research setting. Therefore, each of the exercise interventions assessed in this thesis require either no supervision or minimal supervision of participants for each session.

Recent research suggests that pre-emptive exercise interventions should be targeted at middle-aged and older adults to preserve health and promote healthier ageing (Nitz et al., 2013; Stenholm et al., 2012). As such, healthy, community-dwelling middle-aged and older adults were the target of the exercise interventions implemented herein. The intervention studies separately assessed the effect of Nintendo Wii based balance training, BodyPump™ training and BodyBalance® training.

The focus of the research was to identify the influence of exercise training on a range of clinical and laboratory based balance measures. Each of the training programs implemented within the thesis have the potential to positively impact balance performance. In addition to the common balance measures used in each study, a number of study specific outcome measures were included to better determine the effectiveness of each intervention. For example, health related quality of life was assessed in both the BodyPump™ and BodyBalance® studies while maximal strength and
bone mineral density were assessed in the BodyPump™ study due to its resistance training nature.

1.3 Significance and implications

As described above, due to Australia’s ageing population, age-related deteriorations in balance and mobility affects a growing number of people. Balance and gait impairment is associated with disability (den Ouden, Schuurmans, Arts, & van der Schouw, 2011), reduced independence (Judge, Schechtman, & Cress, 1996) and falls in community-dwelling older adults (Lord, Ward, Williams, & Anstey, 1994; Tinetti, Speechley, & Ginter, 1988). Fortunately, balance and mobility can be enhanced through appropriate exercise (Howe et al., 2011) and it has been suggested that preventative exercise be targeted at the general community as well as those at risk of falling (Sherrington et al., 2011). The significance of the research undertaken within this thesis is that all three interventions examined have the potential to improve balance performance and mobility in community dwelling middle-aged and older adults which can reduce participants’ falls risk and contribute to healthy ageing. Further significance is provided by the novelty of the interventions assessed as although each exercise intervention has been available for several years; their influence on balance has yet to be accurately determined.

Each study undertaken in this thesis also has its own significance. Firstly - low cost, reliable (Clark et al., 2010) and accessible balance training tools such as the Nintendo Wii have been examined in supervised environments but the effectiveness of their use in unsupervised environments is not well established. If effective in an unsupervised environment in community dwelling older adults, Wii based balance training may be suitable to undertake in one’s home which negates travel and time commitments which are both barriers to exercise participation in older adults (Booth, Bauman, Owen, & Gore, 1997; Cohen-Mansfield, Marx, & Guralnik, 2003). The significance of this research is associated with Nintendo Wii balance training being an effective, accessible and easily reproducible balance training intervention capable of improving balance in healthy community dwelling older adults in their own residence.

The research undertaken on BodyPump™ and BodyBalance® training is significant as both programs encompass a growing area of exercise patronage for middle-aged and older adults – namely gym based activities. As a growing number of middle-aged and older adults independently engage in exercise programs, the demand for accessible balance training programs has increased. It is important to explore how these programs can be effective in a home environment where travel and time commitments may be barriers to exercise participation. Each study undertaken in this thesis has its own significance as they provide valuable insight into the effectiveness and accessibility of balance training interventions in community dwelling older adults.
adults take part in these pursuits, the effectiveness of such activities should be known. As both programs are highly reproducible and widely available in fitness facilities globally, their potential reach is substantial. To date, no research has examined the effect of either program on balance or mobility in middle-aged or older adults. A further point of significance is determining the relative safety of each activity. If it is established that a number of injuries or adverse events occur as a result of such training then such information should be disseminated to prevent potential injuries in the community.

1.4 Research Questions

The overarching aim of the thesis was to determine the effectiveness of group based exercise in the form of Nintendo Wii training, BodyPump™ and BodyBalance®. The key link between all these modes of exercise is their impact on measures of balance, mobility and functional task performance. The key research questions were:

1. Does unsupervised Nintendo Wii game play improve balance in community dwelling older adults?

2. Does BodyPump™ improve balance, strength and/or body composition in middle-aged and older adults?

3. Does BodyBalance® improve balance in middle-aged and older adults?

1.5 Research hypotheses

Based on a review of relevant literature, the following research hypotheses were developed:

1. Six weeks of unsupervised Nintendo Wii Fit game play will improve clinical measures of balance in community dwelling older adults compared to control participants.

2. Twenty-six weeks of BodyPump™ will improve clinical measures of balance but will not influence laboratory measures of balance in community dwelling middle-aged and older adults.
3. Twenty-six weeks of BodyPump™ will increase lower and upper body maximal strength in community dwelling middle-aged and older adults.

4. Twenty-six weeks of BodyPump™ will maintain the bone mineral density of the lumbar spine and hip in community dwelling middle-aged and older women.

5. Twenty-six weeks of BodyPump™ will increase fat-free soft tissue mass but will not have any impact on fat mass in community dwelling middle-aged and older women.

6. Twelve weeks of BodyBalance® will improve clinical and laboratory measures of balance in community dwelling middle-aged and older adults.

1.6 Thesis Outline

To test the above research hypotheses and provide answers to the key research questions, three independent studies were designed and implemented. Study one assessed the effectiveness of six weeks of Nintendo Wii based training in community dwelling adults aged 65 to 85 years. Study two assessed the effectiveness of 26 weeks of BodyPump™ training in independent, active community dwelling adults aged 55 to 75 years. And finally, study three assessed the effectiveness of 12 weeks of BodyBalance® training in independent, active community dwelling adults aged 55 to 75 years. This thesis by published research articles will follow the structure outlined below.

Having provided an overview of the research undertaken and its context in chapter one, chapter two will provide an insight into the overarching research design and methods utilised within the research projects and further provide a thematic link between the three studies undertaken for this thesis. Chapters three through six contain the three research articles that have been published or accepted for publication in peer-reviewed journals and a further article that has been submitted to a peer-reviewed journal. Finally, chapter seven provides a discussion of the overall results of the studies, identifies limitations of the research, provides responses to the research questions and hypotheses and importantly addresses the implications of the research.
CHAPTER 2: RESEARCH DESIGN & METHODS

This chapter outlines the research design and methods used for each of the three studies presented for this thesis. Although the research design and methodological similarities assist in linking each of the three studies, the studies are not intended to be directly compared to each other in terms of their effectiveness as each of them provided different training stimuli and were undertaken for different periods of time. A brief justification for the inclusion of each of the major outcome measures used within this thesis will also be provided. While the specific methods of each study are presented independently within each manuscript, this chapter seeks to highlight the research design and methodological aspects common to all three studies presented in this thesis.

2.1 Participants

All participants were active, independent community dwelling adults aged 55 years and over. Active, independent community dwelling older adults were recruited for a number of reasons including:

2.1.1 Safety

As the Nintendo Wii study was conducted unsupervised, it was thought to be safer to recruit adults who were likely to be capable of undertaking challenging balance tasks without supervision. As such, active independent adults were recruited.

The BodyPump™ study required the use of high-repetition resistance training which has seldom been assessed in middle-aged or older adults. For this reason, an active cohort was deemed to be more appropriate.
2.1.2 Pre-emptive nature of interventions

It is well established that deteriorations in a number of physical characteristics such as balance are observable from the fourth and fifth decades of life but many of the consequences associated with these deteriorations do not become apparent until several years later.

As such, the most effective interventions are likely to be those that can improve aspects of balance and functional task performance (among other things) pre-emptively in middle-aged and older adults without evident deficits or impairments. Therefore, effective interventions may delay or prevent many of the associated negative consequences such as impaired mobility and balance.

2.1.3 Specificity

It is this population (those that are active and independent) that are most likely to undertake the interventions assessed – particularly the gym based activities of BodyPump™ and BodyBalance®.

2.2 Controlled trials

All studies were controlled to enable a more accurate determination of whether interventions were effective. The aim was for all studies to be randomised controlled trials (RCTs) but due to a number of recruitment issues with the Nintendo Wii study it could not be randomised. A priori power calculation was used to estimate an appropriate sample using G*Power 3 (Version 3.1.3) (Faul, Erdfelder, Lang, & Buchner, 2007). To perform a general linear model assessing differences between two groups and between genders, with an effect size of 0.25 and power of 0.8, the minimum number of participants required per group was 14 (Barrett & Smerdely, 2002; Henwood & Taaffe, 2005). The aim was to recruit at least 20 participants for each group to account for attrition and it was expected that all participants would be recruited from the two involved retirement villages. Unfortunately, only 29 residents of the two retirement villages volunteered to take part in the study and five of those volunteers preferred to be members of the control group due to travel and other commitments. Consequently, more participants were recruited from a local adult education facility to provide greater power to the study. As such, random assignment to either the intervention or control groups
was not possible because of the relatively few numbers of retirement village residents that volunteered to take part in the project. Consequently the intervention group was comprised of retirement village residents (to allow access to the gaming equipment) while the control group was comprised of retirement village residents similarly aged volunteers from the local adult education facility.

Both the BodyPump™ and BodyBalance® studies were RCTs.

### 2.3 Groups

All studies had participants exercise in pairs or groups. For the Nintendo Wii study participants played in pairs but as there were two consoles in close proximity to each other participants would typically play in small groups of four or five. Both the BodyPump™ and BodyBalance® interventions were undertaken in a group setting with an instructor in a typical fitness facility group exercise room.

### 2.4 Outcome measures

All studies assessed the impact of the specific exercise intervention on clinical tests of balance, mobility and functional task performance together with force platform based balance performance. The balance, mobility and functional performance tasks common to all studies were well established tests that have been used widely in training studies involving middle-aged and older adults. All testing procedures were completed following identical protocols at pre- and post assessments. The tests were single leg stance, the timed up and go (TUG), 30 second chair stand, gait speed and static stance assessment on a force platform. Fear of falling and enjoyment were also assessed for each intervention. Justification for the use of each of these methods now follows.

#### 2.4.1 Single leg stance

Single leg stance time was used as an assessment task as it is easily administered, reliable (M. R. Lin et al., 2004), valid (Drusini et al., 2002; Vellas, Rubenstein, et al., 1997), widely used in training studies (Wolfson et al., 1996), has well established normative values (Springer et
al., 2007) and is predictive of functional decline (M. R. Lin et al., 2004) and injury (Lundin et al., 2014). It should be noted that there can be large variability in single leg stance times within session which is associated with a large measurement error and a large minimum detectable change (Goldberg, Casby, & Wasielewski, 2011). As such, clinical judgement needs to be used in concert with statistical analyses to determine whether observed changes are meaningful. For example, a five second improvement in single leg stance time is unlikely to represent a clinically meaningful change in someone who is already able to maintain their balance for over 30 seconds. In contrast, a five second improvement in an individual that can only balance for three seconds at baseline is likely to be clinically meaningful.

2.4.2 The timed up and go

The timed up and go (TUG) is an easily administered functional task that incorporates transfers, turning and walking. It has established normative values for middle-aged and older adults (Isles, Low Choy, Steer, & Nitz, 2004; Nolan, Nitz, Low Choy, & Illing, 2010), is valid and reliable (M. R. Lin et al., 2004) and predicts functional decline (Huang, Perera, VanSwearingen, & Studenski, 2010).

2.4.3 Gait speed

Gait speed is a predictor of adverse health outcomes such as cognitive impairment, disability (Abellan van Kan et al., 2009) and survival (Studenski et al., 2011) in community-dwelling older adults. The assessment of gait speed is valid and reliable in the community dwelling setting (Rydwik, Bergland, Forsen, & Frändin, 2012) and can be easily performed over the length of several metres using a stopwatch. Although the use of portable specialised equipment is now widely available to assess gait speed, the use of simple field test methods are still very effective and widely used in large prospective studies (Cesari et al., 2009; Jylhä, Guralnik, Balfour, & Fried, 2001; Quach et al., 2011).

2.4.4 30 second chair stand

The sit to stand task represents a complex functional movement that is influenced by muscle strength, balance, sensorimotor and psychological factors (Lord et al., 2002). The ability to perform repeated sit to stands can be measured by either the time it takes to complete a specified number of chair stand repetitions (for example 5 repetitions) or the number of chair stand repetitions possible in a 30-second period. The 30 second version of the sit to stand test
was chosen instead of the five repetition alternative due to possible floor effects observed with the five repetition version (Guralnik et al., 1994; Y.-C. Lin, Davey, & Cochrane, 2001). It is a sensitive and valid tool to assess functional ability (Jones, Rikli, & Beam, 1999) and has normative data for adults aged 60 years and over (Rikli & Jones, 1999).

### 2.4.5 Static stance assessment

Centre of pressure (COP) parameters derived from laboratory grade force plates are the gold standard for balance assessment (Huurnink, Fransz, Kingma, & van Dieën, 2013). Subtle changes that cannot be detected with clinical or subjective assessments can be made with force plate derived measures (Piirtola & Era, 2006) although the majority of balance and resistance training interventions do not include such measurements. This is likely due to the expense and time associated with such testing and there is also great variability in opinion regarding the appropriate assessment time and data acquisition parameters for balance assessment (Carpenter, Frank, Winter, & Peysar, 2001; Melzer, Benjuya, & Kaplanski, 2004; Moghadam et al., 2011). For example, previous balance and resistance training studies in middle aged and older adults have used assessment times of 10 seconds (Bellew, Yates, & Gater, 2003; Chen, Zhou, & Cartwright, 2011; Pluchino et al., 2012), 30 seconds (Holviala et al., 2006; Lelard, Doutrellot, David, & Ahmaidi, 2010) and 60 seconds (Jorgensen et al., 2013; Martínez-Amat et al., 2013) when determining changes in COP. Sampling frequency during balance assessment typically range from 40Hz (Hue et al., 2004; Lelard et al., 2010) to 100Hz (Jorgensen et al., 2013; Seidler & Martin, 1997).

In all three studies presented in this thesis a sampling duration of 30 seconds was chosen as an appropriate assessment time. This duration has been shown to produce valid (Pajala et al., 2008) and reliable (Bauer et al., 2010; Moghadam et al., 2011; Rafał, Janusz, Wiesław, & Robert, 2011) results in older adults. This time was also deemed to be suitable to avoid undue fatigue. Force platform data was sampled at a frequency of 50Hz as frequencies of 40 or 50Hz have been widely used in reliability (Bauer, Groger, Rupprecht, & Gaff mann, 2008; Bauer et al., 2010; Swanenburg et al., 2008), prospective (Maki, Holliday, & Topper, 1994; Pajala et al., 2008) and training studies (Hue et al., 2004; Rugelj, 2010) in older adults.

The standing tasks of comfortable and narrow stance positions were chosen based on previous reliability (Bauer et al., 2010; Lafond, Corriveau, Hebert, & Prince, 2004) and training studies (Holviala et al., 2006; Judge, Whipple, & Wolfson, 1994) along with studies
comparing characteristics of fallers and non-fallers (Melzer et al., 2004; Melzer, Kurz, & Oddsson, 2010). The tasks were also chosen to provide an increasing level of difficulty to participants by reducing their base of support and removing visual input. The position of the feet was standardised and marked for each participant to ensure consistency between testing sessions as there is great variability in preferred foot positions (McIlroy & Maki, 1997) and foot position can substantially effect COP parameters (Kirby, Price, & MacLeod, 1987).

A number of centre of pressure parameters based on traditional measures, stabilogram-diffusion analysis (Collins & De Luca, 1993; Collins, De Luca, Burrows, & Lipsitz, 1995) and fractal dimension analysis (Blaszczyk & Klonowski, 2001; Doyle, Newton, & Burnett, 2005) can be determined from force plate technologies. Traditional parameters include COP range, COP mean velocity, COP path length, root mean square of amplitude and 95% confidence ellipse (Carpenter et al., 2001; Lafond et al., 2004; Moghadam et al., 2011; Swanenburg et al., 2008). A reduction in velocity or range is indicative of an improvement or stabilisation in balance control (Melzer et al., 2004). The COP mean velocity has consistently demonstrated the highest reliability in older adults (Lafond et al., 2004; D. Lin, Seol, Nussbaum, & Madigan, 2008; Moghadam et al., 2011; Rafał et al., 2011) while higher COP ranges in the medio-lateral direction are associated with an increased risk of falling (Maki et al., 1994; Melzer et al., 2004). For the studies presented herein, traditional measures of mean COP velocity and COP range in the antero-posterior and medio-lateral direction were used for analysis due to their established use, discriminant ability and reliability.

It should be noted that non-parametric statistics were used to analyse COP data in the Nintendo Wii and BodyPump™ studies as the majority of the data were not normally distributed (determined by statistical and graphical inspection) while a general linear model was used to assess COP data in the BodyBalance® study as the data were normally distributed. Furthermore, only the BodyPump™ manuscript (chapter five) includes a full summary of COP data as part of the accepted/published paper. As such, full summaries of COP data are presented as additional files relating to the Nintendo Wii and BodyBalance® studies (Chapters 4 and 7 respectively).

2.4.6 Modified physical activity enjoyment scale (PACES)

Enjoyment is both a key motivator and outcome of physical activity participation in middle-aged and older adults (Dacey, Baltzell, & Zaichkowsky, 2008; Kolt, Driver, & Giles, 2004;
Williams et al., 2006). Determining a participant’s enjoyment of the exercise interventions undertaken within this thesis provide another aspect to determine the effectiveness of such activities. The original 18-item PACES was developed for a college-aged population (Kendzierski & DeCarlo, 1991) but has since been modified to target younger (Moore et al., 2009) and older populations (Mullen et al., 2011). The modified eight-item PACES used in each of the studies herein is valid and invariant across different exercise modality and time in community-dwelling older adults (Mullen et al., 2011). Changes in enjoyment based on the PACES are included in the Nintendo Wii manuscript (chapter 4) while PACES values relating to the BodyPump™ and BodyBalance® are included as additional files in (chapters 4 and 7 respectively).

2.4.7 Iconographical falls efficacy scale (IconFES)

Fear of falling is associated with a reduction in physical activity and subsequent increased falls risk (Delbaere et al., 2004). Depending on the level of concern, some people may only be fearful of falling when performing demanding activities such as climbing a ladder while others may be fearful when undertaking simple activities of daily living (Yardley et al., 2005). It has been demonstrated that appropriate exercise interventions can reduce fear of falling in certain populations (Zhang et al., 2006) but fear of falling scales often have strong floor effects in active people which reduces their sensitivity to change following interventions (Delbaere et al., 2010). The IconFES has excellent reliability and construct validity and its main advantage over many other fear of falling questionnaires is its inclusion of more demanding balance-related activities and its ability to assess fear of falling in high-functioning participants (Delbaere, Smith, & Lord, 2011). Despite these advantages, the IconFES is still likely to have floor effects for the highest functioning middle-aged and older adults who have very low levels of fear.

Fear of falling values derived from the 10-item IconFES are presented in the Nintendo Wii (chapter four) and BodyBalance® (chapter six) papers. Reviewers suggested removing fear of falling information from the BodyPump™ manuscript prior to its acceptance so pre- and post-intervention values for the IconFES have been included as an additional file in chapter five.
2.4.8 Other tests

A number of other tests including additional balance or functional tasks, together with strength and body composition assessments were not used across all studies. The inclusion (or exclusion) of these tests were related to suitability, specificity and ongoing learning achieved from undertaking successive studies. Brief justifications for their inclusion or exclusion are provided below.

2.4.8.1 Functional reach and lateral reach

The functional reach and lateral reach tests were used in both balance based interventions (Nintendo Wii and BodyBalance®) but not in the BodyPump™ intervention. This decision was based on the balance tasks previously assessed in balance and resistance training interventions and the potential for change. Improvements in functional reach and lateral reach have been demonstrated with various balance interventions (Bellew et al., 2005; Li, Harmer, Fisher, & McAuley, 2004). The lateral reach test has seldom been used to assess the effect of resistance training on balance and although functional reach has been used as an assessment tool previously, results of previous resistance training interventions suggest that it is not responsive to resistance training (Orr, Raymond, & Fiatarone Singh, 2008). Typically, gait speed and functional movements such as the TUG and sit to stand tasks have been widely used in resistance training interventions and are subject to change (Liu & Latham, 2009).

2.4.8.2 Floor rise to standing

The floor rise to standing test has been used as a timed or scaled functional task in balance or resistance training interventions in older adults (Henwood & Taaffe, 2005; Tatum, Igel, & Bradley, 2009). The task was included as part of assessment in the BodyBalance® study after feedback from BodyPump™ participants (the BodyPump™ study concluded several months before the start of the BodyBalance® study). A number of BodyPump™ participants reported that one of the benefits they noticed following the intervention was their improved ability to rise from the floor. As such, the timed version of the test was included in the BodyBalance® intervention to provide an objective measure of this functional task.
2.4.8.3 Maximal gait speed

It was observed in the Nintendo Wii study that participants may have been walking quicker than normal when normal gait speed was assessed. As a result, maximum gait speed was included in the BodyPump™ and BodyBalance® studies to ensure that there was an evident difference between normal and maximum gait speed (Bohannon, 1997). The ability to walk faster than normal walking pace suggests an ability to adapt and may be important in everyday tasks such as crossing a road. Maximal gait speed is a valid (Rydwik et al., 2012) and reliable (Steffen, Hacker, & Mollinger, 2002) outcome measure. Furthermore, maximal gait speed has been shown to be a more sensitive predictor for functional dependence than normal walking speed in adults aged less than 75 years (Shinkai et al., 2000) and slower maximum walking speed is associated with cognitive decline (Soumaré et al., 2009). As such, improvements in maximal gait speed following an intervention may provide greater information than just normal gait speed alone.

2.4.8.4 One-repetition maximum (1RM)

The effect of each intervention on balance was the main focus of this thesis but the overall effectiveness of each intervention was a further aim. In the case of BodyPump™, maximal strength was deemed to be an integral measure as strength training interventions using various protocols have produced significant improvements in strength (Holviala et al., 2014; Lohne-Seiler, Torstveit, & Anderssen, 2013; Van Roie et al., 2013) in middle-aged and older adults. The 1RM was used as it is considered the gold standard for assessing strength in non-laboratory situations (Kraemer, Ratamess, Fry, & French, 2006; Levinger et al., 2009). It is defined as the maximal weight that can be lifted once with correct lifting technique (Kraemer et al., 2006) and is a reliable method for assessing strength in middle-aged and older adults (Levinger et al., 2009; Schroeder et al., 2007). The leg-press and Smith machine bench-press were chosen as they provide an indication of overall lower and upper body strength, respectively. They are commonly used as outcome measures in training studies (Fatouros et al., 2005; Galvao & Taaffe, 2005; Lohne-Seiler et al., 2013), they are machine based and the prime movements occur in one plane so minimal practice of technique is required. Neither exercise was used during the BodyPump™ training intervention which reduced the likelihood that any improvement observed for the BodyPump™ group would be solely attributed to a learning effect.
Additionally, prediction equations (Simpson et al., 1997) were used to predict squat 1RM based on the identified leg press 1RM. These prediction equations were used to provide an indication of any change in squat strength over the course of the program in terms of percentage predicted squat 1RM.

2.4.8.5 Dual-energy x-ray absorptiometry (DXA)

As for the assessment of 1RM, body composition was deemed to be an important measure associated with the effectiveness of the BodyPump™ intervention. Reductions in bone mineral density and fat-free mass are commonly seen in middle-aged and older adults but resistance training has been shown to positively affect both measures (Bemben & Bemben, 2011; Maddalozzo & Snow, 2000; Marques, Wanderley, et al., 2011). As such, DXA was used to determine changes in bone mineral density, fat-free soft tissue mass and fat mass. The assessment of bone mineral density, fat-free soft tissue mass and fat mass via DXA are well established and the main advantages of DXA assessment is its reliability, validity and precision (Blake, Herd, & Fogelman, 1996; Plank, 2005; Salamone et al., 2000).

2.4.8.6 Self-reported health status/quality of life

Self-reported health status/quality of life was assessed via the SF-36v2 health survey for the BodyPump™ and BodyBalance® studies (license number QM013989). The SF-36v2 is one of the most well used measures of health and quality of life in survey and clinical research. Maintaining or improving health is a key motivator for exercise participation (Kolt et al., 2004) and changes in health status associated with an exercise intervention provide another measure of effectiveness. Although the SF-36v2 has some limitations such as ceiling effects in certain scales such as role emotional (Hawthorne, Osborne, Taylor, & Sansoni, 2007), it has good psychometric properties (Ware, Kosinski, & Dewey, 2000) and has been used successfully in exercise intervention studies (Barrett & Smerdely, 2002; Kovács, Prókai, Mészáros, & Gondos, 2013; Tamari, 2010).

2.4.8.7 Adverse events

An adverse event was defined as any testing or exercise related incident that affected activities of daily living for two or more days or required attention from a doctor or allied health practitioner (eg. Physiotherapist, osteopath).
Table 2.1 Psychometric properties for outcome measures

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Validity</th>
<th>Test-retest reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single leg stance</td>
<td>Able to detect differences in those that were older, had a history of falls or had difficulty with ADLs (M. R. Lin et al., 2004) and predicts injurious falls (Vellas et al., 1997)</td>
<td>ICC = 0.86 – 0.99 (Goldberg, Casby, &amp; Wasielewski, 2011; Springer et al., 2007)</td>
</tr>
<tr>
<td>Timed-up-and go</td>
<td>Able to detect differences in those that were older, had a history of falls or had difficulty with ADLs (M. R. Lin et al., 2004)</td>
<td>ICC = 0.60 (Rockwood, Awalt, Carver, &amp; MacKnight, 2000) r = 0.93 (M. R. Lin et al., 2004)</td>
</tr>
<tr>
<td>Gait speed</td>
<td>Can identify those at high risk of disability and falls (Guralnik et al., 2000; Montero-Odasso et al., 2005)</td>
<td>ICC = 0.88 (Fraensen, Crosbie, &amp; Edmonds, 1997)</td>
</tr>
<tr>
<td>Maximal gait speed</td>
<td>Independent predictor of falls (Chu, Chi, &amp; Chiu, 2005)</td>
<td>ICC = 0.91 (Fraensen et al., 1997)</td>
</tr>
<tr>
<td>30 second chair stand</td>
<td>Able to detect differences between different age groups and activity levels (Jones, Rikli, &amp; Beam, 1999)</td>
<td>ICC = 0.84 – 0.92 (Jones et al., 1999)</td>
</tr>
<tr>
<td>COP AP velocity</td>
<td>COP range and mean velocity are able to discriminate between fallers and non-fallers in narrow stance (Melzer, Benjuya, &amp; Kaplanski, 2004)</td>
<td>ICC = 0.95 (D. Lin, Seol, Nussbaum, &amp; Madigan, 2008)</td>
</tr>
<tr>
<td>COP ML velocity</td>
<td>COP range and mean velocity are able to discriminate between fallers and non-fallers in narrow stance (Melzer, Benjuya, &amp; Kaplanski, 2004)</td>
<td>ICC = 0.9 (Lafond, Corriveau, Hebert, &amp; Prince, 2004)</td>
</tr>
<tr>
<td>COP AP range</td>
<td>ICC = 0.38 (Lafond et al., 2004)</td>
<td>ICC = 0.57 (Lafond et al., 2004)</td>
</tr>
<tr>
<td>COP ML range</td>
<td>ICC = 0.57 (Lafond et al., 2004)</td>
<td>ICC = 0.92 (Duncan, Weiner, Chandler, &amp; Studenski, 1990)</td>
</tr>
<tr>
<td>Functional reach</td>
<td>Able to discriminate between low and high risk of falling (Duncan, Studenski, Chandler, &amp; Prescott, 1992)</td>
<td>ICC = 0.92 (Duncan et al., 2000)</td>
</tr>
<tr>
<td>Lateral reach</td>
<td>Unable to discriminate between fallers and non-fallers (Brauer, Burns, &amp; Galley, 2000)</td>
<td>r = 0.99 (Brauer, Burns, &amp; Galley, 1999)</td>
</tr>
<tr>
<td>Floor rise to standing</td>
<td>Inability to rise from the floor is a predictor for serious fall injuries (Bergland &amp; Laake, 2005)</td>
<td>CV = 5.3% (Henwood &amp; Taaffe, 2005)</td>
</tr>
<tr>
<td>1RM leg press</td>
<td>Reduced lower limb strength predictive of impaired mobility (Visser et al., 2005)</td>
<td>CV = 6.3% (Phillips, Batterham, Valenzuela, &amp; Burkett, 2004)</td>
</tr>
<tr>
<td>1RM bench</td>
<td>Reduced maximal strength predicts functional limitations (Brill et al., 2000)</td>
<td>CV = 5.2% (Phillips et al., 2004)</td>
</tr>
<tr>
<td>Iconographical FES</td>
<td>Significantly higher (worse) scores in older adults, participants with a history of falls and those with poor balance (Delbaere, Smith, &amp; Lord, 2011)</td>
<td>ICC = 0.90 (Delbaere et al., 2011)</td>
</tr>
<tr>
<td>PACES</td>
<td>Higher enjoyment scores associated with lower boredom scores (Kendzierski &amp; DeCarlo, 1991)</td>
<td>ICC = 0.6 - 0.93 (Kendzierski &amp; DeCarlo, 1991; Mullen et al., 2011)</td>
</tr>
<tr>
<td>SF36 v2</td>
<td>The majority of subscales have satisfactory discriminant ability (Kim, Jo, &amp; Lee, 2013)</td>
<td>ICC = 0.7-0.94 (Twiss et al., 2013)</td>
</tr>
<tr>
<td>DXA Lx</td>
<td>DXA measurement is regarded as the reference standard for areal bone mineral density (Kanis et al., 2008)</td>
<td>CV = 1% (Bemben &amp; Bemben, 2011; Kerr et al., 2001)</td>
</tr>
<tr>
<td>DXA femoral neck</td>
<td>CV = 1.5% (Kerr et al., 2001)</td>
<td>CV = 1.5% (Maddalozzo &amp; Snow, 2000)</td>
</tr>
<tr>
<td>DXA total body</td>
<td>CV = 1.5% (Maddalozzo &amp; Snow, 2000)</td>
<td>CV = 1.5% (Maddalozzo &amp; Snow, 2000)</td>
</tr>
<tr>
<td>DXA fat mass</td>
<td>Accurate in assessing body composition in the elderly compared to multi-compartment methods (Salamone et al., 2000; Wang et al., 2010)</td>
<td>CV = 1.1% (Marques et al., 2011)</td>
</tr>
<tr>
<td>DXA fat-free mass</td>
<td>CV = 2.8% (Marques et al., 2011)</td>
<td>CV = 2.8% (Marques et al., 2011)</td>
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</tbody>
</table>

COP = centre of pressure; AP = anterior-posterior; ML = medio-lateral; 1RM = one-repetition maximum; FES = falls efficacy scale; SF36 v2 = short form 36 version 2; DXA = dual-energy x-ray absorptiometry. Validity assessed on discriminant or predictive ability (depending on outcome measure assessed) except for DXA measurements which were based on criterion validation. Test-retest reliability represented by either intraclass correlation coefficients (where 0 = no agreement and 1 = absolute agreement), Pearson’s r (where 0 = no agreement and 1 = absolute agreement) or coefficient of variation (CV).
2.5 Differences in study duration

As detailed above, a number of research design and methodological aspects were kept consistent between all three studies. One aspect that was not uniform between studies was their duration. The duration of each study was largely based on the time expected for observable changes to occur in key outcome measures. For instance, in the Nintendo Wii study it was expected that six weeks would provide enough time for balance improvements to occur. This relatively short time period is also comparable to many previous Nintendo Wii interventions that have lasted for three to eight weeks in older adults (Bieryla & Dold, 2013; Franco, Jacobs, Inzerillo, & Kluzik, 2012; Pluchino et al., 2012; Rendon et al., 2012). The BodyPump™ study continued for 26 weeks as a longer period of time (four to six months) is typically required to observe changes in bone mineral density even though changes in balance and strength are likely to occur much earlier. The BodyBalance® intervention continued for 12 weeks to provide opportunity for improvements in balance to occur and to allow comparison with similar interventions that are typically eight to 12 weeks in duration (Chen et al., 2011; Irez et al., 2011; Tiedemann et al., 2013; Zettergren, Lubeski, & Viverito, 2011).

Summary

This chapter detailed the research design and outcome measures common to all three intervention studies. This chapter also provided further justification for the research designs and the use of each outcome measure. The following chapters comprise published peer-reviewed manuscripts based on the three intervention studies completed for this PhD.
CHAPTER 3: MANUSCRIPT 1

Six Weeks of Unsupervised Nintendo Wii Fit Gaming is Effective at Improving Balance in Independent Older Adults


Abstract

Objective: To determine the effectiveness of unsupervised Nintendo Wii Fit balance training in older adults. Methods: Forty-one older adults were recruited from local retirement villages and educational settings to participate in a six-week two-group repeated measures study. The Wii group (n = 19, 75 ± 6 years) undertook 30 min of unsupervised Wii balance gaming three times per week in their retirement village while the comparison group (n = 22, 74 ± 5 years) continued with their usual exercise program. Participants’ balance abilities were assessed pre- and postintervention. Results: The Wii Fit group demonstrated significant improvements (P < .05) in timed up-and-go, left single-leg balance, lateral reach (left and right), and gait speed compared with the comparison group. Reported levels of enjoyment following game play increased during the study. Conclusion: Six weeks of unsupervised Wii balance training is an effective modality for improving balance in independent older adults.

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<table>
<thead>
<tr>
<th>COP parameter</th>
<th>Pre</th>
<th>Post</th>
<th>Pre</th>
<th>Post</th>
<th>Effect Size&lt;sup&gt;c&lt;/sup&gt;</th>
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<tr>
<td><strong>AP mean velocity (mm/s)</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CSEO</td>
<td>9.24 (5.11-12.88)</td>
<td>7.21 (5.52-12.16)</td>
<td>7.26 (5.58-12.61)</td>
<td>8.38 (4.95-14.13)</td>
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</tr>
<tr>
<td>CSEC</td>
<td>9.00 (5.65-13.67)</td>
<td>10.22 (6.20-14.74)</td>
<td>10.12 (5.93-16.43)</td>
<td>8.20 (5.79-16.18)</td>
<td>0.12</td>
</tr>
<tr>
<td>NSEO&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.84 (6.24-27.14)</td>
<td>10.09 (7.58-23.74)</td>
<td>9.25 (6.46-18.97)</td>
<td>10.51 (6.77-20.34)</td>
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<tr>
<td>NSEC</td>
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<td>11.68 (7.65-26.59)</td>
<td>12.46 (7.29-24.92)</td>
<td>10.59 (6.73-28.89)</td>
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<tr>
<td><strong>ML mean velocity (mm/s)</strong></td>
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<td>14.69 (8.73-24.78)</td>
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<tr>
<td>CSEC</td>
<td>21.06 (14.77-26.55)</td>
<td>19.50 (13.58-30.93)</td>
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<td>20.24 (15.16-31.88)</td>
<td>22.54 (8.78-43.12)</td>
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<td>20.83 (13.89-39.77)</td>
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<td><strong>ML range (mm)</strong></td>
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<tr>
<td>CSEO</td>
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<td>8.03 (4.54-14.68)</td>
<td>5.73 (2.93-14.05)</td>
<td>8.19 (4.56-15.89)</td>
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<td>7.74 (4.56-11.65)</td>
<td>6.69 (4.99-11.81)</td>
<td>6.15 (4.82-12.61)</td>
<td>7.56 (3.89-12.44)</td>
<td>0.36</td>
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<tr>
<td>NSEO&lt;sup&gt;b&lt;/sup&gt;</td>
<td>25.29 (10.11-47.12)</td>
<td>21.52 (8.99-34.44)</td>
<td>25.13 (14.41-40.33)</td>
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<td>27.12 (10.89-47.27)</td>
<td>27.78 (17.62-54.84)</td>
<td>0.71</td>
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Values reported as median (range); AP = anterior-posterior; ML = medio-lateral; CSEO = comfortable stance eyes open; CSEC = comfortable stance eyes closed; NSEO = narrow stance eyes open; NSEC = narrow stance eyes closed; <sup>a</sup> significant (p=0.035) difference between groups at baseline using independent Mann-Whitney U test; <sup>b</sup> significant (p<0.05) difference in mean change between groups using Mann-Whitney U test for two independent groups; <sup>c</sup> effect size calculated as Z score/√N; reductions in mean velocity and range are indicative of improvement in balance control.
CHAPTER 4: MANUSCRIPT 2

Low-load high-repetition resistance training improves strength and gait speed in middle-aged and older adults

2. Title Page

Low-load high-repetition resistance training improves strength and gait speed in middle-aged and older adults

Vaughan P. Nicholson¹, Mark R. McKean¹, Brendan J. Burkett¹

¹School of Health and Sport Sciences, University of the Sunshine Coast, Queensland, Australia

Corresponding author:

Vaughan Nicholson

vaughannicholson@hotmail.com

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Additional online material = 2 tables
Low-load high-repetition resistance training improves strength and gait speed in middle-aged and older adults

Abstract

Objectives: To determine the effect of 26 weeks of low-load high-repetition resistance training (BodyPump™) on maximal strength, gait speed, balance and self-reported health status in healthy, active middle-aged and older adults.

Design: Two-group randomised control trial

Methods: Sixty-eight apparently healthy, active adults aged over 55 years completed either 26 weeks of BodyPump™ training (PUMP) or served as control participants (CON). The BodyPump™ group (n=32, age = 66±4 years) trained twice per week for 26 weeks while the control group (n=36, age = 66 ± 5 years) continued with their normal activities. Leg-press and Smith-machine bench-press one repetition maximum (1RM), gait speed, balance, and self-reported health status were all assessed at baseline and follow-up.

Results: Significant group-by-time interactions in favour of the BodyPump™ group were found for leg-press 1RM (PUMP +13%, CON +3%, p = 0.007, partial $\eta^2 = 0.11$), Smith-machine bench-press 1RM (PUMP +14%, CON +5%, p = 0.001, partial $\eta^2 = 0.18$), normal gait speed (PUMP +23%, CON +9%, p = 0.028, partial $\eta^2 = 0.08$) and single leg balance right (PUMP +24%, CON -7%, p = 0.006, partial $\eta^2 = 0.12$). There were no group-by-time interactions for health status measures. Three participants in the BodyPump™ group withdrew from training due to injury or fear of injury related to training.

Conclusions: Low-load high-repetition resistance training in the form of BodyPump™ is effective at improving maximal strength, gait speed and some aspects of standing balance in adults over 55 years. The training was well tolerated by the majority of participants.

Key words: BodyPump; Postural Balance; Exercise; Ageing; Health status
1. Introduction

The age-related deterioration in measures of strength, balance and gait speed are well established and are typically observable from the fourth and fifth decades of life. Also well recognized is the effectiveness of resistance training at improving these measures in middle-aged and older adults. Many resistance training interventions in middle-aged and older adults have successfully utilised high-load protocols equivalent to ~ 80% one-repetition maximum (1RM) but less attention has been given to low-load (<40% 1RM) resistance training utilising very high (>60) repetitions.

There are conflicting reports as to whether low-load/high-repetition resistance training is effective at improving maximal strength compared to high-load resistance training in older adults. Many of these differences are due to the great variability in the prescribed load and repetition range. Only one study in older adults has utilised a very high-repetition protocol at low-loads similar to that used by Anderson and Kearney (1982) when they identified a repetition training continuum. Significant gains in strength, muscle volume and function were reported after 12 weeks of training in this manner.

Improvements in gait speed and balance performance have been reported following high- and low-load resistance training although there is still only weak evidence that resistance training can be moderately effective at improving balance in older adults. To date, no ideal resistance training load or dose has been identified for the improvement of gait speed and balance. Maintenance of health is a primary motivator for exercise participation in older adults and the use of self-reported tools can provide additional insights into the effect of exercise interventions. Currently the evidence suggests that resistance training does not improve self-reported health status in healthy older adults but the effect of low-load/high-repetition resistance training on these measures has yet to be determined.

A widely available form of low-load/high-repetition resistance training is BodyPump - a pre-choreographed group class that utilises light weights and very high-repetitions (70-100 per body
part) in each workout. The class is available in some 14,000 facilities globally and is the most utilised
group class produced by Les Mills International.\(^{17}\) The pre-choreographed nature of the classes
provides uniformity between fitness facilities which allows for an easily reproducible resistance
training program. Despite the growing number of older adults undertaking gym based activities\(^{18}\) and
the exposure of such a program, there has been no peer reviewed research on the effectiveness of
BodyPump\(^{\text{TM}}\) in middle-aged or older adults.

The aim of this study was to determine the effect of 26 weeks of low-load/high-repetition
resistance training (in the form of BodyPump\(^{\text{TM}}\)) on measures of maximal strength, gait speed,
balance and self-reported health status in active middle-aged and older adults. An age range of 55-75
years was chosen to allow the inclusion of adults in both late middle-age and early old-age. It was
hypothesised that 26 weeks of BodyPump\(^{\text{TM}}\) would increase lower and upper body one-repetition
maximum strength; improve static balance and gait speed; and would have no impact on self-reported
health status.

2. Methods

A two-group, repeated measures, randomised control trial was used to investigate the effects
of 26 weeks of BodyPump\(^{\text{TM}}\) training on adults aged 55-75 years. Based on results of a pilot study and
previous resistance training interventions\(^{6,10}\), a priori power calculation with power set at 0.8 and an
alpha of 0.05 identified a required sample size of 34 per group. To account for a 20% attrition rate a
sample size of 41 per group was required. Due to space and equipment restrictions at the local fitness
facility, the sample size for the BodyPump\(^{\text{TM}}\) group was limited to 40.

Participants were recruited through an adult education facility and via local advertising.
Ninety-five participants were initially assessed for eligibility of which 11 did not meet inclusion
criteria and a further three declined to participate (Figure 1). Eighty-one apparently healthy men and
women undertook baseline testing after providing informed consent conforming to the Declaration of
Helsinki, approved by the Human Research Ethics Committee of the University. Participants were
allocated to either the intervention (PUMP) or control group (CON) on a 1:1 ratio using a computer
generated random number list (stratified for age and gender) after baseline data collection. All participants were physically active, taking part in regular exercise such as walking, cycling and swimming, but had not been involved in formal resistance training in the previous six months. Exclusion criteria included: acute or terminal illness, myocardial infarction in the past six months, recent low impact fracture, or any condition that would interfere with participation in moderate intensity exercise.

PUMP participants undertook 26 weeks of BodyPump™ classes in total. The first four weeks of the intervention served as an orientation and were used to appropriately teach exercise technique and larger rest periods were included. During this phase participants were able to determine appropriate weights for each exercise. From week five onwards all classes were instructed at a level that one would expect to encounter if they took part in a BodyPump™ class at a local fitness centre. Participants were provided with free access to a local fitness facility and were instructed to attend two out of three available classes per week. All classes were instructed by experienced BodyPump™ instructors who were not associated with testing or recruitment of participants. The weights lifted for each exercise were self-selected but were guided by general recommendations provided by the experienced instructor. BodyPump™ program release 83 was used for the duration of the program (supplementary material Appendix 1). Participants recorded the weights lifted during each class for squats, chest press and back exercises (Appendix 1) and any adverse events were also recorded. An adverse event was defined as any incident that occurred during a class that resulted in the participant seeking advice from a health professional or resulted in an inability to undertake normal activities of daily living for at least two days. CON participants did not undergo any training and were instructed to maintain their current level of physical activity for the duration of the study.

A series of assessments were conducted at baseline and post-intervention. One-repetition maximum (1RM) strength was assessed during session one, while gait and balance performance was assessed during session two. Each testing session was separated by 3-5 days. A familiarisation session was held approximately one week prior to 1RM testing to ensure correct lifting technique and to practice lifting sub-maximal loads. During session one lower limb maximal strength was assessed on
an incline leg-press (Calgym, Australia) and upper body strength was assessed on a Smith-machine
bench press (Elite, Australia). Testing commenced after a light cycling warm-up using established
protocols19 with leg-press assessed prior to bench-press.

All balance and mobility measures were assessed with participants unshod. Participants
performed a series of four different standing balance tasks on a strain gauge Bertec 4060-08 force
platform (Bertec Corporation, USA) that was calibrated in accordance with the manufacturer’s
recommendations. Signal processing and data analysis were performed using Qualisys Track Manager
(Gothenburg, Sweden). Data were sampled at a rate of 50 Hz with a cut-off frequency of 10 Hz. The
same order was followed for all participants at each testing session with an increasing level of
difficulty2 – comfortable-stance eyes open, followed by comfortable-stance eyes closed then narrow-
stance eyes open and finally narrow-stance eyes closed. For the comfortable-stance positions
participants stood with their feet at pelvic width, while for the narrow-stance position they stood with
their feet together with the first metatarsal-phalangeal joints and medial malleoli approximating.
Participants were instructed to keep their hands by their sides and to remain as still as possible while
looking straight ahead. Two successful repetitions of 30 seconds in each position were performed with
60 seconds rest between trials. Centre of pressure (COP) displacements were assessed for each task.
COP mean velocity and COP range were assessed in the antero-posterior (AP) and medio-lateral
(ML) direction. Five clinical balance assessments were then conducted in the following order: single
leg stance left and right (60 second limit), the timed-up-and go20, 6 metre walk normal speed, 6 metre
walk fast speed and 30 second chair stand test.21 The mean of two successful trials was used for
analysis for all tasks. Six metre walk times were converted to gait speed (m/s) for analysis.

The SF-36v2® Health Survey (Australian version) was used to assess the self-reported health
status of each participant. The SF36v2® percentage scores were converted to T-scores (Health
Outcomes Scoring Software 4.5) for analysis and interpretation. Energy expenditure derived from
exercise and physical activity was estimated by a seven day activity diary. A metabolic equivalent
(METs) value was assigned to each activity-intensity combination and was used to calculate the
average amount of energy used for exercise by each participant.22
Statistical analyses were performed using IBM SPSS version 20 (Armonk, New York). Normal distribution was assessed by descriptive statistics and visual inspection of histograms. All data are reported as mean and standard deviation (SD) except for data not normally distributed which is presented as median and range. Differences between groups at baseline were assessed by independent t-tests for normally distributed data, and the independent Mann-Whitney U test for data not normally distributed. To assess between-group differences in changes over time, a general linear model (GLM) was used, with time as repeated factor and group as fixed factor for normally distributed data. Baseline values were used as covariates in the GLM for any measures that were different between groups at baseline. Mann-Whitney U tests were used to assess the distribution of change between-groups for outcome measures not normally distributed. A repeated measures GLM with pairwise comparisons and Bonferroni correction was used to detect change in the weight lifted for squats and chest press at week one, five, 13 and 26 of the BodyPump™ program. Effect size estimates were included to provide information regarding the magnitude of any time or group effect. Participants who withdrew from the project or were ineligible for final testing were not included in the final statistical analysis. Statistical significance was set at p < 0.05.

3. Results

Sixty eight participants (PUMP n=32, CON n=36) aged between 58 and 75 years completed all baseline and follow-up testing (Figure 1 and Table 1). All data was normally distributed except for COP derived data. There were baseline group differences in four outcome measures - normal gait speed (p = 0.023), fast gait speed (p = 0.008), role-physical domain of the SF36v2 (p = 0.004), and medio-lateral COP range for narrow-stance eyes closed (p = 0.028).

Significant group-by-time interactions in favour of the PUMP group (Table 2) occurred for 1RM leg-press (F (1, 63) = 7.82, p = 0.007, partial eta² = 0.11), 1RM Smith-machine bench-press (F (1, 62) = 13.12, p = 0.001, partial eta² = 0.18), right single leg stance (F (1,63) = 8.16, p = 0.006, partial eta² = 0.12), normal gait speed (F (1, 63) = 5.03, p = 0.028, partial eta² = 0.08) and weekly METs (F (1, 62) = 9.05, p = 0.004; partial eta² = 0.12). There were significant group differences in
mean change for mean medio-lateral velocity in narrow-stance eyes open (p = 0.006, effect size = 0.01) and narrow-stance eyes closed (p = 0.014, effect size = -0.46). The group differences in these two COP parameters did not provide a consistent direction for improvement in either group (Table 3, supplementary material).

There were significant time effects for 1RM leg-press (F (1, 63) = 20.95, p < 0.001, partial \( \eta^2 = 0.25 \)), Smith-machine bench-press (F (1, 62) = 31.27, p < 0.001, partial \( \eta^2 = 0.34 \)), fast gait speed (F (1, 63) = 23.93, p < 0.001, partial \( \eta^2 = 0.28 \)), 30 second chair stand (F (1, 63) = 14.63, p < 0.001, partial \( \eta^2 = 0.19 \)) and the role-physical domain of the SF36v2 health survey (F (1, 63) = 30.88, p < 0.001, partial \( \eta^2 = 0.33 \)). There were also significant time-by-baseline score effects for the role-physical domain (F (1, 63) = 30.60, p < 0.001, partial \( \eta^2 = 0.33 \)).

There was a significant increase in the amount of weight lifted during PUMP (in terms of percentage of 1RM) for squats between week one (4.4 ± 2.5) and five (8.1 ± 3.6%, p < 0.001), week one and 13 (11.4 ± 6.4%, p<0.001), week one and 26 (11.8 ± 5.1%, p<0.001). There was also an increase in weight between week five and 13 (p<0.001), and between week 5 and 26 (p<0.001). Chest press weight increased between week one (12.8 ± 6.6%) and five (21.6 ± 10.2%, p<0.001), week one and 13 (27.0 ± 12.1%, p<0.001) and week one and 26 (29.0 ± 10.9%, p<0.001). There was also an increase in weight between week five and 13 (p = 0.019), and between week five and 26 (p = 0.006). There was no significant increase in the amount of weight lifted between week 13 and 26 for squats (p = 1.0) or chest press (p = 0.53).

PUMP participants attended 50 ± 12 classes over 26 weeks (range = 16-70 classes) which resulted in a compliance of 89%. Eleven participants attended more than 52 (100%) classes. To avoid a misleading inflation of the compliance, the attendance rate of anyone attending more than 52 classes was 100%. There were nine adverse events reported by nine participants (eight from PUMP) over the course of testing and training. There were two adverse events related to 1RM strength testing - one CON participant reported prolonged (six days) leg muscle soreness after baseline leg-press testing and one PUMP participant injured his supraspinatus tendon during follow-up testing on the Smith-
machine bench-press. Adverse events during BodyPump™ were solely musculoskeletal in nature and were reported by seven participants (21%). Two participants ceased their involvement in the BodyPump™ intervention after exacerbations of knee pain and neck pain, respectively (Figure 1). A further five participants had to modify or omit certain exercises after reporting persistent knee pain (n = 1), low back pain (n = 1) and neck/shoulder pain (n = 3) and were able to continue for the duration of the intervention.

4. Discussion

Supporting the majority of our hypotheses, 26 weeks of low-load/high-repetition resistance training (BodyPump™) increased maximal strength and gait speed in adults aged 58-75 years without improving self-reported health status. Contrary to our hypothesis, there were limited improvements in measures of static balance. To our knowledge, this is the first study to demonstrate that resistance training using low-loads (10-30% 1RM) and very high repetitions can improve maximal strength and gait speed in middle-aged and older adults.

The improvement for leg-press 1RM in the PUMP group (13%) is less than some high-\textsuperscript{4,23} and low-load\textsuperscript{10} resistance training interventions but comparable to others.\textsuperscript{7,9,24} Further gains in strength were likely limited by the lack of progressive overload in the latter part of the intervention. There were negligible increases in the amount of weight lifted for squats between week 13 and 26 of the intervention and as such the amount of weight lifted for squats remained at \textasciitilde 10\% of predicted\textsuperscript{25} squat 1RM for the entire program. Exercises were not strictly performed to fatigue or momentary muscular failure which could also limit strength gains. The 14\% increase for the Smith-machine bench-press in the BodyPump™ group was similar to results from traditional and power-based resistance training interventions.\textsuperscript{24,26}

The mean increase of 0.31m/s in the PUMP group for gait speed is notable as improvements in gait speed predict a substantial reduction in mortality in older adults.\textsuperscript{27} This level of improvement is greater than the typically modest but significant change of 0.08m/s found with resistance training in
older adults and also represents a substantial meaningful change. Although single leg stance (right) performance improved in the PUMP group, there were no consistent improvements among force platform derived measures of static balance. While some have reported improved balance following resistance training in middle-aged and older adults, our results align with previous studies that have not found consistent improvements in measures of static balance following resistance training. The good baseline balance ability of the cohort may have reduced the opportunity for improvement and the tasks assessed may not have sufficiently challenged those with adequate balance. Furthermore, the BodyPump™ classes may not have challenged participants’ balance sufficiently.

The lack of change observed for self-reported health status was hypothesised and has been observed previously with resistance training interventions in older adults. Baseline mean T-scores for all domains of the SF26v2 were higher than previously reported Australian data which may have reduced the likelihood of substantial change in this cohort.

This study provides the first information relating to the potential safety and effectiveness of BodyPump™ in middle-aged and older adults. The program was well attended with a near 90% compliance. The number of adverse events reported during testing and training are comparable to other resistance training interventions in middle-aged and older adults. Overall, the majority (~80%) of participants in the BodyPump™ group did not experience an adverse event nor did they require substantial lifting modifications or omissions.

Some study limitations require attention. Firstly, the lack of progressive overload is a key limitation. The control group received no placebo intervention nor was there an alternative training group for comparison. The balance assessment tasks used in this study may not have provided enough challenge to those with good balance ability, therefore creating a ceiling effect. Post-hoc power analysis revealed insufficient power to detect differences between groups for some clinical balance tasks. Because a healthy, active cohort was utilised for this study, generalizability of these results in sedentary persons, recurrent fallers or those with musculoskeletal impairments or chronic disease cannot be determined.
5. Conclusions

Low-load/high-repetition resistance training in the form of BodyPump™ was effective at improving maximal strength and gait speed in healthy, community dwelling middle-aged and older adults. There were no evident improvements for force plate derived balance measures or self-reported health status. Future research should compare BodyPump™ with other forms of low-load/high-repetition training and traditional progressive resistance training.

6. Practical Implications

- Twenty-six weeks of BodyPump™ training improved maximal leg-press and bench press strength in well-functioning, healthy, active adults aged 58-75 years
- BodyPump™ training improved normal gait speed in individuals aged 58-75 years
- It appears appropriate lifting technique modification and lifting options are required to enable the safe execution of BodyPump™ for some people in the 58-75 age group

Acknowledgements

We are grateful to the Australian Fitness Network for providing PhD scholarship funding and many thanks to Suncoast Fitness Maroochydore for providing free access to BodyPump™ participants throughout the project. Thank you also to Mark Sayers for his assistance with COP data.
References


Table 1. Baseline participant characteristics

<table>
<thead>
<tr>
<th></th>
<th>Pump (N=40)</th>
<th>Control (N=41)</th>
</tr>
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<tbody>
<tr>
<td>Age, years</td>
<td>66.4 ± 4.0</td>
<td>66.3 ± 4.7</td>
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<tr>
<td>Height, cm</td>
<td>167.6 ± 7.3</td>
<td>167.5 ± 8.6</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>74.1 ± 11.2</td>
<td>70.2 ± 12.2</td>
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<tr>
<td>BMI, kg/m$^2$</td>
<td>26.3 ± 3.1</td>
<td>24.9 ± 2.8</td>
</tr>
<tr>
<td>Number of prescribed medications</td>
<td>1.6 ± 1.7</td>
<td>1.1 ± 1.3</td>
</tr>
<tr>
<td>Fallers, ≥1 fall in previous 12 months (%)</td>
<td>2 (5)</td>
<td>2 (5)</td>
</tr>
<tr>
<td>Males, n (%)</td>
<td>9 (23)</td>
<td>10 (24)</td>
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</table>

Values reported as mean ± SD; asignificant difference (p = 0.034) between groups at baseline
Table 2. Pre- and post-intervention values for maximal strength, balance, energy expenditure and self-reported health status

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1RM leg press (kg)</td>
<td>145.7 ± 40.5</td>
<td>164.6 ± 48.4</td>
<td>146.2 ± 49.5</td>
<td>149.9 ± 60.9</td>
<td>&lt;0.001</td>
<td>0.25</td>
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<tr>
<td>1RM bench (kg)</td>
<td>26.6 ± 11.7</td>
<td>30.4 ± 12.4</td>
<td>29.1 ± 13.5</td>
<td>30.6 ± 13.8</td>
<td>&lt;0.001</td>
<td>0.34</td>
</tr>
<tr>
<td>SLS (L) (sec)</td>
<td>34.4 ± 19.9</td>
<td>35.5 ± 20.3</td>
<td>34.8 ± 19.7</td>
<td>35.9 ± 20.6</td>
<td>0.36</td>
<td>0.01</td>
</tr>
<tr>
<td>SLS (R) (sec)</td>
<td>30.4 ± 17.9</td>
<td>37.6 ± 19.5</td>
<td>38.8 ± 21.8</td>
<td>35.9 ± 20.8</td>
<td>0.15</td>
<td>0.03</td>
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<tr>
<td>TUG (sec)</td>
<td>6.15 ± 0.85</td>
<td>6.12 ± 0.77</td>
<td>5.92 ± 0.73</td>
<td>5.93 ± 0.74</td>
<td>0.72</td>
<td>0.00</td>
</tr>
<tr>
<td>Normal Gait (m/s) a</td>
<td>1.33 ± 0.19</td>
<td>1.64 ± 0.42</td>
<td>1.44 ± 0.21</td>
<td>1.57 ± 0.20</td>
<td>0.074</td>
<td>0.05</td>
</tr>
<tr>
<td>Fast gait (m/s)b</td>
<td>1.86 ± 0.24</td>
<td>2.00 ± 0.20</td>
<td>2.03 ± 0.24</td>
<td>2.10 ± 0.22</td>
<td>&lt;0.001</td>
<td>0.28</td>
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<tr>
<td>30s CST (reps)</td>
<td>19.8 ± 4.6</td>
<td>21.0 ± 4.7</td>
<td>19.8 ± 4.0</td>
<td>20.1 ± 6.6</td>
<td>&lt;0.001</td>
<td>0.19</td>
</tr>
<tr>
<td>Weekly exercise METs</td>
<td>31.9 ± 20.6</td>
<td>41.3 ± 18.2</td>
<td>38.6 ± 25.3</td>
<td>39.2 ± 25.9</td>
<td>0.001</td>
<td>0.15</td>
</tr>
<tr>
<td>Physical Function</td>
<td>53.9 ± 2.8</td>
<td>54.3 ± 2.4</td>
<td>54.4 ± 3.0</td>
<td>54.0 ± 3.4</td>
<td>0.78</td>
<td>0.00</td>
</tr>
<tr>
<td>Role-Physical a,b</td>
<td>52.7 ± 5.2</td>
<td>54.5 ± 4.7</td>
<td>55.2 ± 4.2</td>
<td>54.1 ± 5.3</td>
<td>&lt;0.001</td>
<td>0.33</td>
</tr>
<tr>
<td>Bodily Pain</td>
<td>53.1 ± 8.1</td>
<td>52.2 ± 6.6</td>
<td>53.7 ± 6.1</td>
<td>52.9 ± 7.5</td>
<td>0.40</td>
<td>0.01</td>
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<tr>
<td>General Health</td>
<td>57.5 ± 4.4</td>
<td>58.3 ± 4.9</td>
<td>57.7 ± 6.8</td>
<td>56.0 ± 8.1</td>
<td>0.44</td>
<td>0.01</td>
</tr>
<tr>
<td>Vitality</td>
<td>56.4 ± 6.1</td>
<td>57.2 ± 7.2</td>
<td>58.3 ± 4.6</td>
<td>57.2 ± 6.7</td>
<td>0.83</td>
<td>0.00</td>
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<tr>
<td>Social Function</td>
<td>53.5 ± 5.2</td>
<td>54.8 ± 5.1</td>
<td>54.8 ± 5.9</td>
<td>54.8 ± 4.7</td>
<td>0.36</td>
<td>0.01</td>
</tr>
<tr>
<td>Role-Emotional</td>
<td>50.6 ± 7.2</td>
<td>52.6 ± 5.7</td>
<td>53.8 ± 5.1</td>
<td>53.8 ± 5.8</td>
<td>&lt;0.001</td>
<td>0.45</td>
</tr>
<tr>
<td>Mental Health</td>
<td>54.6 ± 6.1</td>
<td>55.2 ± 6.0</td>
<td>54.7 ± 6.3</td>
<td>55.2 ± 5.8</td>
<td>0.48</td>
<td>0.01</td>
</tr>
<tr>
<td>PCS</td>
<td>54.4 ± 4.7</td>
<td>54.5 ± 4.0</td>
<td>55.2 ± 5.4</td>
<td>53.9 ± 5.3</td>
<td>0.36</td>
<td>0.01</td>
</tr>
<tr>
<td>MCS</td>
<td>53.3 ± 6.6</td>
<td>54.7 ± 7.0</td>
<td>55.0 ± 6.5</td>
<td>55.4 ± 5.7</td>
<td>0.37</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Values presented as mean ± SD; SF36v2 used to measure self-reported health status; SLS = single leg stance; TUG = timed-up-and-go; 30s CST = 30s chair stand test; Weekly exercise METs = energy expenditure in metabolic equivalents (METs) based on 7-day exercise diary; PCS = physical components summary of SF36v2; MCS = mental components summary of SF36v2; a significant (p<0.05) difference between groups at baseline; b significant (p<0.05) time-by-baseline score effect.
Figure 1. Project flow chart

Enrolment

Assessed for eligibility (n=95)

Excluded (n= 14)
Not meeting inclusion criteria (n= 11)
Declined to participate (n= 3)

Completed Baseline testing (n= 81)

Randomisation & Allocation

Allocated to intervention (n=40, 12m, 28f)

Allocated to control (n= 41, 12m, 29f)

Follow-Up

Lost to follow-up (n= 8)
Family commitments (n=2), moved overseas (n=1), knee pain during intervention (n=1), neck pain during intervention (n=1), fear of injury from intervention (n=1), fractured radius (n=1, fall at home), travel commitments (n=1)

Lost to follow-up (n= 5)
Moved interstate (n=1), fractured scaphoid (n=1, cycling injury), fractured rib (n=1, during holiday), heart attack (n=1, during holiday), knee surgery (n=1)

Final Analysis

Analysed (n= 32, 9m, 23f)

Analysed (n= 36, 10m, 26f)
Supplementary Table 4-a. General characteristics of a BodyPump™ training session (release 83) and weights used for selected exercises during the 26 week training intervention

<table>
<thead>
<tr>
<th>Track number</th>
<th>Exercise - Name</th>
<th>Approximate repetitions*</th>
<th>Mean weight ± SD week 1</th>
<th>Mean weight ± SD week 5</th>
<th>Mean weight ± SD week 13</th>
<th>Mean weight ± SD week 26</th>
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<tbody>
<tr>
<td>1 – Warm up</td>
<td>Deadlift</td>
<td>24</td>
<td>3.6 ± 2.5 kg</td>
<td>6.9 ± 3.9 kg</td>
<td>9.8 ± 3.1 kg</td>
<td>10.1 ± 3.1 kg</td>
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<tr>
<td></td>
<td>Dead-row</td>
<td>6</td>
<td></td>
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<tr>
<td></td>
<td>Upright row to overhead press</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Overhead press</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Squats</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Squats</td>
<td>8 (per leg)</td>
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<tr>
<td></td>
<td>Bicep curl</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 – Squats</td>
<td>Squats</td>
<td>108</td>
<td>3.6 ± 2.5 kg</td>
<td>6.9 ± 3.9 kg</td>
<td>9.8 ± 3.1 kg</td>
<td>10.1 ± 3.1 kg</td>
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<tr>
<td>3 – Chest</td>
<td>Chest Press</td>
<td>94</td>
<td>3.3 ± 1.9 kg</td>
<td>5.7 ± 5.2 kg</td>
<td>7.1 ± 4.2 kg</td>
<td>7.5 ± 4.4 kg</td>
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<tr>
<td>4 – Back</td>
<td>Dead row</td>
<td>41</td>
<td>3.6 ± 2.0 kg</td>
<td>6.6 ± 5.6 kg</td>
<td>8.1 ± 3.9 kg</td>
<td>8.6 ± 4.2 kg</td>
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<tr>
<td></td>
<td>Dead lift</td>
<td>15</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Clean &amp; press</td>
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<td></td>
<td>Power press</td>
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<tr>
<td>5 – Triceps</td>
<td>Tricep extension</td>
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<td>Tricep press</td>
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<tr>
<td></td>
<td>Standing overhead</td>
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<td>Track</td>
<td>Exercise</td>
<td>Repetitions</td>
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<tr>
<td>6 – Biceps</td>
<td>Extension</td>
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<tr>
<td>7 – Lunges</td>
<td>Bicep curl</td>
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<td></td>
<td>Squat</td>
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<td></td>
<td>Jump squat</td>
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<td>Pulse Jump squat</td>
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<tr>
<td></td>
<td>Lunge</td>
<td>25 (per leg)</td>
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<td>8 – Shoulders</td>
<td>Pushup</td>
<td>36</td>
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<tr>
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<td>Standing rear deltoid raise</td>
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<td></td>
<td>Standing side raise</td>
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<td>Upright row</td>
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<td>Overhead press</td>
<td>16</td>
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<tr>
<td>9 - Core</td>
<td>Crunch</td>
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<td></td>
<td>Hover</td>
<td>14</td>
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<td>10 – Cool down</td>
<td>Stretch/mobility</td>
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*Note: all repetitions are performed in one continuous set within each track*
Supplementary Table 4-b. Pre- and post-intervention values for centre of pressure (COP) parameters BodyPump™ study

<table>
<thead>
<tr>
<th>COP parameter</th>
<th>Stance position</th>
<th>BodyPump (N = 32)</th>
<th>Control (N = 36)</th>
<th>p</th>
<th>Effect Size&lt;sup&gt;c&lt;/sup&gt;</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td></td>
</tr>
<tr>
<td>AP mean velocity (mm/s)</td>
<td>CSEO</td>
<td>0.17 (0.001-0.94)</td>
<td>0.21 (0.001-0.83)</td>
<td>0.22 (0.006-1.22)</td>
<td>0.21 (0.01-0.68)</td>
</tr>
<tr>
<td></td>
<td>CSEC</td>
<td>0.15 (0.001-0.76)</td>
<td>0.18 (0.001-0.72)</td>
<td>0.11 (0.008-0.58)</td>
<td>0.18 (0.001-1.45)</td>
</tr>
<tr>
<td></td>
<td>NSEO</td>
<td>0.29 (0.002-1.31)</td>
<td>0.20 (0.01-0.94)</td>
<td>0.27 (0.006-1.03)</td>
<td>0.20 (0.001-1.41)</td>
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<tr>
<td></td>
<td>NSEC</td>
<td>0.29 (0.01-1.11)</td>
<td>0.31 (0.01-0.84)</td>
<td>0.28 (0.03-1.32)</td>
<td>0.32 (0.01-1.40)</td>
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<tr>
<td>ML mean velocity (mm/s)</td>
<td>CSEO</td>
<td>0.08 (0.003-0.30)</td>
<td>0.09 (0.001-0.56)</td>
<td>0.08 (0.004-0.75)</td>
<td>0.07 (0.001-0.63)</td>
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<tr>
<td></td>
<td>CSEC</td>
<td>0.06 (0.002-0.35)</td>
<td>0.08 (0.001-0.60)</td>
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<td>0.08 (0.001-0.77)</td>
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<tr>
<td></td>
<td>NSEO</td>
<td>0.22 (0.005-0.95)</td>
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<td>0.20 (0.01-1.32)</td>
<td>0.23 (0.01-0.90)</td>
<td>0.31 (0.02-1.76)</td>
<td>0.22 (0.01-1.42)</td>
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<tr>
<td>AP range (mm)</td>
<td>CSEO</td>
<td>16.7 (7.2-33.1)</td>
<td>19.1 (8.6-45.2)</td>
<td>16.4 (7.4-47.3)</td>
<td>19.9 (9.8-52.0)</td>
</tr>
<tr>
<td></td>
<td>CSEC</td>
<td>16.0 (8.2-59.8)</td>
<td>22.6 (9.8-52.3)</td>
<td>19.8 (7.7-51.3)</td>
<td>20.9 (9.1-57.9)</td>
</tr>
<tr>
<td></td>
<td>NSEO</td>
<td>20.8 (12.9-46.0)</td>
<td>29.0 (11.9-73.0)</td>
<td>21.9 (10.9-45.9)</td>
<td>25.1 (13.8-75.8)</td>
</tr>
<tr>
<td></td>
<td>NSEC</td>
<td>23.3 (12.8-80.2)</td>
<td>33.4 (15.3-60.3)</td>
<td>27.8 (10.1-61.4)</td>
<td>33.1 (14.3-96.8)</td>
</tr>
<tr>
<td>ML range (mm)</td>
<td>CSEO</td>
<td>6.0 (3.0-11.9)</td>
<td>8.9 (4.5-22.1)</td>
<td>6.9 (3.4-18.9)</td>
<td>8.9 (4.8-19.7)</td>
</tr>
<tr>
<td></td>
<td>CSEC</td>
<td>5.9 (3.3-34.4)</td>
<td>9.4 (4.9-23.4)</td>
<td>6.4 (2.5-21.3)</td>
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</tr>
<tr>
<td></td>
<td>NSEO</td>
<td>24.3 (13.6-59.4)</td>
<td>32.9 (14.2-57.8)</td>
<td>24.6 (14.9-51.7)</td>
<td>28.5 (7.8-92.8)</td>
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<td></td>
<td>NSEC&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.3 (12.8-74.2)</td>
<td>33.3 (16.4-61.8)</td>
<td>32.7 (13.8-81.2)</td>
<td>35.6 (17.8-71.9)</td>
</tr>
</tbody>
</table>

Values reported as median (range); AP = anterior-posterior; ML = medio-lateral; CSEO = comfortable stance eyes open; CSEC = comfortable stance eyes closed; NSEO = narrow stance eyes open; NSEC = narrow stance eyes closed; <sup>a</sup> significant (p<0.05) difference between groups at baseline using independent Mann-Whitney U test; <sup>b</sup> significant (p<0.05) difference in mean change between groups using Mann-Whitney U test for two independent groups; <sup>c</sup> effect size calculated as Z score/√N; reductions in mean velocity and range are indicative of improvement in balance control.
Supplementary Tables 4-c and 4-d below are provided as additional tables not included in the preceding published manuscript.

**Supplementary Table 4-c. BodyPump™ pre- and post-intervention values for fear of falling as measured by the 10-item Iconographical falls efficacy scale (IconFES)**

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>BodyPump (N=32)</th>
<th>Control (N=36)</th>
<th>Time effect p</th>
<th>Partial $\eta^2$ for Time</th>
<th>Group-by-time interaction p</th>
<th>Partial $\eta^2$ for Group-by-time</th>
</tr>
</thead>
<tbody>
<tr>
<td>IconFES</td>
<td>12.79 ± 2.11</td>
<td>12.13 ± 1.77</td>
<td>13.11 ± 2.72</td>
<td>12.77 ± 2.32</td>
<td>0.029</td>
<td>0.072</td>
</tr>
</tbody>
</table>

Values presented as mean ± SD; lower values indicative of less fear (minimum value achievable is 10).

**Supplementary Table 4-d. Early and late intervention values for enjoyment as measured by the modified physical activity enjoyment scale (PACES) for BodyPump™**

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>BodyPump (N=21)</th>
<th>Paired samples t-test p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PACES</td>
<td>45.16 ± 10.01</td>
<td>41.67 ± 7.18</td>
</tr>
</tbody>
</table>

Values presented as mean ± SD; higher values indicative of higher enjoyment.
CHAPTER 5: MANUSCRIPT 3

Low-load very high-repetition resistance training attenuates lumbar spine bone mineral density in active post-menopausal women


Abstract

This study determined the effect of 6 months of low-load very high-repetition resistance training on bone mineral density (BMD) and body composition in nonosteoporotic middle-aged and older women. Fifty healthy, active community-dwelling women aged 56–75 years took part in the two-group, repeated-measures randomized controlled trial. Participants either undertook 6 months of low-load very high-repetition resistance training in the form of BodyPumpTM or served as control participants. Outcome measures included BMD at the lumbar spine, hip, and total body; total fat mass; fat-free soft tissue mass and maximal isotonic strength. Significant group-by-time in-teractions were found for lumbar spine BMD and maximal strength in favor of the BodyPumpTM group. No favorable effects were found for hip BMD, total body BMD, total fat mass, or fat-free soft tissue mass. Three participants withdrew from the intervention group due to injury or fear of injury associated with training. Under the conditions used in this research, low-load very high-repetition resis- tance training is effective at attenuating losses in lumbar spine BMD compared to controls in healthy, active women aged over 55 years but did not influence hip and total body BMD or fat mass and fat-free soft tissue mass.

This article has been removed due to copyright restrictions. It is available from here: doi: 10.1007/s00223-015-9976-6
CHAPTER 6: MANUSCRIPT 4

Twelve weeks of BodyBalance® training improved balance and functional task performance in middle-aged and older adults

Twelve weeks of BodyBalance® training improved balance and functional task performance in middle-aged and older adults

Vaughan P Nicholson, Mark R McKean, Brendan J Burkett
School of Health and Sport Sciences, University of the Sunshine Coast, Sunshine Coast, QLD, Australia

Purpose: The purpose of the study was to evaluate the effect of BodyBalance® training on balance, functional task performance, fear of falling, and health-related quality of life in adults aged over 55 years.

Participants and methods: A total of 28 healthy, active adults aged 66±5 years completed the randomized controlled trial. Balance, functional task performance, fear of falling, and self-reported quality of life were assessed at baseline and after 12 weeks. Participants either undertook two sessions of BodyBalance per week for 12 weeks (n=15) or continued with their normal activities (n=13).

Results: Significant group-by-time interactions were found for the timed up and go (P=0.038), 30-second chair stand (P=0.037), and mediolateral center-of-pressure range in narrow stance with eyes closed (P=0.017). There were no significant effects on fear of falling or self-reported quality of life.

Conclusion: Twelve weeks of BodyBalance training is effective at improving certain balance and functional tasks in healthy older adults.

Keywords: postural control, yoga, tai chi, center of pressure, exercise

Introduction

Age-related changes in balance and functional task performance are well-established and evident from the fourth and fifth decades of life in men and women.1,2 Deficits in balance are associated with falls,3 difficulties with activities of daily living,4 and poor survival5 in older adults. Fortunately, appropriate exercise can improve balance performance6 and contribute to improved mobility,7 independence, and a reduction in the risk of falling.8 Interventions utilizing traditional or holistic exercises, such as tai chi,9 Pilates,10 and yoga,11 have all been found to improve balance in older adults.

A number of authors have also highlighted the importance of delivering preemptive exercise interventions to middle-aged and older adults before deteriorations in balance and mobility lead to adverse outcomes.12,13 Additionally, such interventions may reduce fear of falling and improve quality of life.14 These aspects are important, as fear of falling is associated with a reduction in physical activity and subsequent increased fall risk,15 while improving health and quality of life are important motivators for exercise in older adults.16

While there are various exercise options that are capable of improving balance in middle-aged and older adults, gym-based activities are becoming increasingly popular in this age-group.17,18 Group fitness classes that incorporate appropriate challenges to balance are likely to be successful at improving balance outcomes.
BodyBalance® (Les Mills) (BodyFlow™ in the US) is one gym-based activity that has the potential to promote improvements in balance, as it is comprised of yoga, tai chi, and Pilates elements, all of which in isolation can successfully improve balance.7,19,20 The prechoreographed class is available in over 14,000 fitness facilities globally, so its potential reach is vast. It has been subject to just one peer-reviewed study, in which benefits in strength, state anxiety, and flexibility were found in young and middle-aged adults.21 The effect of BodyBalance on balance and functional task performance has yet to be determined in middle-aged or older adults.

The primary aim of this study was to determine whether 12 weeks of BodyBalance classes would improve balance and functional task performance in healthy, active adults aged over 55 years. Secondary aims were to determine the effect of BodyBalance training on fear of falling and self-reported quality of life. It was hypothesized that 12 weeks of BodyBalance training would improve measures of balance and functional task performance without having an effect on fear of falling or self-reported quality of life.

Participants and methods

Study design and intervention

A two-group, repeated-measures, randomized controlled trial was used to determine the effect of a 12-week BodyBalance training program. Men and women aged 55–75 years not involved in formal resistance or balance training in the previous 6 months were invited to participate in the study. All participants were physically active, taking part in regular exercise, such as walking, cycling, and swimming. Exclusion criteria included: acute or terminal illness, myocardial infarction in the past 6 months, recent low-impact fracture, or any condition that would interfere with moderate-intensity exercise participation. Participants were recruited through an adult-education facility and via local advertising. All participants provided written informed consent conforming to the Declaration of Helsinki before participating in the study. The study protocol was approved by the Human Research Ethics Committee of the University of the Sunshine Coast.

Participants were allocated to either the intervention (BodyBalance [BB]) or control (CON) group in a 1:1 ratio using a computer generated random-number list (stratified for age and sex). The participants were informed of their allocation after baseline data collection.

Participants in the BB group undertook 12 weeks of BodyBalance classes. Participants were provided with free access to a local fitness facility, and were encouraged to attend two scheduled classes per week. All classes were instructed by experienced group fitness instructors who were not associated with testing or recruitment of participants. The focus of the first 2 weeks of the intervention was for each participant to learn the exercises and postures of the class appropriately. As such, the transitions between postures were deliberately slow in the first 2 weeks. From week 3 onward, all classes were instructed at a level that one would expect to encounter if they took part in a BodyBalance class at a local gym. The class involves a variety of poses and exercises that are derived from yoga, tai chi, and Pilates (Table 1). The class instructor provided basic, intermediate, and advanced options for each pose or exercise. CON-group participants were encouraged to continue with their normal activities, but did not take part in any class.

Measures

All measures were completed during a single session for each participant at baseline and follow-up. Two questionnaires...
were completed at the start of the session to assess fear of falling and self-reported quality of life. The assessment of balance on a force platform was then conducted followed by a battery of established clinical balance assessments and functional tasks.

**Questionnaires**
The 10-item Iconographical Falls Efficacy Scale was completed at the start of each balance-assessment session to provide an indication of each participant’s fear of falling. The Short Form (36) Health Survey (SF-36)-v2 (Australian version) was also completed at baseline and follow-up to assess the self-reported quality of life of each participant. SF-36v2 percentage scores were converted to *t*-scores using Health Outcomes™ Scoring Software 4.5 (QualityMetric, Lincoln, RI, USA) for analysis and interpretation.

**Center-of-pressure balance assessment**
Balance and functional task assessments were conducted at baseline and immediately postintervention. All measures were assessed with participants unshod. Participants performed a series of four different standing-balance tasks on a strain-gauge 4060-08 force platform (Bertec, Columbus, OH, USA). The force plate was calibrated in accordance with the manufacturer’s recommendations. Signal processing and data analysis were performed using Track Manager (Qualisys, Gothenburg, Sweden). Data were sampled at a rate of 50 Hz, with a cutoff frequency of 10 Hz. The balance tasks were comfortable stance (eyes open and closed) and narrow stance (eyes open and closed). For the comfortable stance positions, participants stood with their feet at pelvic width, while for the narrow stance position they stood with their feet together with the first metatarsal–phalangeal joints and medial malleoli touching. Participants were instructed to keep their hands by their sides and to remain as still as possible while looking straight ahead. Two successful repetitions of 30 seconds in each position were performed, with 60 seconds’ rest between trials. The same order was followed for all participants at each testing session: comfortable stance, eyes open, followed by comfortable stance, eyes closed, then narrow stance, eyes open, and finally narrow stance, eyes closed. The mediolateral center-of-pressure (COP) range for each stance position was used for data analysis. The mediolateral COP range is the distance between the maximal and minimal position of the COP in the frontal plane. High test–retest reliability for this COP parameter was found in pilot testing with 20 similar-aged participants (intraclass correlation coefficient 0.86)

**Single-leg balance**
With their eyes open, subjects raised the nonstanding leg so that the raised foot was near but not touching the ankle of the stance limb and maintained that position for as long as long as they could up to a maximum of 60 seconds. Time was measured with a digital stopwatch. Timing commenced when the subject lifted the foot off the floor, and timing ceased when the subject either 1) used their arms (moved arms away from their side) to balance, 2) moved the weight-bearing foot to maintain balance, 3) a maximum of 60 seconds had elapsed, 4) placed their nonstanding leg on the ground, or 5) required assistance to maintain balance. Two successful trials on each leg were recorded (left leg assessed first), and the mean of the two scores was used for analysis.

**Functional reach**
The subject stood with feet a comfortable distance apart behind a line perpendicular and adjacent to a wall (foot position noted for each subject). Subjects were asked to make a fist and to raise the arm closest to the wall to shoulder height, and the position of the third metacarpal was recorded. The subject was then instructed to keep the feet flat on the floor and lean forward as far as possible without losing balance, touching the wall, or taking a step. The position of the third metacarpal was recorded at the point of furthest reach. The functional reach is the difference between the two measures. Two measures were recorded for the right side (left side was used if right shoulder mobility was limited), and the mean used for analysis.

**Lateral reach**
The subject stood with their back to (but not in contact with) a wall. Feet were placed in a standardized position with 0.1 m between the most medial aspects of the heels, with each foot angle out at 30°. To ensure accurate recording of the initial hand position, subjects stood for 10 seconds with both arms abducted and maintained equal weight bearing, and the position of the tip of the third finger was measured. Subjects were given standardized instructions to reach directly sideward as far as possible without overbalancing, taking a step or touching the wall. The perceived maximal reach position was maintained for 3 seconds and recorded. The distance between the initial hand position and maximal reach position is the lateral reach. Two successful trials were performed for each side and the mean used for analysis.

**Timed up and go**
Subjects were seated in a normal armchair (0.44 m high) with their back against the chair. They were instructed to stand
up, walk 3 meters as quickly and safely as possible past a marker on the floor, turn around, walk back to the chair, and sit down with their back against the chair. Time started on the command “Go” and stopped once the subject’s back was against the chair after completing the walk. The mean of two trials was used for analysis.

**Normal gait speed**
Subjects were instructed to stand still with their feet just behind a starting line marked with tape, and then to walk at their “normal, comfortable pace” along a 6-meter course until a few steps past the finish line after the examiner’s command of “Go”. Timing with a digital stopwatch commenced with the first footfall and stopped with the subject’s first footfall after crossing the 6-meter end line. The mean time for two trials was converted to gait speed (m/s) and used for data analysis.

**Fast-gait speed**
Subjects were instructed to stand still with their feet just behind a starting line marked with tape, and then to walk “as quickly as possible without running” along a 6-meter course until a few steps past the finish line after the examiner’s command of “Go”. Timing with a digital stopwatch commenced with the first footfall and stopped with the subject’s first footfall after crossing the 6-meter end line. The mean time for two trials was converted to gait speed (m/s) and used for data analysis.

**Thirty-second chair-stand test**
The 30-second chair stand test was administered using a chair without arms, with a seat height of 0.44 m. The back of the chair was placed against a wall to prevent it from moving during the test. The test began with the subject seated in the middle of the chair, feet approximately shoulder width apart and placed on the floor at an angle slightly behind the knees. Arms were crossed at the wrists and held against the chest. On the “Go” signal, the subject rose to a full stand and then returned back to the initial seated position, then completed as many full stands as possible within 30 seconds. The mean of two trials was used for analysis.

**Floor rise to standing**
The participants started in a supine position with their legs and feet together and arms by their side with palms down. Timing started on the “Go” command, and participants rose to full standing as fast as possible. Timing ceased when the patient was fully upright and had come to a complete stop. The mean of two trials was used for analysis.

**Data analysis**
All data are reported as means and standard deviation. Primary outcomes were changes in balance and functional task performance from baseline in response to the 12-week BodyBalance intervention. Secondary outcomes were changes in fear of falling and self-reported quality of life. Potential differences between groups at baseline were assessed by independent t-tests. A repeated-measures general linear model was used to determine group (BB, CON) and time (baseline, 12 weeks) effects on primary and secondary outcomes. Baseline values were used as covariates in the general linear model for any measures that were different between groups at baseline. Partial $R^2$ was used to determine the effect size for each outcome variable. A priori power calculations were performed for the key balance variables of timed up and go (TUG) and gait speed based on previous research indicating that a sample size of 15 participants per group would be required to provide greater than 80% power at a level of 0.05. To account for a 10% attrition rate, a total of 17 participants per group was required. Analyses were performed using SPSS (IBM, Armonk, NY, USA). Statistical significance was set at $P<0.05$.

**Results**

**Study population and compliance**
Twenty-eight participants aged between 57 and 73 years (BB, $n=15$, age 66±4.9 years; CON, $n=13$, age 66±5.1 years) completed all baseline and follow-up testing (Table 2). All participants were active adults living independently within the community, and did not require assistive devices for ambulation. All BB participants that started the program completed the intervention, with a mean attendance of 22±2.1 classes resulting in an overall compliance of 92%. One BB participant reported ongoing low-back pain during classes, but was able to complete the program and follow-up testing, but did require physiotherapy treatment. No other adverse events were reported during the intervention. Three participants from CON were lost to follow-up.

### Table 2 Baseline participant characteristics

<table>
<thead>
<tr>
<th>Measure</th>
<th>BodyBalance® ($n=15$)</th>
<th>Control ($n=13$)</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>66.0±4.9</td>
<td>65.9±5.1</td>
<td>0.95</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.66±0.09</td>
<td>1.67±0.09</td>
<td>0.61</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.9±19.3</td>
<td>66.7±13.0</td>
<td>0.27</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>26.6±3.9</td>
<td>23.6±2.6</td>
<td>0.034</td>
</tr>
<tr>
<td>Females, males</td>
<td>11, 4</td>
<td>12, 4</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Notes: Values presented as means ± standard deviation; $P$-values based on independent t-tests.
after completing baseline testing (Figure 1). There were no significant individual differences between those who withdrew and those who completed all testing for any primary or secondary outcome measure.

Effects on balance measures and functional tasks

There were no significant differences between groups in any balance measure or functional task at baseline (Table 3). There were significant group-by-time interactions in favor of BB for the 30-second chair-stand test ($F_{1,26}=4.9, P=0.037$, partial $\eta^2=0.18$), the TUG ($F_{1,26}=4.8, P=0.038$, partial $\eta^2=0.17$) and mediolateral COP range in narrow stance, eyes closed ($F_{1,26}=6.2, P=0.017$, partial $\eta^2=0.13$) (Table 3 and Figures 2–4). There was a significant group-by-time interaction for single leg, stance left ($F_{1,26}=5.9, P=0.024$, partial $\eta^2=0.20$), indicating an increase in stance time for CON. There were significant time effects for lateral reach, left ($F_{1,26}=4.9, P=0.037$, partial $\eta^2=0.18$), 30-second chair-stand test ($F_{1,26}=23.0, P<0.001$, partial $\eta^2=0.51$), and mediolateral COP range with comfortable stance, eyes closed ($F_{1,26}=5.7, P=0.022$, partial $\eta^2=0.12$). These time effects all indicated an improvement between baseline and follow-up.

Effects on fear of falling and self-reported quality of life

There were no significant baseline group differences between groups for fear of falling or any self-reported quality-of-life measure (Table 4). There were no significant group-by-time interactions for fear of falling or quality-of-life measures. There was a significant time effect for bodily pain ($F_{1,26}=7.45, P=0.014$, partial $\eta^2=0.29$),

Figure 1 Project flowchart.
### Table 3 Baseline and follow-up values for primary outcome measures, including effect-size estimates and observed power

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>BodyBalance®</th>
<th>Control</th>
<th>Partial $\eta^2$ for time</th>
<th>Group-by-time interaction P</th>
<th>Partial $\eta^2$ for group by time</th>
<th>Observed power for group</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS, left (seconds)</td>
<td>41.1±2.1</td>
<td>36.4±20.6</td>
<td>0.80</td>
<td>0.003</td>
<td>0.24</td>
<td>0.20</td>
</tr>
<tr>
<td>SLS, right (seconds)</td>
<td>38.6±9.5</td>
<td>38.3±19.8</td>
<td>0.74</td>
<td>0.005</td>
<td>0.67</td>
<td>0.008</td>
</tr>
<tr>
<td>Functional reach (cm)</td>
<td>31.8±7.6</td>
<td>32.8±5.3</td>
<td>0.67</td>
<td>0.008</td>
<td>0.59</td>
<td>0.013</td>
</tr>
<tr>
<td>Lateral reach (cm)</td>
<td>20.0±2.8</td>
<td>22.8±4.2</td>
<td>0.037</td>
<td>0.18</td>
<td>0.41</td>
<td>0.03</td>
</tr>
<tr>
<td>Lateral reach, right (cm)</td>
<td>21.9±3.8</td>
<td>23.1±2.3</td>
<td>0.38</td>
<td>0.03</td>
<td>0.66</td>
<td>0.009</td>
</tr>
<tr>
<td>TUG (seconds)</td>
<td>5.7±0.6</td>
<td>5.5±0.53</td>
<td>0.87</td>
<td>0.001</td>
<td>0.38</td>
<td>0.17</td>
</tr>
<tr>
<td>Normal gait speed (m/s)</td>
<td>2.2±0.19</td>
<td>2.2±0.24</td>
<td>0.78</td>
<td>0.004</td>
<td>0.86</td>
<td>0.001</td>
</tr>
<tr>
<td>30-second CST (reps)</td>
<td>22.8±5.5</td>
<td>26.4±6.5</td>
<td>-0.001</td>
<td>0.51</td>
<td>0.037</td>
<td>0.18</td>
</tr>
<tr>
<td>Floor rise to stand (seconds)</td>
<td>3.4±1.5</td>
<td>3.2±1.1</td>
<td>0.32</td>
<td>0.04</td>
<td>0.46</td>
<td>0.02</td>
</tr>
<tr>
<td>ML COP range, CSEO (mm)</td>
<td>9.9±3.3</td>
<td>9.2±5.7</td>
<td>0.40</td>
<td>0.02</td>
<td>0.94</td>
<td>0.00</td>
</tr>
<tr>
<td>ML COP range, CSEC (mm)</td>
<td>10.4±4.8</td>
<td>8.7±3.4</td>
<td>0.02</td>
<td>0.12</td>
<td>0.33</td>
<td>0.02</td>
</tr>
<tr>
<td>ML COP range, NSEO (mm)</td>
<td>28.2±2.4</td>
<td>26.3±1.0</td>
<td>0.07</td>
<td>0.08</td>
<td>0.38</td>
<td>0.02</td>
</tr>
<tr>
<td>ML COP range, NSEC (mm)</td>
<td>36.0±1.8</td>
<td>30.5±14.4</td>
<td>0.11</td>
<td>0.06</td>
<td>0.017</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Note: Values presented as means ± standard deviation.

Abbreviations: SLS, single-leg stance; TUG, timed up and go; CST, chair-stand test; ML, mediolateral; COP, center-of-pressure; CSEO, comfortable stance, eyes open; CSEC, comfortable stance, eyes closed; NSEO, narrow stance, eyes open; NSEC, narrow stance, eyes closed.

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### Discussion

This study provides the first controlled evaluation of the effect of BodyBalance training on balance, functional task performance, fear of falling, and health-related quality of life in middle-aged and older adults. The results of this study partly support the hypothesis that measures of balance and function would improve after 12 weeks of BodyBalance training, and that there would be no evident improvement in fear of falling or self-reported quality of life following the BodyBalance intervention.

The baseline values obtained for this cohort indicated that both groups were comprised of well-functioning participants, with good levels of balance, low fear of falling, and high self-reported quality of life. The baseline values in fear of falling or self-reported quality of life following the BodyBalance intervention were evident in the CON group for single-leg stance left and right, whereas there were no significant improvements in the BB group in the 30-second chair stand test, TUG, and mediolateral COP range in comfortable stance. The improvements observed in the BB group in the 20-second chair stand test, TUG, and mediolateral COP range in comfortable stance partly support the hypothesis that measures of balance and function would improve after 12 weeks of BodyBalance training, and that there would be no evident improvement in fear of falling or self-reported quality of life.

In the context of these interventions, the improvements in balance and functional tasks, including balance, fear of falling, and self-reported quality of life in middle-aged and older adults indicate improvements in the physical components of self-reported quality of life, and that there would be no evident improvement in fear of falling or self-reported quality of life. Greater improvements of falling or self-reported quality of life would be expected after 12 weeks of BodyBalance training, and that there would be no evident improvement in fear of falling or self-reported quality of life. Greater improvements of falling or self-reported quality of life would be expected after 12 weeks of BodyBalance training, and that there would be no evident improvement in fear of falling or self-reported quality of life. Greater improvements of falling or self-reported quality of life would be expected after 12 weeks of BodyBalance training, and that there would be no evident improvement in fear of falling or self-reported quality of life.
The improvements in both the TUG and chair-stand test is of note, as both involve the sit-to-stand transfer: a task that represents a complex functional movement that is influenced by lower-limb strength, balance, and sensorimotor and psychological factors. Performance in the TUG and chair-stand tests are predictive of function and falls in older adults, so any improvement in these tasks is of benefit to even healthy and mobile older adults.

The improvement in mediolateral COP range in narrow stance with eyes closed suggests an improvement in the most challenging static balance task assessed in this study. Lower COP ranges in the mediolateral direction are typically seen in younger adults and nonfallers, while higher COP ranges in both narrow stance and normal stance positions are seen in fallers or those with poor clinical balance. The results of this study are in contrast to previous tai chi interventions that have been unable to demonstrate training-induced improvements in COP displacements in bipedal stance. The results from the current study suggest that static standing-balance improvements provided by the intervention may be best observed in more demanding balance tasks.

Table 4 Baseline and follow-up values for fear of falling (Icon-FES) and self-reported quality-of-life (SF-36v2) domains.

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>BodyBalance®</th>
<th>Control</th>
<th>Time effect, P</th>
<th>Group-by-time interaction, P</th>
<th>Observed power for group-by-time interaction</th>
<th>Observed power for group total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Icon-FES</td>
<td>D.9±1.9</td>
<td>53.3±1.7</td>
<td>0.07</td>
<td>0.004</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>Physical function</td>
<td>54.4±4.1</td>
<td>54.4±4.3</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>Role – physical</td>
<td>D.9±1.9</td>
<td>53.3±1.7</td>
<td>0.07</td>
<td>0.004</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>Body pain</td>
<td>54.1±6.8</td>
<td>54.1±6.8</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>General health</td>
<td>54.1±6.8</td>
<td>54.1±6.8</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>Vitality</td>
<td>57.5±6.5</td>
<td>57.5±6.5</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>Social function</td>
<td>55.2±1.6</td>
<td>55.2±1.6</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>Role – emotional</td>
<td>55.1±6.2</td>
<td>55.1±6.2</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>Mental health</td>
<td>53.1±4.9</td>
<td>53.1±4.9</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>PCS</td>
<td>54.4±7.1</td>
<td>54.4±7.1</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
<tr>
<td>MCS</td>
<td>55.2±1.8</td>
<td>55.2±1.8</td>
<td>0.13</td>
<td>0.003</td>
<td>0.82</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Notes: Values presented as means ± standard deviation; SF-36v2 values presented as norm-based t-scores for each domain.

Abbreviations: Icon-FES, Iconographical Falls Efficacy Scale; SF-36, Short Form (36) Health Survey; PCS, physical components summary; MCS, mental components summary.

Figure 3 Values (means ± standard error) for the 30-second chair-stand test (CST) at baseline and follow-up.

Note: *Significant (P=0.037) group-by-time interaction.

Abbreviation: rep, repetition.

Figure 4 Values (means ± standard error) for mediolateral center-of-pressure (COP) range in comfortable stance with eyes closed at baseline and follow-up.

Note: *Significant (P=0.017) group-by-time interaction.
where visual cues are limited. This is supported by previous studies assessing Pilates41 and tai chi42 that have reported greater disparity in postural stability between exercising participants and controls in more demanding tasks compared to simple balance tasks. Recent work in middle-aged women demonstrated that poor performance in a balance task that confounded the use of vision and somatosensation was the only task to predict future falls.43 The inclusion of more demanding balance tasks, such as those that simultaneously challenge proprioception and vision, may have better identified any improvements provided by the intervention.

The lack of significant improvement in reaching and single leg standing tasks in the BB group was likely due to a number of factors, including the already-good balance performance of participants at baseline and the high variability of some testing measures. For example, participants in the current study had single-leg stance times approximately 10 seconds longer than previously reported normative values,44 while lateral reach was approximately 15% longer than previously reported.2 Although there was a group-by-time interaction in favor of the CON group in single-leg stance, left, it is unlikely this small improvement represents a real change, as this test lacks sensitivity in well-functioning older adults,45 although it is an appropriate tool for predicting functional decline.46 The intervention itself, although comprising elements of activities shown to improve balance, may not have been challenging enough to provide consistent improvements in balance outcome measures. As a number of options were available to participants for each exercise or pose, participants may have inadequately challenged their balance by performing less challenging options. The study duration and volume were likely sufficient to provide improvements in balance, given the positive results of training interventions ranging from 12 to 16 weeks in similar-aged cohorts.7,19,33

Balance-exercise guidelines provided by the American College of Sports Medicine recommend using activities that include: progressively difficult postures that gradually reduce the base of support; dynamic movements that perturb the center of gravity; stress to postural control muscles; or reducing sensory input.47 Like a number of other modalities, such as yoga and tai chi, BodyBalance achieves three of the four recommendations by incorporating progressively difficult postures, dynamic movements that perturb the center of gravity, and stressing postural control muscles. BodyBalance may prove to be a more effective modality if greater challenges to sensory input and dual tasking are incorporated into its choreography.

There were no intervention effects on fear of falling or self-reported quality of life. The lack of change for fear of falling was most likely due to the low baseline values for both groups. Low values represent low levels of fear, which may have produced a floor effect similar to that seen with other fear-of-falling questionnaires.48 Previous studies that have reported reduced fear of falling following balance-based interventions49,50 have typically targeted older adults with a history of falls or impaired balance, and as such those participants are more likely to have higher levels of fear that may be reduced with appropriately targeted programs. The lack of improvement in quality-of-life measures is not surprising given the high baseline scores, which would have limited the potential for improvement. The physical component scores of this cohort were approximately 15% higher than Australian norms, while mental component scores were approximately 5% higher than previously reported.32

A number of study limitations require attention. Firstly, the small sample size and low observed power for a number of measures in this study limited our ability to detect between-group differences (if differences were present). The balance-assessment tasks used in this study may not have provided enough challenge to those with good balance ability, thus creating a ceiling effect and limiting the potential for observing any improvement. Other confounding measures, such as cardiovascular parameters, were not assessed, which may have had an impact on results. As a healthy, active cohort with good balance ability was recruited for this study, the generalizability of these results in sedentary persons, recurrent fallers, or those with balance impairments cannot be determined.

Conclusion

Twelve weeks of BodyBalance training was effective at improving performance in the TUG and 30-second chair-stand test and reducing mediolateral COP range in narrow stance with eyes closed in healthy, active adults aged 59–73 years. BodyBalance training was not effective at improving single-leg balance, reaching tasks, gait speed, or floor rise to standing. BodyBalance training did not positively influence fear of falling or self-reported quality of life any more than habitual activity. It appears that BodyBalance training may be an appropriate modality for enhancing certain aspects of balance and functional performance in this age-group. Future studies should assess the effect of such training on those with impaired balance, a fear of falling, or a history of falls.
Acknowledgment
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Disclosure
The authors report no conflicts of interest in this work.

References


Supplementary Tables 6-a and 6-b below are provided as additional tables not included in the preceding published BodyBalance manuscript.

**Supplementary Table 6-a. Early and late intervention values for enjoyment as measured by the modified physical activity enjoyment scale (PACES) for BodyBalance®**

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>BodyBalance (n=14)</th>
<th>Paired samples t-test p</th>
</tr>
</thead>
<tbody>
<tr>
<td>PACES</td>
<td>36.0 ± 9.0</td>
<td>40.4 ± 10.5</td>
</tr>
</tbody>
</table>

Values presented as mean ± SD; higher values indicative of higher enjoyment
### Supplementary Table 6-b. BodyBalance® pre- and post-intervention values for centre of pressure (COP) parameters

<table>
<thead>
<tr>
<th>COP parameter</th>
<th>Stance position</th>
<th>BodyBalance</th>
<th>Control</th>
<th>Group-by-time interaction p</th>
<th>Partial eta* for Group-by-time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td></td>
</tr>
<tr>
<td>AP mean velocity (mm/s)</td>
<td>CSEO</td>
<td>0.85 ± 2.44</td>
<td>0.92 ± 2.80</td>
<td>0.61 ± 3.05</td>
<td>0.26 ± 2.07</td>
</tr>
<tr>
<td></td>
<td>CSEC</td>
<td>0.35 ± 2.42</td>
<td>0.67 ± 2.31</td>
<td>0.86 ± 2.71</td>
<td>0.55 ± 2.28</td>
</tr>
<tr>
<td></td>
<td>NSEO</td>
<td>1.28 ± 2.85</td>
<td>0.95 ± 3.17</td>
<td>0.23 ± 4.50</td>
<td>0.18 ± 2.54</td>
</tr>
<tr>
<td></td>
<td>NSEC</td>
<td>0.57 ± 3.11</td>
<td>0.44 ± 5.15</td>
<td>0.10 ± 3.46</td>
<td>0.15 ± 5.20</td>
</tr>
<tr>
<td>ML mean velocity (mm/s)</td>
<td>CSEO</td>
<td>0.16 ± 1.24</td>
<td>0.14 ± 1.42</td>
<td>0.29 ± 1.34</td>
<td>0.07 ± 1.40</td>
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<tr>
<td></td>
<td>CSEC</td>
<td>0.21 ± 1.14</td>
<td>0.11 ± 1.08</td>
<td>0.04 ± 1.39</td>
<td>0.17 ± 1.16</td>
</tr>
<tr>
<td></td>
<td>NSEO</td>
<td>0.25 ± 2.40</td>
<td>0.29 ± 2.16</td>
<td>0.42 ± 3.35</td>
<td>1.14 ± 2.65</td>
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<tr>
<td></td>
<td>NSEC</td>
<td>0.38 ± 3.16</td>
<td>0.91 ± 3.25</td>
<td>0.31 ± 2.98</td>
<td>0.35 ± 3.18</td>
</tr>
<tr>
<td>AP range (mm)</td>
<td>CSEO</td>
<td>19.67 ± 5.36</td>
<td>20.00 ± 6.92</td>
<td>19.70 ± 6.08</td>
<td>19.16 ± 9.41</td>
</tr>
<tr>
<td></td>
<td>CSEC</td>
<td>20.95 ± 7.47</td>
<td>21.11 ± 6.98</td>
<td>23.54 ± 7.83</td>
<td>19.49 ± 6.07</td>
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<tr>
<td></td>
<td>NSEO</td>
<td>26.23 ± 6.96</td>
<td>23.61 ± 7.08</td>
<td>25.79 ± 7.64</td>
<td>24.82 ± 7.91</td>
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<tr>
<td></td>
<td>NSEC</td>
<td>30.45 ± 12.09</td>
<td>30.31 ± 8.69</td>
<td>30.27 ± 11.37</td>
<td>31.22 ± 14.84</td>
</tr>
<tr>
<td>ML range (mm)</td>
<td>CSEO</td>
<td>9.85 ± 3.28</td>
<td>9.23 ± 5.71</td>
<td>11.01 ± 4.94</td>
<td>9.73 ± 2.68</td>
</tr>
<tr>
<td></td>
<td>CSEC</td>
<td>10.42 ± 4.82</td>
<td>8.70 ± 3.44</td>
<td>9.79 ± 5.03</td>
<td>8.77 ± 2.29</td>
</tr>
<tr>
<td></td>
<td>NSEO</td>
<td>28.24 ± 12.41</td>
<td>26.36 ± 10.67</td>
<td>29.31 ± 6.09</td>
<td>26.24 ± 6.92</td>
</tr>
<tr>
<td></td>
<td>NSEC</td>
<td>36.02 ± 19.81</td>
<td>30.48 ± 14.39</td>
<td>29.73 ± 9.54</td>
<td>31.27 ± 9.18</td>
</tr>
</tbody>
</table>

Values reported as mean ± SD; AP = anterior-posterior; ML = medio-lateral; CSEO = comfortable stance eyes open; CSEC = comfortable stance eyes closed; NSEO = narrow stance eyes open; NSEC = narrow stance eyes closed; *significant (p<0.05) group-by-time interaction; reductions in mean velocity and range are indicative of improvement in balance control.
CHAPTER 7: DISCUSSION

The aim of the studies described in this thesis was to examine the effect of three different exercise interventions in independent, active adults aged 55 years and over. The effect of these interventions on balance, mobility and functional task performance were of particular interest. Although the results of each study have been discussed in isolation within each respective manuscript, this chapter will tie together the results for the common outcome measures assessed and summarise key discussion points associated with each intervention. The possible mechanisms underlying the exercise effects will also be discussed. Methodological considerations will be addressed and responses to the research questions and hypotheses proposed within the thesis will be reviewed. Finally, implications for clinical practice and recommendations for future research will be considered.

7.1 Main results

Balance, gait and functional task performance were the key outcome measures common to each of the studies undertaken in this thesis. The overall results indicated that all training interventions were effective at improving some aspects of balance, gait and/or functional task performance. The effect of each training intervention on the tasks common to all studies will be discussed and the potential clinical significance of these changes will be examined.

7.1.1 The timed-up-and-go (TUG)

A significant group-by-time interaction occurred for the intervention groups in both balance based interventions (Nintendo Wii and BodyBalance®) indicating an improvement between baseline and follow-up compared to controls. A number of previous studies have reported improvements in the TUG following balance interventions in older adults with impaired balance or a history of falls (Gatts & Woollacott, 2006; Jorgensen et al., 2013; Nitz & Low Choy, 2004; Nnodim et al., 2006). In contrast to the results found herein for Nintendo Wii and BodyBalance® training, a number of studies that have assessed the impact of balance training in apparently healthy middle-aged and older adults (Bieryla & Dold, 2013; Chyu et
al., 2010; Zettergren et al., 2011) found no evident improvements in the TUG. Previous studies in healthy older adults have been limited by very small group numbers which limited their ability to detect group differences should they exist. The improvements in the TUG following Wii and BodyBalance® training align with the conclusions of a Cochrane review that reported that interventions utilising gait, balance co-ordination and functional task exercises and three dimensional activities such as Tai Chi and dance were effective at improving the TUG in adults over 60 years (Howe et al., 2011).

There were no improvements for the TUG following BodyPump™ which is consistent with some previous studies reporting a lack of change in the TUG in healthy older adults following resistance training (De Vreede et al., 2005). Others have reported improvements in excess of 10% following high-load resistance training in elderly men (Fatouros et al., 2005; Sousa & Sampaio, 2005). Baseline TUG times were typically quicker than those reported in previous studies which may have limited the opportunity for further improvement but the lack of improvement in the TUG may be more due to a combination of the modest strength gains and the limited challenge to balance provided by the intervention. This is supported by the fact that TUG improved following BodyBalance® which recruited a very similar cohort but provided a greater balance challenge to participants.

### 7.1.2 Repeated chair stand

There was no improvement in the repeated chair stand following Nintendo Wii based training which is in contrast to a supervised 10 week Wii based study that reported a significant improvement in the number of repetitions completed in 30 seconds (Jorgensen et al., 2013). The differences in the results of the two Wii based studies are most likely due to the differing balance abilities of the two cohorts. Both studies recruited similarly aged older adults but participants recruited for the Jorgensen et al (2013) study had self-reported poor to average balance and contained a higher proportion of fallers (30%) than the Wii study (10%) presented herein. The baseline repeated chair stand values for Jorgensen (2013) were approximately 30% less than those reported for the Wii study which will have provided greater scope for improvement.
There were no group based differences in the repeated chair stand test following 26 weeks of BodyPump™ training. Many previous studies have used the five repetition chair stand instead of the 30 second chair stand but both tests assess the repeated performance of a specific transfer task and are influenced by sensorimotor, balance, and psychological processes (Lord et al., 2002). There are conflicting results within the literature with some reporting no change following resistance training (Earles, Judge, & Gunnarsson, 2001; Judge et al., 1994; Schlicht et al., 2001) while others have reported significant improvements in community dwelling older adults following resistance training (Galvao & Taaffe, 2005; Henwood, Riek, & Taaffe, 2008; Taaffe, Duret, Wheeler, & Marcus, 1999). As with the TUG, the limited effects on the repeated chair stand are likely due to modest leg strength gains and the limited challenge to balance provided by the intervention. Judging by the trend for improvement by the control groups in each study, there also appears to be a learning effect associated with this task.

The number of repetitions completed for the repeated chair stand increased following 12 weeks of BodyBalance® training. The impact of yoga and tai chi on sit to stand performance have been mixed with some reporting improvements following Yoga (Tiedemann et al., 2013) and Tai Chi (Manson et al., 2013) while others have been unable to detect changes after 24 weeks of Tai Chi (Chyu et al., 2010) and four weeks of Yoga (K.-M. Chen & Tseng, 2008), respectively. The repeated chair stand test is influenced by muscle strength, balance, sensorimotor and psychological factors (Lord, Murray, Chapman, Munro, & Tiedemann, 2002). Although improvements in maximal strength cannot be discounted, it is most likely that the improvements identified following BodyBalance® training were due to enhanced balance and sensorimotor function.

7.1.3 Gait speed

Normal gait speed increased after Nintendo Wii based training. The small improvement of 0.04 m/s found after Wii based training represents a small meaningful change (Perera et al., 2006) but is unlikely to represent a clinically significant improvement in an already independent and mobile cohort. The improvement is much less than the 0.29 m/s found after 12 weeks of Wii based training in older adults with impaired balance (Agmon et al., 2011) although the baseline gait speed of that cohort was some 0.3 m/s less than the cohort examined herein.
Normal gait speed increased by 0.31 m/s following BodyPump™ training which represents a substantial meaningful change (Perera et al., 2006) and is almost identical to changes reported following 20 weeks of high-load resistance training utilising three sets per exercise in men and women aged 65-78 years (Galvao & Taaffe, 2005). More substantial improvements in gait speed have been reported following moderate- and high-load resistance training in middle-aged and older adults (Kalapotharakos et al., 2005) while others have found no change in normal gait speed after approximately twenty-six weeks of resistance training (Buchner et al., 1997; Henwood et al., 2008). There were no improvements in maximal gait speed following the BodyPump™ intervention which is in agreement with results from a previous low-load high-repetition resistance training program in adults aged 60 years plus (Van Roie et al., 2013).

There was no change in gait speed after BodyBalance® training which adds to the mixed results associated with yoga, tai chi and Pilates based interventions. Some have found improvements after Yoga (Tiedemann et al., 2013) and Pilates (Newell et al., 2012) while others have been unable to show improvements following Yoga (Zettergren et al., 2011) and Tai Chi (Zhang et al., 2006) in healthy older adults.

**7.1.4 Single leg balance**

Single leg stance times on the left leg increased following six weeks of Nintendo Wii based training but there were no improvements following 12 weeks of BodyBalance®. Mixed results have been reported following balance training in older adults with some reporting no change in single leg stance times (Shigematsu et al., 2002; Suzuki, Kim, Yoshida, & Ishizaki, 2004) while others have reported improvements following various balance interventions (Johansson & Jarnlo, 1991; Oken et al., 2006; Wolfson et al., 1996; Zhang et al., 2006). In their six month dance-based aerobic intervention Shigematsu (2002) was unable to detect any change in single leg stance times in community dwelling adults aged over 70 years. In contrast, Johansson and Jarnlo (1991) found single leg stance times improved by up to 40% in 70 year old women after just five weeks of balance training that incorporated dancing and weight transfer tasks. Weight transfer tasks were present in the majority of games played during the Nintendo Wii intervention which are likely to have contributed to the improvements observed for single leg stance on the left. It was expected that single leg stance would also improve following BodyBalance® training due to the large focus on weight transfers in standing and the adoption on single leg standing postures in some of the yoga
based poses. Certainly other yoga based interventions have reported improvements in a number of balance measures including single leg stance (Brown, Koziol, & Lotz, 2008; K.-M. Chen & Tseng, 2008; Oken et al., 2006). Oken (2006) reported an almost 10 second improvement (32%) in single leg stance time following six months of training in one the few randomised controlled trials conducted on yoga in older adults.

Improvements in single leg stance right were found after 26 weeks of BodyPump™ training. There were no evident improvements for single leg stance left however. A number of studies have reported that moderate- and high-load resistance training interventions of at least 12 weeks duration were unable to improve single leg stance times in older adults any more than control conditions (Buchner et al., 1997; Earles et al., 2001; Topp et al., 1993; Wolfson et al., 1996). Some have reported substantial improvements in single leg stance after 10 months of self-paced resistance training (Rooks et al., 1997) but generally there appears to be a paucity of literature assessing single leg stance in low-load resistance training interventions. To the best of my knowledge, this is the first study to assess changes in single leg stance following a low-load high-repetition resistance training program.

It has been suggested by some that changes in single leg stance time should exceed 24 seconds to be considered a real change (Goldberg et al., 2011). If such an improvement is required to signify a real change or a clinically meaningful change, the test may not be sensitive to change in those with either good or poor balance ability. Therefore, as with any outcome measure, any improvements observed need to be considered in the context of the cohort being assessed. For example, the seven second improvement observed for single leg stance right following BodyPump™ is unlikely to represent a meaningful change for such a high functioning group who already had a baseline mean stance time of 30 seconds and could be regarded as having a low falls risk based on this test (Hurvitz et al., 2000). Certainly a similar improvement in adults with impaired balance may indicate a more meaningful change. For example, those with single leg stance times of less than 10 seconds have a 2.6 times higher risk for future hip fracture than similar aged peers who can balance for over 10 seconds. While an improvement of one second in single leg stance time resulted in a 5% lower age-adjusted risk of a hip fracture (Lundin et al., 2014). Certainly single leg stance ability is a very useful assessment tool in middle-aged and older adults as poor stance time are predictive of functional decline (M. R. Lin et al., 2004) and falls in older adults (Vellas, Wayne, et al., 1997).
7.1.5 COP parameters

The large majority of centre of pressure (COP) parameters did not change following any intervention assessed herein. The only COP parameter to improve in favour of an intervention was medio-lateral COP range in narrow stance eyes closed following BodyBalance® training. The lack of improvement following Nintendo Wii training is supported by the limited number of studies that have assessed posturography during Wii based interventions (Jorgensen et al., 2013; Pluchino et al., 2012). There was no change in COP velocity following 10 weeks of supervised Wii training in older adults with self-reported impaired balance (Jorgensen et al., 2013) and no group effect on any COP measure following eight weeks of Wii training in older adults with a mean age of 72.5 years (Pluchino et al., 2012).

The lack of improvement in COP parameters following BodyPump™ training align with the few resistance training studies that have assessed static bipedal stance (Bellew et al., 2003; Holviala et al., 2006; Judge, Lindsey, Underwood, & Winsemius, 1993). Bellew (2006) found no improvement in sway range in the antero-posterior or medio-lateral direction after 12 weeks of low volume resistance training. Interestingly, sway range in the medio-lateral direction actually increased for men. Holviala (2006) reported no improvements in COP displacement or velocity in middle-aged or older adults following 21 weeks of moderate-heavy resistance training while there was no effect on bilateral stance sway measures following six moths of resistance training at 70% 1RM in women aged 62-75 years (Judge et al., 1993).

The majority of interventions that are comparable to BodyBalance® – such as those that have incorporated tai chi or Pilates have been unable to identify improvements in sway or COP parameters in bilateral stance positions on a firm surface (M.-L. Bird et al., 2012; Y.-S. Chen et al., 2011; Kaesler et al., 2007; Lelard et al., 2010; Newell et al., 2012). For example, there was no change in COP displacement after 12 weeks of tai chi in healthy adults aged 65-85 years (Y.-S. Chen et al., 2011) and no change in COP displacements or velocity after 12 weeks of tai chi in adults aged 70 to 85 years (Lelard et al., 2010). Improvements in COP parameters have typically occurred on compliant surfaces following similar interventions (M.-L. Bird & Fell, 2014; Kaesler et al., 2007).

It is likely that very few changes occurred in COP parameters because the balance tasks used to assess COP were too easy for some participants resulting in relative floor effects. In both
balance and resistance training interventions where improvements in COP or body sway have been observed, they have occurred in more complex balance tasks on compliant surfaces (M.-L. Bird & Fell, 2014; M.-L. Bird, Hill, Ball, & Williams, 2009; Kaesler et al., 2007; Liu-Ambrose et al., 2004) or in single leg stance positions (Marques et al., 2011). Thus, more difficult assessment tasks that provide a greater challenge to proprioception should be included when changes in COP parameters are of interest. Furthermore, although COP velocity and range are regarded as reliable COP assessment parameters in older adults (Lafond et al., 2004; Swanenburg et al., 2008), the ideal duration and number of tests required to achieve high reliability and reduce measurement error is open to interpretation. Although the sampling duration and repetitions assessed in the studies presented herein are very similar to previous intervention studies (Holviala et al., 2006; Hue et al., 2004; Lelard et al., 2010), it has been suggested by some that sampling durations of up to six minutes (Carpenter et al., 2001; van der Kooij, Campbell, & Carpenter, 2011) and up to five repetitions should be used to increase the reliability of measures (Corriveau, Hebert, Prince, & Raiche, 2001; Ruhe, Fejer, & Walker, 2010). Due to the number of balance tests conducted (both laboratory and clinical) during each testing session it was decided that two repetitions of 30 seconds for each task would be appropriate to allow for the capture of COP variables without causing undue fatigue to participants. Nonetheless, it is possible that the lower frequency components of the COP signal were missed by using the relatively short sampling duration of 30 seconds and by only including two repetitions of each task a degree of measurement error related to biological variability is likely to have occurred. Thus, any potential improvements that may have occurred in static balance as a result of balance or resistance training not have been identified.

7.2 Enjoyment

Enjoyment was assessed in participants in each intervention group through a modified version of the physical activity enjoyment scale (PACES) (Mullen et al., 2011). Enjoyment increased significantly from week one to six for the Nintendo Wii cohort, while it remained unchanged for BodyPump™ and BodyBalance® groups. As discussed in chapter four, it is likely that levels of enjoyment grew as participants began to master the games and challenge their own abilities during the Nintendo Wii study. The development of social interactions and relationships within the small playing groups may have also made the gaming process more enjoyable. The maintenance of measured enjoyment for the BodyPump™ and
BodyBalance® participants may be related to the dynamic nature of the classes. Exercise
difficulty and challenge was increased throughout the programs (particularly for
BodyBalance) which may have provided continual challenges to participants. The social
interaction aspect of the class is likely to have assisted in providing ongoing enjoyment.

## 7.3 Fear of falling

None of the interventions investigated had a significant impact on fear of falling. This is not
surprising given the already low baseline values observed in all studies and the generally
good balance ability and gait speed demonstrated by the participants in the studies.
Reductions in fear of falling or responsiveness to change following exercise interventions are
more likely to occur in those with higher levels of fear and in more frail populations
(Delbaere et al., 2010; Wolf et al., 1996; Zhang et al., 2006). One of the main advantages of
the iconographical falls efficacy scale (IconFES) is its purported ability to assess fear of
falling in high functioning older people and its potential sensitivity to change (Delbaere et al.,
2011). It appears that in such an active, independent cohort the IconFES may suffer from
floor effects similar to other fear of falling questionnaires.

## 7.4 Potential mechanisms

There are a number of potential mechanisms that are responsible for balance improvements
following appropriate exercise interventions. Although aging is associated with a decline in
muscle strength and a number of sensory systems that are integral to the maintenance of
balance, these characteristics are highly adaptive and if appropriately challenged can be
improved. For balance to improve participants must perform tasks that challenge the
neuromuscular system to become more efficient (Rose, 2005). Balance exercise guidelines
provided by the American College of Sports Medicine (ACSM) recommend using activities
that include: progressively difficult postures that gradually reduce the base of support;
dynamic movements that perturb the centre of gravity; stressing postural control muscles; or
reducing sensory input (Chodzko-Zajko et al., 2009). In addition to these recommendations,
Australian guidelines suggest providing further challenge by incorporating dual task activities
(Tiedemann, Sherrington, Close, & Lord, 2011).

Using the above guidelines it is apparent that the two balance interventions assessed in this
thesis (Nintendo Wii and BodyBalance®) used a selection of activities recommended but did
not include all aspects suggested in the guidelines. The Nintendo Wii intervention included dynamic movements that perturbed the centre of gravity by leaning and quickly shifting the centre of gravity left and right in response to on screen commands. Dual task activities were also present in the Wii intervention by requiring participants to shift their centre of gravity while using the hand controller for all games and by shifting the centre of gravity quickly while doing sums during *Perfect ten*. In contrast, the BodyBalance® intervention primarily used progressively difficult postures that gradually reduced the base of support such as single leg stance positions. Both interventions stressed postural muscles of the lower limb but neither intervention reduced sensory input by either reducing vision or using a soft surface to challenge proprioception. Both balance based interventions resulted in improvements in a selection of balance and mobility based tasks. Overall these improvements in a select number of outcome measures align with much of the literature that has examined balance training interventions in healthy older adults.

The improvements observed for a small selection of balance tasks following BodyPump™ are also in accordance with much of the literature. A systematic review assessing the effectiveness of resistance training on balance performance in older adults reported that there was no significant improvement in the majority of balance assessment tasks (Orr et al., 2008). In the 29 studies reviewed, a total of 68 balance tests were analysed and just 22% of tests improved significantly after resistance training. Improvements were more commonly seen in functional balance tests and similar improvements were observed following either low- or high-load resistance training.

From a physiological stand point these improvements are likely due to improvements in neuromuscular control. Balance training has been shown to reduce the onset latency of postural muscles in older adults (Granacher, Gollhofer, & Strass, 2006; Hu & Woollacott, 1994b) and increase the rate of force development in young adults (Gruber & Gollhofer, 2004). It has also been suggested that an enhanced sensitivity of muscle spindles via the gamma motor system may be partly responsible for improved postural control following balance training (Granacher et al., 2006). These physiological variables were not assessed in the studies presented herein but if older adults are presented with activities that challenge balance correcting strategies or altered sensory conditions then they can adopt and maintain appropriate postural control strategies (Hu & Woollacott, 1994a) leading to improved performance. Additionally, improvements in executive function have been associated with
improvements in balance (K. Z. H. Li et al., 2010) and gait speed (Liu-Ambrose et al., 2010) in older adults. These results suggest that motor control can be improved by enhancing cognitive processes. As such, the improvements observed in the Nintendo Wii study may have been partly due to the dual tasking processes that occurred during game play. Improved balance and gait speed following BodyPump™ may be due to a number of factors that can be influenced by resistance training. More effective synchronization of motor units (M. G. Bemben & Murphy, 2001; Häkkinen et al., 1998), decreased variability of force production (Hortobágyi et al., 2001) and improved coordination between agonist and antagonist muscles (Häkkinen, Kraemer, Newton, & Alen, 2001; Van Cutsem, Duchateau, & Hainaut, 1998) are all associated with resistance training.

7.5 Limitations

There were a number of limitations associated with each study in addition to the limitations already detailed in each manuscript. While there were specific limitations associated with each study such as the lack of randomisation in the Nintendo Wii study, other limitations were common to all three studies presented in the thesis.

7.5.1 External validity

The results of each study can only be generalised to active, independent adults. It is unlikely that the effect on balance performance, compliance and adverse events would be replicated if the same series of studies was conducted on older adults with balance impairments, a history of multiple falls or those with high levels of fear of falling. The similar inclusion and exclusion criteria established for each study ensured that non-sedentary, independent community dwelling middle-aged and older adults were recruited. This is equally true for the results found for muscle strength and bone mineral density in the BodyPump™ study. Different responses to training may occur in more sedentary individuals or those with low bone density.

7.5.2 Blinding

The assessor was not blinded to group allocation at follow-up assessments for balance, gait and functional performance tasks. This could potentially lead to bias if a particular outcome
was desired. No particular outcome was desired by assessors for any intervention and there were no conflicts of interest. To minimise this potential bias, the baseline results of each participant were not analysed until the completion of follow-up assessments. As such, the assessor did not have an accurate indication of each participant’s baseline ability. Despite this, the lack of blinding is a limitation of all the studies.

7.5.3 Testing

The internal validity of the studies may have been reduced by some of the testing procedures utilised. Although a battery of tests was used that were valid and reliable and in many cases sensitive to change, the same assessor completed baseline and follow-up testing. Although a limitation of the studies, the ability to accurately assess each task was enhanced by ensuring all assessment tasks were conducted methodically and followed established protocols wherever possible. Additionally, the majority of balance tasks utilised for centre of pressure assessment were too easy for such a healthy, active cohort of middle-aged and older adults. More challenging tasks involving compliant surfaces, functional tasks and dual tasking are likely to have provided a better indication of balance changes in such a cohort.

7.5.4 Follow-up

The lack of follow-up assessment after the completion of the studies is a further common limitation. Although there were improvements in certain balance, mobility and functional task parameters in each study, it is not known how temporary these changes were. Follow-up assessment six to 12 weeks after the completion of each study would have provided an indication of whether each intervention provided lasting effects. A lack of follow-up for falls data can also be regarded as a limitation of the studies. It should be noted that it was not the intention of these studies to determine their effectiveness as falls prevention strategies but rather to determine their effect on balance, mobility and functional task performance.
7.6 Responses to research questions

1. Does unsupervised Nintendo Wii game play improve balance and gait speed in community dwelling older adults?

    *Unsupervised Nintendo Wii game play does improve certain aspects of balance and gait speed in community dwelling older adults.*

2. Does BodyPump™ improve balance, strength, bone mineral density and body composition in middle-aged and older adults?

    *BodyPump™ improves selected aspects of balance in middle-aged and older adults. BodyPump™ improves strength and maintains lumbar spine bone mineral density but does not improve hip or total body bone mineral density nor does it improve body composition as measured by fat mass or fat-free soft tissue mass in middle-aged and older adults.*

3. Does BodyBalance® improve balance in middle-aged and older adults?

    *BodyBalance® improves selected aspects of balance in middle-aged and older adults?*
7.1 Responses to research hypotheses

1. Six weeks of unsupervised Nintendo Wii Fit game play will improve clinical measures of balance in community dwelling older adults compared to control participants.

   *Six weeks of unsupervised Nintendo Wii Fit game play improved some clinical measures of balance in community dwelling older adults compared to control participants.*

2. Twenty-six weeks of BodyPump™ will improve clinical measures of balance but will not influence laboratory measures of balance in community dwelling middle-aged and older adults.

   *Twenty-six weeks of BodyPump™ improved select clinical measures of balance but did not influence laboratory measures of balance in community dwelling middle-aged and older adults.*

3. Twenty-six weeks of BodyPump™ will increase lower and upper body maximal strength in community dwelling middle-aged and older adults.

   *Twenty-six weeks of BodyPump™ did increase lower and upper body maximal strength in community dwelling middle-aged and older adults.*

4. Twenty-six weeks of BodyPump™ will maintain the bone mineral density of the lumbar spine and hip in community dwelling middle-aged and older women.

   *Twenty-six weeks of BodyPump™ did maintain the bone mineral density of the lumbar spine but did not positively influence bone mineral density at the hip in community dwelling middle-aged and older women.*
5. Twenty-six weeks of BodyPump™ will increase fat-free soft tissue mass but will not have any impact on fat mass in community dwelling middle-aged and older women.

\textit{Twenty-six weeks of BodyPump™ did not have a positive effect on fat-free soft tissue mass or fat mass in community dwelling middle-aged and older women.}

6. Twelve weeks of BodyBalance® will improve clinical and laboratory measures of balance in community dwelling middle-aged and older adults.

\textit{Twelve weeks of BodyBalance® did improve some clinical and laboratory measures of balance in community dwelling middle-aged and older adults.}
7.8 Conclusions and Practical applications

1. Unsupervised Nintendo Wii based gaming is effective at improving balance performance, gait speed and some functional task performance in independent older adults.

2. Unsupervised Nintendo Wii based gaming appears to be safe in independent older adults provided they are given adequate instruction and guidelines prior to the adoption of such activity.

3. Nintendo Wii game play was enjoyed by the majority of participants but this is at least partly attributable to the group based interactions associated with the gaming.

4. Low-load high-repetition resistance training is effective at improving certain aspects of balance, mobility and functional performance in active adults aged between 55 and 75 years. As the number of adverse events reported throughout the BodyPump program was higher than many other resistance training programs of similar durations, such training is unlikely to be suitable for a number of middle-aged and older adults.

5. Low-load high-repetition resistance training promotes only modest improvements in maximal muscle strength.

6. Low-load high-repetition resistance training is effective at maintaining lumbar spine bone mineral density in women aged over 55 years. The osteogenic effect of such training is likely to be greater if training is performed for longer and if loads are progressively increased.

7. Low-load high-repetition resistance training may be an attractive alternative to high-load resistance training to those that are apprehensive about lifting heavy loads or those that prefer a group environment.

8. It appears that training at repetition ranges of 80 to 100 is achievable when training loads are equivalent to 10-15% of squat/predicted squat 1RM and approximately 30% for chest press. The results of this study provide a guideline for future low-load high-repetition resistance training interventions in adults aged over 55 years.
9. A number of participants that undertook BodyPump™ required exercise modification to minimise shoulder, neck and knee pain. Modifications were most often required for shoulder press, upright rows and lunges. The ability of instructors and clinicians to provide appropriate exercise modifications is a key factor in allowing middle-aged and older adults to safely maintain high repetition resistance training.

10. Comprising tai chi, yoga and Pilates components, BodyBalance® is effective at improving certain aspects of balance and functional task performance. As such it may be a suitable option for balance enhancement in older adults. It is worth noting that the first three weeks of the program was modified to provide easier transitions between poses. As such, the rate of adverse events may have been higher if participants were exposed to full classes from the beginning of the program.

11. A number of established balance assessment tasks are prone to ceiling effects in active middle-aged and older adults. As such, balance tasks that include visual and proprioceptive challenges should be included in any balance test battery in active middle-aged and older adults to provide appropriate challenge.

12. The Iconographical falls efficacy scale appears to suffer from floor effects in active, independent middle-aged and older adults so may not be suitable in that group.

### 7.9 Recommendations for future research

1. Unsupervised Nintendo Wii balance training should be compared to other established forms of balance training in independent older adults to determine whether balance training on the Nintendo Wii provides equivalent improvements in balance.

2. BodyPump™ training or other forms of low-load high-repetition resistance training should be compared to traditional high-load resistance training in terms of their effect on balance, muscle strength and bone mineral density. Objective progression models should be used to increase training loads.
3. The effect of BodyPump™ or low-load high-repetition resistance training should be assessed in those with low bone mass and should be assessed for a longer duration (12 to 18 months).

4. BodyBalance® training should be compared to tai chi, yoga or Pilates to determine whether it produces superior improvements in balance, mobility and functional task performance.

5. The effectiveness of BodyBalance® should be assessed in middle-aged and older adults with impaired balance.

6. Future research assessing the effectiveness of any of these training modalities should re-assess key outcome measures several weeks or months after the completion of training to determine the longevity of any intervention improvements.
CHAPTER 8: REFERENCES


Toullette, C., Toursel, C., & Olivier, N. (2012). Wii Fit® training vs. Adapted Physical Activities: which one is the most appropriate to improve the balance of independent senior subjects? A randomized controlled study. *Clinical Rehabilitation, 26*(9), 827-835.


Appendix 1: Manuscript One Authors' Endorsements

Manuscript One

Six Weeks of Unsupervised Nintendo Wii Fit Gaming is Effective at Improving Balance in Independent Older Adults

Vaughan Patrick Nicholson\textsuperscript{1}, Mark McKe\textsuperscript{1}, John Lowe\textsuperscript{1}, Christine Fawcett\textsuperscript{2}, and Brendan Burkett\textsuperscript{1}

\textsuperscript{1}School of Health and Sport Sciences, University of the Sunshine Coast Australia, Sippy Downs, QLD, Australia. \textsuperscript{2}Sunshine Coast Hospital and Health Service, Sippy Downs, QLD, Australia. Journal of Aging and Physical Activity \textit{in Press} doi: 10.1123/japa.2013-0148

I, Vaughan Patrick Nicholson, contributed to the research design, participant recruitment, data collection, data analysis and manuscript preparation for the paper entitled \textit{Six Weeks of Unsupervised Nintendo Wii Fit Gaming is Effective at Improving Balance in Independent Older Adults}.

I, as a co-author, endorse that this level of contribution by the candidate indicated above is appropriate.

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Manuscript One

Six Weeks of Unsupervised Nintendo Wii Fit Gaming is Effective at Improving Balance in Independent Older Adults

Vaughan Patrick Nicholson¹, Mark McKeán¹, John Lowe¹, Christine Fawcett², and Brendan Burkett¹

¹School of Health and Sport Sciences, University of the Sunshine Coast Australia, Sippy Downs, QLD, Australia. ²Sunshine Coast Hospital and Health Service, Sippy Downs, QLD, Australia.


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Appendix 2: Manuscript Two Authors' Endorsements

**Manuscript Two**

*Low-load high-repetition resistance training improves strength and gait speed in middle-aged and older adults*

Vaughan P. Nicholson\(^1\), Mark R. McKean\(^1\), Brendan J. Burkett\(^1\)

\(^1\)School of Health and Sport Sciences, University of the Sunshine Coast Australia, Sippy Downs, QLD, Australia.


I, Vaughan Patrick Nicholson, contributed to the research design, participant recruitment, data collection, data analysis and manuscript preparation for the paper entitled *Low-load high-repetition resistance training improves strength and gait speed in middle-aged and older adults.*

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Appendix 3: Manuscript Three Authors’ Endorsements

**Manuscript Three**

Low-load high-repetition resistance training maintains lumbar spine bone mineral density in post-menopausal women

Vaughan P. Nicholson¹, Mark R. McKean¹, Gary J. Slater¹, Ava Kerr¹, Brendan J. Burkett¹,

¹School of Health and Sport Sciences, University of the Sunshine Coast Australia, Sippy Downs, QLD, Australia.

Submitted to *Calcified Tissue International*

I, Vaughan Patrick Nicholson, contributed to the research design, participant recruitment, data analysis and manuscript preparation for the paper entitled *Low-load high-repetition resistance training maintains lumbar spine bone mineral density in post-menopausal women*.

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Low-load high-repetition resistance training maintains lumbar spine bone mineral density in post-menopausal women

Vaughan P. Nicholson¹, Mark R. McKeaⁿ, Gary J. Slater¹, Ava Kerr¹, Brendan J. Burkett¹,

¹School of Health and Sport Sciences, University of the Sunshine Coast Australia, Sippy Downs, QLD, Australia.

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Appendix 4: Manuscript Four Authors' Endorsements

Manuscript Four

Twelve weeks of BodyBalance™ training improved balance and functional task performance in middle-aged and older adults

Vaughan P. Nicholson¹, Mark R. McKeen¹, Brendan J. Burkett¹

¹School of Health and Sport Sciences, University of the Sunshine Coast Australia, Sippy Downs, QLD, Australia.

Clinical Interventions in Aging

I, Vaughan Patrick Nicholson, contributed to the research design, participant recruitment, data collection, data analysis and manuscript preparation for the paper entitled Twelve weeks of BodyBalance™ training improved balance and functional task performance in middle-aged and older adults.

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