THE USE OF NOVEL TECHNOLOGY TO DELIVER FALLS PREVENTION EXERCISE TO OLDER ADULTS

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Publications:

Howes, S.C., Charles, D.K., Marley, J., Pedlow, K. and McDonough, S.M. (2017). Gaming for Health: Systematic review and meta-analysis of the physical and cognitive effects of active computer gaming in older adults. *Physical Therapy*, p.pzx088.

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ABSTRACT

Background: Active computer gaming (ACG) may be a potentially safe and enjoyable way for older people to participate in exercise. Development of a bespoke system by an interdisciplinary team, and involving older adults throughout its development, may optimise usability and acceptability.

Aims: To develop an ACG system to deliver strength and balance exercises to older people, and to evaluate older adults' use and perceptions of its safety, usability and acceptability.

Methods: Development of the ACG system was an iterative process by an interdisciplinary team of clinicians and game developers. User-centred design provided invaluable insight into older adults' requirements and preferences; this supplemented guidance from the literature (including a systematic review of trials using ACG) to optimise usability and acceptability of the ACG system.

Results: Prototype 1 was developed for Kinect, and suitable for two viewing mediums, a 21" monitor and the Oculus Rift head-mounted display (HMD). Following a single use of each viewing condition, prototype 1 was perceived positively by older adults (n=9). Participants had a strong preference for a screen display compared to using a HMD. Additional instruction and support was frequently required by participants when completing a single use of each study condition. Findings from this phase of user testing, including observations and feedback provided by participants, were used to modify the ACG system.

Evaluation of repeated use with prototype 2, used with a 32" monitor, suggested high levels of usability and acceptability in older adults (n=7). The level of additional instruction required tended to reduce with repeated exposure to the ACG system. The level of participation was also influenced by physical health and competing priorities.

Conclusions: Overall findings of this thesis highlighted older people were willing to try novel technologies, both for health benefits and enjoyment. ACG features, including feedback, improved older adults' motivation to use the system; and, non-gaming features related to additional support were facilitators of use of the system. This thesis reflects on knowledge gained through collaborative working within a team of clinicians and developers, in terms of communication and organisation to ensure mutual understanding, management of tasks and resolution of usability issues.

LIST OF ABBREVIATIONS AND ACRONYMS

ACG	Active computer gaming
AE	Adverse event
AFRIS	Attitudes to Balance and Falls-Related Interventions Scale
AM	Ana Matkovic
BBS	Berg Balance Scale
BCT	Behaviour change technique
BCTTv1	Behaviour Change Techniques Taxonomy version 1
CA	California
CB	Calvin Brannigan
CI	Confidence interval
DC	Darryl Charles
DH	Dominic Holmes
F	Female
FaME	Falls Management Exercise Programme
FES-I	Falls Efficacy Scale-International
GC	Geoffrey Chaponneau
GDS-15	15-item Geriatric Depression Scale
GRADE	Grading of Recommendations Assessment, Development and Evaluation
IQR	Interquartile range
IW	Iseult Wilson
JM	Joanne Marley
KP	Katy Pedlow
M	Male

MMSE	Mini-mental State Examination
N	Number
NICE	National institute for Health and Care Excellence
NM	Nathan McKenna
OEP	Otage Exercise Programme
ORECNI	Office for Research Ethics Committees Northern Ireland
PD	Peter Diehl
PPI	Patient, carer and public involvement
RCT	Randomised controlled trial
RGB	Red green blue
rPAR-Q	Revised Physical Activity Readiness Questionnaire
SD	Standard deviation
SH	Sarah Howes
SMcD	Suzanne McDonough
SMD	Standardised mean difference
SPPB	Short Physical Performance Battery
SUS	System Usability Scale
UCD	User-centred design
USA	United States of America
VR	Virtual reality
WA	Washington

DECLARATION

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1 INTRODUCTION

1.1 Background

1.1.1 An ageing population

It is anticipated that over the next 25 years the number of adults over 65 years will increase by 88% (Quah et al. 2011), with the United Nations (2004) predicting that, by 2050, 20% of the population will be over 80 years old. While this merits the advances in health care, immunisation and sanitation, it also places significant strain on health care services. Living longer does not necessarily mean living well, with current lifestyles leading to an increase in long-term conditions, and the prevalence of multi-morbidities increasing with age (Barnett et al. 2012).

Within the ageing population, reduced participation in daily activities and a reduction in physical activity lead to deconditioning, impaired function and reduced independence. Physical and cognitive decline in older age is additionally associated with an increased risk of falls. It is estimated that approximately a third of adults aged 65 and over will fall each year, making falls the greatest cause for hospitalisation in older adults (Masud & Morris 2001; Finucane et al. 2014). Falls in this population have large implications on both the individual and health care services. Besides the direct financial cost of treatment following a fall, many older adults that experience a fall never return to their previous level of function. As well as reduced mobility and independence, older adults experience a fear of falling, reduced confidence and even depression, which further restricts their daily activities. This has contributed to a greater proportion of older adults who have fallen requiring some assistance with basic activities of daily living (Tinetti and Williams 1997, Baker et al. 2014).

1.1.2 Healthy ageing

Physical activity in older adults is associated with higher levels of physical function and independence (Chou et al. 2012, Pahor et al. 2014), as well as reduced cognitive decline (Angevaren et al. 2008) and falls prevention (Gillespie et al. 2012). The American College of Sports Medicine (Nelson et al. 2007) recommend at least 150 minutes of moderate exercise per week, or 30minutes on most days, for older adults; this should include aerobic, strength, balance and flexibility training. The Start Active, Stay Active report by the four UK Chief Medical Officers (Department of Health, 2011) supports this, adding that it is appropriate to reach the recommended amount of physical activity in short bouts of 10 minutes or more of moderate intensity. This report recommends physical activity promoting muscle strength on at least two days for older people, and incorporation of balance and coordination physical activity on at least two days for older people at risk of falls.

National Institute for Health and Care Excellence (NICE) guidelines (NICE 2013) also recommend strength and balance exercise programmes twice per week for older adults living in the community who are at risk of falls. A Cochrane review concluded that exercise significantly reduces both the risk and rate of falls in older adults (Gillespie et al. 2012). Evidence supports exercise alone to be as effective as a multifaceted falls prevention intervention (Campbell and Robertson 2007); and exercise that includes a balance component, with participants in standing, has shown a further reduction in the risk of falls compared to general exercise (Sherrington et al. 2011). It is estimated that up to 42% of falls can be prevented by well-designed exercise programmes, such as the Otago Exercise Programme (Sherrington et al. 2011); and a dose-response relation has been observed, with at least 2 hours per week for six months producing the largest benefit (Sherrington et al. 2011).

Despite the importance of remaining active into older age, the majority of older adults do not meet physical activity and exercise recommendations. For various social reasons, older adults adopt a more sedentary lifestyle and the majority do not meet these physical activity recommendations, with only 10% of people aged over 65 meeting the recommendations, and almost 70% being classed as inactive due to achieving less than one bout of moderate intensity physical activity per week (Taylor et al. 2004). Older

adults report various barriers to physical activity including poor physical health, lack of guidance and social support, fear, lack of interest, and environmental constraints (Baert et al. 2011; Moschny et al. 2011). Common barriers to exercise programmes reported by older adults include physical limitations and problems with access (Taylor 2014, Franco et al. 2015). Additionally, falls prevention exercise can be viewed as boring (Robinson et al. 2014), contributing to low levels of uptake and adherence to such programmes.

Evidence suggests that interventions that are underpinned by behaviour change models lead to higher recruitment, motivation and adherence (National Institute for Health and Care Excellence 2007; Abraham et al. 2009) and that study design can promote behaviour change to encourage long term adherence (National Institute for Health and Care Excellence 2014; Michie & Abraham 2004). The World Health Organisation (2007) notes that behaviour change relies on factors including social support, self-efficacy, opportunity to make active choices, person-centred goals, regular and accurate feedback on one's progress, and reinforcement of behaviour including incentives, rewards and recognition. Behaviour change of an individual also relies on access to the resources to do so, perception that it will be of benefit, and that the benefits will outweigh the cost. These theories coincide with the behaviour change taxonomy (v1), developed by Michie et al. (2013) which combines 19 behaviour change frameworks to provide a standardised and well-defined taxonomy of active components of behaviour change, considering the importance of physical and psychological capacity, physical and social opportunity, and automatic and reflective motivation on behaviour (Figure 1.1). The taxonomy provides a standardised way to identify behaviour change techniques (BCTs) reported in research papers and to define components of an intervention (Michie et al. 2014).
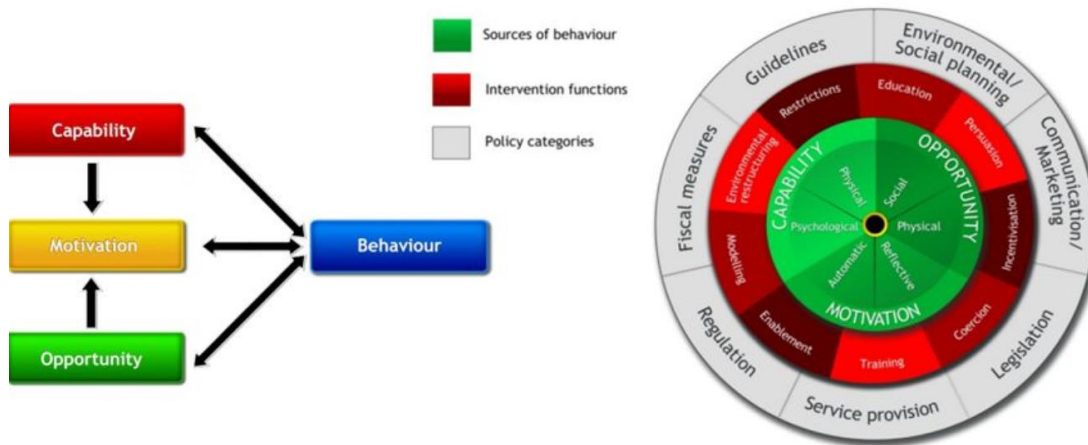
Figure 1.1 Behaviour Change Wheel (Michie et al. 2014)

The Behaviour Change Wheel summarises a behaviour change framework based on the influence of the importance of physical and psychological capacity, physical and social opportunity, and automatic and reflective motivation on behaviour.

1.1.3 Technology for health

As technology becomes more accessible and affordable, its use in healthcare is increasing. Technology is being used in a variety of ways; from clinical administration systems and electronic consulting to technology based assessment and interventions (Pagliari et al. 2007). This has advanced to investigating the use of commercially available systems, such as the Nintendo Wii, for the assessment of balance (Chang et al. 2013) and balance training (Manlapaz et al. 2017), as well as treatment for other clinical presentations.

Active computer gaming (ACG) is becoming recognised as a safe and enjoyable way for older people to participate in exercise and activities that may otherwise be difficult. Both commercially available gaming systems, such as Nintendo Wii and Xbox Kinect, and bespoke games specifically designed for older adults have been used as interventions in trials to investigate their safety, feasibility and effectiveness. Results have indicated that ACG can contribute to slowing the deterioration of health and function associated with ageing; with favourable results in outcomes such as balance, confidence, functional mobility, and self-reported quality of life and mental health

domains, when compared to a control or another treatment (Peng et al. 2012; Miller et al. 2014; Chao et al. 2015; Dennett and Taylor 2015).

A previous review of the literature for ACG (Bleakley et al. 2015) showed preliminary evidence to support ACG as a safe and effective intervention for promoting physical activity in older adults, which may have physical and cognitive benefits. These findings were supported in a more recent review of Wii exergames in older adults (Chao et al. 2015). Reviews in this area consistently report limitations in the quality of study design and a lack of reporting of the gaming intervention with regards to content, interface design and game demands suited to the target population to maximise behavioural and social influences in the older adult population (Larsen et al. 2013; Wiemeyer & Kliem 2012). Another review evaluated the effects and limitations of ACG in enabling physical activity in the home environment (Miller et al. 2014); however, there was limited reporting on the level of assistance and support required to ensure safety, and none of the trials included older adults with frailty or high risk of falls. Additionally, a lack of reporting on adherence, retention and follow up gives limited information on the long-term feasibility of ACG interventions in this population. The current evidence base lacks consensus on what aspects of gaming intervention design can optimise enjoyment, motivation and behaviour change, to ultimately improve long term adherence in the older adult population, as well as whether ACG are a safe and appropriate mode of physical activity, in which older adults can participate unsupervised at home.

ACG is method of enabling physical activity in the older adult population to improve health outcomes. ACG interventions may be engaging and motivating in nature, improving adherence to exercise. Game design can be manipulated to produce physical activity and rehabilitation interventions that provide an appropriate opportunity, suitable for older adult participants' capabilities and that can increase motivation in this population through both intrinsic and extrinsic features, and thus have the potential to promote behaviour change (Figure 1.1).

1.2 Rationale

As technology advances and ACG and virtual reality (VR) technologies become more affordable and accessible, it is anticipated that they will be more widely used in

rehabilitation. However, there is limited evidence of older adults' experience and perceptions of using novel technologies for strength and balance exercise. Additionally, involving older people in the development process may optimise design to meet the needs of older people to increase adoption of the ACG technology (De Vito Dabbs et al. 2009; Proffitt and Lange 2012; Brox et al. 2017).

Drawing expertise from an interdisciplinary team ensures optimum development of technology systems for health (Pagliari et al. 2007; Cannon-Bowers 2010). There is a lack of information available on the interdisciplinary collaboration involved in development of health technologies, particularly ACG technologies. Interdisciplinary collaboration is observed in a number of research teams involved in developing ACG technologies (McNaney et al. 2015; Perez et al. 2017); however, specific processes used in the management of the interdisciplinary teams and details of the effectiveness of the collaborations are seldom present in research reports.

1.3 Aims and organisation of the thesis

1.3.1 Aim

The main aim of this thesis was to evaluate the safety, usability and acceptability of using novel technology to deliver strength and balance exercise to older people.

1.3.2 Objectives

i)   The first objective was to iteratively develop an ACG system designed specifically to deliver strength and balance exercise to meet the requirements and preferences of older people, even frail older adults and those at high risk of falling

ii)   The second objective involved evaluating older adults' use and perceptions of the ACG system. Specific aims of each stage of the research are presented within their chapters.

1.3.3 Organisation of the thesis

This thesis consists of eight chapters describing the iterative development process involved in the development of an ACG system to deliver strength and balance

exercises to older people. The current chapter has provided the background and rationale for the study. Chapter 2 presents a systematic review and meta-analysis of the physical and cognitive health benefits of ACG in older adults, evaluating the quality of the evidence using the GRADE approach (Atkins et al. 2004). This chapter also presents information on ACG intervention delivery, including population, setting, dose and level of supervision, and the use of BCTs in current ACG interventions. The additional information presented in this chapter informed the development of the ACG system.

Chapter 3 presents an overview and rationale of the methods employed in the iterative development of two prototypes of the ACG system. Explored within this chapter are principles behind interdisciplinary collaboration and user-centred design, including how these were applied in the current research project. The chapter aims to describe in detail the process involved in the ACG system development; from initial workshops to discuss requirements and potential game design ideas, through game development and modification, based on findings from user testing, contributing to the development of the second prototype.

Chapters 4 and 6 describe prototypes 1 and 2, respectively. They provide in depth information about the features of the respective prototypes, highlighting how each stage of the development process influenced design and development of the ACG system. Chapter 4 provides information about the specific technology used and the exercises implemented within the system including game features. Chapter 6 describes modifications to the system made following feedback from user testing of prototype 1.

Chapter 5 reports the methods used and main findings from user testing of prototype 1 of the ACG system. Nine older adults participated in this study phase to assess the safety, usability and acceptability of the ACG system during a single use of the system displayed on flat screen and using a VR headset in older adults. Outcomes of interest were evaluated both quantitatively and qualitatively. Quantitative data was collected via completion of questionnaires following use of the ACG system; additionally, participant ability to complete use of the system and assistance required was tabulated. Qualitative data included observation of system use, comments made during use, and responses provided during semi-structured interviews following use of the ACG system.

Chapter 7 presents the methods used and main findings from user testing of prototype 2 of the ACG system. Seven older adults participated in this study phase to assess the safety, usability and acceptability of the ACG system with repeated use in older adults.

Chapter 8 provides discussion of the key findings including factors identified to play a key role in the design, development and evaluation of the ACG system. The chapter reflects on the strengths and challenges encountered with interdisciplinary collaboration, describing lessons learned to aid future collaborations. It considers the development of bespoke ACG systems specifically designed to deliver exercise compared with commercially available systems for use with older people. The chapter ends by discussing factors related to adoption of ACG technologies by older people.

2 GAMING FOR HEALTH: A SYSTEMATIC REVIEW AND META-ANALYSIS OF THE PHYSICAL AND COGNITIVE EFFECTS OF ACTIVE COMPUTER GAMING IN OLDER ADULTS

2.1 Chapter overview

Background: Active computer gaming (ACG) is method of facilitating physical activity in older people to improve health outcomes

Purpose: To update and extend a systematic review of the evidence for ACG to determine its effect on physical and cognitive health in older adults.

Data Sources: MEDLINE, EMBASE, CENTRAL in the Cochrane Library and PsycINFO databases were searched from the date of the previous review (2011) to May 2016.

Study selection: Eligible articles were RCTs investigating the effect of ACG in adults aged 65 and older.

Data extraction: Thirty-five studies were eligible for inclusion. Two review authors independently conducted data extraction, risk of bias assessment and coding of behaviour change techniques (BCTs). Outcomes of interest were analysed as continuous data and pooled as standardised mean differences (SMD) and 95% confidence intervals (CI). The GRADE approach was used to determine the quality of the evidence.

Data synthesis: N=106 BCTs were coded in the included studies (mean = 3.02). Data were pooled for five main outcomes of interest. Significant moderate effects in favour of ACG were observed for balance [SMD 0.52, 95% CI 0.24, 0.79; 17 studies; 743 participants]; functional exercise capacity when intervention delivery was >120minutes per week [SMD 0.53, 95% CI 0.15, 0.90; 5 studies; 116 participants]; and, cognitive function [SMD -0.48, 95% CI -0.80,-0.17; 8 studies; 459 participants]. There was no significant effect observed for functional mobility or fear of falling.

Limitations: The quality of the evidence for all comparisons was graded low or very low.

Conclusions: At present we have very little confidence that ACG improves physical and cognitive outcomes in older adults.

2.2 Background

Aging is associated with reduced independence due to physical and cognitive decline. Engaging in higher levels of physical activity is associated with higher levels of physical function and independence in older adults (Chou et al. 2012). The American College of Sports Medicine recommend at least 150 minutes of moderate exercise per week for older adults (Nelson et al. 2007), while a systematic review by Sherrington et al. (2011) recommends interventions of at least 120 minutes per week for falls prevention.

Active computer gaming (ACG) combines digital gaming with physical exertion; users perform bodily movements as, or to manipulate, a controller to interact with objects within a virtual environment. Commercially available gaming systems, such as the Nintendo Wii and Xbox Kinect, aimed at the entertainment market where the general population can engage in games, have increased in popularity, accessibility and

affordability (Kooiman and Sheehan 2015). Such systems are being adapted for rehabilitation purposes providing a potentially more engaging mode of exercise. Additionally, bespoke ACG systems have been specifically designed to deliver tailored rehabilitation exercise to meet the ability and needs of clinical populations.

Both commercially available gaming systems and games specifically designed for older adults have been used as interventions in trials to investigate their safety, feasibility and effectiveness. A number of reviews, including a previous review by this team (Bleakley et al. 2015), have provided preliminary evidence to support ACG as a safe and effective intervention for promoting physical activity in older adults, which may have physical and cognitive health benefits. ACG may contribute to slowing the deterioration of health and function associated with aging, with favourable results in outcomes such as balance, confidence, functional mobility, and cognitive function, when compared to a control or another treatment (Bleakley et al. 2015). These findings were supported in a more recent review of Wii games in older adults (Chao et al. 2015). Two other reviews evaluated the effects of ACG in enabling physical activity in the home environment (Miller et al. 2014) and for exercise and rehabilitation (Skjaeret et al. 2016); however, inclusion of interventions for older adults with neurological conditions limits the applicability of the findings to older people experiencing normal age-related decline. Reviews in this area report limitations in the quality of study design (Miller et al. 2014; Bleakley et al. 2015; Chao et al. 2015; Skjaeret et al. 2016). As such, previous systematic reviews have been unable to pool data for physical and cognitive health outcomes related to aging.

Additionally, the processes by which these results are produced have not been explored. The current evidence base lacks consensus on what aspects of gaming intervention design and delivery can optimise enjoyment and motivation, to ultimately improve adherence to exercise in older adults, as well as whether ACG are a safe and appropriate mode of achieving exercise and activity levels associated with improved health outcomes. The Behaviour Change Techniques Taxonomy version 1 (BCTTv1) provides a standardised and well-defined taxonomy of active components of behaviour change (Michie et al. 2013).

ACG is method of facilitating physical activity in the older adult population to improve health outcomes. Quantifying the effect of ACG, as well as identifying the behaviour change techniques (BCTs) adopted in ACG interventions for older adults may provide invaluable insight into the components associated with effectiveness and long-term adherence to ACG interventions.

2.3 Aims and Objectives

2.3.1 Aim

To update and extend a systematic review (Bleakley et al. 2015) of the available evidence for the physical and cognitive effects of ACG in older adults, and to explore ACG design and intervention delivery.

2.3.2 Objectives

    i.   Determine the effect of ACG on physical health outcomes, particularly those related to balance and mobility

   ii.   Determine the effect of ACG on cognitive health outcomes

 iii.   Explore adherence with, and delivery of interventions (ie. dose, setting, supervision)

 iv.   Identify BCTs used to improve adherence to ACG interventions for older adults, and code them according to the BCTTv1.

2.4 Methods

The review protocol was developed a priori and registered on Prospero (CRD42015017227). One notable change from the protocol was the decision to only report on randomised controlled trials (RCTs) given the increased volume of such studies in the five year time period since the first review (n=3 RCTs in 2011 versus n=35 RCTs in 2016).

2.4.1 Data sources and searches

Four electronic databases (MEDLINE, EMBASE, CENTRAL in the Cochrane Library, and PsycINFO) were searched initially in February 2015, and updated in May 2016, to

identify trials published since the previous systematic review (July 2011). Predefined search strategies, including a range of subject headings and key words based on those used in the systematic review being updated (Bleakley et al. 2015), were developed with assistance of the school librarian and piloted prior to use. The MEDLINE search strategy can be found in Table 2.1 and additional search strategies are included in Appendix 1. One review author (SH) screened all titles and abstracts, and then retrieved full text reports for the papers that met the inclusion criteria for full eligibility screening, using standardised criteria. Any queries were resolved by discussion with a second reviewer (SMcD). Article reference lists were hand-searched and the RCTs included in the previous systematic review were screened for inclusion in the current review.

2.4.2 Study Selection

This review included full-text articles of RCTs or quasi- RCTs published in English, and aimed at improving physical and cognitive function in older adults aged >65 years, excluding those requiring specific rehabilitation, for example following injury or stroke. Any intervention that used ACG as all or part of its delivery versus an inactive or active control was eligible for inclusion. ACG was defined as a digital game that requires players to interact with objects within a virtual environment using some part of their body as, or to manipulate, a controller, and requiring some physical exertion. Primary outcomes of interest were related to physical and cognitive function. Physical function outcomes included balance, functional mobility, and functional exercise capacity. Cognitive tests included memory screening instruments, and measures of components of cognitive function including executive control, visuospatial skills and processing speed. Secondary outcomes of interest included fear of falling.

Table 2.1 MEDLINE search strategy

Database: Ovid MEDLINE(R) <2011 to current>	
Search Strategy:	
1	Aging/ or Aged/ or "Aged, 80 and over"/ or Geriatrics/ or older adults.mp.
2	Computer-Assisted Instruction/ or Computers/ or User-Computer Interface/ or Computer Simulation/ or interactive computer$.mp. or Software/
3	Video Games/ or Games, Experimental/ or gam$.mp.
4	Virtual reality exposure therapy/ or virtual reality.mp.
5	Therapy, Computer-Assisted/ or visual feedback.mp.
6	exergam$.mp or serious gam$.mp. or computer gam$
7	Postural Balance/ or balance.mp.
8	Muscle Strength/ or strength.mp.
9	Range of Motion, Articular/ or flexibility.mp
10	Exercise/ or Physical Fitness / or Health status/ or aerobic fitness.mp. or physical activity.mp.
11	Accidental falls/ or fall prevention.mp.
12	Motivation/ or motivation.mp.
13	Patient compliance/ or adherence.mp.
14	Mental Health/ or psychological well being.mp.
15	Cognition/ or memory/ or cognitive function.mp.
16	"Quality of life"/
17	Health behaviour/ or behaviour change.mp. or Self-efficacy/
18	2 or 3 or 4 or 5 or 6
19	7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17
20	1 and 18 and 19
21	Limit to yr="2011- Current"

2.4.3 Data extraction and quality assessment

Study details and data were extracted independently by three reviewers (100%SH, 50%AM, 50%PD) using a customised form (Appendix 2), piloted prior to use. The form was used to record relevant data on methods, participants (sample/age/baseline characteristics), outcomes, and results (means and their standard deviations), including any other relevant information. Additional data of interest included that related to delivery of interventions, occurrence of adverse events (AEs) and adherence levels. Two coders (SH, JM) independently coded BCTs aimed at improving participants' adherence, using a form based on the BCTTv1 (Appendix 2; Michie et al. 2013), which was also piloted prior to use. Adherence was defined as performance of the intervention as prescribed, in terms of frequency, duration, technique and/or effort. Two authors (SH, KP) independently assessed each included study using the Cochrane tool for assessing risk of bias (Appendix 3; Higgins et al. 2011) according to four criteria: randomisation, allocation concealment, blinded outcome assessment, and incomplete follow-up; grading on each criterion as having low, high, or unclear risk of bias. The kappa statistic was calculated individually for each criterion then averaged to formally assess the level of agreement of the two authors in assessing risk of bias (Landis & Koch 1977).

To avoid double counting in studies with multiple intervention arms, the ACG intervention was compared only to the minimal intervention control. Where data were not presented in a form that enabled quantitative pooling, attempts were made to contact the authors for additional information. Where this was not possible, estimates were calculated from the published data, as per the method suggested by the Cochrane Collaboration Chapter 7 (7.3.5 obtaining mean SD from median and IQR and 7.7.3.2 Obtaining SD from CIs; Higgins et al. 2011). Where tabulated results were not presented, an attempt was made to extract data from graphs. Where it was not possible to obtain missing data, the study was excluded from the meta-analysis.

2.4.4 Data Synthesis and Analysis

Following qualitative assessment of intervention heterogeneity, data were assessed for statistical heterogeneity using the I^2 statistic. Data were analysed as continuous data, and presented as standardised mean differences (SMD) and 95% confidence intervals

(CIs) to pool outcomes presented using different scales and units. Meta-analyses were carried out using RevMan v.5.3 to compare physical and cognitive function outcomes and fear of falling between ACG intervention and control groups. Where substantial heterogeneity was identified ($I^2 > 50\%$), studies were pooled using the random effects model; otherwise a fixed effects model was used. Effect sizes were summarised as follows: SMD <0.40=small; 0.40-0.70=moderate; >0.70=large (Cohen 1988). The GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach was used to determine the quality of the evidence (Atkins et al. 2004). Evidence was downgraded based on pre-defined criteria, including: limitations in design or implementation, where a large proportion of data was from low quality trials; indirectness of evidence, in terms of population, intervention, control or outcomes; high levels of heterogeneity, where $I_2 > 50\%$; imprecision of results, where the 95% CI included no effect or is wider than 0.8; and, high probability of publication bias. Reasons for grade applied to each comparison were explained in summary of findings tables.

Sub-group analysis was performed according to control group: ACG versus inactive control; or, active control, which included traditional exercise or physiotherapy care. A second sub-group analysis was conducted for intervention dose; sub-groups differentiated studies that delivered a dose of <120minutes/week, ≥120minutes/week and ≥150minutes/week, based on recommendations for exercise dose in older adults (Nelson et al. 2007, Sherrington et al. 2011). Sensitivity analyses were carried out to assess the impact of excluding trials with higher risk of bias in the meta-analysis.

2.5 Results

2.5.1 Description of studies

The study selection process is summarised in Figure 2.1. Of 3804 records identified from the searches, 63 full text reports were retrieved and screened for eligibility. Three studies were included from the review being updated (Bleakley et al. 2015); the remaining nine studies were ineligible due to excluded intervention design (not an ACG) or study type (non-RCT). An updated search (May 2016) identified an additional 1291 references, of which the full texts were retrieved for 41 references.

This review included 35 studies, with 1838 participants. Study characteristics are summarised in Table 2.2. Of the randomised study types included, n=25 were described as RCTs (Barcelos et al. 2015, Bieryla et al. 2013, Chow et al. 2015, Daniel et al. 2012, Duque et al. 2013, Franco et al. 2012, Fu et al. 2015, Hagedorn et al. 2010, Haslinger et al. 2015, Hughes et al. 2014, Jorgensen et al. 2013, Karahan et al. 2015, Kim et al. 2013, Laver et al. 2012, Lee et al. 2014, Lee et al. 2015, Maillot et al. 2012, Padala et al. 2012, Pichierri et al. 2012, Pluchino et al. 2012, Rendon et al. 2012, Sato et al. 2015, Szturm et al. 2011, Toulotte et al. 2012, Whyatt et al. 2015); five as block-RCTs (Eggenberger et al. 2015, Gschwind et al. 2015, Schoene et al. 2013, Schoene et al. 2015 and Wolf et al. 2003); three as cluster-RCTs (Anderson-Hanley et al. 2012, Chao et al. 2014, Heiden et al. 2010); and two as quasi-RCTs (Bateni et al. 2012, Kahlbaugh et al. 2011). Included trials ranged in sample size from 12 to 200. The mean sample size was 53 participants. 70.7% of participants were female. The mean (standard deviation) age of included participants was 77 (5) years. The majority of studies included healthy older adults (n=23; Anderson-Hanley et al. 2012, Barcelos et al. 2015, Bieryla et al. 2013, Chow et al. 2015, Eggenberger et al. 2015, Franco et al. 2012, Gschwind et al. 2015, Haslinger et al. 2015, Heiden et al. 2010, Kahlbaugh et al. 2011, Karahan et al. 2015, Kim et al. 2013, Lee et al. 2014, Lee et al. 2015, Maillot et al. 2012, Pichierri et al. 2012, Pluchino et al. 2012, Rendon et al. 2012, Sato et al. 2015, Schoene et al. 2013, Schoene et al. 2015, Whyatt et al. 2015, and Wolf et al. 2003). Nine studies recruited participants at high risk of falls; this may have been defined by referral to a falls clinic (Duque et al. 2013, Hagedorn et al. 2010, Szturm et al. 2011), incidence of falls (Bateni et al. 2012, Fu et al. 2015, Toulotte et al. 2012), poor performance on balance measure (Chao et al. 2014, Padala et al. 2012), or self-report of impaired balance (Jorgensen et al. 2013). One study (Daniel et al. 2012) recruited participants identified as frail, while one study (Laver et al. 2012) recruited hospital in-patients who had previously been independent. Individuals with mild cognitive impairment were included in two studies: one in which participants also had a balance impairment (Padala et al. 2012, as above); and one which included participants with varied levels of mobility (Hughes et al. 2014).
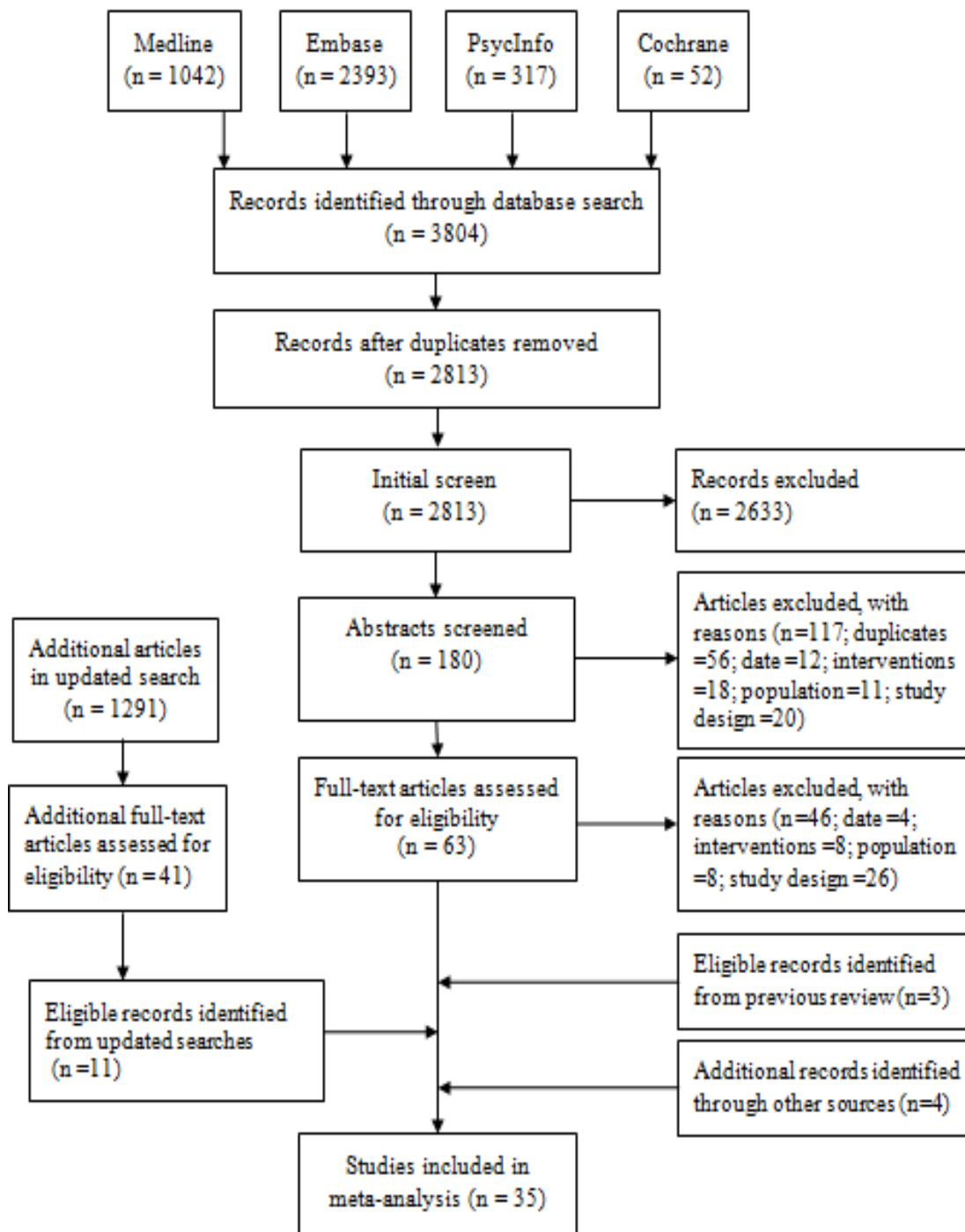
Figure 2.1 PRISMA flowchart

Table 2.2 Table summarising study characteristics

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
Anderson-Hanley 2012 Cluster RCT	79 (78)	78.76 (8.1)	NR – fairly healthy	Cybercycle – static bike 3d tours Executive function N=38; 8 dropouts	45 minutes x 5 sessions per week for 3 months	static bike with bio-feedback info (e.g., HR and mileage) N=41; 8 dropouts	Significantly improved in ACG group: • Executive function. NS difference: • Secondary cognitive outcomes
Barcelos 2015 RCT	64 (60)	82.2 (9.7)	Healthy	Static bike + virtual reality game Executive function N=25; 15 dropouts	20 minutes x 2 per week – 45 minutes x 3-5 per week for 3 months	Static bike + virtual environment N=23; 13 dropouts	Significantly improved in higher cognitive demand ACG group: • Stroop test NS difference: • Other cognitive outcomes
Bateni 2012 Quasi-RCT (one non-rand group)	18 (56)	73.0 (13.7)	High falls risk >2 falls in last year	Wii Balance N=6; 1 dropout	3 times per week for 4 weeks	Physio N= 6; 0 dropouts Physio& wii N= 6; 1 dropout	Physio alone or physio + ACG improvement greater than ACG alone: • BBS
Bieryla 2013 RCT (maintained	12 (83)	81.5 (5.5)	Independent Healthy	Wii Balance N=6; 2	30 minutes x 3 per week for 3 weeks	Inactive control N=6; 1 dropout	Significant improvement only in ACG: • BBS

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
one male in each group)				dropouts			NS difference: • Fullerton Advanced Balance Scale • FRT • TUG
Chao 2014 Cluster RCT	32 (75)	85.2 (6.5)	Healthy Baseline BBS (<45) is indicative of high risk of falls	Wii + motivation intervention Strength and balance N=16; 1 dropout	60 minutes x 2 per week for 4 weeks	Education 30 minutes x 1 per week for 4 weeks N=16; 1 dropout	Significant improvement only in ACG: • BBS • GDS-15 • TUG NS difference: • 6MWT • SF-8 • FES • Self-efficacy
Chow 2015 RCT	20 (65)	69 (NR)	Healthy	Cyber-golf Balance N=10; Dropouts NR	30-45 minutes daily for 2 weeks	Table games N=10; Dropouts NR	Significant improvement in ACG group: • FRT • SLT NS difference: • TUG
Daniel 2012 RCT	23 (61)	77 (5.3)	Frail	Wii Strength and	45 minutes x 3 per week	Seated exercise N=8; 0	Improvements seen in all measures inferential statistics

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
				balance N=8; 0 dropouts	for 15 weeks	dropouts Inactive control N=7; 2 dropouts	not used: • SFT • Chair stands • Up and go • Sit and reach • 6MWT • ABC
Duque 2013 RCT	70 (61)	76.80 (9.0)	Balance impaired	Bespoke Balance rehab unit followed by usual falls clinic care Balance & vestibular N=30; 2 dropouts	30 minutes x 2 per week for 6 weeks.	Usual falls clinic care (education, OEP, Home ax, eye and ear ax, vitamin D) N=40; NR dropouts	**Posturography** improved post-intervention but returned to baseline 9/12 after finishing programme
Eggenberger 2015 a&b Block-RCT	89 (65)	78.87(NR)	Healthy	Video game dancing Physical and cognitive outcomes N=30; 6 dropouts	60 minutes x 2 per week for 6 months	1) Treadmill + verbal memory task N= 29; 7 dropouts 2) Treadmill only	Significant improvements in ACG group: • Some cognitive outcomes Similar improvements across all groups: • Gait • SPPB

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
						N= 30; 5 dropouts	• 6MWT NS difference: • GDS-15 • FES-I
Franco 2012 RCT	32 (78)	78.27 (6)	Healthy Independently mobile with or without aid	Wii + HEP Strength & balance N=14; 3 dropouts	10-15 minutes x 2 per week for 3 weeks	Matter of balance exercise (30-45mins session) N=13; 2 dropouts Inactive control N=10	NS difference: • BBS • Tinetti Gait and Balance Assessment • SF-36 • Enjoyment questionnaire
Fu 2015 RCT	60 (65)	Intervention: 82.4 (3.8) Control: 82.3 (4.3)	Balance impaired, nursing home residents	Wii fit Balance N=30 2 dropouts	60 minutes x 3 per week for 6 weeks	Traditional strength & balance training (same dose) N=30; 3 dropouts	Improvements in both groups, greater improvement in ACG group: • Quadriceps strength • Reaction time • Postural sway • PPA • Incidence of falls
Gschwind 2015	153 (61)	74.7 (6.3)	Healthy	iStoppFalls Strength & balance	60 minutes x 3 per week for 16 weeks	Education booklet N=75; 13	Improvements in ACG group: • PPA Improvements only associated

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
Block-RCT				N=78 15 dropouts		dropouts	with adherence: • Postural sway • Reaction time • Executive function • Quality of life
Hagedorn 2010 RCT	35 recruited 27 completed (67)	81.3 (6.9)	Balance impaired / frail Referred to falls and balance clinic	Computer feedback balance training + strength/ endurance exercise N=15; dropouts NR	1.5 hours x 2 per week for 12 weeks	Traditional balance training + strength/ endurance exercise N=12; dropouts NR	ACG results comparable to traditional balance training for all outcomes: • Muscle force tests • Sit to stand • Bicep curls • TUG • 6MWT • Modified Clinical And Sensory Interaction And Balance Test • One legged stand / tandem stand • BBS • Dynamic Gait Index • FES-I
Haslinger 2014	44 (59)	72.7 (6.9)	Healthy	Active balance system	24 minutes x 2 per week	Inactive control N=22; 3	Significantly improved in ACG group:

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
RCT				Balance N=22 2 dropouts	for 9 weeks	dropouts	• TUG • 5STS • Walk test NS difference: • Quad strength • Posturography
Heiden 2010 Cluster RCT	16 (69)	77 (NR)	Community dwelling Attending community ran seated exercise class	Games-based balance bio-feedback exercise + seated exercise Balance N=9; dropouts NR	30 minutes x 2 per week + 1 hour x 2 per week for eight weeks	Normal daily activity (including seated exercise) N=7; Dropouts NR	Significantly improved in ACG compared to control group: • Postural sway, reaction time • Functional balance (CB&M scale) Significantly improved in both groups: • 6MWT
Hughes 2014 RCT	20 (70)	77.4 (5.8)	MCI Community dwelling	Wii Physical N=10	90 minutes x 1 session per week for 24 weeks	Healthy Ageing Education Program N=10	Significant improvement in favour of ACG: • subjective cognitive functioning and physical functioning (CSRQ) NS difference: • Cognitive functioning (CAMCI) • gait speed

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
Jorgensen 2013 RCT	58 (69)	75.0 (6)	Balance impaired	Wii Balance N=28; 5 dropouts	35 minutes x 2 per week for 10 weeks	Placebo - insoles	Significant improvement in favour of ACG: • Muscle power • TUG • FES-I • 30sec chair stand test NS difference: • Postural balance
Kahlbaugh 2011 Quasi RCT (one non-rand group)	36 (89)	82.0 (9.8)	Healthy	Wii N=16; 0 dropouts	1 hour session per week for 10 weeks	TV control N=13; 1 dropout Inactive control N=7; 0 dropouts	Positive outcomes in favour of ACG: • UCLA loneliness scale NS group differences: • PA levels • PANAS • Life satisfaction • SF-36
Karahan 2015 RCT	100 (43)	Intervention: 71.3 (6.1) Control: 71.5 (4.7)	Healthy	Kinect sports exergame N=54; 6 dropouts	30 minutes x 5 per week for 6 weeks	Home exercise programme N=46; 4 dropouts	Greater significant improvement for ACG: • BBS • TUG NS difference: • SF-36
Kim 2013	36 (86)	67.05 (3.7)	Healthy	Kinect	1 hour	Inactive control	Significant between group

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
RCT				Tai chi and yoga N=18; 0 dropouts	session x 3 per week for 8 weeks	N=18; 4 dropouts	differences post-intervention in favour of ACG: • Muscle power (hip) NS group differences: • Balance control/GRF (except in eyes closed conditions)
Laver 2012 Block-RCT	44 (80)	84.9 (4.5)	Hospital inpatients, previously high function	Wii Strength & balance N=22; 2 dropouts	25 minutes x 5 sessions per week for the duration of the patient's stay	Rehabilitation exercise N=22; 0 dropouts	Significant between group differences /session in favour of ACG: • TUG • MBBS NS differences: • SPPB • TIADL • FIM • ABC • EQ5D
Lee 2014 RCT	82 (71)	75.2 (6.6)	Healthy	Wii Strength and balance N=40	45 minutes x 3 sessions per week for 10 weeks	Group Fitness Exercise N=42	Improved for both groups: • Balance Efficacy Scale • Gait velocity • Stride length • Swing time

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
							• Cadence • Double support
Lee 2015 RCT	54 (100)	Intervention: 68.8 (4.6) Control: 67.7 (4.3)	Healthy	Tai chi virtual reality game Strength and balance N=26 4 dropouts	60 minutes x 3 per week for 8 weeks	Group exercise N=28; 3 dropouts	Greater improvement in ACG group: • Mental health • Leg strength Improved for both groups: • Quality of life • Secondary physical outcomes
Maillot 2014 RCT	32 (84)	71.5 (NR)	Healthy	Wii Balance and fitness N=16; 1 dropout	1 hour x 2 sessions per week for 12 weeks	Inactive control N=16; 1 dropout	Moderate significant effect in favour of ACG: • 6MWT • 8ft up and go, • Chair stands • Executive function
Padala 2012 RCT	22 (73)	80.45 (7.5)	MCI Balance impaired	Wii Strength and balance N=11; 1 dropout	30 minutes x 5 sessions per week for 8 weeks	Walking group N=11; 1 dropout	Significant improvement only in ACG group: • BBS Comparable significant improve in both groups

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
							• Tinetti POMA NS Difference: • TUG • Functional ADL • QoL • MMSE.
Pichierri 2012 RCT	22 (82) 31 recruited	86.2 (4.6)	Healthy	Dance mat (cognitive motor programme) + strength and balance exercise N=15; 4 dropouts	60 minutes x 2 per week for 12 weeks	strength and balance exercise alone n=16; 5 dropouts	Both groups improved. Between group differences favouring ACG group for some dual task tests: • Gait analysis under single and dual task conditions

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
Pluchino 2012 Block RCT	40 (63)	72.50 (8.4)	Healthy	Wii Balance N=12; 4 dropouts	60 minutes x 2 sessions per week for 8 weeks	Balance exercise N=14; 6 dropouts Tai chi N=14; 3 dropouts	NS difference: • FES • TUG • OLS • FRT • Tinetti • Falls Risk Ax • Posturography
Rendon 2012 RCT	40 (65)	84.50 (NR)	Healthy	Wii Balance N=20; 4 dropouts	35-45 minutes x 3 per week for 6 weeks	Inactive control N=20; 2 dropouts	Significant improvement compared to control: • 8-ft up and go • ABC NS Difference: • GDS-15

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
Sato 2015 RCT	57 (80)	69.25 (5.41)	Healthy	Kinect Balance N=29; 1 dropout	40-60 minutes x 2-3 per week for up to 24 times	Inactive control N=28; 2 dropouts	Significant improvement in ACG group: • BBS • FRT • Chair stand test • Gait analysis
Schoene 2013 Block RCT	32 (NR) 37 recruited 5 dropouts	78 (5)	Healthy	Dance mat Physical N=18; 3 dropouts	15-20 minutes x 2-3 per week for 8 weeks (Suggested)	Inactive control N=19; 2 dropouts	Significant improvement compared to control: • CSRT • TUG (dual task) • PPA NS Difference: • 5 STS • Alternate Step Test • Cognitive function • Fear of falling
Schoene 2015 Block RCT	90 (67)	81.5 (7.0)	Healthy	Dance mat Physical N=47 8 dropouts	20 minutes x 3 per week for 16 weeks	Education booklet only N=43; 1 dropout	Significant improvement in ACG group: • Processing speed • Visuospatial ability • Executive function • Fear of falling

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
							NS difference: • Stroop stepping test
Szturm 2011 RCT	30 (63)	80.8 (6.5)	Balance impaired	Bespoke Balance N=15; 2 dropouts	45 minutes x 2 sessions per week for 8 weeks	Balance exercise N=15; 1 dropout	Results comparable to traditional exercise or greater for ACG group: • BBS • TUG • ABC
Toulotte 2012 RCT	38 (58)	75.09 (10.26)	Healthy	Wii Balance N=9; 0 dropouts Adapted physical activity + Wii N=9; 0 dropouts	1 hour x 1 per week for 12 weeks	Adapted physical activity N=9; 0 dropouts Inactive control N=9; 0 dropouts	Adapted Physical Activities training alone improves balance and adding Wii Fit® does not confer a major additional benefit: • Unipedal test – balance eyes open, then eyes closed • Tinetti test – static balance • Wii Fit Test
Whyatt 2015 RCT	84 (80)	Intervention: 77.18 (6.59) Control: 76.62 (7.28)	Community dwelling; included both high and low risk of falls	Wii Balance N=42 2 dropouts	30 minutes x 2 per week for 5 weeks	Logging daily activity only N=42; 0 dropouts	Significantly improved ACG group: • BBS • ABC

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
Wolf 2003 Block-RCT	200 (81)	76.2 (4.7)	Healthy	Computerized balance training N=64 Dropouts not clearly reported (n=~11)	45 minutes x once per week for 15 weeks	Education N=64; dropouts not clearly reported (n=~10) Tai Chi N=72; dropouts not clearly reported (n=~12)	Greater improvement in ACG group: • Cardiovascular endurance (distance) Greater improvement in tai chi group: • Strength (grip) NS difference: • Flexibility • Body composition • Lawton and Brody IADL scale • CES-D scale • Fear of Falling

Key- General	Physical outcomes	Psychosocial outcomes
ACG – active computer gaming intervention Ax - assessment HEP – home exercise programme HR – heart rate IV - intervention MCI – mild cognitive impairment NR – not reported NS- non-significant	Measures of Balance BBS – Berg Balance Scale FRT – Functional Reach Test CB&M – scale - Community Balance and Mobility Scale OLS – One leg stand test GRF – Ground reaction force MBBS – Modified Berg Balance Scale POMA – Performance Oriented Mobility	Measures of fear of falling FES – Falls Efficacy Scale FES-I – Falls Efficacy Scale International ABC - Activities-Specific Confidence Scale Measures of cognitive health MMSE – Mini-Mental State Examination CAMCI – Computerized Assessment of Mild Cognitive Impairment

Study ID Study type	Number of participants (% female)	Mean (SD) age	Participant health and co-morbidities	ACG Intervention Rx Goal (N=)	Dose IV Duration IV	Description of control	Main findings
OEP – Otago Exercise Programme PA – physical activity QoL – Quality of life RCT – randomized controlled trial Rx - treatment SD – standard deviation			Assessment PPA – Physiological Performance Assessment Measures of physical function 5 STS – five sit to stand test SFT – Senior Fitness Test SPPB – Short Physical Performance Battery ADL – Activities of Daily Living IADL – Instrumental Activities of Daily Living TIADL – Timed Instrumental Activities of Daily Living FIM – Functional Independence Measure FRT – Functional reach test SLT – single-leg test Measures of functional mobility TUG – Timed Up and Go Test Measures of functional exercise capacity 6MWT – Six Minute Walk Test			Measures of quality of life SF-8 – 8-item Short Form Health Survey SF-36 - 36-Item Short Form Health Survey EQ-5D – Euro-Qol 5dimensional questionnaire CSRQ - Cognitive Self-Report Questionnaire Measures of mental health GDS-15 – 15-item Geriatric Depression Scale CES-D - Centre for Epidemiologic Studies-Depression scale PANAS – Positive and Negative Affects Scale	

2.5.2 Intervention delivery

A table summarising intervention delivery can be found in Table 2.3. Analysis of intervention dose in terms of minutes delivered per week indicated that 19/35 included studies delivered a dose of at least 120 minutes intervention per week (Sherrington et al. 2011), ten of which delivered 150 minutes or more (Nelson et al. 2007). Intervention setting was reported in 25 studies; the majority of studies were conducted in a clinical or research setting (n=14), and only three studies were unsupervised. Incidence of AEs was not clearly reported in 25/35 papers, and five studies reported no incidence of AEs. Where reported, AEs ranged from one to thirteen in the intervention group. Where AEs were reported for both the intervention and control groups, the number of AEs reported was similar in both groups. Adherence, defined as the number of sessions completed by participants in comparison to the total number of sessions allocated or recommended taking into account the number of drop outs, was included, or possible to calculate using data provided, for the intervention group in 17 studies. The mean adherence rate across these studies was 78.8%. Adherence for the comparison group was provided in nine of these studies (mean=77.9%).

Twenty-seven papers reported at least one BCT aimed at improving adherence. A total of 106 BCTs were coded in the included studies (range 0–13; mean = 3.02). BCTs related to *Feedback and monitoring* were observed most frequently (n=29), delivered via instantaneous visual feedback provided by the ACG. Scoring in ACG was also reported in included studies aimed at increasing participant effort and adherence; this was coded as *Feedback on behaviour* and *Non-specific reward*. There was no significant correlation observed between number of BCTs and participant adherence (r= 0.04, p=0.87). A summary of BCTs coded can be found in Appendix 4.

Table 2.3 Table summarising intervention delivery (dose, supervision, setting, adverse events, adherence)

Study ID	Dose (minutes/ week)	Supervision	Setting	Adverse events (study-related)		Adherence	
				Intervention group	Control group	Intervention group	Control group
Anderson-Hanley 2012	225	NR	Living facility	7 AE (4)	6 AE (4)	NR	NR
Bateni 2012	40-225	SV	Clinic/laboratory	NR	NR	NR	NR
Barcelos 2015	90	NR	Living facility	NR	NR	95.8%	77%
Bieryla 2013	90	SV	NR	NR	NR	67.5%	n/a
Chao 2014	60	SV	Living facility	0 AE	0 AE	NR	NR
Chow 2015	150	SV	NR	NR	NR	NR	NR
Daniel 2012	135	SV	Clinic/laboratory	NR	NR	86%	86%
Duque2013	60	SV	Falls clinic	NR	NR	91%	NR
Eggenberger 2015	120	SV	Clinic/laboratory	NR	NR	67.4%	72.6%
Franco2012	25	SV	Clinic/lab	NR	NR	79%	84%
Fu 2015	180	SV	Clinic/laboratory	NR	NR	NR	NR
Gschwind 2015	180	No SV	Living facility	0 AE	0 AE	49%	n/a
Hagedorn 2010	180	SV	Falls clinic	NR	NR	NR	NR
Haslinger 2015	46	NR	Clinic/laboratory	NR	NR	91%	n/a
Heiden 2010	180	SV	Community centre	NR	NR	NR	NR
Hughes 2014	90	NR	Community centre	NR	NR	NR	NR
Jorgensen 2013	70	SV	NR	NR	NR	63%	n/a
Kahlbaugh 2011	60	NR	Living facility	NR	NR	NR	NR
Karahan 2015	150	SV	Clinic/ laboratory	0 AE	0 AE	NR	NR

Study ID	Dose (minutes/ week)	Supervision	Setting	Adverse events (study-related)		Adherence	
				Intervention group	Control group	Intervention group	Control group
Kim 2013	180	No SV	Clinic/ laboratory	NR	NR	NR	NR
Laver 2012	125	SV	Living facility	13 AE (10)	10 AE (9)	90%	91%
Lee 2014	135	NR	NR	NR	NR	NR	NR
Lee 2015	180	SV	Clinic/ laboratory	NR	NR	76.4%	71.2%
Maillot 2012	120	SV	NR	NR	NR	91%	n/a
Padala 2012	150	SV	Living facility	1 AE (0 AE)	1 AE (0 AE)	56%	66%
Pichierri 2012	120	NR	Clinic/ laboratory	NR	NR	70%	60%
Pluchino 2012	120	NR	Clinic/ laboratory	NR	NR	NR	NR
Rendon 2012	120	NR	NR	2 AE (2 AE)	0 AEs	NR	NR
Sato 2015	80-180	SV	NR	NR	NR	NR	NR
Schoene 2013	45	No SV	Living facility	0 AEs	0 AE	86%	n/a
Schoene 2015	60	No SV	Living facility	1 AE (1 AE)	0 AE	93.4%	n/a
Szturm 2011	90	SV	Day hospital	NR	NR	87%	93%
Toulotte 2012	60	NR	NR	NR	NR	NR	NR
Whyatt 2015	30	SV	NR	NR	NR	NR	NR
Wolf 2003	45	SV	NR	NR	NR	NR	NR
SV – supervision		NR – not reported		AE – adverse event(s)			

Figure 2.2 Risk of bias summary for included studies

2.5.3 Risk of bias in included studies

Risk of bias of included studies is summarised in Figure 2.2 and Figure 2.3. There was substantial agreement between the two independent reviewers, with a kappa of 0.67 (Landis and Koch 1977). Information on random sequence generation and allocation concealment was frequently poorly reported in the included studies. Risk of detection bias was assessed as low in almost half of the studies, with 15 RCTs reporting blinded outcome assessors. Fourteen studies reported intention-to-treat analysis, and were assessed as having low risk of bias due to incomplete follow-up data. Other sources of bias included small sample sizes, observed across the majority of included studies. Baseline differences between intervention and control groups were observed in five studies. No conflicts of interest were declared or identified in any of the included studies.
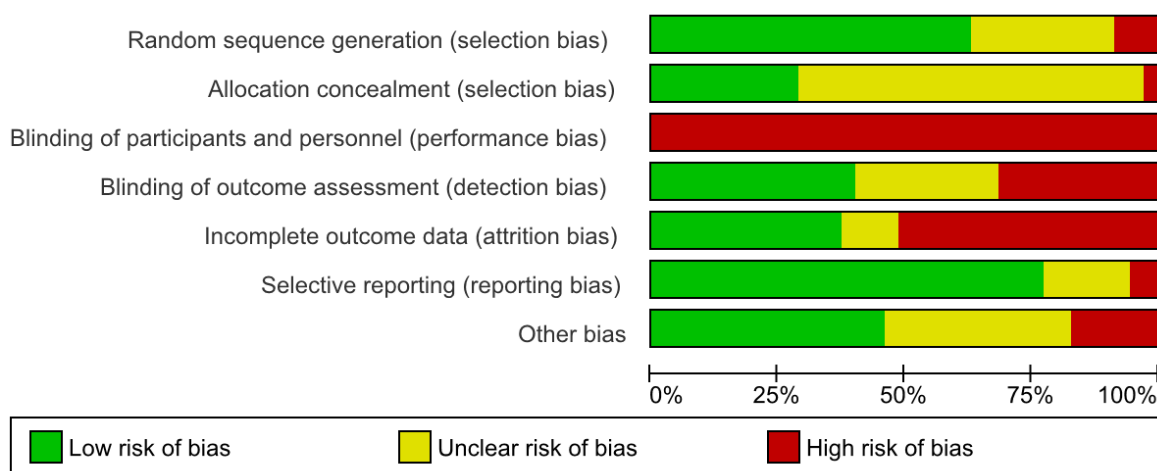
Figure 2.3 Risk of bias graph for included studies

2.5.4 Effects of interventions

Summary of findings tables can be found in Table 2.4. Forest plots for all analyses can be found in Appendix 5.

Seventeen trials measured balance and presented results eligible for inclusion in the analysis (Figure 2.4). Pooling of data from 743 participants provided low quality evidence that there was a moderate significant difference in favour of ACG [SMD 0.52,

95% CI 0.24, 0.79]. Sensitivity analysis removing six studies at high risk of bias did not alter these results [SMD 0.55, 95% CI 0.19, 0.91; n=555]. Sub-group analyses differentiating between types of control showed similar improvements in both sub-groups, suggesting that ACG may improve older adults' balance more than no treatment or an alternative intervention. In a sub-group analysis conducted to explore whether magnitude of effect was affected by ACG intervention dose the largest effect size was observed when intervention dose was >150minutes/week.

Study or Subgroup	Favours [experimental] Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.3.1 Balance versus active control								
Bateni 2012	46	7.4	6	46	8.9	6	3.8%	0.00 [-1.13, 1.13]
Duque 2013	143.3	33	30	118	43	40	7.8%	0.64 [0.15, 1.13]
Fu 2015	-2.4	1	30	-3.3	1.2	30	7.5%	0.80 [0.28, 1.33]
Hagedorn 2010	42.5	6.2	15	41.8	7.2	12	5.8%	0.10 [-0.66, 0.86]
Heiden 2010	63	3.5	9	54	7.5	7	3.7%	1.53 [0.37, 2.69]
Karahan 2015	54.91	2.67	48	51.16	4.14	42	8.1%	1.08 [0.64, 1.53]
Laver 2012	48.1	6.57	22	46.29	8.84	22	7.0%	0.23 [-0.36, 0.82]
Padala 2012	49.6	5.7	11	46.6	8.7	11	5.2%	0.39 [-0.45, 1.24]
Pluchino 2012	27.08	2.45	12	27.63	0.74	14	5.7%	-0.31 [-1.08, 0.47]
Szturm 2011	47	1.3	13	45	2.6	14	5.5%	0.93 [0.13, 1.73]
Subtotal (95% CI)			196			198	59.9%	0.56 [0.25, 0.87]
Heterogeneity: Tau² = 0.11; Chi² = 17.91, df = 9 (P = 0.04); I² = 50%								
Test for overall effect: Z = 3.57 (P = 0.0004)								
1.3.2 Balance versus inactive control								
Bieryla 2013	53	1.15	6	49.8	6.26	6	3.6%	0.66 [-0.52, 1.83]
Chao 2014	43.93	6.34	15	42.13	11.2	15	6.1%	0.19 [-0.53, 0.91]
Franco 2012	52	5.4	11	50.7	6	11	5.3%	0.22 [-0.62, 1.06]
Gschwind 2015	-0.41	0.95	78	-0.39	0.8	75	9.0%	-0.02 [-0.34, 0.29]
Schoene 2013	-1.15	0.8	15	-1.56	0.8	17	6.1%	0.50 [-0.21, 1.21]
Toulotte 2012	-16.3	1.04	9	-21.2	1.19	9	1.9%	4.18 [2.38, 5.97]
Whyatt 2015	50.1	6.4	40	46.9	9.21	42	8.1%	0.40 [-0.04, 0.84]
Subtotal (95% CI)			174			175	40.1%	0.51 [0.02, 1.01]
Heterogeneity: Tau² = 0.28; Chi² = 22.54, df = 6 (P = 0.0010); I² = 73%								
Test for overall effect: Z = 2.02 (P = 0.04)								
Total (95% CI)			370			373	100.0%	0.52 [0.24, 0.79]
Heterogeneity: Tau² = 0.20; Chi² = 46.38, df = 16 (P < 0.0001); I² = 66%								
Test for overall effect: Z = 3.66 (P = 0.0002)								
Test for subgroup differences: Chi² = 0.03, df = 1 (P = 0.87), I² = 0%								

Figure 2.4 Effect of ACG on balance; sub-group analysis according to control group

Sixteen studies (n= 670 participants) evaluated the effect of ACG on functional mobility using outcomes in which a lower score indicated better performance (for example, the Timed Up and Go test), and provided very low quality evidence of no significant effect [SMD -0.13, 95% CI -0.36, 0.09]. Sub-group and sensitivity analyses did not influence this finding.

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
1.5.3 Dose <120 mins/week								
Chao 2014	262.86	103.07	15	216.22	104.05	15	10.6%	0.44 [-0.29, 1.16]
Wolf 2003	0.58	0.08	50	0.58	0.11	52	37.1%	0.00 [-0.39, 0.39]
Subtotal (95% CI)			65			67	47.7%	0.10 [-0.24, 0.44]
Heterogeneity: Chi² = 1.09, df = 1 (P = 0.30); I² = 8%								
Test for overall effect: Z = 0.56 (P = 0.58)								
1.5.4 Dose >120 mins/week								
Daniel 2012	632	228	8	425	236	8	5.2%	0.84 [-0.19, 1.88]
Eggenberger 2015	560	81.33	15	538	81.33	15	10.8%	0.26 [-0.46, 0.98]
Hagedorn 2010	333	76	14	257	74	10	7.4%	0.98 [0.11, 1.84]
Heiden 2010	517	25	9	492	45	7	5.3%	0.68 [-0.35, 1.70]
Maillot 2012	469.22	125.14	15	439.91	88.12	15	10.8%	0.26 [-0.46, 0.98]
Subtotal (95% CI)			61			55	39.6%	0.53 [0.15, 0.90]
Heterogeneity: Chi² = 2.50, df = 4 (P = 0.64); I² = 0%								
Test for overall effect: Z = 2.76 (P = 0.006)								
1.5.5 Dose >150 mins/week								
Hagedorn 2010	333	76	14	257	74	10	7.4%	0.98 [0.11, 1.84]
Heiden 2010	517	25	9	492	45	7	5.3%	0.68 [-0.35, 1.70]
Subtotal (95% CI)			23			17	12.8%	0.85 [0.19, 1.51]
Heterogeneity: Chi² = 0.19, df = 1 (P = 0.66); I² = 0%								
Test for overall effect: Z = 2.52 (P = 0.01)								
Total (95% CI)			126			122	100.0%	0.29 [0.04, 0.55]
Heterogeneity: Chi² = 6.36, df = 6 (P = 0.38); I² = 6%								
Test for overall effect: Z = 2.27 (P = 0.02)								
Test for subgroup differences: Chi² = 2.77, df = 1 (P = 0.10), I² = 63.9%								

Figure 2.5 Effect of ACG on functional exercise capacity; sub-group analysis according to intervention dose

Seven studies (n= 248 participants) evaluated the effect of ACG on functional exercise capacity (Figure 2.5), using outcomes in which a higher score indicated better performance (for example, the Six-Minute Walk Test), and found a small significant effect in favour of ACG [0.29, 95%CI 0.04, 0.55]. Sensitivity analysis removing studies of lower methodological quality (n=3), altered results indicating a non-significant effect [SMD -0.34, 95% CI -0.79, 0.10; n=172]. Sub-group analysis differentiating between types of control did not indicate a significant effect. In the sub-group analysis according to delivery dose of the ACG intervention the magnitude of effect increased with delivery dose, with a moderate significant effect that persisted following sensitivity analysis for studies that delivered >120 minutes/week [SMD 0.53, 95% CI 0.15, 0.90], and a large significant effect for those delivering >150 minutes/week [SMD 0.85, 95% CI 0.19, 1.51]. This evidence was graded as very low quality.

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Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
3.1.1 Executive function tracking task versus active control								
Anderson-Hanley 2012	39.26	29.84	38	85.34	65.65	41	15.7%	-0.88 [-1.35, -0.42]
Barcelos 2015	2.05	0.41	8	2.92	1.62	8	6.9%	-0.70 [-1.71, 0.32]
Eggenberger 2015	72.81	37.64	24	87.6	52.16	25	13.5%	-0.32 [-0.88, 0.25]
Subtotal (95% CI)			70			74	36.1%	-0.65 [-1.03, -0.28]
Heterogeneity: Tau² = 0.02; Chi² = 2.30, df = 2 (P = 0.32); I² = 13%								
Test for overall effect: Z = 3.43 (P = 0.0006)								
3.1.2 Executive function tracking task versus inactive								
Gschwind 2015	60.2	34.6	78	56.8	33.8	75	19.2%	0.10 [-0.22, 0.42]
Hughes 2014	0.02	0.01	10	0.03	0.01	9	7.4%	-0.96 [-1.92, 0.01]
Maillot 2012	-15.42	20.27	15	3.7	28.54	15	10.3%	-0.75 [-1.50, -0.01]
Schoene 2013	43	15	15	74	61	17	10.7%	-0.66 [-1.38, 0.05]
Schoene 2015	74.9	35.5	39	90.5	58.5	42	16.3%	-0.32 [-0.76, 0.12]
Subtotal (95% CI)			157			158	63.9%	-0.40 [-0.79, 0.00]
Heterogeneity: Tau² = 0.11; Chi² = 9.73, df = 4 (P = 0.05); I² = 59%								
Test for overall effect: Z = 1.94 (P = 0.05)								
Total (95% CI)			227			232	100.0%	-0.48 [-0.80, -0.17]
Heterogeneity: Tau² = 0.11; Chi² = 16.63, df = 7 (P = 0.02); I² = 58%								
Test for overall effect: Z = 2.99 (P = 0.003)								
Test for subgroup differences: Chi² = 0.85, df = 1 (P = 0.36), I² = 0%								

Figure 2.6 Effect of ACG on cognitive function; sub-group analysis according to control group

Eight studies (n= 459 participants) evaluated the effect of ACG on cognitive function using a tracking task, where participants were timed to accurately join the dots in a pre-defined sequence (Figure 2.6), and provided low quality evidence of a moderate significant difference in favour of ACG [SMD -0.48, 95% CI -0.80,-0.17]. Sensitivity analysis did not change the results. Sub-group analyses differentiating between types of control and delivery dose did not indicate a significant difference.

Sixteen studies (n= 816 participants) evaluated the effect of ACG on fear of falling and provided very low quality evidence of no significant effect [SMD 0.18, 95% CI -0.16, 0.53]. Sensitivity and sub-group analyses according to control and delivery dose did not produce a significant effect.

Table 2.4 Summary of findings tables

Comparison: ACG versus active control						
Outcomes	Number of studies	Number of participants		Effect	Quality of the evidence (GRADE)	Comment
		ACG group	Control group			
Balance	10	196	198	0.56 [0.25, 0.87]	Low	a ~30% data from low quality studies; however, sensitivity analysis does not change findings (not serious - do not downgrade); b studies included healthy and balance impaired participants (not serious - do not downgrade); c I_2=50% (serious - downgrade 1); d small sample size (serious - downgrade 1)
Functional mobility	6	133	127	-0.12 [-0.48, 025]	Very low	a ~40% data from low quality studies (very serious - downgrade 1); d small sample size, wide CI (serious - downgrade 2)
Functional exercise capacity	3	38	32	0.58 [0.09, 1.07]	Very low	a ~45% data from one low quality study; however, sensitivity analysis increased effect size (serious - downgrade 1); d small sample size; wide CI (serious - downgrade 2)
Cognitive function	3	70	74	-0.65 [-1.03, -0.28]	Low	a ~50% data from low quality studies; however, sensitivity analysis increased effect size (serious - downgrade 1); d small sample size (serious - downgrade 1)
Fear of falling	8	157	168	0.28 [-0.50, 1.05]	Very low	a ~40% data from low quality studies (serious - downgrade 1) c I_2=90% (serious - downgrade 1); d small sample size, CI passes 0 (serious - downgrade 1)

Table 2.4 Summary of findings tables (continued)

Comparison: ACG versus inactive control						
Outcomes	Number of studies	Number of participants		Effect	Quality of the evidence (GRADE)	Comment
		ACG group	Control group			
Balance	7	174	175	0.51 [0.02, 1.01]	Very low	*a* ~40% data from low quality studies (very serious - downgrade 1); *c* I^2=73% (serious - downgrade 1); *d* small sample size, wide CI (serious - downgrade 1)
Functional mobility	10	205	205	-0.14 [-0.45, 0.17]	Very low	*a* ~50% data from high quality studies (serious - downgrade 1); *c* I^2=51% (serious - downgrade 1); *d* small sample size, CI passes 0 (serious - downgrade 1)
Functional exercise capacity	4	88	90	0.19 [-0.11, 0.48]	Very low	*a* ~60% data from one high quality study, remaining 40% low quality studies (very serious -downgrade 2); *d* small sample size, CI passes 0 (serious - downgrade 1)
Cognitive function	5	157	158	-0.40 [-0.79, 0.00]	Low	*a c* I^2=59% (serious - downgrade 1); *d* small sample size, wide CI (serious - downgrade 1)
Fear of falling	8	242	249	0.10 [-0.09, 0.29]	Low	*a* ~30% data from low quality studies (serious - downgrade 1); *d* CI passes 0 (serious - downgrade 1)

a- Study limitations (risk of bias)
b- Inconsistency of results
c- Indirectness of evidence
d- Imprecision (wide confidence intervals -CI)
e- Publication bias

2.6 Discussion

This updated and extended review identified, graded and synthesised 35 studies from the available literature for ACG in older adults. Overall, it presented low to very low quality evidence that ACG has a moderate significant effect on balance and cognitive function in older people, as well as on functional exercise capacity when delivered for at least 120 minutes per week, and that ACG has no effect on functional mobility or fear of falling. The majority of studies included in this review included healthy participants, and delivered more than 120 minutes of ACG intervention per week. Only nine studies were conducted in the home environment, and only three studies were unsupervised. Participant adherence and AEs were not well reported in the included studies; however, where reported, adherence rates were high and incidence of AEs was low, and both were comparable in intervention and control groups. Whilst it was not possible to establish a relationship between use of BCTs and adherence to an intervention, coding of BCTs aimed at increasing participant adherence highlighted key components of ACG such as instantaneous visual feedback and scoring that cannot easily be replicated in traditional therapy.

The main outcomes analysed in this review are associated with age-related physiological decline. Interventions that improve physical and cognitive performance could have significant benefit in the aging population, improving their ability to complete daily tasks, reducing their risk of falls and promoting independence (Chou et al. 2012). This review found that ACG interventions were associated with significant improvements in balance, but that ACG is no more effective than no treatment, other therapy or exercise for functional mobility. There are a number of explanations that ACG interventions may have had a moderate significant effect on one outcome associated with falls risk yet no effect on another. The included studies delivered ACG interventions aimed at improving aspects of physical function through various mechanisms, including weight shifting, stepping practice, strength exercises and general fitness training. By nature, the vast majority of training was standing on the spot and facing forward; while this may have challenged participants sufficiently to improve balance outcomes, the transferability to functional mobility tasks may be limited. This highlights the importance of tailoring ACG interventions to older adults' specific needs for daily function. For the analysis of functional mobility, data were pooled for the

Timed Up and Go test, a validated measure, considered to have high levels of sensitivity and reliability in this population (Shumway-Cook et al. 2000). The majority of studies included healthy older adults with a high level of function; participants in only four of the sixteen studies included in this analysis had a baseline Timed Up and Go time of >13.5 seconds, the cut-off time indicative of increased falls risk (Shumway-Cook et al. 2000). This may have contributed to a lower potential for change. A recent review (Dennett and Taylor 2015) evaluated computer-based electronic devices for improving a range of outcomes associated with falls risk; it found an effect on balance only in participants with a primary health condition and, in line with this review, found no effect on mobility in either healthy older adults or those with impaired function.

ACG brings promise for self-led exercise interventions for even the most frail, potentially independently within their own homes (Bleakley et al. 2015). Only nine of the reviewed studies included older people with balance impairment, providing limited information on the safety and efficacy of ACG in a population group that has most need for and potentially the most limited ability to access traditional modes of exercise. To date, the evidence base has not provided information sufficient to establish whether ACG can be recommended for unsupervised home use. Further research is required to establish its feasibility, in terms of whether older people are able to use ACG safely, and the level of adherence with independent participation. In this review, incidence of AEs was poorly reported, and there was inconsistency in the reporting of assistance required by users. To increase safety, many of the interventions included in this review provided close supervision, the option of additional hand support to prevent of loss of balance, and safety mats in case of a fall. A systematic review of home-based ACG interventions (Miller et al. 2014) found that assistance and supervision were often required, particularly in interventions including older people. It also noted a lack of reporting of incidence of AEs. Consistent reporting of AEs, as well as how frequently additional measures were required by participants could provide additional information on the feasibility of ACG in older adults, potentially allowing future studies to consider investigating home-based, unsupervised ACG interventions.

Adherence to physical activity programs is generally high (>70%) in older adults (Bauman et al. 2016). Adherence rates of the included intervention groups were similarly high, and were comparable to those of a traditional exercise or therapy control; however, more consistent reporting of participant adherence in all ACG trials would

permit a thorough comparison of adherence rates and factors influencing variations. ACG is being used in rehabilitation with the assumption that it is fun and motivating, and will, therefore, improve adherence. This review aimed to explore the properties of ACG interventions associated with improved adherence through coding BCTs. Detail of interventions and game design were generally poorly described in terms of promoting adherence, with research in this area still at the stage of testing intervention efficacy, rather than methods of encouraging long-term adherence. A review of the prevalence of BCTs in 18 fitness games (Lyons et al. 2013) directly coded games and identified a mean of 11.4 strategies per game. This review coded BCTs reported in the papers, and, therefore, may have underrated the use of within-game BCTs. Clear and consistent reporting of BCTs would allow replication of successful interventions. Providing feedback promotes learning and behaviour change, and was frequently observed in the reviewed papers. Instantaneous feedback was delivered in a number of ways: via an avatar that reflects the participant's body posture in real time; auditory and visual feedback on performance; and, scoring. This provides the user with not only information on performance and progress, but also adds novelty and enjoyment that may encourage increased participation.

2.6.1 Limitations

This review highlights that ACG is a growing area of research. Despite the advances in this research area, trials with small sample size and limited methodological quality persist, causing downgrading of the quality of the evidence to low and very low level for all outcomes (Table 2.4). As such, evidence presented in the current review should be interpreted with caution. Many of the included studies did not use methods to increase internal validity, such as concealed randomisation, blinded outcome assessment, or intention-to-treat analysis; however, sensitivity analyses continued to support the positive effect of ACG. Small studies, as included in this review, may overestimate the effect of the intervention on the outcomes of interest and contribute to imprecision of results; even after pooling data the total number of observations remained small, limiting the generalisability of the findings. At present, the use of ACG for health over traditional exercise and therapy in older adult populations cannot be recommended with confidence. Additionally, as expected in this population, the studies

in this review included a higher ratio of women than men, thus limiting our confidence in the applicability of these findings to men.

2.7 Conclusion

Findings of this review suggest that ACG may provide positive physical and cognitive health benefits greater than those observed following no treatment, traditional exercise or rehabilitation interventions for balance, functional exercise capacity and cognitive function. The available literature did not provide evidence of its effectiveness in improving mobility or fear of falling. The quality of the evidence for all outcomes of interest was low to very low. As such, in order to state with confidence whether or not ACG is an effective tool for improving older adults' health, there is a need for adequately powered, robust RCTs with blinded outcome assessment, and strategies to address follow-up of drop-outs to overcome problems related to missing outcome data. Future research should focus on home-based, self-led interventions with reduced supervision to evaluate the safety and feasibility of ACG for independent practice. Additional trials including older adults with impaired physical function would permit evaluation of the applicability of ACG to this population. Clear reporting of BCTs within ACG interventions could be promising in development of an ACG intervention that enhances user motivation and promotes long-term adherence to achieve the dose required for improved health outcomes.

2.7.1 Implications for this research study

The evidence base for the use of ACG for older adults' health is currently limited; however, this review indicated that ACG was a safe mode of exercise for older adults with positive effects on physical and cognitive health outcomes including balance. Most of the included studies investigated commercially available gaming systems, such as the Nintendo Wii and Xbox Kinect. However, as these games are developed for healthy adults, they do not always match the ability of clinical populations, such as older adults, or meet their therapeutic needs. Bespoke systems designed specifically to deliver tailored rehabilitation exercise may meet the requirements of this population. Bespoke ACG systems could also help overcome challenges, such as those related to physical ability, cognitive function and self-efficacy, faced by older adults when engaging with technology, and improve their usability and acceptability.

3 DEVELOPMENT OF THE CONTENT FOR THE ACG SYSTEM

3.1 Chapter overview

Interdisciplinary collaboration and user involvement, in the design and development processes, may optimise the usability and acceptability of technology applications developed for healthcare purposes. The aim of this project was to iteratively develop an ACG system to deliver strength and balance exercise to older adults. This chapter describes how elements of interdisciplinary collaboration and user-centred design were applied to develop a research outline of the methods used to iteratively develop two prototypes of an ACG system designed to deliver strength and balance exercise to older adults.

3.2 Background

3.2.1 Technology for health

As technology advances and becomes more accessible, its use in healthcare is growing. Despite a number of applications that could support successful ageing, such as assistive devices, e-health, sensor-based monitoring, and preventative and rehabilitative systems, a number of factors affect their uptake and acceptance in a generation not familiar with technology (Peek et al. 2014).

ACG is one such technology becoming more commonly used in health research with older people and in clinical practice, with potential to provide an accessible and enjoyable way for older people to engage with exercise. Commercially available ACG systems, such as WiiFit, may not meet the needs of older adults. Physical and cognitive

limitations experienced by older adults may impact their use of ACG systems designed to be entertaining for healthy adults, with older adults reporting requirements of speed and coordination that exceeded their ability and frustration when games provided negative feedback (Chao et al. 2015).

The Technology Acceptance Model (TAM; Figure 3.1; Davis, 1989) outlines the factors influencing technology adoption. User experience with an ACG system impacts user perceptions on its ease of use and usefulness and behavioural intention of use, predicting their future use of the system. While earlier research has focused on the effectiveness of ACG on outcomes of interest (Miller et al. 2014; Bleakley et al. 2015; Chao et al. 2015; Dennett and Taylor 2015), usability and acceptability are becoming recognised as important factors affecting uptake and engagement with ACG interventions in older adults (Nawaz et al 2015).
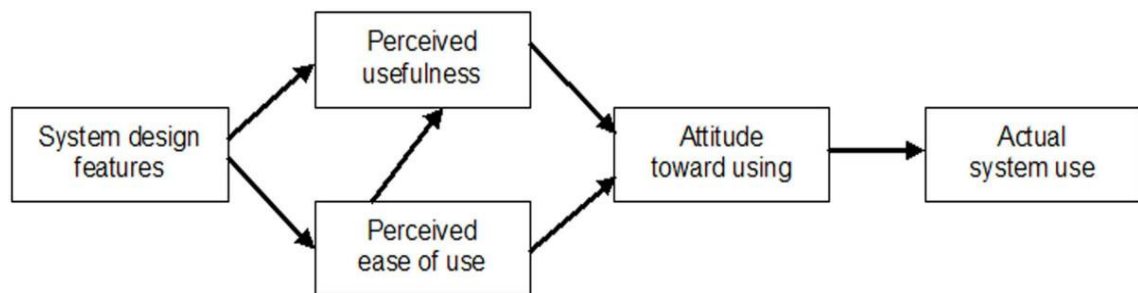
Figure 3.1 Technology Acceptance Model

Usability describes the ease of use and learnability of a system in a specified context of use by specified users to achieve specified goals with: effectiveness, the degree to which users can complete the tasks; efficiency, the degree of accuracy with which users complete their tasks; and, satisfaction, the extent to which the expectations are met (ISO, 1998). Acceptability refers to the extent to which participants perceive ACG to be acceptable, commonly evaluated in ACG systems in terms of enjoyment, ease of use, learnability, desire to play again, perceived usefulness, participant attitudes and intentions for use (Nawaz et al. 2015).

The development of successful rehabilitation technologies requires effective collaboration between clinicians and developers, and involvement of users in the design and development process.

3.2.2 Interdisciplinary Collaboration

Interdisciplinary collaboration within healthcare is the foundation of effective practice, involving multi-disciplinary teams of medics, nurses and allied health professionals. There is a wealth of literature available providing guidelines and models for effective interdisciplinary collaboration for the holistic treatment of a number of health conditions and population groups. This highlights the importance of interdisciplinary collaboration for safe and effective patient care (Royal College of Nursing, 2006; Manser, 2009; Zwarenstein et al. 2009; Interprofessional Education Collaborative Expert Panel, 2011).

Factors influencing the success of interdisciplinary collaboration in the healthcare setting (Interprofessional Education Collaborative Expert Panel, 2011) include:

- Interdisciplinary values and ethics for the collaboration allow both disciplines to develop a shared purpose and shared commitment to more effective interventions.
- Knowledge of the roles and responsibilities within the collaboration concedes an understanding of how they complement each other, while respecting the diversity of each discipline
- Communication competencies, including communicating a willingness to collaborate, the use of language and jargon, delivery of feedback and team meetings and updates, particularly when the team is likely based across different sites, are vital to the success of an interdisciplinary collaboration
- Teamwork involves adopting team-working behaviours and using skills such as problem solving, decision making and accountability, shared goals.

As the use of technology integrates into the health and rehabilitation setting, interdisciplinary collaboration extends to the computer scientists involved in the development of rehabilitation technologies. Development of games for health requires interdisciplinary collaboration between two fields, health sciences and computer sciences. To develop safe and effective interventions it is necessary to draw on the expertise of clinicians and developers. Computer scientists develop programmes that can be optimised with input from clinicians, who can share their knowledge and experience of rehabilitation, exercise and the target population. This is particularly

important in the current study population due to other health conditions experienced by older adults. Clinicians can provide insight through their understanding of common comorbidities, including their clinical presentation and their implications for physical activity. In developing the protocol for this study, we considered procedures for managing common health conditions associated with ageing; these included general deconditioning, cognitive impairment such as dementia, vision impairments including cataracts, joint problems including osteoarthritis and joint replacement, cardiovascular conditions including heart disease and stroke.

The current interdisciplinary research team reflected on the aforementioned factors influencing success of interdisciplinary collaboration (Interprofessional Education Collaborative Expert Panel, 2011), adapting them to collaboration across the fields of health and computer sciences. Additional considerations are required for effective collaboration between the two very diverse disciplines of health and computer science. These involve an understanding of the different models and approaches used within each discipline.

3.2.2.1 Health and rehabilitation research

Clinical practice is based on evidence based practice, with an emphasis on evidence from high quality research. Health research involves the identification of a need for an intervention followed by the rigorous evaluation of interventions through clinical trials investigating the effectiveness of the intervention for specific outcomes within a specific population. Outcomes of interest include physical outcomes, psychological outcomes and social outcomes, as well as evaluation of the safety or risks associated with an intervention. Whether qualitative or quantitative, high quality health research involves robust methods including detailed planning, recording of procedures, and transparent participant sampling and data analysis.

Feasibility and piloting
Testing procedures
Estimating recruitment and retention
Determining sample size

Development
Identifying the evidence base
Identifying or developing theory
Modelling process and outcomes

Evaluation
Assessing effectiveness
Understanding change process
Assessing cost effectiveness

Implementation
Dissemination
Surveillance and monitoring
Long term follow-up

Figure 3.2 MRC framework of complex interventions

The MRC complex interventions model (Campbell et al. 2000; Craig et al. 2008) is often used in health research. The key elements do not necessarily follow a linear or cyclical process (Figure 3.2). This process involves several phases of each element using qualitative and quantitative methods to define components of the intervention anticipating potential barriers; explore appropriate intervention and study design, testing different versions of the intervention for feasibility and acceptability and piloting the proposed study design; a main trial to assess effectiveness; and a final phase monitoring implementation of the intervention in practice. The MRC framework provides limited detail on how to develop an intervention; some of the processes used in games development, including user-centred design, could fill this gap.

3.2.2.2 Game development approach

This discipline is faced with a need to keep up with the rate of technology advancement; the focus is on innovation and rapid development. Development of software involves evolutionary and iterative prototyping employed by models such as the Spiral Model (Boehm, 1988; Figure 3.3). It involves determining objectives and requirements; development and testing through observations and feedback; refining and developing of iterations; and, progressing to evaluation of an operational prototype.
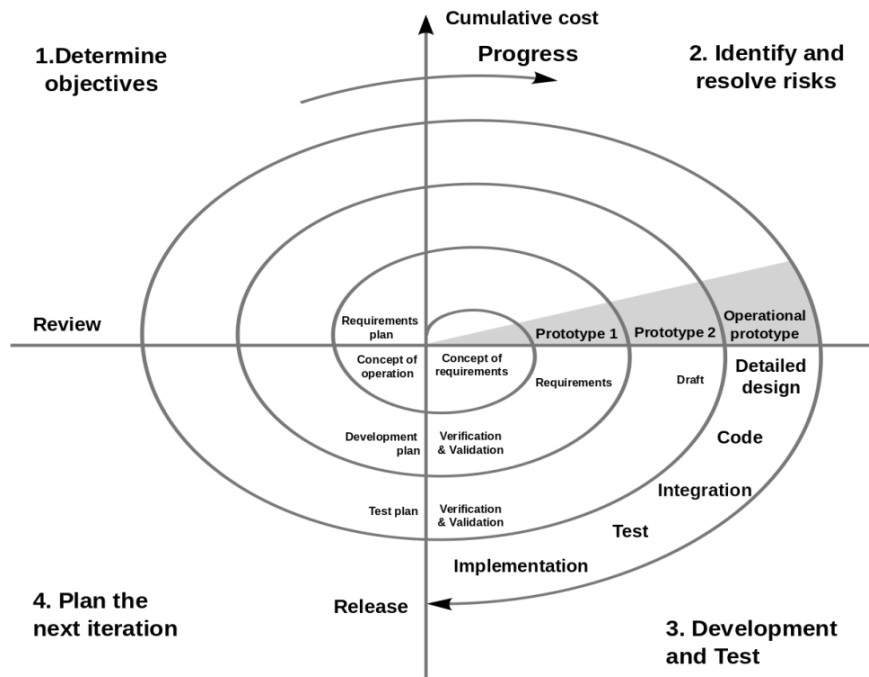
Figure 3.3 Spiral model for software development

In industry, many organisations do not use formal system development methodologies (Fitzgerald 1998), rather working to produce software to meet defined functionality criteria and requirements within the constraints placed on time and resources. Outcomes of interest in this field look at optimising design and ensuring software is fit for purpose in terms of usability and engagement. Evaluation of the impact on end users is a lower priority with iterations tested in a small convenience sample of users against criteria including accuracy, appropriateness, usability, maintainability, efficacy and safety (Henderson et al. 1999).

3.2.2.3 Collaborative Approach

The MRC framework outlines a robust way to evaluate interventions within health research; however, recommendations for this framework have included greater attention to development and piloting and a more iterative approach to the evaluation process (Craig et al. 2008). The iterative process used in games development may be appropriate in the early stages of development of a novel intervention such as this project. Additionally, a focus on user perceptions during the development of interventions is one way to optimise acceptability and usability. However, while usability and user engagement are often outcomes of interest in this field, the need for

rapid development can often lead to limited user involvement in the design process and user testing (Pagliari et al. 2007). Adopting a user-centred design approach may prevent problems with usability and acceptability during roll-out for users who are not as familiar with technology as the developers.

The models in both health research and software development include common elements: concept formation; needs assessment; and, evaluation (Pagliari, 2007). Differing terminology, procedures and outcomes used in the two disciplines may pose a barrier to a collaborative approach to planning and development. However, an understanding can help develop a shared purpose enabling both disciplines to work together to optimise the development of health technologies. Interdisciplinary collaboration can also facilitate the implementation of high quality evaluation and user involvement in the design and development processes. This will improve safety, usability and appropriateness of new interventions, thus improving the acceptability and reducing the risk of problems during roll-out. Interdisciplinary collaboration can help health technology progress from research to practice.

3.2.3 User-centred design (UCD)

Patient, Carer and Public Involvement (PPI) describes the active involvement of patients and other stakeholders, for example people from organisations that represent a patient group, in the planning and conduct of research (INVOLVE, 2012). PPI is becoming recognised as pivotal to research with INVOLVE providing resources to guide researchers involving members of the public in research, including different approaches such as consultation, collaboration and user-controlled research (INVOLVE, 2012), to provide insight that optimises the quality and relevance of the research.

Input from end users early in the design and development phase of an ACG system is one way to optimise its usability and acceptability. Older adults face a variety of challenges when engaging with ACG technologies. One study described challenges related to physical changes, cognitive changes and self-efficacy; stating that many of these could be avoided by involving older adults in the design and testing of such systems (McLaughlin et al. 2012). UCD is used in software development to optimise usability of a system as rapidly as possible; it includes task analysis, usability testing, observations and feedback from users (Fisk et al. 2009). There is limited information

published in the area of UCD for the development of rehabilitative technologies delivering falls prevention exercises for older adults, the topic of this thesis.

To use a UCD approach, one previous research team conducted workshops with older people to discuss requirements, brainstorm and sketch ideas, followed by a games session giving older adults the opportunity to play an initial prototype (Uzor et al. 2012). Proffitt and Lange (2013) describe an iterative process involving an interdisciplinary team and stakeholders in the design and development of a system for falls prevention (Figure 3.4). This included focus groups to explore barriers and facilitators to engagement, iterative user testing of prototypes and semi structured interviews to explore user experience.
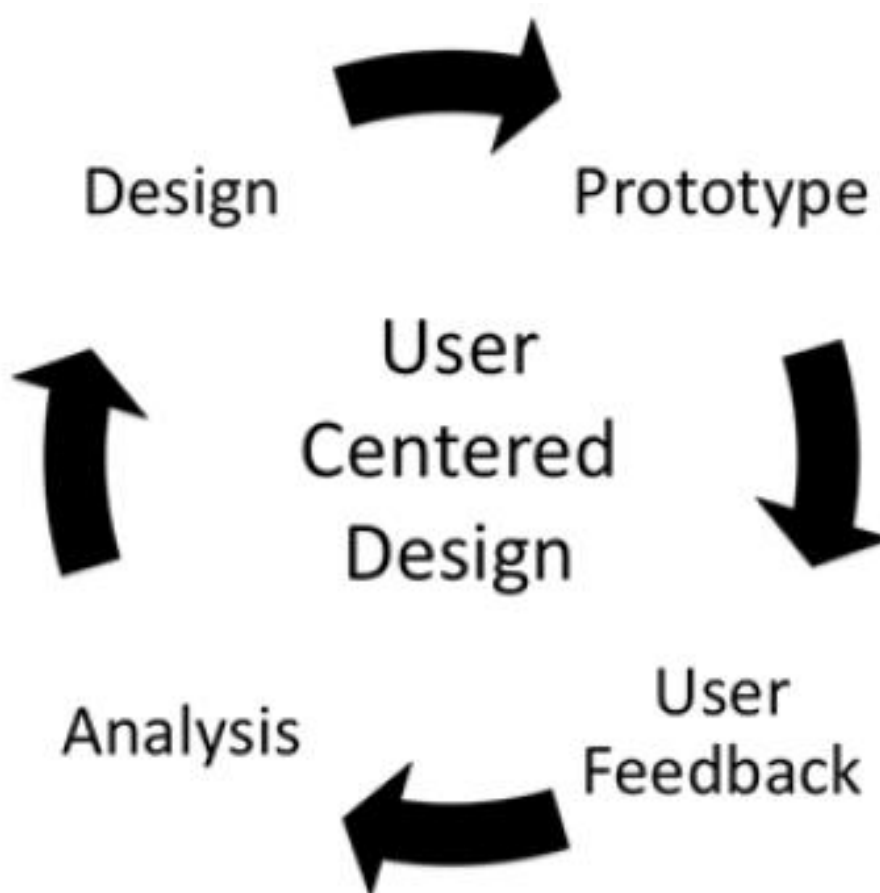
Figure 3.4 UCD approach used by Proffitt and Lange (2013)

More recently, a protocol for UCD for ACG for older adults has been suggested (Brox et al. 2017). This protocol includes: gathering requirements from the literature, background information on the population, discussions about their requirements and observations of their use with commercial games; an iterative design and

implementation process influenced by user feedback during observations, structured and semi-structured interviews and discussions; and an evaluation phase, involving piloting of the final prototype with new participants (Figure 3.5).
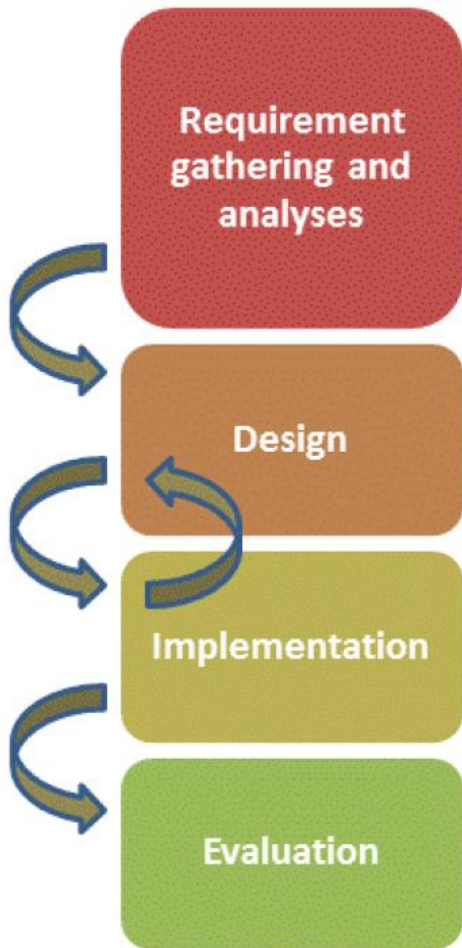
Figure 3.5 UCD approach used by Brox et al. (2017)

Therefore, these three studies (Uzor et al. 2012; Proffitt and Lange 2013; Brox et al. 2017) were used to develop a protocol for user-centred design in this chapter.

3.3 Aims and objectives

3.3.1 Aim

To iteratively develop an ACG system to deliver strength and balance exercise to older adults.

3.3.2 Objectives

i) To develop an ACG and VR system suitable for display with two viewing mediums: on flat screen and using the Oculus Rift VR headset (prototype 1)

ii) To modify this system, based on the findings from user testing phase 1, to optimise its usability and acceptability for repeated use by older adults (prototype 2)
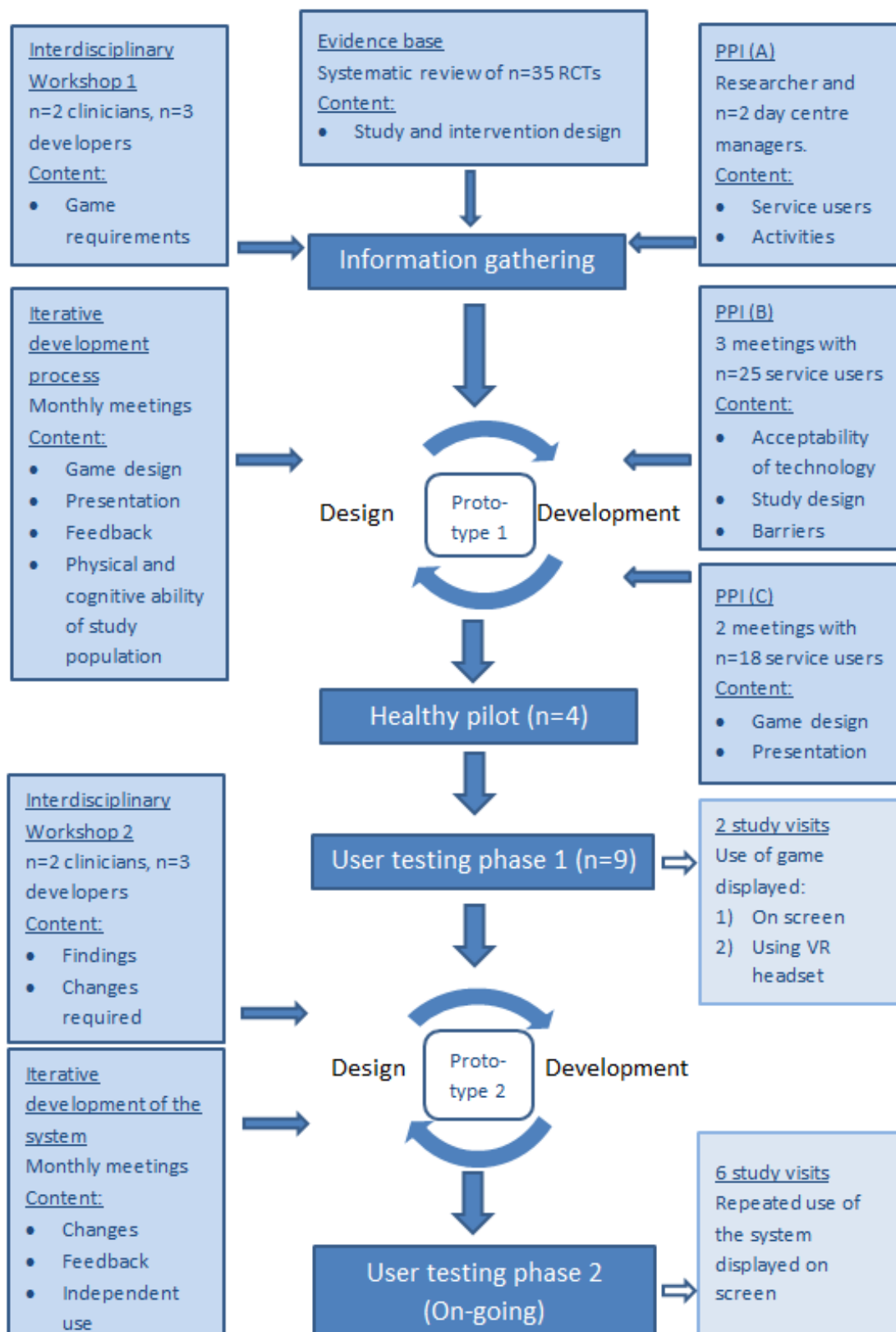
Figure 3.6 Research outline

3.4 Methods

This section describes the methods used by the research team, including interdisciplinary collaboration and user involvement, in the development of the ACG system. An outline for the development of the ACG system is shown in Figure 3.6. Descriptions of prototypes 1 and 2 of the ACG system are presented in Chapters 4 and 6, respectively.

3.4.1 Information gathering for prototype 1

The design of the ACG system was influenced by information gathered through a review of the evidence base, an interdisciplinary workshop conducted with the research team and meetings held with managers of day centres for older people.

3.4.1.1 Evidence base

A systematic review of the evidence for the use of ACG for health benefits was conducted. The full review is included in Chapter 2. The literature and available guidelines were also consulted to identify an evidence-based exercise programme for falls prevention in older adults.

3.4.1.2 Interdisciplinary workshop 1

An interdisciplinary workshop, conducted at Ulster University Coleraine Campus (November 2015), was attended by n=2 clinicians (SH, SMcD) and n=3 developers (DC, DH, GC) to discuss the requirements of the system. Prior to the workshop, SH sent information to the development team to allow them to improve their understanding and prepare for the meeting. This information included background to the study, literature search findings, intervention requirements from a clinical perspective, and relevant references. The requirements of the ACG system included embedding evidence-based strength and balance exercises in a game format developed to allow delivery of appropriate exercise dose. During the interdisciplinary workshop, exercises from the chosen exercise programme were described and demonstrated to the interdisciplinary team. The developers described how available technologies could be used to implement the exercises in game format to inform the choice of system to use. Each exercise was considered individually in terms of its suitability to be delivered within the chosen system. Suitable exercises were ranked according to perceived technical difficulty to

implement, with each exercise scored from 0 (not difficult)-10 (extremely difficult). The team agreed to initially work on development of the four technically easiest tasks. These tasks would deliver exercises for strength and balance.

3.4.1.3 PPI – service providers consulted

As mentioned in the introduction, including lay people in health research can provide insight that may influence the development and conduct of research; this is considered to improve the quality of the research (Entwistle et al. 1998). The role of users is central to the development of innovations and the time point in the research cycle in which user involvement is included is critical (Savory, 2010). Given the novel research area, it was considered to be important to use PPI approaches to develop the intervention.

Both day centre managers and service users were actively involved in the study from an early stage, influencing the study design and the development of the system. During the information gathering stage (December 2014 - March 2015), meetings were conducted with managers of two Age NI day centres for older adults. Information was gathered relating to the service provided by the centres, including the number of days it operated, the daily routine and the activities provided, and the service users, including the number of service users in total and daily, their level of function and needs, and their activity preferences.

3.4.2 Design and development of prototype 1

The design and development of prototype 1 was an iterative process involving regular interdisciplinary meetings. Service users were also involved at two points in the design and development process (see Figure 3.6).

3.4.2.1 Iterative development of prototype 1 - Interdisciplinary meetings

Although the two disciplines were located on different campuses, efforts were made to ensure that development of the game was collaborative. Monthly face-to-face meetings were conducted (eight meetings from March to October 2016), supplemented by video and phone calls to discuss the design of the game and review the progress with its development.

Meetings in the early stages of the process involved choosing a game design to deliver each exercise that had been selected during the interdisciplinary workshop. Suggestions were made for how each exercise could be implemented within the game. Factors influencing decisions included what would be interesting for older people, what would match the theme of the virtual environment, how they would be implemented technically, and what would be achievable to develop within our time frame. To enable collaboration between the two disciplines, a task list was compiled, and tasks were prioritised at the first meeting. At each follow-up meeting this was reviewed. Issues and queries faced by the developers in implementing were discussed to ensure that the first prototype was designed appropriately to meet the needs of the study population. Several iterations of the system were reviewed by the interdisciplinary team and modifications were made following testing by the clinician team members.

3.4.2.2 PPI - Service user involvement

Service users (n=25) were consulted during the early stages of development (July 2015). During three scoping meetings, they were shown images and given information about the technology and its potential for a falls prevention intervention, and given the opportunity to provide feedback. Handwritten notes were made on their questions, views, concerns and recommendations. Later in the development process (July 2016), two meetings were conducted with service users (n=18) to discuss the game design and choice of exercises. The exercises included in the game were demonstrated to the service users followed by the opportunity to provide feedback on the choice of exercises. During these meetings, the service users were also consulted about the presentation of the game. Images of screen grabs from the game were shown to the users in small groups of 2-3, and they were given the opportunity to provide feedback on their perceptions of the game design, colours, clarity and ease of reading of the text. This included use of colour and ease of reading.

3.4.3 Piloting of prototype 1

Prior to user testing with older adults, the ACG system was piloted by four healthy adults who were not familiar with the technology, to assess their experience of using the equipment and to identify issues and concerns prior to testing the system with older adults. The system was set up in the university and users were asked to "think aloud" as

they completed the two study conditions. Handwritten notes were collected of users' comments and technical issues encountered during their use of the system.

3.4.4 User testing of prototype 1

The ACG system, a detailed description of which is presented in Chapter 4, was tested on n=9 older adults. The methods and results of this are presented in Chapter 5.

3.4.5 Design and development of prototype 2

The findings from user testing of prototype 1 were used to make modifications to the system. Handwritten notes and video recordings collected during user testing phase 1 were analysed by SH to identify common factors affecting usability of the system. Transcriptions from semi-structured interviews and comments made by participants during use of prototype 1 were reviewed to identify factors influencing acceptability of the system. All findings were considered in terms of their relationship with other available literature in this area. In developing prototype 2, modifications to the system were based on recommendations and guidelines from the current evidence base to ensure that the system was modified to meet the requirements and preferences of the population, to optimise usability and acceptability.

3.4.5.1 Interdisciplinary workshop 2

A second interdisciplinary workshop with n=2 clinicians (SH, SMcD) and n=3 developers (DC, DH, CB) was conducted following completion of data collection for the user testing of prototype 1 (November 2016). A presentation was delivered to the interdisciplinary team by SH to share findings from user testing phase 1 including issues that had been encountered. Potential ways to develop the intervention were discussed, considering the suitability of the system and amendments that would be required for progression to the next study phase. Potential outcomes of interest and aims for the next study phase were discussed. Following this workshop, SH considered the current evidence available for each of the points considered.

3.4.5.2 Iterative development of prototype 2 – Interdisciplinary collaboration

The interdisciplinary research team considered methods of enabling more autonomous use of the system, as well as modifying the delivery of feedback to explore its effect on engagement and user experience. During early interdisciplinary team meetings (December 2016), information from the current literature was shared to aid decision making about modifications to the system to develop prototype 2. Additionally, technical issues experienced during phase 1 that had been recorded in a troubleshooting document (Appendix 6) were discussed. Plans to resolve technical issues, to allow for a more fluid experience, and ways to implement changes to the system were listed. A list of tasks was created and tasks were scored based on their difficulty to implement technically. Primary tasks to approach were agreed. Progress on the task list was reviewed during monthly interdisciplinary team meetings (five meetings from December 2016 to April 2017), and weekly progress reports via email or phone call. New components of the system were tested by the research team at interdisciplinary meetings and screen grabs showing modifications to the presentation were reviewed by the research team more frequently via email. On completion, prototype 2 was piloted by SH, prior to user testing. A technical member of the team, attended the first user testing day of prototype 2 to ensure there were no problems during set up of the system or with calibration.

3.4.6 User testing of prototype 2

Repeated use of the second prototype of the ACG system, a detailed description of which is presented in Chapter 6, was tested on n=7 older adults. The methods and results of this are presented in Chapter 7.

4 DESCRIPTION OF PROTOTYPE 1

4.1 Chapter overview

This chapter describes prototype 1 of the ACG system developed to deliver falls prevention exercise to older adults, making reference to how it was developed at each stage of the iterative development process (Figure 3.6), the methods of which are described in Chapter 3.

4.2 Information gathering

4.2.1 Evidence base

A systematic review of the evidence, presented in Chapter 2, had indicated that ACG was a safe mode of exercise for older adults with positive effects on physical and cognitive health outcomes including balance; however, most ACG interventions were conducted with healthy older adults in a clinical environment with supervision. The research team had considered ACG as a potential way to promote independent exercise and rehabilitation in older adults; however, findings of this review did not provide sufficient evidence of their safety for unsupervised home use in older adults with impaired physical function associated with ageing.

NICE guidelines and Cochrane reviews support the use of strength and balance exercises to reduce the risk of falls in older adults (National Institute for Health and Care Excellence 2013; Gillespie et al. 2012), while strong evidence suggests that falls can be prevented by well-designed evidence-based exercise programmes (Sherrington et

al. 2011). Two such programmes are the Falls Management Exercise (FaME) programme (Skelton et al 1999) and the Otago Exercise Programme (OEP) (Campbell et al. 1997). The FaME is designed as a group-based programme with a number of fitness components, such as strength and balance, flexibility and core stability with three progression phases; while the OEP is an individualised, home-based programme with strength and balance exercises that can be progressed in difficulty. A large RCT comparing the FaME and OEP with usual care indicated that both interventions were safe, with no significant differences in adverse reactions to the programmes; that both improved participants' balance confidence significantly compared with usual care; and, that, although the FaME programme significantly improved self-reported moderate to vigorous physical activity and reduced falls compared with the OEP, delivery of the OEP is less expensive than the FaME programme (Iliffe et al. 2014). Comparison of the delivery of the programmes indicated that the OEP would be the most appropriate for the development of an ACG system because it is targeted at individuals and can be home-based.

The OEP is an exercise intervention developed to increase strength, balance and endurance in older adults (Gardner et al. 2001). The programme includes: gentle warm up exercises; strength training exercises for the hip extensors, knee extensors, hip abductors and ankle muscles; balance retraining exercises including dynamic balance exercises knee bends, backwards walking, walking and turning around, sideways walking and single leg standing; and a walking plan. It can be individually tailored and increased in difficulty to adapt to the varied physical function levels of older people, as well as to improvements in physical function as a result of participation in the programme. The OEP is suitable for independent, home-based delivery with regular follow-up support provided by a health professional. The OEP has been rigorously investigated since its development stages in terms of efficacy to improve balance and prevent falls over time (Campbell et al. 1997; Campbell et al. 1999), health economics (Robertson et al. 2001a; Robertson et al. 2001b), and its application in practice (Gardner et al. 2002). The OEP continues to be backed by a number of systematic reviews (Robertson et al. 2002; Thomas et al. 2010; Sherrington et al. 2011).

None of the RCTs included in the systematic review reported in Chapter 2 had based their intervention on the OEP; however, additional literature searching identified a number of studies that had delivered the OEP in novel ways. An RCT investigating the

use of video-support to deliver the OEP, following three familiarisation sessions with a physiotherapist, has successfully been used with community-dwelling older adults in a group setting, with positive outcomes in balance, mobility and strength, and good attendance rates (Benavent-Caballer et al. 2016). One research group included evaluation of a prototype by older adults in the development of a webcam based system to deliver OEP with audio and video instruction, feedback on correctness of exercises and navigational tools to enable independent home-based use by older adults (Doyle et al. 2010). Older adults provided feedback on their preferences for the system, including a 'matchstick man' rather than video image of themselves displayed on screen; a 'ding' rather than verbal feedback which was considered distracting; large text and additional prompts to aid navigation. In a post-task interview, health benefits, feedback related to progress over time and monitoring were factors that participants felt would influence engagement with the system. An interdisciplinary team developed a system to deliver three OEP exercises using Kinect motion tracking to enable users, n=18 healthy older adults aged 56-76, to interact with virtual objects displayed on a screen (Im et al. 2015). Outcomes included participation level, performance outcomes in each game and changes in Berg Balance Scale and Timed Up and Go, with positive results following ten sessions of 30 minutes each conducted over four weeks. A recent study used a Kinect based rehabilitation system with games based on exercises from both the OEP and FaME programme (Meekes and Stanmore 2017), with twelve older people in assisted living facilities. The study used mixed methods, through observations, questionnaires and interviews following use of the system, to explore motivational determinants in terms of the TAM (Davis, 1989) and the eight elements of game enjoyment included in the Game Flow Model developed by Sweetser and Wyeth (2005). Results from this study indicated that enjoyment increased participants' motivation to use the system, and that confidence was another factor contributing to both their motivation for uptake and continuing to engage with the system. During one study, OEP exercises were displayed using a VR headset; however, it is not clear how interactive the system was, in terms of tracking participants' movements (Yoo et al. 2013). Whilst the results showed that the experimental group attained improvements in balance, gait and balance confidence comparable to or greater than the control group who completed traditional OEP exercise, limited information was reported on the usability and acceptability of the system in this population. Current research available

suggests that delivery of the OEP using ACG has been received positively by older adults and may have positive effects on some health outcomes. There is limited evidence on older adults' experience of completing OEP exercises displayed using a VR headset.

4.2.2 Interdisciplinary workshop

4.2.2.1 Overview of the technology

Following introduction to the OEP exercises, the research team considered available technologies that could be used for the ACG intervention. To allow users to interact with the virtual environment, motion tracking was required. The effect of a VR headset on user experience in this population was an outcome of interest; therefore, the proposed system was developed suitable for two viewing mediums: study condition A, displayed on flat screen; and, study condition B, displayed using the Oculus Rift VR headset.

The Kinect sensor (Microsoft Corp., WA, USA; Figure 4.1A) is a motion sensor technology that combines a red-green-blue (RGB) camera and depth sensor (Totilo, 2010) to track full-body movement in three dimensions (3D) (Figure 4.1B & 4.1C). The Kinect sensor can be used to track the user and collect data on their body position to control an avatar displayed on-screen. This permits controller-free active gaming which is suited to rehabilitative exercise for older adults, and the preferred controller style of older adults, compared to button only, as on a hand-held controller, and mixed gaming, such as Nintendo Wii (Gerling et al. 2012; Pham & Theng 2012). As the Kinect sensor has been developed for commercially available household entertainment games, the skeletal tracking has been developed to account for variances in user, in terms of size, shape, clothing and poses, and environment, in terms of lighting, furniture and other objects within the home environment (Zhang 2012). Other commercially available systems such as the Wii Fit balance board and dance step mats include elevated platforms; the Kinect system does not require the user to step onto or stand on an elevated platform making it a potentially safer system for older adults.

The Oculus Rift (consumer version 1) (Oculus VR., CA., USA; Figure 4.2) is a VR headset that features a lens panel display for each eye. The design of the Oculus Rift VR headset allows users to wear glasses, and the width between the lenses is easily adjusted

to suit the varying facial shapes of users. The foam padding around the faceplate and adjustable straps improve user comfort whilst wearing the headset. Additionally, the 2160x1200 pixel resolution and refresh rate of 90Hz represent a higher quality display than with earlier VR headsets, allowing users to experience a smooth immersive VR experience whilst preventing negative effects such as motion sickness (Desai et al. 2014). The headphones integrated within the system provide users with 3D sound effect. A sensor, usually placed on the desk in front of the user, picks up infrared light emitted by the headset to track the user's movement. This tracking is suited to use in sitting and standing, and walking within the 110° boundary of the sensor (www.oculus.com).

Unity 3D (Unity Technologies, San Francisco, CA.,USA.) is a game engine that can be used to develop video games for multiple platforms, including mobile devices, personal computers and websites. Both 2D and 3D games can be created using Unity (www.unity3d.com/unity). Unity 3D was chosen for the development of the ACG content as it has the largest development community support and readily accessible development tools making it appropriate for rapid development. Additionally, the research team had expertise and experience in developing with Unity3D.
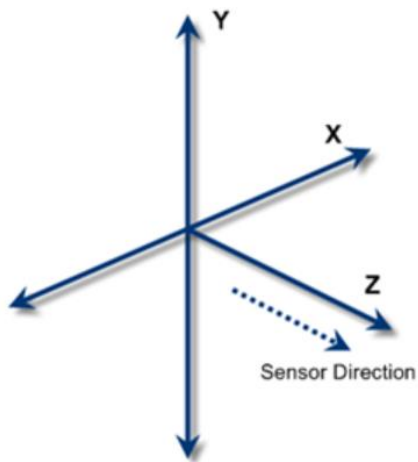
B   C
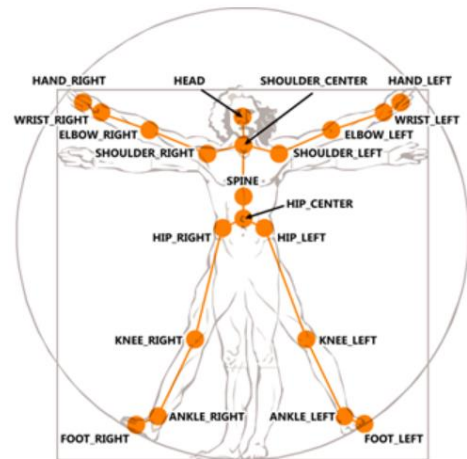
Figure 4.1 Images of Kinect

A- Image of the Kinect sensor; B- Tracking by the Kinect sensor is 3D; C- Joints tracked by the Kinect sensor

Figure 4.2 Images of Oculus Rift headset and sensor

4.2.2.2 Game design

At the first interdisciplinary team meeting, the research team were introduced to the OEP exercises, made familiar with some of the terminology and given demonstrations of the exercises. The development team were able to share their experience on whether they thought bodily movements involved in these exercises could be detected easily by the Kinect and, therefore, if they could be included in the game. They additionally shared insight on the different components of gaming that could be used to promote user motivation and engagement. Feedback, challenge and rewards are three mechanisms by which games can increase enjoyment, motivation and engagement (Lyons 2015). Feedback can be delivered in a number of ways both during and following play providing information on progress and performance that can be compared with previous achievements, with other players, or with specific goals. Feedback can also include delivery of rewards such as points, trophies and badges, progress on a progress bar, and unlocked levels. Challenge can be increased within games as a skill is acquired to maintain motivation, and can include the opportunity to compete with others (Lyons 2015). It was commented that many of these components mirrored techniques used to promote behaviour change to improve adherence to a health-related intervention; this had contributed to the rationale to extract BCTs from the papers included in the systematic review presented in Chapter 2. Table 4.1 provides examples of ACG features that map to BCTs. An understanding of the common ground between gaming and health helped develop a shared purpose on this project.

Table 4.1 Table of ACG features that map to BCTs

ACG feature	BCTs
Short verbal explanation of bodily movement required αβ	4.1 Instruction on how to perform a behaviour
Video demonstration or virtual instructor	4.1 Instruction on how to perform a behaviour 8.1 Behavioural practice/ rehearsal
Delivers OEP exercises displayed visually using ACG system αβ	8.1 Behavioural practice/ rehearsal 2.2 Feedback on behaviour
Visual and audio to indicate when user has been successful/ unsuccessful αβ	2.2 Feedback on behaviour
Progressing levels of difficulty	8.7 Graded tasks
Score displayed at end of challenge αβ	2.2 Feedback on behaviour 10.3 Non-specific reward
α – included in prototype 1; β – included in prototype 2	

At the end of the meeting both the disciplines had an improved understanding of the clinical requirements of the system, how the user could interact with the system to achieve the clinical aims, ways to optimise engagement, and potential issues to development. Table 4.2 outlines the potential of each OEP exercise to be delivered within a Kinect game. The team considered how difficult each would be to implement technically, scoring them from 0 (not difficult) - 10 (extremely difficult) and n/a when an exercise was considered unsuitable, accounting for components of each exercise that might affect the accuracy of the tracking and how difficult it may be to overcome these issues. Exercises that would be suitable for Kinect tracking were mainly those performed in the frontal plane using large bodily movements, for example sideways walking and leg abductions. Exercises considered to be difficult to implement included

those for which depth perception would be required by the Kinect camera, for example stepping forwards and backwards. Exercises considered unsuitable included those that the Kinect camera may not easily be able to track, for example heel-toe standing and walking as the Kinect camera cannot reliably track the narrow base when one foot is placed in front of the other, sometimes mistaking this as one leg. The team agreed to initially work on development of the four technically easiest tasks: Side Hip Strengthening; Knee Bends; One Leg Stand; Sideways Walking.

Table 4.2 Table outlining potential of OEP exercises to be delivered within the Kinect game

Otago exercise	Implementation within game	Difficulty to implement	Include
Walking	Not possible with Kinect only. Potential for stepping forwards and backwards, but depth perception tracking of Kinect difficult. Consider using a body gesture, such as an arm or leg movement, to initiate forward movement through the environment	2/10	?
Front knee strengthening	Difficult for Kinect to track as participant would be positioned in sitting	n/a	No
Back knee strengthening	Difficult for Kinect to track as lifting foot behind	n/a	No
Side hip strengthening	Kinect would be able to detect this movement easily Participant abducts leg to collide with object; for example, kicks a ball	2/10	Yes
Calf raises	Kinect may be able to track the height of participant to indicate they had raised onto	4/10	?

Otago exercise	Implementation within game	Difficulty to implement	Include
	toes; however, difficult as range of movement may be small		
Toe raises	Difficult for Kinect to track small movement of toes lifting	n/a	No
Knee bends	Kinect would be able to detect this movement easily Participant bends knees to duck below object; for example, ducks below a passing log	3/10	Yes
Toe walking/ heel walking	Difficult for Kinect to track small movement of heels/toes lifted. Depth perception tracking of Kinect difficult for walking.	6/10	No
Heel to toe stand/walking	Step one foot in front of the other – narrow base of support – unsure if Kinect can reliably detect this movement as one leg	n/a	No
One leg stand	Kinect would be able to detect this movement easily Participant stands on one leg in response to virtual environment; for example to avoid collision with a rising hazard	2/10	Yes
Sideways walking	Kinect would be able to detect this movement easily Participant steps sideways according to	3/10	Yes

Otago exercise	Implementation within game	Difficulty to implement	Include
	virtual environment; for example to avoid collision with oncoming hazard Kinect camera range will not allow 10 steps as per OEP		
Sit to stand	Kinect would be able to detect this movement Requires more strength by participants Similar to knee bends	n/a	No
Backwards walking	Depth perception tracking of Kinect difficult for walking	3/10	No
Walk and turn (figure of 8)	Depth perception tracking of Kinect difficult for walking. Number of direction changes involved to perform this exercise.	10/10	No

4.2.3 PPI – service providers consulted

During the two meetings with day centre managers, information was gathered about the day centre and the service users as summarised in Appendices 7 & 8. From these meetings, it was possible to gain an understanding of the physical and cognitive abilities of the service users, and that, although some activity preferences differed between the two centres, all service users enjoyed the social stimulation provided through the activities, and particularly enjoyed the competitive aspect of some of the games.

The two day centre managers were consulted and gave their support to the study being conducted within the day centre setting. Additional information was provided about

appropriate space to use within the centre and how the study would fit within the daily routine. The researcher (SH) also liaised with the day centre managers in developing appropriate procedures for screening and recruitment, and to discuss the potential eligibility of the service users to participate in the study. One of the managers was concerned that some of the service users may struggle with some of the items on the cognitive screening tool, the Mini-mental State Examination (MMSE), due to poor literacy and numeracy skills as they come from a lower socioeconomic area. The other manager stated that the group of service users had high levels of interest in exercise and falls prevention, regularly completing armchair exercise, fracture falls exercise and advice including how to get up from the floor. Within this group it was anticipated that physical limitations and health problems experienced by the service users may be a barrier to participation. Both day centre managers were happy to help identify potential service users who would be eligible and happy to participate in the study.

4.3 Design and development of prototype 1

Initially the concept for game design involved the player progressing along a path through a virtual environment and completing tasks based on the OEP exercises as challenges along the way. The decision was made to use mini-games, as short challenges the player would encounter along the journey through the virtual environment, to allow for the delivery of the number of repetitions or dose of exercises recommended in the OEP manual. Additionally, in comparison to playing one longer game, mini-games were the preference of all participants in a study to understand older adults' acceptance of an active gaming program (Evertsen & Brox 2015). The theme decided for the virtual environment was a forest walk. The rationale for this was that walking along a path within a forest park would be familiar to most of the study population, and is generally viewed as a pleasant experience. Initially, stepping on the spot was considered as the movement to allow the player to progress through the environment; however, due to time constraints and complications implementing this functionality, it was decided that the journey between mini-games would be automatic. As such, the player could view the virtual forest scene between mini-games as the bird flies, but had no control over this.

An avatar was chosen to represent the users' bodily movements tracked by the Kinect sensor and display them on screen. This provided real-time feedback on their

performance of the movements and additional feedback about the range and direction of movement required to successfully perform the tasks required for each game. An avatar is an interactive representation of a user (Meadows, 2008). Users of virtual worlds often customise their own avatars; their preferences have been explored (Ducheneaut et al. 2009). Relevant findings included that "older users" generally prefer an avatar that looks like an idealised version of themselves, but perhaps younger. However, it is more likely that female users would prefer an idealised version of self than in male users, who tend to prefer avatars that stand out. The age range of "older users" in this study was not specified but appeared to be significantly lower than our study population (possibly around 40 years old), thus limiting the applicability of its findings to the preferences of older adults in the current study. Initially a character that did not display user's bodily movements was chosen as an avatar for the game (seen later in Figure 4.7); this was chosen as it was easily accessed and free to use. We considered using a more lifelike avatar that was more like the user; however, it was decided it would be appropriate to use a white figure to display body movements rather than a character. This meant the avatar would provide feedback on users' movement but not necessarily appeal to the user with their appearance, or conversely have an appearance that the user did not find appealing.

Description of each exercise included from the OEP, along with the "Otago World" game design, and changes made following testing of the system during the interdisciplinary team meetings are described below.

4.3.1 Interdisciplinary collaboration

Development of the system was an iterative process based on repeated testing and reviews of the system by the team at regular meetings, which also facilitated discussion and resolution of queries and issues as they arose during the development process. Clinician members of the research team were not familiar with gaming but had experience of the physical and cognitive abilities of the study population group. The clinician researchers identified components of the system that non-gamers or older adults may have problems with, both cognitively and physically, and suggested ways to overcome ambiguities and inconsistencies in the system. This is reflected in the description of the games within the system described below.

4.3.1.1 Knee Bends

Otago exercise: Individuals can perform this exercise with or without hand support. They are instructed to stand with their feet hip width apart and their toes facing forward, then bend their knees and push their bottom backwards to perform each knee bend. The suggested dose is to perform 8 to 10 good quality repetitions.

"Otago World" game design: The avatar arrives at a forest area with a wall in front. The player stands on the "X" with their feet hip width apart. The aim of the game is for the player to duck below logs as they approach towards the avatar from the wall ahead. The motion of the user's head was tracked. Verbal instruction delivered by the system at the beginning of the game instructs the player to squat down by bending their knees to successfully avoid collision with the log, and then return to standing once the log has passed. Ten logs approach from the wall, as per the exercise prescription from the OEP.

System changes related to delivery: To allow users to achieve an appropriate dose, it was first considered to continue this game until the user had completed ten successful Knee Bends. To prevent continuous game play if the player was unable to complete Knee Bends, it was suggested that if the user had not completed ten successful Knee Bends by a pre-defined number of logs, for example twenty, the game could be terminated and the user would progress to the next game. This was considered to be unsuitable as users with lower level of function may be less successful in avoiding the logs, resulting in additional attempts. This may be demotivating as well as difficult for older people who are deconditioned or have functional limitations, as anticipated in the target population. Consequently, it was decided that only ten logs would approach, and that improved score, by increasing the number of successful repetitions, could be used as a measure of improved performance in the game.

To make study condition B, display using the VR headset, more immersive, it was decided to use first person viewing. As seen in Figure 4.3 below, users did not see the white avatar for this game when completing study condition B, viewing with the Oculus Rift head-set.

A   B

C   D
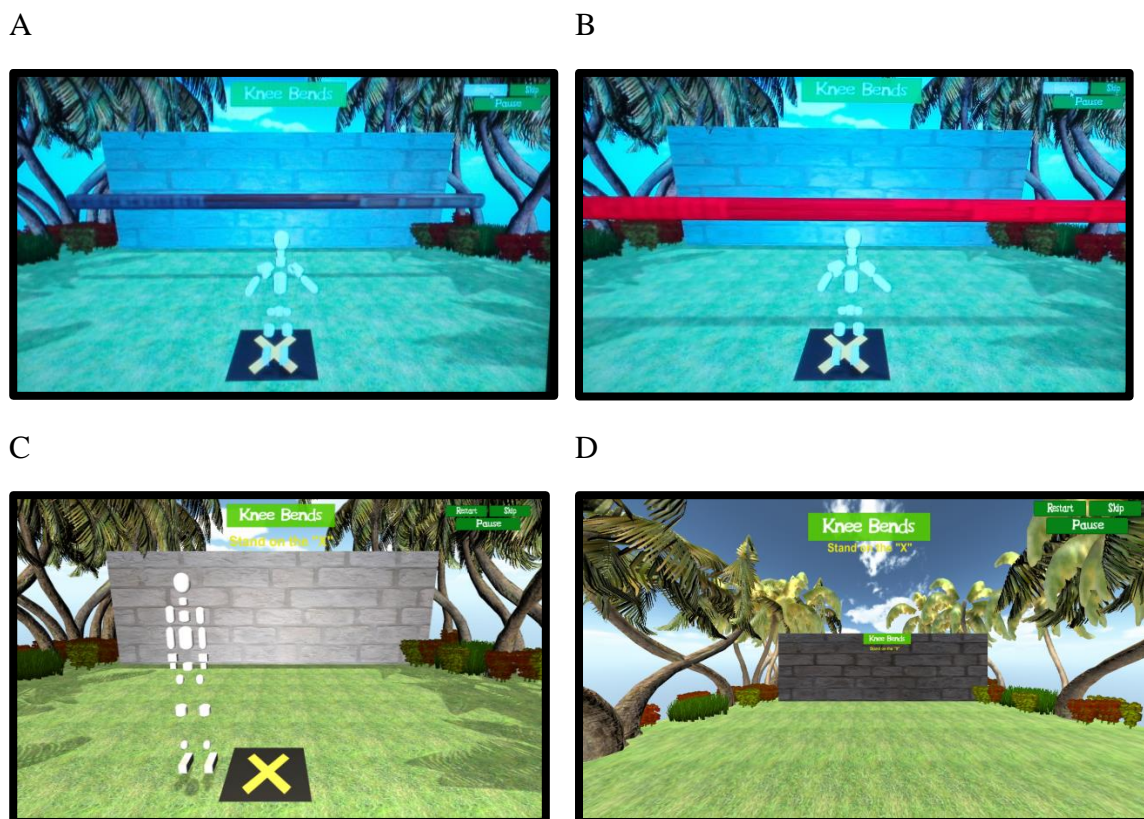
Figure 4.3 Knee Bends

> A – The aim of this game is to perform knee bends to duck below oncoming
> logs; B - As the logs approach they turn red to indicate when the user should
> perform the knee bend; C - Study condition A used third person view; D - Study
> condition B used first person view

System changes related to feedback: In the original discussions about game design, the
importance of tasks being achievable by older users was fundamental. The research
team discussed that timing of the games should be slow to ensure that users can safely
perform the exercises whilst being successful in the game. For Knee Bends this
included slowing down the speed that the logs travelled. This meant that users could see
each logs arriving for approximately 3 seconds, allowing them time to prepare for
performing each knee bend. Testing of the first version of the game highlighted that
users were ducking earlier than they needed to; users were ducking as soon as they saw
the log emerge from the wall and squatting down for the duration that the log was
visible. This resulted in the need to stay in position for a prolonged period while the log
passed. Performing this movement for a prolonged period was not necessary to be

successful in the game, nor was it required for completion of the OEP exercise. Holding a knee bend position is physically challenging, and may have caused difficulty and unnecessary discomfort for older adult users. Although it was also only necessary for the user to duck whilst the log was immediately overhead; successful completion of each Knee Bend was inconsistent as after performing the movement too soon, the user often stood up too soon. As such, although the user had performed a knee bend movement correctly, they would receive the feedback that they had been unsuccessful. This may have caused confusion and demotivation to continue play in the study population. This had not been identified by the developers, as they were familiar with gaming and the tasks required for such a game, therefore intuitively knowing that they only had to perform a knee bend when the log approached the figure on-screen. However, during clinician testing, the requirement of additional instruction and/or feedback by the developers, who gave hints when to duck and when to stand up again, indicated that the timing of the task was unclear. Changes were iteratively made to the game to prevent the anticipated prolonged Knee Bend movement during user testing with the older adult users. Initially, the position of the light source for the scene was modified to change the shadow that the log made to give the user more feedback on the position of the log approaching the user. To account for possible vision impairments and to reduce the cognitive load for older adult users, it was decided that a more definite indication of when to perform each knee bend would be appropriate. In the following iteration of the Knee Bends game, to make it clear to users that only a short duration knee bend was required for each log, the time to perform the knee bend movement for each passing log was signalled by the log turning red just prior to it passing overhead, prompting the user to perform the exercise to avoid collision (Figure 4.3). Clinician testing of this feature improved performance.

System changes related to calibration: When the game was first tested, the logs approached at a standard height, most likely based on the height of the developer. This meant that a taller user would have to duck significantly more than a user of shorter stature; this may have been an unachievable range of movement to expect from the study population. Additionally, at this point a user who was 160cm tall did not have to bend their knees at all to successfully avoid collision with the oncoming logs. This inconsistency with the challenge of the task dependent on the user's stature was addressed by calibration of the Kinect to the user's height prior to the start of gameplay. When the Knee Bends game begins and the Kinect has detected the user, it calculates

their height. The height of the log is then adjusted accordingly, and moves towards the user with an offset (value = 0.3f which is approximately 30centimetres), such that users can perform successful Knee Bends with an achievable range of movement.

4.3.1.2 Side hip strengthening (Leg Abductions)

Otago exercise: Individuals can use hand support for this exercise. The exercise is performed by lifting the leg slowly out to the side. The OEP manual instructs individuals to maintain an upright posture, keep their toes pointing forwards and to lower their leg slowly to rest their weight back over both feet briefly between repetitions. The suggested dose is to perform 8 to 10 good quality repetitions.

"Otago World" game design: This game was called Leg Abductions. The avatar arrives at a scene with a football net. The player stands on the "X" with their feet hip width apart. The user is informed by audio provided by the system that this game is for side hip strengthening. The aim of this game is to gently kick balls as they appear at the left or right side, by lifting their leg out to the side. In this game the Kinect motion sensor tracks the user's foot. Verbal instruction provided by the system at the beginning of the game also asks users to keep their leg straight and their foot facing forward. During the game, balls appear at the side of the avatar; when the user lifts there leg to collide with the ball, the ball disappears (Figure 4.4).

A   B
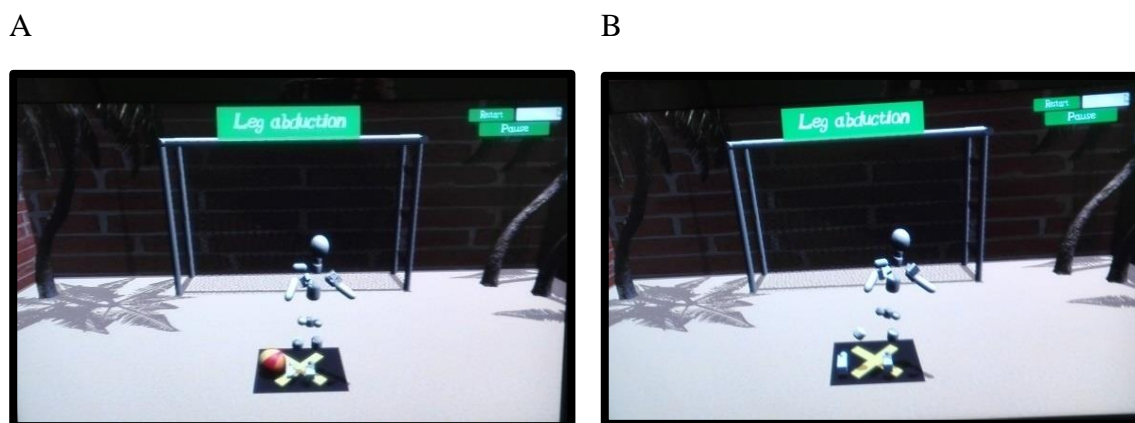
Figure 4.4 Leg Abduction

A – The aim of this game is to perform leg abductions to reach balls that appear to the side of the avatar; B – The ball disappears when it is reached.

System changes: Variables that were anticipated to affect older adults' usability of this game included: the length of time they had to reach the ball; and the ability to progress through the game if they were unsuccessful reaching a ball; the range of movement required to successfully reach the ball.

System changes related to delivery: In order to ensure that users performed each leg abduction in a controlled manner, it was agreed that each ball would appear for a prolonged period of time and that there would be time after one ball disappears prior to the following ball appearing to allow the user to return their leg to the floor, as per the OEP guidance. The time between each ball appearing was five seconds; as such, if the user successfully reached the ball it would disappear and they would return their leg to the floor awaiting the next ball for the remainder of the five seconds. If they were unsuccessful in reaching the ball, it would disappear after four seconds and the next ball would appear one second later.

System changes related to calibration: During testing of the first version of the Leg Abduction game by research team members, users were observed performing compensatory side bends during leg abductions to reach the ball. It was agreed that the range of movement required to successfully contact the ball with each leg abduction may be unrealistic for the study population. The research team considered that older adults may have limitations and that ability would vary in performance of this movement. Consequently, it was decided to incorporate a three repetition calibration of leg abductions on each side prior to commencing the 10 each side as per suggestion by the OEP. For each calibration repetition, the ball appeared at incremental distances (x + 0.20f, x + 0.25f and x + 0.30f). The y-axis value (the height of each ball) was also experimented with to ensure that users performed a leg abduction by raising their leg rather than stepping to the side. The system used the mean range achieved during these repetitions to assign the distance that the ball would be placed during the 10 repetitions of the game.

4.3.1.3 Sideways walking

Otago exercise: Individuals can use hand support or place their hand on their hips for this exercise. The OEP manual instructs individuals to take 10 steps to the side, keeping the hips forward and the knees soft, then repeat the other way.

"Otago World" game design: The avatar arrives at a forest scene lined by logs. Verbal instruction delivered by the system at the beginning of the game informed the user that this game is for stepping and balance. The aim of this game is to avoid the walls as they advance from ahead by stepping to the left and right. For this game, the Kinect tracked the users' head to determine if the user had collided with the wall. Verbal instruction included instruction that users should stand up tall with their hands on their hips and take steps to the side whilst facing forward. Due to the detection area of the Kinect camera and space restrictions in the area within the day centres that would be allocated to this study, it was not feasible for the user to take 10 consecutive steps to each side as recommended in the OEP manual. During the game five walls advance from each side, alternately from right and left. The width of the walls was altered to allow users to take 3-5 steps, dependent on stride length, to the side to avoid collision with each wall. This was considered to deliver a similar total number of sideways steps as the OEP manual.

System changes related to delivery: During clinician testing of the first version of this game, it was noted that the user had to perform the side steps quickly to successfully avoid collision with each wall. In order to ensure that the speed chosen would be appropriate for older adults, the research team iteratively trialled different velocities for the oncoming log wall. A speed was chosen that would allow users to successfully avoid collision with the wall whilst stepping safely in a controlled manner.

To make study condition B more immersive, it was decided to use first person viewing for the sideways walking mini-game. As seen in Figure 4.5, users did not see the white avatar for this game when completing study condition B, viewing with the Oculus Rift head-set.

A   B

C   D

Figure 4.5 Sideways Walking

A- Users begin on the X as the wall begins to approach; B – Users must step to the side to avoid collision with the oncoming wall; C - Study condition A – Third person view was displayed on the screen; D - Study condition B – First person view was displayed using the VR headset.

4.3.1.4 One leg standing

Otago exercise: This exercise can be performed with or without hand support. Individuals are instructed to stand tall and balance on one leg while keeping the support knee soft. The OEP recommends holding this position for 10 seconds on each leg.

"Otago World" game design: The task chosen for this game involved the user lifting their foot to avoid the water rising on either the left or right side (Figure 4.6). The user's foot is tracked during this game to determine collision with the water. The user is

instructed to stand on the "X" in the centre of a sandy area. Verbal instruction provided by the system at the beginning of the game instructed users to stand tall and look ahead as they raise their foot off the floor. The water rises for 10 seconds, during which the user should try to hold their balance on one foot to avoid it touching the water. To successfully avoid collision with the water the user must raise their foot 0.12f, the equivalent of 12 centimetres, from the floor.

System changes related to delivery: It was anticipated that some of the study population would not be able to maintain a One Leg Stand position for ten seconds. Considerations in light of this included: a control at the bottom of the screen to reduce the number of seconds for each One Leg Stand; instruction provided at the beginning of the game included encouraging users that if they were unable to maintain the One Leg Stand for the full duration to lift their foot again for the remaining time; scoring for this game would be a cumulative score of the number of seconds that the user's foot was elevated regardless of the number of times that it hit the water.

A   **B**

Figure 4.6 One Leg Stand

A – The aim of this game it to raise a leg to avoid the rising water; B – A splash shown provides feedback that the foot has hit the water.

4.3.1.5 Other changes to prototype 1 during the design and development process

In addition to the specific changes required for each game following initial testing, more general changes were made to the game. These included changes to the presentation, feedback and scoring, and music and sounds of the system, as well as changes to adapt to users' cognitive and physical abilities.

4.3.1.5.1 Presentation

Efforts were made to ensure that a contrasting colour was used for the text on screen. On testing of the initial version, it was difficult to read the text on some of the backgrounds. For example, as shown in Figure 4.7, yellow was easily read against the green trees but difficult to read against the light blue sky, and the pink text was easy to read against solid green but more difficult against a textured background. This is particularly important to avoid for older adults as research indicates patterned backgrounds make reading harder for this population (Hawthorn 2000). Web design guidelines for older adults recommend conservative use of colour and avoiding coloured text placed on a coloured background due to reduced visual perception and colour sensitivity in ageing (Kurniawancan & Zaphiris 2005). We considered that a gender neutral colour may be preferable to ensure the game would appeal to both male and female users. A number of different colours were trialled, before deciding to use white text displayed on a contrasting solid green box background; this ensured that all text was clear to read regardless of the background in each game. Colours in the blue-green range are not recommended for older people due to reduced sensitivity to these colours (Hawthorn 2000); however, during validation of the guidelines, older adults responded that this was only important when blue and green were used in close proximity (Kurniawancan & Zaphiris 2005).

Other changes included:

- The amount of information that was presented in text format on screen was reduced to allow for increased font size for ease of reading.
- Care was taken to ensure that the terminology used was standardised between the OEP, "Otago World" text on-screen and verbal instructions provided by the game (Inconsistencies can be seen in Figure 4.8 in the names of each game).

- It was decided to include a pause and restart button. This would allow users to restart the mini game if they wished, beginning at the instructions. This could be used if participants had not heard the instructions or understood them clearly, or if they had a technical problem that has affected their ability to use the game, or their experience of doing so. This would also allow them to replay a game if they wished. Older adults involved in the user-centred design for an active gaming system identified inclusion of a pause button as an important game feature (Proffitt and Lange, 2013).

A

B

Figure 4.7 Screenshots of an earlier version of the game

A- In this image, the yellow text is easily read in front of trees; the pink text difficult to read against the leafy textured background; B – In this image, the yellow text is difficult to read against sky and broken background; pink text is easy to read against solid green on left, but difficult to read against textured background on right.

4.3.1.5.2 Feedback and scoring

Feedback from an action can be intrinsic (from the sensory system of the individual performing the movement on how it felt) or extrinsic (augmented, additional feedback from an external source such as a therapist) (McBean and van Wijke 2012). ACG systems can provide extrinsic feedback that may be visual, auditory or sensory; this is often integrated, with ACG systems using multiple types of feedback (Lyons et al 2013; Lyons 2015). Feedback is associated with learning, self-efficacy and motivation; within ACG systems this can be provided both automatically and explicitly, during and following play (Kim et al. 2014; Lyons 2015). Performance feedback can include feedback on quality or outcome of a movement; knowledge of results is information about the outcome of performing a skill, while knowledge of performance describes the movement characteristics that led to the performance outcome (McBean and van Wijke 2012). Feedback should be meaningful, providing information to facilitate correct performance of the movement without overloading the user. Within the current ACG system feedback was used and modified to provide more in-depth feedback suited to the ability and experience of older adult users.

Knowledge of performance: Visual feedback is provided via an avatar on-screen that provides the user with real-time feedback on their performance of the movement. The user can use this to compare their movement to the correct movement required to successfully complete the task, providing some knowledge of performance. Prescriptive feedback providing knowledge of performance can help during the acquisition of a skill; however, due to technical difficulty to implement within the time frame, the current system is unable to provide prescriptive feedback, such as what went wrong and how to correct it. Additional feedback, providing knowledge of performance of the task and points to correct technique, was provided verbally by SH. As the user becomes familiar with the task required, reduction of this type of feedback allows the user to use internal feedback to monitor performance (McBean and van Wijke 2012).

Knowledge of results: Scoring is descriptive feedback and provides the user with knowledge of results; it may also provide a sense of accomplishment or evoke a competitive nature and a desire to improve (Proffitt and Lange, 2013), thus motivating users to continue to play. In a qualitative study to aid in the development of a system to

provide enhanced feedback during stroke rehabilitation exercise, both patients and therapists thought that providing numerical scores related to performance were a useful addition, suggesting that a user could compete with oneself over time (Loudon et al. 2012). The feedback provided by the ACG system developed was mostly descriptive providing knowledge of results; it indicated successful or unsuccessful movement. Concurrent feedback was provided via a tick or x displayed on screen to indicate successful completion of each repetition of the task. At the end of the four mini-games, terminal feedback was provided via a score board displaying the users' scores in the four games.

Other use of feedback within the system: The importance of auditory and visual cues to guide users' progress through use of the ACG system were considered, and implemented as described below:

- As referred to in the description of each mini-game, the ACG system provided auditory instructions provided by the system to introduce the task and the purpose of the task, ie "this exercise is for balance". Instructions also provide information about how to perform the task, emphasising important parts of the movement required. The audio instructions were recorded based on the written descriptions and instructions within the OEP manual, to match the instruction that might be provided by a therapist delivering the OEP as part of usual care.

- The ACG system presented challenges visually within the virtual environment which were completed by performing the respective OEP exercises; reacting to the challenges displayed guided the number of repetitions completed. In a study comparing participants following a paper-based exercise programme and exercises delivered by an interactive system, when following a booklet some participants did not complete the prescribed number of repetitions as they required memory to track the number of repetitions completed (Ayoade et al. 2013). Exercise guided by the system could ensure that users complete the required exercise dose optimising the therapeutic effect of the exercise.

- As well as collecting points and a score, older people have reported wanting a game to provide additional information on gameplay such as the time taken to play and the time left to play (Proffitt and Lange, 2013). Considering this, in the first version of the game, a timer was displayed in the top right hand corner of the screen, the number of points collected was displayed in the top right hand corner of the screen,

and a progress chart showing progression towards the end of the game was displayed in the top middle of the screen (Figure 4.7). On testing the game during interdisciplinary meetings, it was determined that it was difficult to understand what each numerical figure represented and difficult to pay attention to the score when trying to play the game. This rendered this feedback redundant. It was decided to remove all scores from the screen to reduce cognitive load of older adults.

4.3.1.5.3 Music and sounds

Background music in games has advanced from simple melodies or "chiptunes" to a "dynamic soundtrack" that supplements the information provided to the player to create atmosphere and changing dependent on the player's actions or performance (Seabrook 2008, Vass 2013). Older adults attending a workshop to try commercially available gaming systems reported that they found the music in these games annoying and noisy (Nawaz et al. 2014); in contrast, older adults involved in user-centred design of an active gaming intervention reported that music appropriate for the population was a key aspect in increasing motivation to play a game for exercise (Proffitt and Lange, 2013). We considered sourcing music that they might recognise and like as background music. We were also concerned that players might attempt to keep time with the music and, therefore, ensured that the music was chosen was not at a fast tempo. We decided on the *Disney World's Fantasyland Village Haus Full Area Music Loop* available at: https://www.youtube.com/watch?v=nHoSk5GM2Ps [Accessed 5 April 2017]; this included instrumentals of songs featured in Disney films.

Consideration was also given to the decline in hearing associated with ageing, which affects the types of sounds easily heard and understood by older people. Older people find lower pitched tones easier to hear, and may find synthetic speech harder to understand (Ijsselsteijn et al. 2007). Consequently, verbal instructions provided by the game were recorded by SH rather than generated electronically. When recording verbal instructions, speech rates were kept slow, less than 140 words per minute, with appropriate grammatical pauses (Fisk et al. 2009).

4.3.1.5.4 Users' physical ability

It was necessary to adapt each game to the capability of the user, for example, calibrating to the participant's height, range of movement, balance (described in detail in the description of each game). It was also decided to ensure that the area that recognises the character's collision with an object was large in order to ensure the user could be successful to improve their confidence and self-efficacy whilst playing. We discussed the potential to change this as the user gained more experience and accuracy, in that the area could become smaller to increase the challenge to the user; however, this was not implemented due to time constraints.

With the inclusion of older people with varied levels of function and their potential use of walking aids for daily activities, we considered that participants may require hand support whilst completing exercises, and an assistant close by to ensure their safety. The Kinect sensor is able to track two users; however, this game was adapted to only detect one person (the user) and to ignore a second body if it was beside or behind the primary user. There were some limitations to this: if the intended user (the participant) was not the first person detected (generally the closest user) the incorrect user (the researcher or the assistant) would be tracked; if the researcher or assistant crossed in front of the primary user, tracking would be lost and recalibration would be necessary to continue play.

The team discussed the use of a walking aid with the system. The Kinect is a reasonably stable tracking device; therefore, once the user was detected, a zimmer frame could be introduced. The tracking was tested with a zimmer frame in front of the user. The Kinect was able to hold tracking of the user fairly well, but there were some minor inaccuracies in the tracking of the user's lower limbs. Alternatively, options were explored, and use of one or two chairs for hand support did not affect the tracking within the games. It was possible to place chairs for hand support during all games excluding "side stepping".

Other similar considerations made for the study population included user clothing; many older women wear skirts that come below the knee, potentially blocking the Kinect tracking of the user's lower limbs. Additionally, large or baggy clothes may make it difficult for the Kinect to detect the user's joints accurately. This would be monitored in testing; results presented in Chapter 5.

4.3.1.5.5 Users' cognitive ability

Methods of delivering instruction on how to play the game were discussed. A previous study reported that older adults listened to the sounds and dialogues rather than reading the text or other information displayed on screen (Evertsen & Brox 2015) and guidance recommends using sound to complement visual information to overcome problems related to vision (Zaphiris et al. 2006). We considered written instructions, verbal messages and demonstrations. We decided to display short messages on screen, such as the name of the exercise to be performed, and instruction to "stand on the X". We considered that older people may have impaired vision and slowed cognition, and decided to record audio messages describing the exercises and providing instructions on how to complete them. Audio messages were recorded based on the written descriptions and instructions within the OEP manual.

Often in commercial entertainment games there is a lot of information provided about performance and progress through the game. Previous studies have conducted workshops testing commercially available games with older adults; this population express a preference for simple gaming interfaces (Nawaz et al. 2014). It was decided to keep the information provided on screen minimal to reduce the cognitive load, and consideration was given to ensuring that the information presented would be important and meaningful to the user. We iteratively piloted different types of feedback, such as a small score board in the top right corner, communicating information on successes and misses, on time completed and remaining, on steps and repetitions completed (an example can be seen in Figure 4.7). We were concerned that these may be distracting and decided to postpone feedback on performance until the end of the four games.

Due to both decline in visual perception and cognitive function associated with ageing, it was necessary to consider the font style in terms of size and colour for ease of reading. An example of this was the score board (Figure 4.8). The score board in the initial prototype presented the user's score for each game providing information on the successes and misses. The font was very small and difficult to read. Additionally, the information was not presented in a way that was easy to quickly understand, which may have been particularly confusing for older adult users. The score board screen was

revised to make the information shared easier to understand at a glance, and the font size could be made larger due to less information being presented.

A

B

Figure 4.8 A score board displays users' results for each game

A- The initial score board used a small font to present a large amount of information; B- The final version of the score board used for user testing; modification to improve both ease of reading and ease of understanding by users included reduction of the amount of information presented, changing the format of the scores, and increasing the font size.

4.3.2 PPI - Service user involvement

Input during the early design phase: After being showed images of the technology, including VR headsets, and receiving information about the study, the older adults expressed interest in the study. Many said they would be willing to participate, but that they would not be willing and/or able to travel to the university to take part. The outcomes of the meetings led to the decision to conduct the testing within the day centres rather than in the university research centre.

Input later in the development phase: During small workshop style meetings, older adults were given information about the ACG system and asked to provide feedback in order to refine the system. Many of the service users spoke about arthritis and osteoporosis as barriers to exercise, sometimes referring to having a good side and a bad side, and that their ability to complete the exercises would differ left/right accordingly. The Knee Bends exercise was most frequently noted by the service users to be perceived as most difficult, usually because of a "bad knee". The research team considered changing the order of the games so that users who were unable to perform the knee bend movement during the first game or had difficulty doing so were not disheartened; however, it was decided to reduce the depth required to be successful so that participants with physical limitations and mobility restrictions could complete the movements successfully if they initiated the movement and made a small knee bend.

The service users for the most part thought that the other exercises seemed easier, and some stated that they completed similar exercises at home, prescribed by physiotherapists for hip or knee pain or following orthopaedic surgery. Many expressed that they would prefer completing the exercises with chair support, to improve their confidence in performing the exercises. Most of the service users seemed very interested and keen to try the games, while some of the service users asked if they could try the game now, or said they would stand up to see if they could do the individual exercises. This provided a good indication that they may be willing to take part in the study when it commenced.

Day centre service users all stated that they could read the instructions and print within the games easily. They felt that all the colours were easy to see and read. Several service users reported that they thought the font size used on the score sheet at the end was too

small and that too much information was presented. Comments and suggestions were fed back to the research team and implemented as appropriate.

4.4 Piloting the system with healthy adults

Four healthy adults, all female aged 22-29 years, piloted study condition A and study condition B. Feedback on the system was positive with users commenting that they did not think the scene would be as realistic; however, some concerns were noticed during use of VR headset. It was identified that, in the VR headset condition, the journey between games 1 and 2, Knee Bends and Leg Abduction, was very quick. One user became unsteady and, when questioned, she said she felt like she had to duck under obstacles on the journey as she was during the game and that when she looked down whilst wearing the VR headset, it felt as though the ground was moving beneath her. The other three users also commented that it felt that they were going to fall or hit something and that the journey came to a very abrupt stop (Appendix 9). These findings enabled the researcher to plan to warn users about the speed of the journey, provide additional instruction that it is not necessary to react to the scene and that they will pass through automatically. We made the decision to encourage users to sit down during the break between games, although were unsure how this would affect the tracking of the user at the beginning of the next game, particularly if the user was slow from sit to stand. Comments from users about difficulty maintaining a straight line when performing Sideways Walking in the VR headset condition led to the decision to ensure that the researcher and a research assistant would stand on either side of the area to ensure participant safety. One user commented that they could not keep their balance during the One Leg Stand performed with the VR headset on; this enabled us to plan to have hand support available for all participants during participation in the study, particularly the VR condition.

4.5 User testing of prototype 1

The results of this phase are presented in Chapter 5. One main draw of novel technologies for exercise is their potential for independent use. Results from the user testing of prototype 1 indicated that participants had required high levels of support and additional instruction when completing a single use of each study condition. Repeated use may influence the level of support and additional instruction required. Additionally,

older adults' perceptions of the technologies may change over time due to increased learning and familiarity.

5 OLDER ADULTS' EXPERIENCE OF ACG AND VR – PHASE 1

5.1 Chapter overview

This chapter presents the methods and main findings from the first phase of user testing. This study assessed the safety, usability and acceptability of prototype 1 of the ACG system in older adults. The system was designed to deliver falls prevention exercise via ACG and VR, and developed for display on two viewing mediums, on a flat screen and with an Oculus Rift VR headset. Outcomes of interest were evaluated through observation, questionnaires and semi-structured interviews.

5.2 Background

As described in Chapter 2, ACG is a collective term used to define digital games that require players to interact with objects within a virtual context using some part of their body as, or to manipulate, a controller, and requiring some physical exertion. The use of novel technology through ACG to deliver preventative and rehabilitative exercise is increasing. Results presented in Chapter 2 indicated that ACG may improve health outcomes related to falls risk including balance, functional exercise capacity and cognitive function in older adults. These findings are supported by other reviews of the literature in this area (Miller et al. 2014; Chao et al. 2015). Whilst emerging evidence supports the use of ACG for health benefits, continued engagement with ACG is dependent on older adults' perceptions of the usability and acceptability of the systems. A scoping review indicated that older adults perceived the usability and acceptability of ACG for balance exercise positively (Nawaz et al. 2015). Feedback in the form of body awareness, visual feedback and scoring, competition and challenge, and social interaction contributed to positive attitudes to such interventions; however,

inappropriate speed and complexity and lack of support with set-up and use are factors that can reduce older adults' experience with ACG interventions (Nawaz et al. 2015). Chapter 3 reflected on how ACG systems specifically developed to meet the requirements and abilities of older adults may overcome some of the challenges older adults face when engaging with ACG.

Much of the available research in this area has included ACG systems displaying the content on screen; these systems have been well received by older people (Chao et al 2015; Nawaz et al. 2015; Proffitt et al. 2015). Technologies delivering fully-immersive virtual experiences, such as VR headsets, are becoming more accessible and affordable. These could provide older adults with a more immersive and realistic virtual environment (Lu and Mattiasson 2013; Howard 2017), potentially influencing their enjoyment and allowing them to experience activities that may not otherwise be possible. The use of VR headsets in healthcare has included the management of a number of types of conditions: physical, for example, upper limb rehabilitation post-stroke (Holmes et al. 2016); cognitive, for example, with Alzheimer's disease (García-Betances et al. 2015) and autistic spectrum disorder (Newbutt et al. 2017); psychological, for example, anxiety, phobias and eating disorders (Riva et al. 2016; Dascal et al. 2017). Most of these conditions are suited to treatment in sitting.

Some studies have recently explored the use of fully-immersive VR in standing, walking on the spot and treadmill walking in healthy participants (Nilson et al. 2016; Yoo and Kay 2016), and other clinical populations such as stroke (Corbetta et al. 2015), multiple sclerosis (Peruzzi et al. 2016) and Parkinson's disease (Kim et al. 2017). Of the studies included in the systematic review reported in Chapter 2, only one RCT included a fully-immersive VR system for balance training in older adults (Duque et al 2013). This study used a balance rehabilitation unit previously tested in other clinical populations (Suarez et al. 2000; Suarez et al. 2009). In a study investigating treadmill walking in a fully immersive VR environment, healthy older adults (n=11, mean age 66±3 years) were capable of using immersive VR with minimal adverse effects, although as expected were more dynamically unstable than their younger counterparts (Kim et al. 2017). Findings from a study that evaluated a VR system based on the OEP on women suggested that the experimental group (n=11, mean age 75.64±5.57) attained improvements in balance, gait and balance confidence comparable to or greater than the

control group (n=10, mean age 72.90±3.41) who completed traditional OEP exercise (Yoo et al. 2013). During this study, the experimental group viewed OEP exercises displayed using a VR headset; however, it is not clear how interactive the system was, in terms of tracking participants' movements. Additionally, although the positive outcomes show promise for such VR systems, this study reports limited information on the usability and acceptability of the system in this population. This study included only females; it may not be appropriate to generalise the findings for one gender to both.

ACG and VR provide a potential way to increase older adults' participation in exercise, such as strength and balance exercises. As previously described in Chapter 3, older adults' uptake and continued engagement with ACG and VR is dependent on their perceptions of the usability and acceptability of the systems (Davis, 1989; Nawaz et al 2015). There is limited research into older adults' use of a VR headset whilst completing exercises in standing; one study investigating this was conducted in Korea, did not include male participants, and provided limited data related to older adults' experience using the technology (Yoo et al. 2013). This study includes both male and female participants in a United Kingdom setting. It explores older adults' experience of a system developed to deliver exercise in standing based on the OEP, comparing their experience of ACG and VR displayed on screen and using the Oculus Rift, respectively. It builds on understanding of older adults' experience with ACG and VR systems and their perceptions of their usability and acceptability. This may optimise older adults' engagement with exercise interventions delivered using ACG and VR. Assessing older adults' use of such systems allows for modifications to be made to improve the usability and acceptability of such systems.

5.3 Aims and Objectives

5.3.1 Aim

The aim of the study was to assess the safety, usability and acceptability of a system designed to deliver falls prevention exercise via ACG and VR using two viewing mediums in older adults.

5.3.2 Objectives

i. Assess older adults' ability to safely complete falls prevention exercises delivered via ACG displayed on a screen and a head-mounted display, including additional assistance required.

ii. Explore older adults' perceptions of the usability of the system using the System Usability Scale (SUS)

iii. Explore older adults' perceptions of the acceptability of the system using the Attitudes to Balance and Falls-Related Interventions Scale (AFRIS) and semi-structured interviews.

5.4 Methods

5.4.1 Study design

The planned study design was a cross-sectional study with randomised conditions assessing single use of each viewing medium. This study was approved by the Office for Research Ethics Committees Northern Ireland (ORECNI; Appendix 10).

5.4.2 Setting

This study was carried out at two Age NI day centres located in urban areas: Anna House and Skainos Building. The study was carried out over one (screen condition only) or two visits (screen and VR conditions) conducted in the day centre that the participant attended.

5.4.3 Participants

Eligibility criteria are summarised in Table 5.1. Individuals were eligible for inclusion if they were aged over 65 years, were independently mobile with or without a walking aid, such that they were living at home or in supported living for older people, and had stable health as indicated by their GP and the Physical Activity Readiness Questionnaire (rPAR-Q; Thomas et al. 1992; Appendix 11). Older adults with a current acute or uncontrolled medical condition or health problems for which hospital admission or admission to a nursing home was necessary were excluded; as were individuals with significant cognitive impairment, as indicated by a score of <21 in the Mini-Mental

State Examination (MMSE; Folstein et al. 1975; Appendix 12), such that they would be unable to follow verbal or written instruction.

Participants were recruited through the two Age NI day centres; Anna House and Skainos. Anna House is described as a general centre for older adults who may present with functional limitations and require assistance with activities of daily living. Skainos Building is a social centre where service users have a higher level of physical function and therefore the purpose is to prevent social isolation. Users of both centres may present with cognitive impairment; however, on initial assessment following referral to the day centres, older adults with a diagnosis of a dementia-related disease would not be eligible to attend. Service users attended their day centre between one and five sessions per week, with Anna House having one session daily and Skainos Building having morning and afternoon sessions daily.

Study eligibility criteria were introduced to the day centre staff enabling them to identify potential participants. Potentially eligible individuals attended a short presentation during three sessions (Appendix 13). Following this, interested service users were pre-screened using the revised rPAR-Q and the MMSE. Participant information sheets (Appendix 14) were given to those who were eligible and interested in participating in the study. GPs of each eligible participant were contacted via letter (Appendix 15) and given an opportunity (14 days) to share any concerns about their participation, after which informed written consent (Appendix 16) was obtained from eligible participants. In order to explore barriers to participation in the study, a record was kept of the reasons for exclusion of those not interested or not eligible for inclusion in the study.

Table 5.1 Eligibility criteria

Inclusion Criteria	Exclusion Criteria
Males and females aged ≥ 65 years	Bed or wheel chair bound.
Independently mobile with/without walking aid	Significant cognitive impairment (MMSE <21), unable to follow verbal or written instruction
Stable physical health as indicated by GP and according to rPAR-Q	Current acute, or uncontrolled medical condition that would not tolerate physical activity
Fluency in English (verbal and written)	
Willing and able (MMSE >21) to consent	Unwilling or unable to consent.
rPAR-Q – revised Physical Activity Readiness Questionnaire; *MMSE* – Mini Mental State Examination	

5.4.4 Materials – study software and study hardware

The ACG content was developed using Unity 3D software (Unity Technologies SF Inc., San Fransisco, CA, USA). The software ran on an Alienware PC (Alienware Corps., Miami, FL, USA.) connected to a Microsoft Kinect Camera (Microsoft Corps. Redmond, WA, USA.) mounted on a tripod positioned at 85cm above desk height, to track user movements. The ACG content was developed for display using the two viewing mediums, a 21inch monitor (screen condition A) and the Oculus Rift head-mounted display (Oculus VR., Irvine, CA. USA.; VR condition B), described below.

5.4.5 "Otago World" mini-games

The ACG content is described in depth in Chapter 4. "Otago World" included four mini-games to deliver exercise tasks based on four exercises included in the OEP (Province et al. 1995): Knee Bends; Leg Abduction; Sideways Walking; One Leg Stand (Table 5.2). In each mini-game, the Kinect camera tracked the participant displaying their bodily movements on the screen as a white figure (Figure 5.1). At the beginning of each game, the participant was instructed to stand on the yellow "X" to allow for

calibration; the Kinect used this position as a reference point to track users' movements and success in each task. Additionally, prior to beginning the Knee Bends game, the height of the logs was calibrated to the height of the participant.

Table 5.2 "Otago World" mini-games

This table summarises the task required to complete OEP exercise in each mini-game, including dose, and variation in viewing style for study condition A and study condition B.

Otago game		Task	Dose	Notes
Game 1	Knee Bends	The user bends knees to duck below passing logs	10 repetitions	Screen condition A: third person VR condition B: first person
Game 2	Leg Abduction	The user raises leg to strike balls positioned to the side	10 repetitions each side	Screen (A) and VR (B) conditions: third person
Game 3	Sideways Walking	The user sidesteps to avoid oncoming walls	10 walls	Screen condition A: third person VR condition B: first person
Game 4	One Leg Stand	The user stands on one leg to avoid rising water	3 times 10 second stand each leg	Screen (A) and VR (B)conditions: third person

A

B

C

D
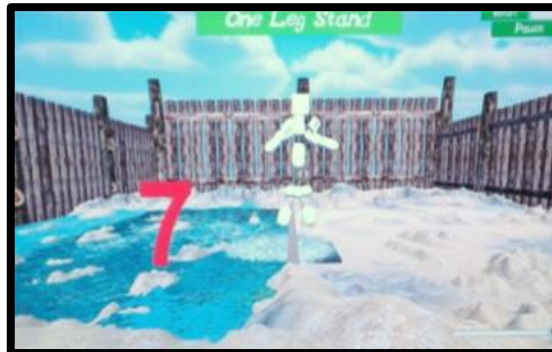
Figure 5.1 A-D Images of "Otago World" mini-games

A- Knee Bends; B- Leg Abduction; C- Sideways Walking; D- One Leg Stand

5.4.6 Interaction

Verbal instruction was provided by the system prior to the start of each mini-game. The verbal instruction introduced the exercise, included an explanation of the purpose of the exercise followed by a brief instruction on how to perform the exercise as per the instructions in the OEP:

"You have arrived at Game 1 – Knee Bends. This game is for leg strength. Duck below the passing logs. Do this by standing up tall and looking ahead, then squatting down by bending your knees. When the log turns red, duck below it. When it passes you can stand up again".

5.4.6.1 Knowledge of performance

Visual feedback was provided via a full-body skeleton on-screen that displayed the user's bodily movements (Figure 5.1) as tracked by the Kinect camera. Additionally, if a participant had difficulty completing a task, additional instruction was provided by SH. For example, participants were given additional instruction about correct foot position for calibration, maintaining upright posture during play and the direction of the movement required completing the Leg Abduction game.

5.4.6.2 Knowledge of results

In games 1-3 following each repetition, feedback was delivered via a green tick, indicating the success of the action, or a red 'X', indicating an unsuccessful action. Additionally, in game 2, "Leg Abduction", the balls disappeared when successfully reached by the participant's foot, and in game 4, "One Leg Stand", when the participant's foot was not raised sufficiently a splash would be shown from the water. Following completion of the four mini-games, a score board was shown, displaying scores for each game as well as a score rating in which stars became highlighted based on overall performance (Figure 5.2).

Figure 5.2 Image of screen displaying user scores

5.4.7 Study conditions

There were two study conditions to explore the effect of the viewing medium on the outcomes of interest:

A.   Use of the "Otago World" mini-games displayed on a screen (21")

B.   Use of the "Otago World" mini-games with a VR headset (Oculus Rift)

The study protocol outlined a plan for randomisation of study conditions. The purpose of this was to negate any impact on overall user experience that may be influenced by study condition order; for example, as the user becomes more familiar with the equipment, they may find it more acceptable, or, if users have a strong negative experience of the first study condition, it may negatively influence their experience of the following study condition. However, during a pilot of both study conditions, four healthy participants who were aged less than 65 years (mean age 25 years; range 22-29) required additional instruction or assistance on their first use of the VR headset and some reported feeling unsteady, particularly during the journey through the virtual environment between games. Following this the research team recognised that older adults would benefit from familiarisation with the system prior to the introduction of the VR headset; therefore, it was decided that all study participants should complete study condition A prior to study condition B.

The same mini-games were displayed for each study condition: during study condition A (study visit 1), the game was displayed on a 21inch monitor placed on a table directly below the Kinect camera; during study condition B (study visit 2), the game was displayed in the Oculus Rift (Oculus VR., Irvine, CA., USA.) VR head-mounted display. This enabled some of the mini-games to be displayed in first person, providing a more immersive experience (See Table 5.2 for notes on display).

5.4.8 Procedure

Two researchers (SH, NM) were present throughout testing. One researcher (NM) demonstrated the use of the system and mini-games, while the other (SH) highlighted key features of use and gave the participant the opportunity to ask any questions. Participants were advised to ask for any verbal or physical assistance that they may

require at any stage, and to make comment with regards to their ability to complete each task and difficulty experienced doing so. Participants were instructed to stand approximately 1.5 metres from the Kinect camera, to enable successful calibration (Figure 5.3). Participants were guided through the calibration and participation by the researcher (SH), who made hand-written notes on the ability of each participant to use the system and any comments made.
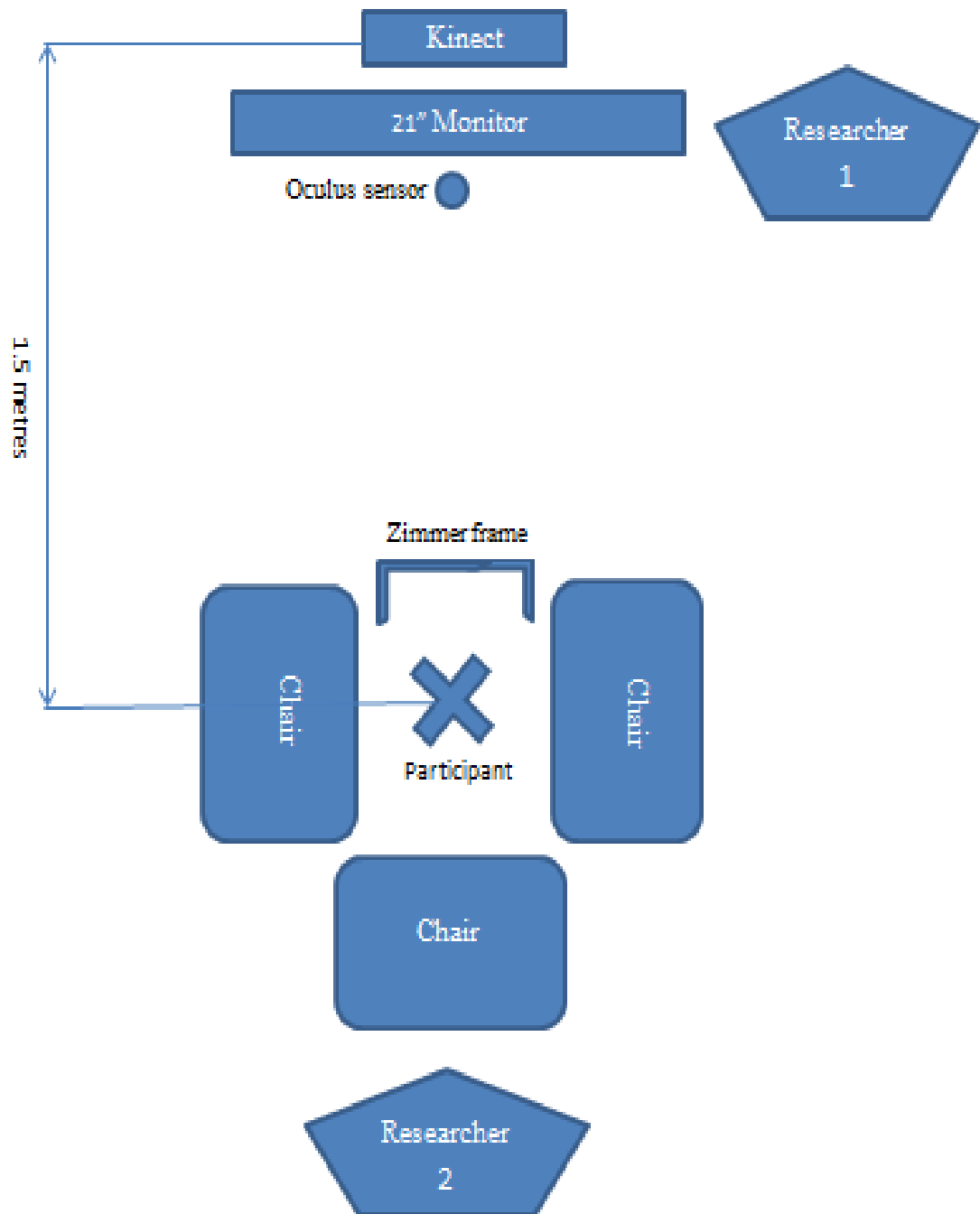
Figure 5.3 Diagram showing equipment set-up

5.4.9 Participant safety

The system was developed to be able to detect the movements of the user with a zimmer frame placed in front to enable participants to use their own walking aid for hand support where required. It was not possible for the system to detect the user's movement with a delta rollator due to the bulk of its frame obstructing the Kinect camera view of the participant's lower limbs. During games 1, 2 and 4, as tasks were performed standing on the spot, it was possible to place a chair on either side of the participant for hand support, and another chair behind the participant should they require a rest. The purpose of this was threefold: to improve participants' confidence, as falls efficacy scores indicated that most participants had high concern about falling; to enable them to play despite physical limitations, and it was expected that some may have low exercise tolerance due to de-conditioning; and, to ensure safety, so that participants could reach for hand support should they lose their balance. Additionally, one researcher (NM) stood behind the participant to provide close supervision at all times. Due to the nature of the task in game 3 Sideways Walking, it was not possible to position chairs for hand support. To ensure participant safety, as informed by the ACG system's pilot with healthy adults in Chapter 3, the two researchers stood at either side of the gaming area to closely supervise participants during this game. Participants were able to complete Sideways Walking with no hand support or with their walking stick or zimmer frame.

5.4.10 Outcome measures

5.4.10.1 Outcomes of interest

5.4.10.1.1 Safety

A safety checklist pro-forma, piloted on non-study participants prior to use, was completed by SH for each participant. Both safety components and practical aspects of using the equipment were documented during participants' use of the system (Appendix 17).

5.4.10.1.2 Usability

Details of additional verbal and physical assistance required, as well as any participant comments were recorded on the safety pro-forma (Appendix 17). Sessions were video recorded for retrospective analysis to supplement hand-written observations.

The SUS, a reliable and valid measure of perceived usability (Brooke 1996), was completed by participants after each study condition. This scale comprises 10 items (Table 5.3) which are rated on a 5-point Likert scale ranging from 1 "strongly disagree" to 5 "strongly agree" to subjectively evaluate their perceptions of the ease of use and usability of the system. Scores above 70 indicate acceptable usability, while scores below 50 indicate unacceptably low usability (Bangor et al. 2008). This scale has recently been used to evaluate falls prevention interventions (Meldrum et al. 2012; Uzor & Baillie, 2014; Vaziri et al. 2016).

Table 5.3 Items of the System Usability Scale.
I think that I would like to use this system frequently.
I found this system unnecessarily complex.
I thought this system was easy to use.
I think that I would need assistance to be able to use this system.
I found the various functions in this system were well integrated.
I thought there was too much inconsistency in this system.
I would imagine that most people would learn to use this system very quickly.
I found this system very cumbersome/awkward to use.
I felt very confident using this system.
I needed to learn a lot of things before I could get going with this system.

5.4.10.1.3 Acceptability

Acceptability was measured using the AFRIS. The scale is based on the Theory of Planned Behaviour and includes 6 items (Table 4.4) which are rated on a 7-point Likert

scale ranging from 1 "strongly disagree" to 7 "strongly agree". The AFRIS items consider the following components of acceptability: attitudes; subjective norm; perceived behavioural control; identity; and, intention (Yardley & Donovan-Hall 2006 & 2007).

Responses to the individual items of the AFRIS and any comments made by participants were explored in a semi-structured interview, recorded after the practical aspect. Interview questions were developed based on the aims of the semi-structured interviews (see Appendix 18), which included: to explore user experience and views on using the equipment; whether they found it useful and enjoyable; to identify any concerns; to explore appropriate usage time and setting; and, to gain understanding into barriers and facilitators to future participation. Semi-structured interviews lasted approximately 10 minutes, depending on the amount of information shared by the participant.

Table 5.4 Items of the Attitudes to Balance and Falls-Related Interventions Scale.

Doing falls prevention exercise using virtual reality would be good for me.

Doing falls prevention exercise using virtual reality would make me feel confident.

Other people whose opinions matter to me (e.g. family, friends, doctor) would think it was a good idea for me to do falls prevention exercise using virtual reality.

If I wanted to, it would be easy for me to do falls prevention exercise using virtual reality.

I am the kind of person who should do falls prevention exercise using virtual reality.

I intend to do falls prevention exercise using virtual reality if I am offered the opportunity.

5.4.10.2 Initial assessment

On study visit 1, prior to use of the game, demographic information was collected including participant age, gender, falls in the last 12 months, walking aid use and number of medications (Appendix 19).

5.4.10.2.1 Physical function

Physical function was assessed using the Short Physical Performance Battery (SPPB; Guralnik et al 1994; Appendix 20), a reliable test validated to measure three components of lower-extremity function in older people: chair rise for strength and endurance, standing balance in three different stances, and gait speed over 4 metres using their usual walking aid. The maximum score was 12, indicating excellent function. The SPPB scores were used for classification of participants' functioning level. Participants who were independently mobile and scored ≥10 in the SPPB were included in the higher functioning group. The lower functioning group included participants who had functional limitations related to activities of daily living and/or mobility and scored <10 in the SPPB. The study protocol outlined that participants in the higher functioning group would be invited to use the VR technology first.

5.4.10.2.2 Balance

Balance was assessed according to the Berg Balance Scale (BBS; Appendix 21), a 14-item scale developed as a clinical measure of functional balance in older adults that has shown psychometric properties of validity and reliability (Berg et al. 1991 & 1995). It is scored from 0-56, with scores indicating the following: 41-56 = low fall risk; 21-40 = medium fall risk; and 0 –20 = high fall risk.

5.4.10.2.3 Fear of falling

Fear of falling was measured using the Falls Efficacy Scale-International (FES-I; Appendix 22), a 16-item scale which measures the level of concern about falling during activities inside and outside the home on a four point Likert scale (1=not at all concerned to 4=very concerned), with the total score indicating the following: low concern: 16–19; moderate concern: 20–27; high concern: 28–64. The FES-I has been shown to be a valid measure with excellent internal and test–retest reliability for older adults (Yardley, Beyer et al 2005).

5.4.10.2.4 Mental health

Mental health was measured using the 15-item Geriatric Depression Scale (GDS-15; Appendix 23). A score higher than 5 points is suggestive of depression and scores of greater than 10 almost always indicates depression (Brown & Schinka, 2005). This

scale has demonstrated internal consistency reliability and construct and criterion validity in older adults with low and high functional impairment (Friedman et al. 2005).

5.4.11 Data analysis

Statistical analysis was performed using SPSS software (version 23). The data was checked for normality, then appropriate descriptive analyses were used to summarise participant characteristics and outcomes. Interviews were transcribed, and interpretation, synthesis and data reduction undertaken independently by two members of the research team (SH, NM), applying an inductive content analysis approach. After familiarisation with the data, a coding frame was developed to facilitate coding of key concepts related to acceptability of equipment, followed by identification of the relevant themes as they emerged.

5.5 Results

5.5.1 Recruitment

Thirty-eight Age NI day centre service users attended one of three information sessions. 15 service users were not interested in participating in the study for various reasons: health reasons (n=8); no interest (n=6); too many questions to determine eligibility (n=1). Eligibility screening was completed for 23 participants; individuals were excluded due to cognitive impairment (n=5), registered blind (n=1) or inadequate level of mobility (n=1). Reasons for exclusion were disclosed to the manager of the individual's day centre; none of the reasons for exclusion were unexpected. Letters were sent to the GPs of 16 service users who met the criteria for inclusion in the study. GPs were advised to contact the research team within two weeks if they had any concerns about an individual participating; n=0 GPs responded with concerns. Nine of the sixteen eligible service users were invited to participate in this stage of testing. Participants were invited to participate in the two study visits when their consent had been obtained. When it was deemed that enough data had been collected to inform changes required for the next stage of the study, the remaining eligible service users were informed that they would be contacted again to participate in the next stage of the testing.

5.5.2 Demographics

Nine participants (5 female/ 4 male) were included in this study; their mean (SD) age was 82.2 (6.3) years. Many participants used a walking aid at home (n=5) or when outside their home (n=7). Six out of nine reported having fallen at least once in the last 12 months; none of these resulted in hospital admission, fallers did not contact a health care professional about their fall, no faller reported severe injury and only n=1 reported bruising. Four participants had a high risk of falling, as indicated by BBS score <40, while the remaining five attained a BBS score >45; however, only one participant scored ≥10 in the SPPB, eligible for inclusion in the higher functioning group. The decision was made to deviate from the protocol to allow participants with an SPPB score <10 to participate in the study prior to testing with higher functioning participants. Participant characteristics are presented in Table 5.5.

Table 5.5 Characteristics of study population

Characteristic		Result
Age, mean (SD)		82.2 (6.3)
Gender, n	Male	4
	Female	5
Walking aid use at home, n	None	4
	Walking stick	2
	Rollator	2
	Wheeled zimmer frame	1
	Wheel chair	0
Walking aid use outside home, n	None	2
	Walking stick	3

Characteristic	Result
Rollator	2
Wheeled zimmer frame	1
Wheel chair	1
Fallen in last 12 months, n	6
Falls in last 12 months, mean (SD)	1.78 (3.2)
Number of medications, mean (SD)	4.5 (3.4)
Mini-Mental State Examination, mean(SD) *Range of measure 0-30; higher score = better*	27.6 (1.9)
Short Physical Performance Battery, mean (SD) *Range of measure 0-12; higher score = better*	6.4 (2.7)
Berg Balance Scale, mean (SD) *Range of measure 0-56; higher score = better*	42.4 (12)
Falls Efficacy Scale – International, mean (SD) *Range of measure 16-64; lower score = better*	36.3 (11.1)
Geriatric Depression Scale – 15, mean (SD) *Range of measure 0-15; lower score = better*	2.86 (2.4)

The initial results suggested incongruity between participants' BBS and SPPB scores, with mean scores indicating participants had a high level of balance (BBS >40) but low physical function (SPPB <10). Shapiro-Wilk tests indicated that the data for SPPB and BBS were normally distributed, and a linear relationship was observed (Figure 5.4); therefore, Pearson's correlation co-efficient was used and showed a significant correlation between SPPB and BBS ($r = 0.79$, $p = 0.011$). One outlier obtained 54/56 on BBS and 5/12 on SPPB (red circle on scatter plot); an explanation may be that, although

this participant was independent and active daily, they had an old knee injury that prevented them from performing sit to stand without using their hands, automatically scoring no marks in the lower limb strength item of the SPPB.
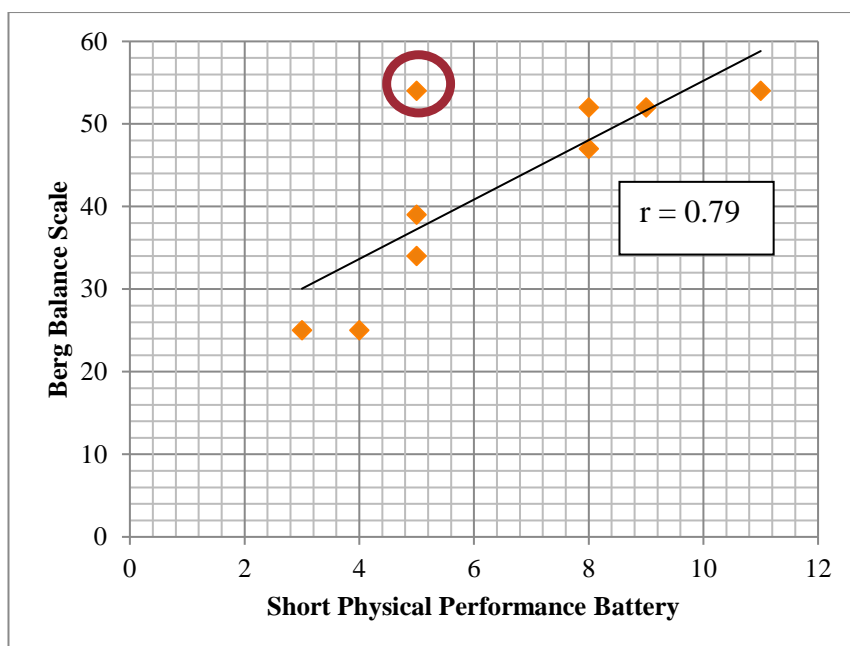
Figure 5.4 Scatter plot showing correlation between BBS and SPPB scores

5.5.3 Safety and usability

5.5.3.1 Study condition A

Study condition A, the "Otago World" mini-games displayed on screen, was completed by all participants (n=9); of these, n=4 also completed study condition B, the "Otago World" mini-games displayed on Oculus Rift VR headset. Reasons for not completing study condition B included: n=2 refused; n=1 due to sickness on study visit 2; n=2 were considered unsafe to test study condition B due to high risk of falls (n=1) and inability to follow game on-screen (n=1). Completion of each study condition is described below.

The overall rate of completion of the "Otago World" mini-games in study condition A by study participants (n=9) was 82.9% (Table 5.6). Mini-games were not completed due to: reduced confidence (for example, n=4 did not wish to attempt Sideways Walking as they would not have hand support or their walking aid); physical limitation (for example, n=1 was unable to perform Knee Bends to sufficient depth due to wearing a

knee splint that limited their range of movement); fatigue (for example, n=1 started but did not complete Leg Abduction due to the number of repetitions); or a technical difficulty (for example, the Kinect would not detect one participant during Knee Bends so this game was skipped). Additional hand support was frequently used by participants (23/29 = 79%), using two chairs placed at either side of the participant (15/29= 51.7%) or one chair or walking stick (8/29= 27.5%). Two hand support was most frequently used by participants, particularly for Leg Abduction (6/8= 75%) and One Leg Stand (6/9= 67%) games. Additional instruction was required by participants frequently (21/29= 72%), particularly during the Leg Abduction game (7/8= 88%). No users required physical assistance during study condition A. One safety concern was reported during study condition A, when a participant became unsteady whilst rising from a knee bend; the participant regained their balance without requiring physical assistance and was able to resume play.

5.5.3.2 Study condition B

The overall rate of completion of study condition B by study participants (n=4) was 62.5% (Table 5.7). Game 3 Sideways Walking and game 4 One Leg Stand that could not be completed due to a technical difficulty. One participant did not complete any games in this study condition as they did not wish to continue after becoming unsteady (detailed below). Additional hand support was required by participants for all games in this study condition. Participants most frequently used two hand support (4/5= 80%). Participants were provided with additional verbal instruction frequently (4/5= 80%) and physical assistance was required on three occasions. Two safety concerns were reported during study condition B: n=1 became unsteady and felt disorientated with the VR headset on during the journey to the first game, started game 1 Knee Bends, but decided to discontinue with testing; n=1 ducked in response to the virtual environment during the journey between games 1 and 2, but regained their balance with minimal physical assistance and was able to resume play.

5.5.3.1 Summary of technical difficulties

Technical difficulties experienced and the measures taken to overcome them during piloting and testing with older adults are detailed in Appendix 6. The most common technical difficulties were related to problems with calibration; these included the

Kinect not detecting the participant to enable the start of play. This may have been due to participant posture, objects in the environment such as the chairs for hand support obstructing view, the Kinect detecting the member of the research team who was standing behind participant to provide supervision rather than the participant. Instruction was provided regarding maintaining upright posture, raising the upper limbs and maintaining a hip-width foot stance to allow the Kinect to recognise the participant more easily. Efforts were made to reposition objects and/or the researchers out of view of the Kinect sensor during calibration, as required, whilst maintaining participant safety. Following these measures, SH would press restart to re-calibrate. If the game would not calibrate, it would be necessary to close down and reopen the software to reset the system. If the Kinect was still unable to detect the participant, the game would be skipped. The software for study condition B, had a fault that did not permit skipping game 3 Sideways Walking. Four participants had skipped this game due to low confidence during study condition A. As we could not skip for study condition B, we planned to let the game run while the participant rested; however, this game would not calibrate for any participant so no participant was able to complete study condition B game 3 Sideways Walking or game 4 One Leg Stand.

Table 5.6 Summary of study condition A

	Number of participants who were able to complete	Two hand support	One hand support	No hand support	Additional instruction	Physical assistance	Safety concerns
Knee Bends	7/9 (n=1 physical limitation; n=1 technical difficulty*)	3/7	1/7	3/7	5/7	none	N=1 unsteady rising on one knee bend
Leg Abduction	8/9 (n=1 started then skipped this game)	6/8	2/8	0/8	7/8	none	none
Side Stepping	5/9 (n=4, physical limitation/ reduced confidence)	0/5	N=2 used walking stick	3/5	3/5	none	none
One Leg Stand	9/9	6/9	3/9	0/9	4/9	none	none
%	29/35* = 82.9	15/ 29 = 51.7	8/29 = 27.5	6/29 = 20.7	21/29= 72%	0	1
* technical difficulties not included in calculation for completion rate							

Table 5.7 Summary of study condition B

	Number of participants who were able to complete	Two hand support	One hand support	No hand support	Additional instruction	Physical assistance	Safety concerns
Knee Bends	2/4 (n=1 physical limitation; n=1 became unsteady)	2/2	0/2	0/2	1/2	3/4 (unsteady)	N=1 became unsteady during journey
Leg Abduction	3/4 (n=1 did not continue following unsteady)	2/3	1/3	0/3	3/3	0/3	N=1 ducked during journey
Side Stepping	0/3 (technical difficulty*)	n/a	n/a	n/a	n/a	n/a	n/a
One Leg Stand	0/3 (technical difficulty*)	n/a	n/a	n/a	n/a	n/a	n/a
%	5/8=62.5*	4/5= 80	1/5= 20	0	4/5= 80	3/7=43	
* technical difficulties not included in calculation for completion rate							

5.5.4 Usability and acceptability

5.5.4.1 SUS scores

The SUS was completed by participants following study condition A (n=9); the median (IQR) was 70.0 (56.25-75.0), indicating acceptable usability (Figure 5.5; Bangor et al. 2008; Vaziri et al. 2016). No participant scored study condition A ≤ 50. It was also completed by participants following study condition B (n=4); the median (IQR) was 52.5 (40.63-55.0). Two participants scored study condition B ≤ 50, indicating unsuitably low usability. During the semi-structured interviews, participants reported satisfaction with the system in terms of enjoyment and ease of use: "it was presented well and I enjoyed it actually… I found the system, once it was explained to me, it was quite simple to use. It was quite easy… Admittedly I did get a bit tired at the end there but I thought it was quite good" (Pt16, 77 years, male). For study condition A, while 7/9 participants indicated agreement with the SUS item 4, "I think that I would need assistance to be able to use this system", 7/9 also agreed, or strongly agreed, with item 7, "I would imagine that most people would learn to use this system very quickly".
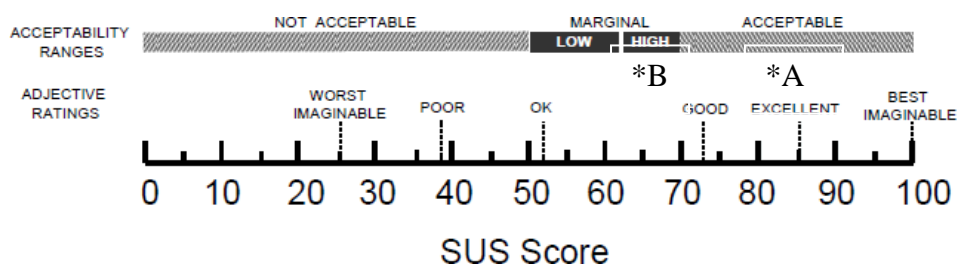
Figure 5.5 Acceptability ranges and adjective ratings provide additional interpretation of SUS scores. SUS scores for study conditions indicated by *.

5.5.4.2 AFRIS scores

The AFRIS was completed by 8 participants (n=1 did not complete the AFRIS due to time constraints). Results showed positive attitudes to the intervention; 35.5 (32.25-36.75) out of 42. All items scored similarly to normative values (Table 5.8; Yardley & Donovan-Hall 2007; Illiffe et al. 2014). Answers to the AFRIS were further explored during the semi-structured interviews.

Table 5.8 Median AFRIS scores compared to normative values

Item	Score (median)	Normative value (median)
Attitudes	6.0	5.5
Subjective norm	6.0	5.5
Perceived behavioural control	6.0	6.0
Identity	6.0	6.0
Intention	6.0	6.0

5.5.5 Qualitative findings

Five participants completed semi-structured interviews after interacting with the VR system to explore their attitudes to the "Otago World" mini-game. Interviews were scheduled for study visit 2 following completion of both study conditions. Four participants had completed both study conditions, and completed the semi-structured interview after study condition B. One additional participant who had not completed both study conditions due to sickness completed the semi-structured interview after study condition A. The remaining four participants who did not complete study condition B did not complete a semi-structured interview. Comments made by participants (n=9) whilst using the system and hand-written notes made during testing of the system were tabulated, and provided additional qualitative data. Participants' attitudes to the "Otago World" game were influenced by several factors which were categorised into three over-arching themes: User experience; motivation; and, ability to participate. All quotes could be coded into one of these themes, and some were coded to more than one theme. A summary of themes, sub-themes, category groups and participant quote examples are included in Table 5.9 to support the detailed description in the main text.

Table 5.9 Themes, sub-themes, categories and example quotes

Themes	Sub-themes	Categories	Examples
User experience	Enjoyment of "Otago World" game	-	"I think it would be very good, you know, it sounds interesting" (Pt5, 86 years, female); "Game seemed a bit long" (Pt5, 86 years, female); "Very good. Yes, I thought it was interesting, just to be able to see around and see all the different scenes… But it would have taken a bit of getting used to?" (Pt13, 79 years, female); "All in all I was very happy with the system… It was presented well and I enjoyed it actually… Admittedly I did get a bit tired at the end there but I thought it was quite good" (Pt16, 77 years, male).
	Virtual reality	Choice of display Problems Comfort Feedback	"Well I liked the screen. The headset, well it wasn't bad, but it seemed to be faster" (Pt13, 79 years, female). "I think the headphones make you a wee bit giddy…. particularly when it's speeding up to you, and over these bridges, you're not sure whether you're getting over the bridges… It was fast…. Maybe I could be able to trust it, you know it's a feeling you get" (Pt1, 85 years, male); "I didn't feel right…. I think if I'd too much of it, I would feel sick… I'm ok but I know myself it could have been dodgy for me… with the headset the movement was throwing me off a bit I think, and making me feel sort of disorientated and dizzy" (Pt5, 86 years, female); "Oh, it's unsteadying that. Isn't it? False horizons." (Pt7, 81

Themes	Sub-themes	Categories	Examples
			years, male); "I didn't like so much the one with the glasses on. I preferred the screen because you could orientate yourself with your surroundings, whereas with that you couldn't. Or at least I couldn't" (Pt7, 81 years, male); "It was a bit fast…. It gave me a light head" (Pt13, 79 years, female). [On comfort of headset] "That's fine" (Pt5, 86 years, female); "I think it was harder to get the balls with the headset" (Pt13, 79 years, female); "it's all on coordination. I found a couple of them I was actually too close, when I thought in my mind it was clear" (Pt16, 77 years, male).
	Ease of use	Ease of use /usability Learning Repetition	"I could probably use it… easy enough" (Pt1, 85 years, male); "I found the system, once it was explained to me, it was quite simple to use. It was quite easy" (Pt16, 79 years, male); "easy enough to follow" (Pt 20, 70 years, male); "Once you got the first one over, you knew how low you had to go to get under. If the log came at variant heights, it would make it more difficult" (Pt16, 79 years, male); "It's hard to put a time on it. I mean I only did one session there and, I mean, it would take a lot of improvement" (Pt16, 77 years, male); "If we were doing the same thing I don't think it would take all that long" (Pt5, 86 years, female); "It shouldn't take very long, because it's repetitive isn't it? I suppose if you did it say 4 or 5 times you'd have it sussed out by then. Well you should have (Pt7, 81 years, male).

Themes	Sub-themes	Categories	Examples
Motivation	Enjoyment	-	"I wouldn't be all that terribly fussed" (Pt1, 85 years, male); "Because you'd come so familiar with it that it would be useless" (Pt7, 81 years, male).
	Exercise preference	Exercise experience Game vs exercise	"I tend to think it would make it more enjoyable, because if you are on your own and doing ordinary exercises it becomes very mundane and you get disinterested quickly. But if you have the animation and that it makes it much more enjoyable (Pt16, 77 years, male).
	Perceived usefulness	General Personal	"I think it would be very helpful. As I said, it helps with both balance and coordination" (Pt16, 77 years, male); "I'm not so sure whether 'I' would find it useful. No I don't think I need to do it" (Pt1, 85 years, male); [on usefulness of scores] It is, it is, you see the areas that you need to improve on… [motivating] Yes. Very much so" (Pt16, 77 years, male).
	Intention for use	Future use Acceptable dose	"Well I come to the Age NI twice a week now, and probably twice a week or once a week even would be beneficial" (Pt7, 81 years, male); "as frequently as I needed to maybe if you rested a bit more in between you might improve your ratings" (Pt16, 77 years, male); "Once

Themes	Sub-themes	Categories	Examples
			you get used to the system and it is beneficial to you, you know, where you do it is irrelevant… using the system and if you are using it properly and it does tend to help your balance and that you could get to the stage were you are using it by yourself. I mean that would be the aim really" (Pt16, 77 years, male).
Ability to participate	Age and ability	Age Adapting to ability Physical limitation Confidence/Self-efficacy Cognitive	"I play them at my own speed…whenever I go in, I can do whatever I want at my speed" (Pt1, 85 years, male); "balance is more my problem" (Pt5, 86 years, female); "there's only this left leg that I wouldn't be able to put out the same as the right leg…. That's the only thing that really stops me" (Pt13, 79 years, female); "it was difficult in some movements, which I always have anyway in ordinary circumstances" (Pt16, 77 years, male); "So you just lose that confidence you had, maybe because you're getting older and wiser but nonetheless" (Pt7, 81 years, male); "you just had to be really alert to get your foot out and your foot in" (Pt13, 79 years, female).
	Support	Social	"I would prefer to have somebody… Well for instance you saying to me "Sit down, the

Themes	Sub-themes	Categories	Examples
		Practical	chair is right behind you". You know it is going to be there, but still, it gives you the confidence to know that somebody is actually telling you that" (Pt7, 81 years, male);"If you need instructions, there's always an instructor there if you want to consult them. And they can say to you, "This is the way you do that machine". Either you set it up, or you time it to whatever.

5.5.5.1 User experience

Participants were asked their views on playing the game; user experience was related to enjoyment of the game, VR experience and ease of use. Participants reported finding the game "interesting" and enjoyed playing:

> "All in all I was very happy with the system… It was presented well and I enjoyed it actually… Admittedly I did get a bit tired at the end there but I thought it was quite good" (Pt16, 77 years, male).

> "Very good. Yes, I thought it was interesting, just to be able to see around and see all the different scenes… But it would have taken a bit of getting used to." (Pt13, 79 years, female).

All participants expressed a preference for study condition A, preferring their experience playing the game displayed on screen version rather than using the VR headset:

> "I didn't like so much the one with the glasses on. I preferred the screen because you could orientate yourself with your surroundings, whereas with that you couldn't. Or at least I couldn't" (Pt7, 81 years, male).

Low levels of satisfaction with using the VR headset were related to user experience; participants described the problems they had faced, including feeling disorientated:

> "I think the headphones make you a wee bit giddy…. particularly when it's speeding up to you, and over these bridges, you're not sure whether you're getting over the bridges… It was fast…. Maybe I could be able to trust it, you know it's a feeling you get" (Pt1, 85 years, male).

> "I didn't feel right…. I think if I'd too much of it, I would feel sick… I'm ok but I know myself it could have been dodgy for me… with the headset the movement was throwing me off a bit I think, and making me feel sort of disorientated and dizzy" (Pt5, 86 years, female).

> "Oh, it's unsteadying that. Isn't it? False horizons" (Pt7, 81 years, male).

> "It was a bit fast…. It gave me a light head" (Pt13, 79 years, female).

Participants described their perceptions of the ease of use of the system; they described the requirement for a period of "getting used to" and "figuring" or "sussing out" the system. Participants often recognised each game from the instruction and demonstration provided by the researcher prior to game play; additionally verbal instruction was provided via the system prior to each game:

"quite sufficient, but you just had to concentrate more on them" (Pt7, 81 years, male).

"I found the system, once it was explained to me, it was quite simple to use. It was quite easy" (Pt16, 77 years, male).

Comments made by participants during play described use of feedback on performance to guide them during the game:

"Once you got the first one over, you knew how low you had to go to get under. If the log came at variant heights, it would make it more difficult" (Pt16, 77 years, male).

(Excerpt from video recording of Pt16 during "Leg Abduction" game)

Pt16: "Not bad, but I was kicking my foot forwards earlier rather than side backwards".

R1:   "How did you find it to correct?"

Pt16: "It was all right once I figured it out".

Perceptions of the learnability of the system were mostly positive, and were influenced by factors such as repetition within the game:

"It shouldn't take very long, because it's repetitive isn't it?"(Pt7,81 years, male).

"If we were doing the same thing I don't think it would take all that long" (Pt5, 86 years, female).

Learning was also a factor for motivation as participants suggested that enjoyment may decrease if users become over-familiar with the games:

"Because you'd come so familiar with it that it would be useless".

5.5.5.2 Motivation

Participants were asked about their intention for future use of the game, including their views on appropriate dose, setting and supervision, and factors that may influence their motivation for future use. Participants described their enjoyment of the game, their exercise preferences including their previous exercise experience and the perceived usefulness of the game.

In general participants reported that they found the game enjoyable. One participant was regularly physically active in their social life, playing golf and bowls and attending the gym weekly, while two others completed exercise prescribed by a health care professional either at home or at a day care facility. Some participants reported higher levels of enjoyment while playing the game than with general exercise:

"Oh, make it more enjoyable, because at least you have something to think about" (Pt7,81 years, male).

"I tend to think it would make it more enjoyable, because if you are on your own and doing ordinary exercises it becomes very mundane and you get disinterested quickly. But if you have the animation and that it makes it much more enjoyable" (Pt16, 77 years, male).

Perceived usefulness was coded as sub-theme that may influence motivation. This was reported both generally and in terms of what participants felt the game was useful for; participants felt that it would be useful for the limitations they had previously described:

"It gives *me* confidence" (Pt7, 81 years, male)

"I think it would be very helpful. As I said, it helps with both balance and coordination" (Pt16, 77 years, male).

(Discussing the usefulness of scoring in the game)

> "It is, it is, you see the areas that you need to improve on… (Researcher [R1]: is it motivating?) Yes. Very much so" (Pt16, 77 years, male).

However, one participant indicated they did not identify as someone who should use the game:

> "I'm not so sure whether 'I' would find it useful. No I don't think I need to do it" (Pt1, 85 years, male).

In relation to intention for future use, all participants stated that they would be happy to try the game again. Some made suggestions as to the dose, setting and supervision level they thought would be appropriate:

(Excerpt from semi-structured interview with Pt5, 86 years, female)

> R1:   Do you think it would be something you would like to use in the future?
>
> Pt5:   Yes.
>
> R1:   And how frequently do you think you would like to use it?
>
> Pt5:   Maybe once a week.
>
> R1:   And if you were to use it, how long would you like to do it for each time?
>
> Pt5:   I would say half an hour would be enough.
>
> R1:   Em, do you think it is something that you would like to do at home, or here, or what kind of setting?
>
> Pt5:   I think here, in company would be better.
>
> "Well I come to the Age NI twice a week now, and probably twice a week or once a week even would be beneficial" (Pt7, 81 years, male).

Participants also reported a willingness to play the game as much as would be required both to see improvements in performance in the game and achieve goals such as improved physical function to enable independent play:

> "Again, using the system and if you are using it properly and it does tend to help your balance and that you could get to the stage were you are using it by yourself. I mean that would be the aim really" (Pt16, 77 years, male).

5.5.5.3 Ability to participate

Participants reported the effect of their level of function on their perceived ability to play. They described the effect of age-related physical limitations such as impaired balance, coordination and muscle weakness on their performance of the game as well as in daily activities:

> "Not being able to balance is more my problem" (Pt5, 86 years, female).

> "There's only this left leg that I wouldn't be able to put out the same as the right leg…. That's the only thing that really stops me" (Pt13, 79 years, female).

> "It was difficult in some movements, which I always have anyway in ordinary circumstances" (Pt16, 77 years, male).

References to their beliefs in their own capability reflected reduced confidence; however, participating in the game had a positive effect on their confidence:

> "So you just lose that confidence you had, maybe because you're getting older and wiser but nonetheless" (Pt7, 81 years, male).

> "It proves to me I can do it, it's been a long while since I did anything like that" (Pt7, 81 years, male).

Requirement for additional support to facilitate the use of the game was recorded in the handwritten notes taken during testing; this included hand support and additional instruction provided. The requirement of additional support, both practical and social,

was also reflected as a preference in comments made during the semi-structured interviews:

> "I don't think I could have done that thing with the ball without holding on" (Pt7, 81 years, male).

> "I would prefer to have somebody… Well for instance you saying to me "Sit down, the chair is right behind you". You know it is going to be there, but still, it gives you the confidence to know that somebody is actually telling you that" (Pt7, 81 years, male).

One participant, who is regularly physically active including individual gym exercise, highlighted the importance of having support to enable his independent exercise:

> "If you need instructions, there's always an instructor there if you want to consult them. And they can say to you, 'This is the way you do that machine'. Either you set it up, or you time it to whatever. Or they'll say, 'We don't recommend you do more than 10 minutes on a particular machine'" (Pt1, 85 years, male).

5.5.5.4 Overlapping categories

During data analysis interrelated categories were identified. The "repetitive" nature of the system was coded as influenced their acceptability of the game in terms of: the participants' ability to participate in playing the game, in terms of learnability; their user experience, as it enabled ease of use; and, also their motivation to play, in that repetitiveness may reduce motivation to play over time.

(Excerpt from semi-structured interview with Pt7, 81 years, male.)

> R1: How long do you think it would take you to learn the system, and get used to it?

> Pt7: Oh, that's a difficult one. It shouldn't take very long, because it's repetitive isn't it? I suppose if you did it say 4 or 5 times you'd have it sussed out by then. Well you should have.

R1: When you say it's repetitive you're using that to say it would be easy to learn, but do you think it would quite quickly that that could have an impact on your interest and motivation to do it?

Pt7: Oh, very much so. Because you'd come so familiar with it that it would be useless.

5.6 Discussion

5.6.1 Summary of findings

This study provides information on older adults' experience of a VR system designed to deliver exercise for falls prevention. All participants (n=9) completed a single use of the VR game displayed on screen, while n=4 completed a single use of the VR game displayed using a VR headset. There were no safety concerns during use of the system; however, participants often required additional support, such as hand support, to use the system. Attitudes to the system were generally positive, and participants' SUS scores indicated acceptable usability of the screen display, but marginally low usability of the VR headset display. Preference of the screen version was also evident in the semi-structured interviews with participants following use of the system. Overall results from the semi-structured interviews and comments recorded during use of the system suggested that the participants viewed the VR game, particularly when displayed on screen, as an acceptable mode of exercise; they found the game enjoyable and useful. They reported willingness to use the system in the future, confidence in their ability to do so and a preference for use within the day care setting rather than at home.

5.6.2 Safety and usability

As described in Chapter 2, current evidence has not provided sufficient information to establish whether ACG can be recommended for unsupervised use by older adults. This systematic review reported that most interventions were supervised, but noted inconsistencies in the reporting of adverse events and assistance required by participants. Another recent systematic review assessing the use of the Wii Fit in healthy older adults (Manlapaz et al. 2017) identified supervision and monitoring as procedures commonly used to address safety and technical issues in included studies, and a systematic review of home-based gaming interventions (Miller et al. 2014) found that assistance and supervision were often required, particularly with older adults.

This study, therefore, included measures to address potential safety issues, including close supervision and the availability of hand support. The use of these was monitored in order to inform a future study. No adverse events occurred during use of the system; however, all the participants used the hand support provided during at least one game and additional instruction was often provided to ensure correct performance of the exercises embedded within the VR game. Participants reported a preference for using the system with support, both practical and social, with comments made during use and during the semi-structured interviews suggesting that such support improved their confidence to play the game. Similar findings were observed in an RCT, included in the systematic review reported in Chapter 2, investigating balance exercises performed using the Wii Fit (Rendon et al. 2012). Safety measures included close supervision, a walking aid placed in front and a chair close by should the participants require a break. Authors highlighted cause for concern that none of the participants (n=40), of which 6 (15%) regularly used a walking aid, were able to complete the ACG programme without availing of assistance, and suggested that independent practice would not be feasible in this population. In the current study, 5/9 (56%) participants regularly used a walking aid, so it was expected that additional support would be required. Consequently, the findings of this study suggest that measures, such as providing hand support, may allow older adults with mobility limitations, such that they require a walking aid, to safely participate in falls prevention exercise delivered via ACG.

Findings of this study showed that older adults required high levels of additional instruction and support during a single use of this ACG system. It is unclear whether this level of additional support would be required if older adults were given the opportunity to become familiar with the system and the tasks included. Repeated exposure to the system may provide older adults an opportunity for learning. This may improve familiarity with the requirements of the games, and reduce their reliance on additional instruction during play. Additionally, repeated use of the ACG system may improve older adults' confidence during use contributing to reduced requirement of additional support. Reduced requirement of instruction and support during use of the ACG system may facilitate progression to more autonomous use with reduced supervision. Such approaches have been used in the testing and design of mobile and digital interventions where autonomous use is a requirement for the behaviour (Crane et

al. 2017). This study compared users' first impressions of a mobile app to reduce excessive alcohol consumption with their perceptions after at least two weeks using the app. Feeling lost and unsure of what to do whilst using the app was reported following first use of the app; however, following a period of familiarisation this perception was no longer expressed by app users (Crane et al. 2017).

5.6.3 Acceptability

Acceptability of the VR system by the participants was influenced by their user experience, including enjoyment, ease of use and perceived usefulness. Participants reported enjoyment and found the ACG exercises more enjoyable than traditional exercise. Studies investigating the use of commercially available games, such as the Wii Fit, in older adults have reported similar levels of satisfaction (Franco et al. 2012, Hughes et al. 2014). One male participant in the study suggested that with repeated use over time users may become overfamiliar with the games; a similar finding was made in evaluation of the iStoppFalls system in which some male users felt the games became boring and were not challenging over time (Vaziri et al. 2016). This suggests that, without variety and progression, ACG interventions may lose their novelty for older adult users, becoming mundane and uninteresting, potentially limiting one of their major advantages over traditional rehabilitative exercise interventions.

While the sustainability of a falls prevention intervention relies on optimising adherence and retention, it is also important to consider the acceptability of an intervention in terms of uptake. The most common reason for declining to participate was related to individuals' belief that they would be unable to participate due to health conditions or physical limitations (n=8). Due to ethical considerations, further exploration of these individuals' health and reasons for declining to participate was not permitted; this limits our ability to draw conclusions on whether this reason provided was warranted or was influenced by low self-efficacy. Six day centre service users declined to participate as they were not interested in the intervention. It is not possible to draw conclusion on whether these individuals were not interested in participating in exercise or, more specifically, in an ACG exercise intervention. In a hospital-based study using the Wii Fit for rehabilitation in older adults, 10/80 eligible individuals stated their reason for not consenting to participate in the study was that they wanted conventional therapy rather than Wii Fit (Laver et al. 2012). Additionally, a discrete choice experiment within this

pilot RCT explored factors such as mode of delivery, challenge, cost and recovery associated with the therapy options (Laver et al. 2011). It found that, at baseline, mode of delivery of therapy, namely Wii Fit versus conventional therapy did not influence participants' choice of treatment, but that over time this became a more important factor, with participants preferring conventional therapy. Although these findings challenged the belief that ACG interventions would be more enjoyable and motivating than traditional therapy, two suggestions this research team provided included the use of interventions specifically developed for older adults and increased number of sessions to allow older adults to become more familiar with the technology.

5.6.4 Familiarisation with VR

Prior to testing with older adult users, the decision was made to deviate from the protocol and omit randomisation of the viewing mediums. This study involved introducing novel technology to older adults, and thus should allow for a period of familiarisation. It was anticipated that introduction to the virtual environment of the game displayed on screen would prepare participants for the scene displayed using the VR headset. Other studies have used familiarisation methods with older adults such as viewing a paper prototype of a bespoke game (Nawaz et al. 2014) or playing commercial Kinect games prior to testing a bespoke Kinect game for falls prevention (Evertsen and Brox 2015).

On reflection, the decision to deviate from the protocol was appropriate as following use with the screen display two participants were assessed as unsafe to use the VR headset display due to falls risk (n=1) and inability to follow visual cues within game (n=1). Additionally, two participants did not wish to continue as they were not interested in using the VR headset. During use of the VR headset, one participant ducked in response to passing a branch of a tree during the automatic journey through the virtual environment; a similar response was observed in the healthy pilot of the game (described in Chapter 4), suggesting that this would be a common problem with this viewing medium. One participant also became unsteady using the VR headset during a journey through the environment between the first and second games. It had been anticipated that this journey may be too fast following the healthy pilot, and participants were given reassurance prior to this section of the game and offered the

option of sitting for this journey. Consequently, participants that used both viewing mediums preferred the screen display over the VR headset. Ageing is associated with reduced sensitivity of sensory receptors (Goble et al. 2009); this is associated with an increased reliance on visual feedback for postural control (Simoneau et al. 1999; Woollacott and Shumway-Cook 2002). Older adults' experience of VR may be influenced by the disruption/ absence of visual feedback from the real environment when wearing the VR headset. Similar findings were also observed in balance-impaired adults aged 59-69 years who reported feeling insecure when playing a VR skiing game displayed using the Oculus Rift VR headset compared with on screen (Epure et al. 2016). As an extension of this, it may be suggested that further opportunity for repeated use of the ACG system may contribute to familiarity with the system. Becoming familiarised with the system may influence older adults' perceptions of the usability and acceptability of the system.

5.6.5 User experience limited by technical issues

Of note, none of the participants were able to complete the last two games using the VR headset due to technical difficulties. Technical issues were frequently experienced during use of the system; these were recorded along with measures taken to overcome them to enable play (Appendix 6). These steps were carried out by SH or direct instruction was given to the participant to allow continuation of gameplay. This would limit independent use of the system by older adults in its current format; however, it is unclear if repeated use of the system would enable older adults to learn strategies to overcome the most common difficulties, for example, standing with feet hip width apart and raising one or both arms to allow successful calibration. Nonetheless, other studies evaluated older adults' experience using ACG and VR exercise interventions have reported that users experienced frustration interacting with virtual systems (Proffitt et al. 2015) and that users criticised technical issues with such systems (Vaziri et al. 2016); this highlights that technical issues are a problem common to bespoke systems designed to deliver rehabilitative exercise and that such issues may negatively affect the acceptability of the system. In this study, participants did not comment on technical issues during use or in the semi-structured interviews. It is possible that the participant did not notice the technical issues, or were not concerned by them as they were fixed by SH. It could also be suggested that, participants did not comment on the technical issues as they wanted to respond with what they felt was the appropriate answer. The

intervention was introduced and delivered by the researcher that conducted the semi-structured interviews; this provides a potential limitation to qualitative findings.

5.6.6 Baseline of population compared to other literature

Many studies investigating the use of ACG to deliver exercise interventions to older adult populations have employed restrictive eligibility criteria, for example, excluding participants who require a walking aid. This limits the applicability of the findings to a small sub-group of older people defined by the eligibility criteria. This study aimed to be as inclusive as possible to explore if the system was suitable for use by older adults attending day centres, including those with physical limitations requiring walking aids and increased risk of falls. These populations were considered as in most need and with most limited access to falls prevention interventions. Reflective of this, the mean scores for the SPPB and the BBS for the participants indicated lower functioning and increased risk of falling. Reflecting on RCTs included in the systematic review completed in Chapter 2, nine out of thirty-five measured balance using the BBS, and most of the included studies (23/35) included healthy participants. Participants in the current study had similar BBS scores to studies including participants who were classified as having a balance impairment (Chao et al. 2014), lived in assisted living (Padala et al. 2012), attended physiotherapy (Bateni et al. 2012) and falls clinics (Hagedorn et al. 2010).

5.6.7 Limitations of this study

There are a number of limitations related to the study population and study design. The sample size of this study was small, potentially limiting the ability to draw conclusions based on its findings. However, research on the number of participants required for usability testing indicates that 5-10 participants are sufficient (Faulkner et al. 2003; Virzi et al. 1992); with some suggestion that multiple small tests are more valuable in allowing iterative changes to be made based on findings with smaller numbers of users (Nielson et al. 2000). As such, the current sample size is considered to have provided sufficient information to inform the development of the next stage of the study. The findings of this study suggested that older adults perceived ACG to be an acceptable way to deliver exercises for falls prevention; however, recruitment and conduct of the study was in day centres for older people. The specific population and setting may limit the generalisability of the findings to all older adults; however, the study population

included those at high risk of falls, thus providing information about the perceptions of those most in need of an ACG intervention for strength and balance exercise. Additionally, participants were volunteers who may have had an interest in exercise and/or gaming, and may, therefore, have had more positive perceptions and experience with the ACG system. As previously mentioned above, the same researcher recruited participants, conducted testing of the ACG system and semi-structured interviews; this may have influenced feedback from participants. The researcher was always present during use of the ACG system; this social interaction may have affected user experience. Also, each participant completed only one session with each study condition. Observations and feedback from further use and familiarisation with the ACG system may have provided additional information on the safety, usability and acceptability of the system in this population.

5.7 Conclusion

The findings of this study suggest that an ACG system developed to deliver OEP exercises was perceived positively in terms of safety, usability and acceptability by older adults. Participants had a strong preference for a screen display compared to using an Oculus Rift VR headset. Additional instruction and support was frequently required by participants when completing a single use of each study condition. Future research could explore the influence of repeated use on the level of support and additional instruction required. Additionally, older adults' perceptions of the technologies may change over time due to increased learning and familiarity.

6 DESCRIPTION OF PROTOTYPE 2

6.1 Chapter overview

This chapter describes prototype 2 of the ACG system developed to deliver falls prevention exercise to older adults. In line with the iterative process summarised in Chapter 3 and Figure 3.6, the findings of the user testing of prototype 1, presented in Chapter 5, were used to identify modifications required for the iterative development of prototype 2.

6.2 Design and development of prototype 2

While the findings of the user testing of prototype 1 indicated the safety, usability and acceptability of the system to deliver OEP exercises to older adults, participants had required high levels of additional instruction. This may be attributable to the declines in physical and cognitive performance that are observed, even in healthy ageing. These contribute to impaired balance and physical function, but also influence the ability of older adults to learn new tasks. Performance is lower in older adults than younger adults due to neurophysiologic and physiological changes, including sensory limitations, reduced processing speeds and motor limitations; older adults can take up to twice as long as younger adults to learn a new technology (Charness et al 2009). Older adults are able to achieve gains in performance with instruction and practice, albeit at a slower rate than younger adults (Voelcker-Rehage, 2008; Reuter-Lorenz et al. 2010; Seidler et al. 2010). Providing a longer learning phase, to become familiar with and practice using a new system, may influence its acceptance in older adults.

Increased cost of learning may impact the acceptance of novel technologies in this population, with perceived benefits of use and ease of use associated with increased

technology acceptance (Mitzner et al. 2010). Research into usage and perceptions of technology through the lifespan has identified cognitive ability, computer self-efficacy and computer anxiety as mediating factors in the relationship between age and technology (Czaja et al. 2006). Many of the challenges associated with introducing technology to older adults can be avoided through game design appropriate to the population (McLaughlin et al. 2012). Guidelines for designing for older adults include use of simple and intuitive interfaces to reduce the cognitive load, and encouraging feedback and achievement of some success to reduce computer anxiety and increase computer self-efficacy (Czaja et al. 2006; Ijsselsteijn et al. 2007; Fisk et al. 2009). Implementing these guidelines in the modification of the ACG system may optimise its usability and acceptability in older adults.

6.2.1 Interdisciplinary workshop 2

Main findings from the first user testing phase, presented in detail in Chapter 5, are summarised in Table 6.1. Factors affecting usability and acceptability of the system included a unanimous preference of the screen display condition over the VR headset and the frequent requirement of support and additional instruction to successfully complete the games. The initial purpose of developing an ACG system for falls prevention exercises was to enable independent use by older adults. The amount of additional support and feedback provided by the researcher during phase 1 suggested that, in its current format, independent use of the game by the study population would not be possible.

Table 6.1 Summary of the main findings from user testing of prototype 1

Main findings
Preference of study condition A: game displayed on flat screen
No safety concerns; participants reported high levels of usability and acceptability for the screen version
High level of assistance required, including navigation of the system and chair support
High level of additional instruction required, during set-up and play
Technical problems, eg. with calibration, mean it is necessary that a researcher is close by in order to restart system

During the interdisciplinary workshop, the team considered potential new outcomes of interest for the next study phase. From discussion of the findings from user testing of prototype 1 (Table 6.1) and current evidence, the two main ideas to progress the system development emerged: changing the type and timing of feedback provided and exploring the effect that this would have on user experience, motivation and learning; and, modifications that would enable more autonomous use by older adults, such as independent navigation of the system by the user, and detection and correction of incorrect movements by the system to reduce the need for additional instruction from the researcher. It was determined that limited conclusions could be drawn on the effectiveness of different feedback provided by the system due to the small number of participants anticipated for inclusion in the following study. The effect of changing the type and timing of feedback was, therefore, omitted as an outcome of interest; however, ways to optimise user experience by modifying the feedback provided by the system were considered in the development of prototype 2. Modifications to the system to enable more independent use by users were considered in interdisciplinary meetings during the development of prototype 2, and are discussed below. Additionally, given that during phase 1 older adults had required high levels of additional instruction during a single use of the system, it was considered that older people may require a longer learning period, and that the need for additional instruction and support would decrease

over time (Sigrist et al. 2013). Assessing the amount of additional instruction required with repeated use would help develop an understanding of the learnability of the system in older adults. Ways to make the system more suitable for repeated use were considered in the design and development for prototype 2.

6.2.2 Iterative development of prototype 2 – Interdisciplinary collaboration

In the early design stage of this phase, during interdisciplinary team meetings, a list of possible modifications to the system was compiled based on the findings from user testing including technical problems experienced (Appendix 6) and feedback about user experience (Table 6.2). Given the dissatisfaction with the VR headset, it was decided to remove the VR condition from phase 2 of the user testing. The size of the screen was increased from 21" to 32" to increase the immersion of the system. Primary tasks for modification of the ACG system were identified: voice recognition or the use of the user's arm gesture as a mouse to enable autonomous use; remove journeys; change background music (Table 6.2). Other modifications included changing the feedback delivered by the system and collecting user data.

Table 6.2 List prioritising tasks

Tasks discussed	Difficulty
Change music and lower volume	2/10
Sound and particle effects as feedback	2/10
Arm gesture as mouse in 3d Above would enable: - User to navigate menu screen - User able to press restart/recalibrate - User could rate exertion and enjoyment at end of game and decide whether to continue/ play again/quit	7/10
Remove journeys and replace with score of game – create stationary screen with the score	5/10

Tasks discussed	Difficulty
Username/User image to identify users to track scores over time.	6/10
Video demo to play during audio instruction then disappear	8/10
Detecting incorrect movement	10/10
Alternative: make a rule for researcher on giving feedback or additional instruction. Generic, as a game would. And at specific times.	n/a

Based on the rating of technical difficulty to implement, not all modifications were possible; for example, it was not possible to implement voice recognition or use of the arm gesture as controller given the complexity of implementing this within the time frame. Changes made to the system for this phase included creating individual user profiles to log users' scores and their feedback on each session in terms of enjoyment and rate of perceived difficulty. This would allow users to track their performance over time. The mechanism of feedback was modified to include sound and visual effects. Table 6.3 summarises how modifications planned for prototype 2 address problems identified during user testing of prototype 1. These modifications are described in detail below, including how the rationale and development of these modifications were influenced by available literature and guidelines.

Table 6.3 Table summarising how modifications planned for prototype 2 addressed problems identified during user testing of prototype 1

Modification	Problem identified and addressed
Enjoyment and difficulty rating via ACG system	High level of requirement of additional support during user testing Enable user choice during play Responding to questions prompted by system may reduce the requirement for interaction with the researcher promoting independent use

Modification	Problem identified and addressed
User data collected (scores and ratings)	Requirement for system to be suitable for repeated use Potential to use scores to motivate participants during repeated use
Multi-modal feedback	High level of requirement of additional instruction Importance of feedback for learning Requirement for system to be suitable for repeated use Importance of feedback for motivation
Changes made to individual mini-games	Changes to improve success rates Changes to fix bugs

6.2.2.1 User profiles

Choice and control have been identified by older adults as important factors for motivation and engagement with falls-related technologies including sensors and systems delivering preventative exercise (Hawley-Hague et al 2014, Proffitt and Lange 2013). The initial prototype used in the last phase of user testing had a pause button, to allow users to rest during use of the system. For this phase, this has been modified to enable more user choice and control over gameplay. When the game is paused, the player can choose to resume or quit the game. A rating screen has been added following play. The rating of exertion was based on the Borg scale (Borg 1998); users are asked "How hard was this?" with an option of nine levels of exertion from "not at all" to "very, very hard" (Figure 6.1). For enjoyment, users are asked "How happy are you with the system?" with six options from "very happy" to "very unhappy" (Figure 6.2). Users could reflect on these ratings to decide whether to continue play. As user control on the system was not implemented, SH inputted this into the system. The exertion and enjoyment ratings for each session were stored in the user database. It may be possible to use these to explore the effect of repeated use on users' perceptions of exertion and enjoyment of the game.

Figure 6.1 Difficulty rating screen displayed following completion of the game
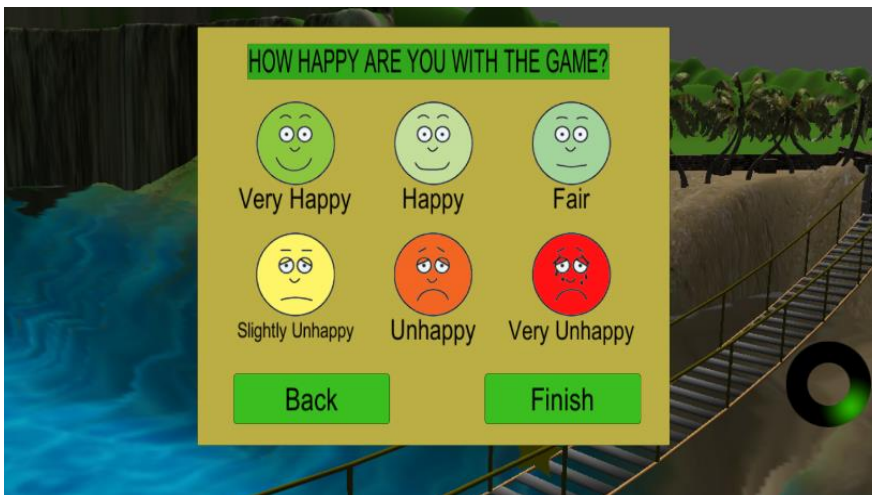
Figure 6.2 Enjoyment rating screen displayed following completion of the game

PlayerPrefs is a built-in function on Unity3D that saves the users' data to an external Microsoft Excel file. This was used to collect and store data on user scores in each game and their levels of exertion and enjoyment. The scores and ratings recorded for each use by the same user can be found in one Excel file, enabling tracking of users' scores and ratings over time. The team considered using data collected related to performance (scores), exertion and enjoyment over time as another way to explore the effect of repeated use of the ACG system. The plan was to have the player choose their player profile at the beginning of play so the user could see their previous score to encourage

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them to try and beat it (Proffitt and Lange 2013), prior to play. Unfortunately, there was difficulty implementing this technically; therefore, prior to commencing play in study visits, where possible, SH identified some aspects of game play from the previous session as the system would have done if this had been implemented. Figure 6.3 shows the screen used to select the user profile.

Figure 6.3 Data related to use including scores and ratings were collected in each user's profile

6.2.2.2 Feedback

Current literature has not drawn conclusions on the most effective types of feedback for performance and motivation with ACG interventions in older adults. Feedback, in terms of frequency and timing, was another variable that could be modified to explore optimum timing for feedback in this population. Timing of feedback is important for learning and motivation, the appropriate frequency and timing of feedback is dependent on the stage of learning (Sigrist et al. 2013). The prototype developed for phase one provided visual feedback to indicate successful or unsuccessful movement during play with scores displayed after completion of all four games. We considered modifying the type of feedback, with the addition of auditory feedback such as a "ping" and additional visual feedback such as sparkles and fireworks to indicate successful performance (Proffitt and Lange 2013).

We considered exploring the effect of changing feedback on performance and experience as an outcome of interest to fill this gap in the literature; however, this was

not chosen for a number of reasons. The need to develop multiple versions of the system with different feedback conditions would be complex, labour intensive and time consuming for the volunteer technical support (CB) we had recruited for this phase. The small numbers of participants anticipated to be recruited for this stage would provide limited reliable evidence about optimum feedback in this population. Additionally, the multiple possible combinations for feedback in gaming may be a burden to participants testing multiple versions of the same games multiple times to explore the effect of different types, frequencies and timings of feedback.

High levels of feedback during ACG have been shown to induce greatest levels of enjoyment and energy expenditure during play (Kim et al. 2014). We agreed to make some changes to the feedback provided by the system to enhance the interactivity and user experience. Modifications to feedback provided by the system included:

Sound and particle effects: Multimodal feedback is considered to enhance learning in a number of ways, including by reducing the cognitive load and by compensating should imprecise information be obtained from one modality (Sigrist et al. 2013). Reducing the cognitive load is important for older adults; additionally, multimodal feedback would overcome problems related to vision or hearing impairments in this population, by allowing the user to use their sense of choice when playing. In addition to the "tick" and "x" visual feedback displayed in the previous version of the game, auditory feedback to indicate a successful or unsuccessful movement was added to games 1-3 of this version of the game. Additional visual and auditory feedback was added to game 4 One Leg Stand to provide users with more information to reduce the requirement for additional instruction by the researcher, thus promoting more independent use by participants. A count down was displayed on screen counting down 10 seconds for each one leg stand performed. The colour of the numbers was shown on screen in green when the user's foot was out of the water, indicating they were successfully performing the movement, and red when their foot touched the water. A splash sound was added as auditory feedback that they were not successfully performing the one leg stand. This was to encourage them to lift their leg again or to lift it higher to perform the movement correctly.

Timing of feedback: More frequent delivery of feedback on performance can aid learning when an individual is introduced to a new task (Sigrist et al. 2013). Displaying the score of each mini-game immediately following its completion rather than at the end of play was implemented by removing the journey between games and replacing it with a stationary screen displaying the score board (Figure 6.4). This updated the player on their progress through the game and their scores. We considered implementing a bar displaying the score achieved, as this would be an easy to understand visual presentation of performance rather that numerical scores presented as fractions. This was not possible to be implemented as it affected the collation of scores data for each use by each user. It was not possible to correct this within the time frame.
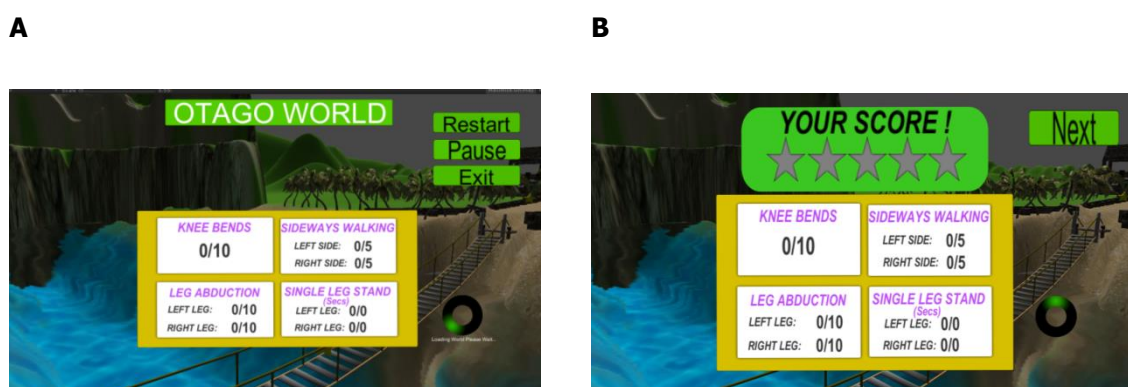
Figure 6.4 Scores were displayed during and following play

A- A score board displayed, rather than the virtual journey in prototype 1, updated the user on their progress through the game and their score. B- After completing the game, scores were displayed with an overall star rating.

Achievements: Achievements in gaming are rewards that players will receive for completion of specific tasks. These can improve engagement and motivation to play (Hamari and Eranti 2011). Four achievements were included in this prototype: entering the game; five knee bends, not consecutive; 10 abductions, not consecutive; reaching the finish line. These were displayed in a window users could navigate to via the pause button. It was considered that older people may not click into this during play and pop-ups for each achievement were suggested to let users know they were gaining achievements; however, there was difficulty implementing this.

Sounds and music: The volume of the music was lowered in comparison to the verbal instruction, and the music was changed to match the tempo of each mini-game.

6.2.2.3 Reducing the need for additional instruction

The research team discussed ways to overcome the heavy reliance on input from the researcher to enable more independent use. A video demonstration could be embedded within the game showing users how to correctly perform the exercises. Although visual learning strategies such as video demonstration are well established (Sigrist et al. 2013), in a study comparing game delivery in older adults, all participants felt concurrent video demonstration to be confusing in terms of timing and pace as well as scoring (Doyle et al. 2010). Considering this, it was decided that a concurrent demonstration video may cause the user to follow the speed of the movement of the demonstrator rather than interacting with the task in the game. One way of overcoming this was the display of a demonstration video during the audio instruction which disappeared prior to play; this was assessed as being too difficult to implement within the time constraints of the project (Table 6.2).

To overcome the requirement for additional instruction provided by the researcher to ensure correct performance of the movement, we considered identifying the most common additional instructions provided by the researcher during use, such as incorrect technique or missed instructions, and identifying ways that the Kinect could detect these and if they were detected the system could provide the additional instruction. This would reduce reliance on the researcher for additional instruction, enabling more autonomous play. An example of this would be during Leg Abduction if the user was raising their leg out with some hip and/or knee flexion rather than directly into abduction along the Y-axis, as frequently observed during phase 1, the Kinect could detect a discrepancy in the Z-axis tracking of the leg and the system could provide additional auditory feedback to correct the user's technique, such as "lift your leg out to the side". Another example considered was if the user was leaning their trunk to the side during One Leg Stand, the Kinect would detect the altered trunk position and the instruction "try to stand tall and keep looking ahead" could be reiterated as per the instruction provided prior to beginning the game. This was determined to be too difficult to implement within the timescale of the research project (Table 6.2). We considered generic feedback by the researcher delivering additional instruction or correction if an error was observed during use. Frequency of researcher input would be recorded during use of the system and verified by watching the video recordings. This

could be used to explore the effect of repeated use on the amount of feedback required by older adults. This would be reflective of the learnability of the games and their requirements but also influenced by users' cognitive ability and memory.

6.2.2.4 Towards autonomous use of the system

In the prototype developed for phase one, the researcher was required to set up the system, press start, restart the system if calibration was not successful, manage other technical issues, provide additional instruction, ensure additional hand support was accessible to the user as and when required, give feedback to correct technique and provide additional feedback on performance. The research team considered which of these aspects of researcher involvement were modifiable to increase autonomous use of the system.

The use of voice control or arm gesture control was considered to enable to user to control play rather than the user. This would enable the user to navigate a menu screen, press start and recalibrate the system as required, the user could rate their level of enjoyment and exertion and use this to decide whether to continue, pause or quit play. This was considered too difficult to implement within the timeframe of this study (Table 6.2). Although it would have been useful to evaluate older adults' ability to navigate the system independently to gain insight into the usability of this feature, unsupervised use was not indicated given the level of additional support required by users during the previous study phase.

6.2.2.5 Other changes made to individual mini-games

Knee Bends: In the previous phase, restrictions in knee range of movement had made it difficult for one user to perform sufficient movement to be successful in this game. We had considered including calibration repetitions as in the Leg Abductions game to gather data on the available range then set the height of the walls at this level, to ensure that the difficulty of the task matched the user's ability. An alternative to this was softening the collision area to increase the likelihood of success. This was tested by the research team and by healthy adults prior to testing on the study population.

Hip abductions: In prototype 1, a tick or x was displayed as visual feedback for both the calibration repetitions and those that contributed to the score; however, it was identified that visual feedback was inconsistent during the calibration repetitions. There was a

technical difficulty when trying to fix this. The decision was therefore made to remove all feedback from the calibration repetitions. Visual and auditory feedback would be provided for each repetition following; only those that contributed to the score. Given that one of the main draws of gaming for exercise is to reduce monotony, a suggested modification following phase 1 was to change the sequence, from 10 right abductions followed by 10 left abductions to 5 repetitions with the right then 5 on the left then another five with the right and another 5 with the left. It was suggested that this may break up the task and make it more enjoyable for the user. This was not implemented due to time restrictions.

6.3 User testing of prototype 2

The results of this phase are presented in Chapter 7. Findings suggested that participants' use of additional hand support was not influenced by repeated use of the system, but that the requirement for additional instruction may decrease with repeated use. Participants reported high levels of usability and acceptability; however, the low completion rate of sessions suggests there may be problems with long-term engagement and adoption with the ACG system. Factors influencing older adults' perceptions on the acceptability of the technologies included their beliefs about how applicable ACG was to their own health, their previous experience of recreational or therapeutic exercise, and their engagement with the system, including their own personal motivation, factors that facilitated their use of the system and system features that increased motivation and engagement.

7 THE EFFECT OF REPEATED USE ON OLDER ADULTS' ACCEPTABILITY OF ACG

7.1 Chapter overview

This chapter presents the methods and main findings from the second phase of user testing. This study assessed the safety, usability and acceptability of prototype 2 of the ACG system with repeated use in older adults. Outcomes of interest were evaluated through observation, questionnaires and semi-structured interviews.

7.2 Background

As previously described, there is promise for ACG to provide an accessible way to deliver preventative and rehabilitative exercise to older adults. Older adults' perceptions and attitudes towards the usability and acceptability of ACG are critical to its uptake and continued engagement in this population (Nawaz et al 2015). Previously described in Chapter 6, in the acceptance and adoption of technology, older adults face barriers related to increased cost of learning and computer anxiety (Czaja et al. 2006, Mitzner et al. 2010). Nonetheless, although older adults' technology usage is behind other portions of the population, the technology divide is narrowing (Zickuhr and Madden 2012).

Development of ACG systems designed specifically to meet the needs of older people, with consideration of their physical and cognitive function may improve the acceptance and adoption of ACG in this population (McLaughlin et al. 2012; Smith and Schoene 2012). Guidelines recommend simple user interfaces, clear and encouraging feedback, and facilitation to support learning and use to increase usability and acceptability of technology in older adults (Czaja et al. 2006; Ijsselsteijn et al. 2007; Fisk et al. 2009; Barnard et al. 2013).

Accounting for the longer learning phase required by older adults (Voelcker-Rehage, 2008; Charness et al 2009; Reuter-Lorenz et al. 2010; Seidler et al. 2010), repeated use of an ACG system may allow for familiarisation, thus influencing older adults' attitudes towards its acceptance. Other studies have used familiarisation methods with older adults such as viewing a paper prototype of a bespoke game (Nawaz et al. 2014) or playing commercial Kinect games prior to testing a bespoke Kinect game for falls prevention (Evertsen and Brox 2015). Findings from user testing of prototype 1 (Chapter 5) also suggested that a period of familiarisation was of benefit during the introduction of novel technology to older adults. Additionally, it was observed that with single use of the ACG system, high levels of additional instruction were required for use of the system.

A number of game features traditionally included in entertainment games, such as scoring, tracking progress, goal-setting and competition, can be implemented to encourage repeated use of an ACG system in older adults (Smith and Schoene 2012). As previously noted in Chapters 2 and 4, these features map closely to BCTs related to *Goals and planning, Feedback and monitoring*, and *Comparison of behaviour* (Table 4.1). Chapter 6 describes how these game features have been implemented in the current prototype. The TAM, previously described in Chapter 3 (Figure 3.1) describes how attitudes towards use influence behavioural intentions and actual system use (Davis, 1989). There is a need for an in depth evaluation of older adults' perceptions of ACG, exploring how system features and repeated use can influence the usability and acceptability of an ACG system developed specifically to deliver strength and balance exercises based on the OEP to older adults.

7.3 Aims and Objectives

7.3.1 Aim

The aim of the study was to explore the safety, usability and acceptability of a system designed to deliver falls prevention exercise using ACG with repeated use in older adults.

7.3.2 Objectives

i) Explore older adults' ability to safely complete falls prevention exercises delivered via ACG with repeated use.

ii) Explore older adults' perceptions of the usability of the system with repeated use, using the System Usability Scale.

iii) Explore older adults' experience with repeated use of the system, using the AFRIS and semi-structured interviews.

7.4 Methods

7.4.1 Study design

The study design used repeated measures in a single group, combining both quantitative and qualitative methods. This study was approved by the Office for Research Ethics Committees Northern Ireland (ORECNI; Appendix 10).

7.4.2 Setting

This study comprised up to six visits of up to one hour each carried out at two Age NI day centres located in urban areas: Anna House and Skainos Building.

7.4.3 Participants

Eligibility criteria were as in the previous study phase and are summarised again in Table 7.1. Recruitment was through the two Age NI day centres; participants who had participated in the previous study phase were invited to take part.

Table 7.1 Eligibility criteria

Inclusion Criteria	Exclusion Criteria
Males and females aged ≥ 65 years	Bed or wheel chair bound.
Independently mobile with/without walking aid	Significant cognitive impairment (MMSE <21), unable to follow verbal or written instruction
Stable physical health as indicated by GP and according to rPAR-Q	Current acute, or uncontrolled medical condition that would not tolerate physical activity
Fluency in English (verbal and written)	
Willing and able (MMSE >21) to consent	Unwilling or unable to consent.

7.4.4 Materials – study software and study hardware

The ACG content was developed using Unity 3D software (Unity Technologies SF Inc., San Fransisco, CA, USA). The software ran on an Alienware PC (Alienware Corps., Miami, FL, USA.) connected to a Microsoft Kinect Camera (Microsoft Corps. Redmond, WA, USA) mounted on a tripod positioned at 85cm above desk height, to track user movements, and was displayed using a 32" LED screen.

7.4.5 "Otago World" mini-games

The ACG system included four mini-games to deliver exercise tasks based on four exercises included in the OEP (Province et al. 1995): Knee Bends; Leg Abduction; Sideways Walking; One Leg Stand (described in Chapters 3 and 4). Changes made to the system following the first user testing phase are described in Chapter 6. Prototype 2 included modified type and timing of feedback; both auditory and visual real-time feedback was delivered during play and scores were presented at the end of each mini-game. User profiles logged participants' scores for each use of the system, and collected participants' ratings of perceived difficulty and enjoyment following each use.

7.4.6 Procedure

Participants were invited to complete up to six uses of the ACG system, preferably two per week for three weeks, to explore how repeated use affected their perceptions of the usability and acceptability of the ACG system. Independent use was encouraged for this phase; however, one researcher (SH) was present to provide supervision to ensure participant safety. The researcher demonstrated the use of the system, highlighted key features of use and gave the participant the opportunity to ask any questions. Participants were encouraged to think aloud and comment on their use of the technology as they played, including any problems they encountered, and were instructed to ask for additional instruction, if necessary. Handwritten notes were made by the researcher to document participant use of the system. During play, the researcher only offered additional instruction if it was requested, or if the researcher felt it was necessary, for example if there was a technical issue or to maintain participant safety. Following use of the ACG system, scores may have been reviewed in comparison with previous performances. Additionally, the participant may have been given suggestions on how to improve or progress based on their performance, and may have been reminded of these prior to commencing the next session.

7.4.7 Participant safety

As described previously, participants were able to use two chairs placed at either side for hand support during games 1, 2 and 4 as tasks were performed standing on the spot. Another chair was positioned behind the participant should they require a rest. Participants were able to complete game 3 Sideways Walking with no hand support or with their walking stick or zimmer frame. Prior to use of the system, participants were encouraged to use only the hand support they required.

7.4.8 Outcome measures

7.4.8.1 Outcomes of interest

7.4.8.1.1 Safety and usability

The safety checklist pro-forma, used in the previous user testing phase, was completed by the researcher (SH) during each study visit, documenting safety components and practical aspects of using the equipment (Appendix 17). Details of additional verbal and

physical assistance required, and participant comments were also recorded on the safety pro-forma, to assess usability. Additional verbal instruction required during participants' use of the system was categorised as: related to set-up, for instruction to help participants overcome technical problems such as difficulty calibrating or losing tracking; related to play, for instruction related to correcting technique and answering participants' questions. Sessions were video recorded for retrospective analysis to supplement hand-written observations. The SUS (Brooke 1996) was completed by participants after each use of the system, to explore perceptions of usability with repeated use. Scores above 70 indicate acceptable usability, while scores below 50 indicate unacceptably low usability (Bangor et al. 2008; Figure 5.5). Participants' scores achieved in each game were logged for each session and used to provide feedback for participants, as described in Chapter 6, and also to explore any variance in scores achieved with repeated use of the system.

7.4.8.1.2 Acceptability

Acceptability was measured using the AFRIS (Yardley & Donovan-Hall 2006 & 2007; Figure 5.6). Additionally, the system allowed participants to rate their enjoyment; it asked "How happy were you with the system?" with six options from 1="very unhappy" to 6="very happy" displayed on screen at the end of the game. The system also allowed participants to rate their difficulty; it asked "How hard was it?" with nine options from 1="not at all" to 9="extremely hard". These functions are described in more detail in Chapter 6. Ratings were logged after each use of the ACG system to explore variance in user experience with repeated use of the ACG system. User experience was explored in a semi-structured interview, audio recorded after the practical aspect on the last study visit. Reflecting on the scoping nature of the semi-structured interviews conducted in the previous study phase, the interview schedule was iteratively developed, through consultation with IW, to provide an in-depth exploration of factors influencing older adults' experience of using the system. The number of questions was reduced, and the scope of each question was broadened. Additionally, as the semi-structured interviews were conducted by the same individual (SH) that had introduced the study and been present during their use of the ACG system, questions were structured in an effort to reduce the influence of participants' desire to provide the "right answer". An example of this is wording of a question to understand participants'

reasons for using ACG; rather than asking "why" they agreed to use the ACG system, the question asked "what benefits" they hoped to get from using the system. Also, rather than asking participants to describe their problems with the system, the question asked them to provide suggestions for a future system. Appendix 24 presents two versions of the interview schedule; an initial version was developed, as described above, and following the first interview SH met with IW to discuss ways to refine the interview schedule for subsequent participants. Semi-structured interviews lasted approximately 25 minutes, depending on the amount of information shared by the participant.

7.4.8.2 Initial assessment

As described in the previous study phase (Chapter 5), demographic information and participant characteristics were collected prior to use of the system (Appendix 19). Participant characteristics were measured as follows: physical function, using the SPPB (Guralnik et al. 1994; (Appendix 20); balance, using the BBS (Berg et al. 1991 & 1995; (Appendix 21); fear of falling, using the FES-I (Yardley et al. 2005; (Appendix 22); mental health, using the GDS-15 (Friedman et al. 2005; (Appendix 23).

7.4.9 Data analysis

Statistical analysis was performed using SPSS software (version 23). The data was checked for normality, then appropriate descriptive analyses were used to summarise participant characteristics and outcomes. Pearson's R, or the non-parametric equivalent, Spearman's rho, were used to explore the relationship between factors related to usability and acceptability. A correlation co-efficient of >0.7 reflected a strong correlation, 0.5-0.7 reflected a moderate correlation, and <0.5 reflected a weak correlation (Nunnally 1978). Statistical significance was accepted at a p-value < 0.05 for all analyses. The study protocol had outlined plans to use a repeated measured ANOVA, or the non-parametric equivalent, Friedmans's test, to explore change in SUS and AFRIS scores over time; however, the low completion rates by an already small study population limited the value of this analysis and it is, therefore, not reported. Interviews were transcribed, and interpretation, synthesis and data reduction undertaken independently by two members of the research team, applying an inductive content analysis approach. After familiarisation with the data, a coding frame was developed to facilitate coding of key concepts related to acceptability of equipment, followed by identification of the relevant themes as they emerged.

7.5 Results

7.5.1 Demographics

Initially, ten service users from two AgeNI day centres were identified as interested and eligible according to eligibility criteria (Table 7.1) to participate in this study investigating the repeated use of an ACG system to deliver falls prevention exercise to older people. Three participants declined their first use of the system on ≥1 occasions, and were not included in the analyses. Reasons provided for non-participation were health-related (n=2, one individual reported knee pain and reduced confidence following a fall at home on two occasions; n=1 reported painful joints; n=3, one individual reported an upper respiratory tract infection on three occasions) or related to individuals wishing to attend the scheduled activities within the day centre (n=4, two individuals declined to participate as they wished to attend bingo scheduled in the centre on at least one occasion).

Seven participants, aged 73-88 years, completed at least one session using the ACG system. Participant characteristics, baseline measures and number of sessions completed are presented in Table 7.2. Three participants regularly used a walking aid. BBS scores indicated that one participant (female, aged 82) was at high risk of falls. According to SPPB scores, n=3 participants (all male) had high level of physical functioning (SPPB score >10), and n=4 participants (1 male/ 3 female) had lower level of physical functioning (SPPB score <10). According to FES-I scores, n=1 had low concern about falling (FES-I score 16-19), n=2 had moderate concern about falling (FES-I score 20-27) and n=4 had high concern about falling (FES-I score 28-64); however, none of the participants reported having a fall in the last twelve months.

Table 7.2 Participant characteristics and number of sessions completed

| Participant | Gender | Age | Walking aid use | Measure (range of measure) | | | Sessions completed |
				SPPB* (0-12)	BBS* (0-56)	FES-I¥ (16-64)	
A	Male	81	None	11	52	30	5
B	Male	78	Walking stick	7	48	32	5
C	Female	76	None	8	52	22	1
D	Male	86	None	11	54	21	3
E	Female	88	Rollator	5	42	48	2
F	Female	82	Rollator	3	34	33	1
G	Male	73	None	11	54	16	5
* -higher score = better ¥ lower score = better							

7.5.2 Safety and usability

Safety and usability were assessed during use of the system, based on the rate of completion of ACG sessions; participants' ability to complete the mini-games; incidence on adverse events; additional support provided, such as use of hand support and requirement of additional instruction; and, score achieved during use of the ACG system. Comments by participants during use of the system, and their responses during the semi-structured interviews enhanced understanding of some of the observational findings.

7.5.2.1 Completion of the ACG sessions

Each participant was invited to complete up to six sessions using the ACG system. The seven included participants completed 22 / 42 sessions (52%), with n=4 participants completing at least half of the scheduled sessions. None of the participants completed six sessions. Reasons reported for non-completion of n=20 sessions included health-related reasons (n=12 sessions), participants' non-attendance at the day centre on scheduled study days (n=4 sessions), other activities scheduled at the day centre (n=3 sessions), and disinterest in continuing use of the system (n=1 session).

A summary of participants' use of the system is presented in Table 7.3. Six participants were able to complete all four games during each use of the ACG system, while n=1 participant (participant G) who attended one visit attempted all games but did not complete Sideways Walking due to feeling unsteady without her walking aid. There were no adverse events during the study; however, one participant reported some muscle soreness following their first session.

7.5.2.2 Use of hand support

A summary of the level of hand support required by participants during use of the ACG system is shown in Table 7.3. The level of hand support required for each game varied by participant but did not tend to change with repeated use of the system. Participants were most likely to use hand support during One Leg Stand (22/22) and Leg Abductions (16/22). N=4 participants were able to complete Knee Bends with no hand support on at least one visit; n=2 participants were able to complete Leg Abduction with no hand support on at least one visit; n=6 participants were able to complete Sideways Walking with no hand support on at least one visit; and, n=0 participants were able to complete One Leg Stand with no hand support on one visit. Observation of participants' use of the system indicated that some participants tended to use the hand support available to them (two chairs placed at either side) even if it was more than they required. When a participant was observed using increased hand support, this may have been queried by SH. For example, Participant A used two hand support during Knee Bends on visit 4 after completing the game successfully with no hand support on previous visits 2 and 3. When asked, they responded, "Well I got full marks this time". Additionally, after managing well on previous visits, a goal of reducing hand support during games was

discussed with Participant G at the beginning of study visits 3 and 4; however, during use of the system Participant G continued to use the same level of hand support as in the previous sessions for all games. Two participants expressed a preference for progressing from two hand support to fingertip support with two hands, rather than progressing to one hand support, this was categorised as two hand support:

> "You see, with the least touch I can do it, but without it I can't" (Pt A, M, 81 years)

Overall, having a chair available improved participants' confidence to enable them to use the ACG system; one participant stated:

> "If you have the chair, I do need the support, no doubt about it, and I would have to have the chair there all the time. But I mean… if I had the chair I would feel secure enough to do the exercises, there's no doubt about that." (Pt B; M, 78 years)

Table 7.3 Summary of system use across visits

Study visit (Number of participants)	Hand support used by participants who completed each game			
	Knee Bends	Leg Abductions	Sideways Walking	One Leg Stand
1 (7)	4/7 (two hands, n=2; one hand, n=2)	5/7 (two hands, n=2; one hand, n=3)	1/6* (one hand)	7/7 (two hands, n=5; one hand, n=2)
2 (5)	2/5 (two hands)	3/5 (two hands, n=2; one hand, n=1)	1/5 (one hand)	5/5 (two hands, n=3; one hand, n=1)
3 (4)	1/4 (two hands)	3/4 (two hands, n=1; one hand, n=2)	1/4 (one hand)	4/4 (two hands, n=1; one hand, n=3)
4 (3)	2/3 (two hands)	3/3 (two hands, n=1; one hand, n=2)	1/3 (one hand)	3/3 (two hands, n=2; one hand, n=1)
5 (3)	1/3 (two hands)	2/3 (two hands, n=1; one hand, n=1)	0/3	3/3 (two hands, n=1; one hand, n=2)
* one participant did not complete this mini-game				

7.5.2.3 Additional verbal instruction

Additional verbal instruction required during participants' use of the system that was related to set-up is summarised in Figure 7.1, and additional instruction required that was related to play is presented in Figure 7.2. Appendix 25 presents details of the instruction required by participants during use of the system.

The median (inter-quartile range; IQR) frequency of instruction related to set-up in a session was 2 (1-2). Looking more closely at participants A, B and G, who completed the greatest number of ACG sessions, it seemed that some participants required a higher frequency of instruction on their first use of the system, which decreased on their second use of the system, but the frequency of instruction did not decrease with further uses of the ACG system. Higher frequency of instruction related to set-up was observed when participants were unable to find the correct position on the X for calibration at the beginning of a game, for example visit 1 for participants E and G; the reduction in instruction related to set-up on visit 2 may have been related to these participants learning how to find the correct position with less instruction. Conversely, a higher frequency of additional instruction included providing additional instruction to enable successful calibration if the Kinect did not start tracking the participant easily, for example visit 4 for participant A; while participants may learn to manage technical difficulties like this, the requirement for this type of instruction could be reduced if technical changes made the calibration of the system more consistent.

The median (IQR) frequency of additional instruction related to play, for example to correct timing or technique of movement to improve success in the game, was 3 (2-8). Participants A, B and G, who completed the greatest number of ACG sessions, required a higher frequency of instruction on their first use of the system that decreased with further uses of the ACG system. For example, participant G required n=23 additional instructions on the first visit, and on the last visit required n=5 additional instructions. Participant G was observed to ask for additional instructions to clarify the aim of games and the movement required on all study visits; nonetheless the frequency of additional instruction required reduced from visit 1 to visit 5. It is not clear whether having the researcher in view influenced his tendency to ask for additional instruction as reassurance, rather than to use the instruction provided by the system along with memory and problem-solving skills. The adaptation of the system to provide additional

prompts if it detects an error or a delay in commencing play may reduce the need for additional instruction related to play.

7.5.2.4 Participant scores in games

Participants' total scores are presented in Figure 7.3. Total scores over n=22 visits were high; the median (IQR) was 85.5 (77.8-93) out of 100. The three participants that completed 5 visits, participants A, B and G, increased their total score from visits 1 to 5 by 14, 21 and 6 points, respectively.

Participants placed varied degree of importance on achieving and improving their score:

> "A score shows, a good score shows that you are capable of participation of the game and, you know, you can maybe try and increase it." (Pt B, M, 78 years)

> "I was looking at those marks for the other three things and I did well in them so I was happy with that, but I'm not so happy with the balance thing but I don't think that there is anything I can do short-term about that." (Pt A, M, 81 years)

It should be noted that for Leg Abduction, calibration determined the range of movement required to successfully reach the ball; this automatic change in difficulty did not influence the score. Participants did not receive feedback on the range of movement achieved during the calibration repetitions, and variance in performance on the calibration repetitions was not collected. This may make it more difficult to assess improvement in this game over time.
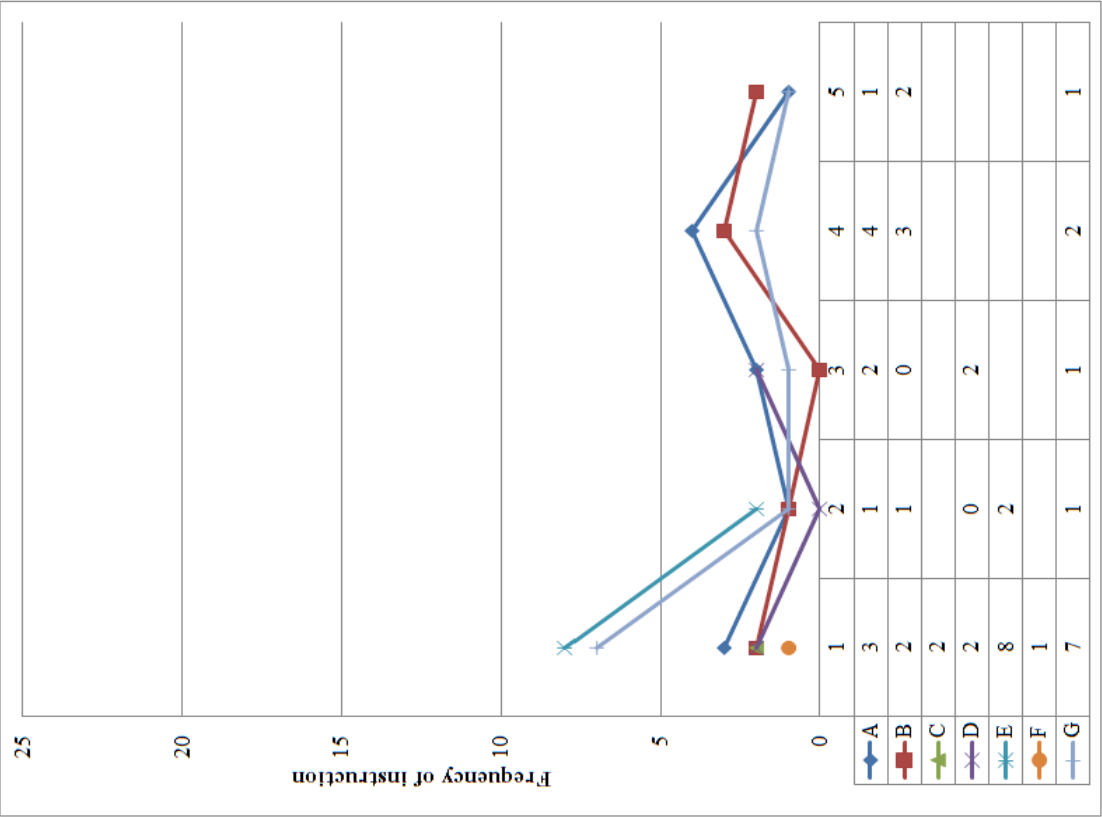
Figure 7.1 Frequency of instruction related to set-up across visits
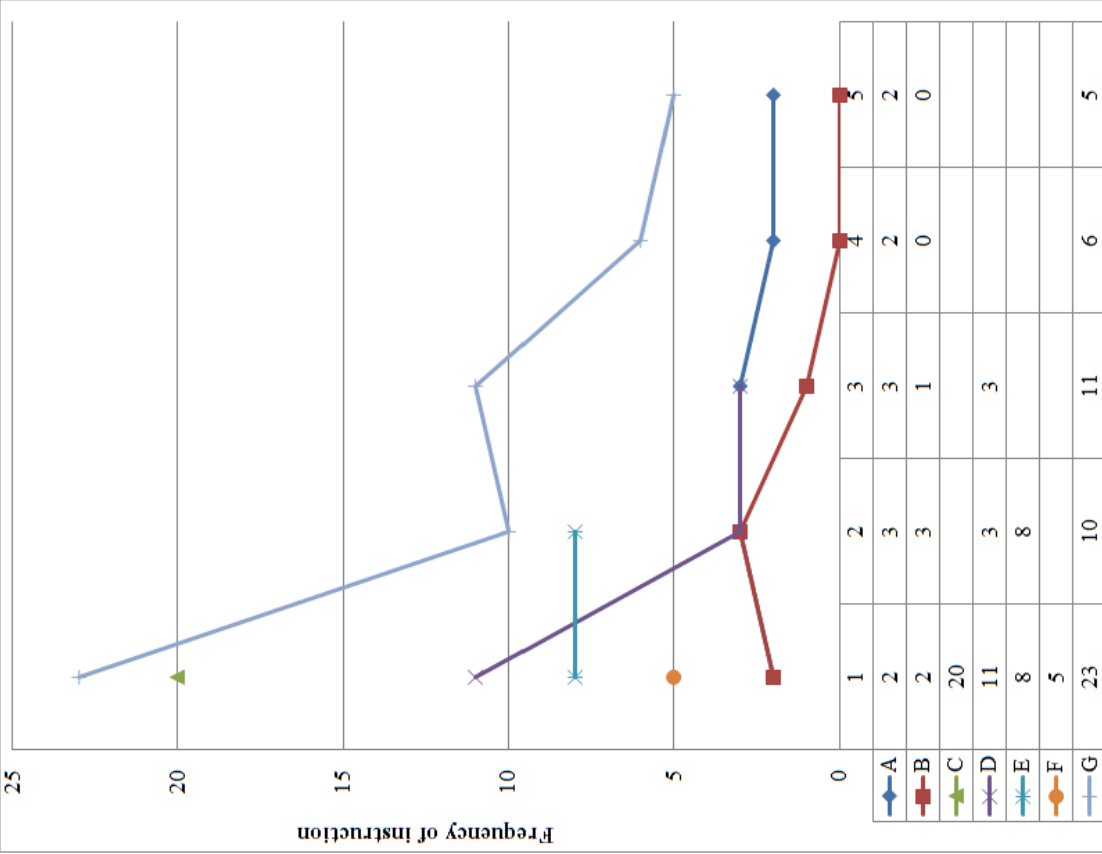
Figure 7.2 Frequency of instruction related to play across visits

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	1	2	3	4	5
A	82	95	83	94	96
B	69	71	70	82	90
C	84				
D	89	95	88		
E	77	80			
F	73				
G	87	77	94	93	93
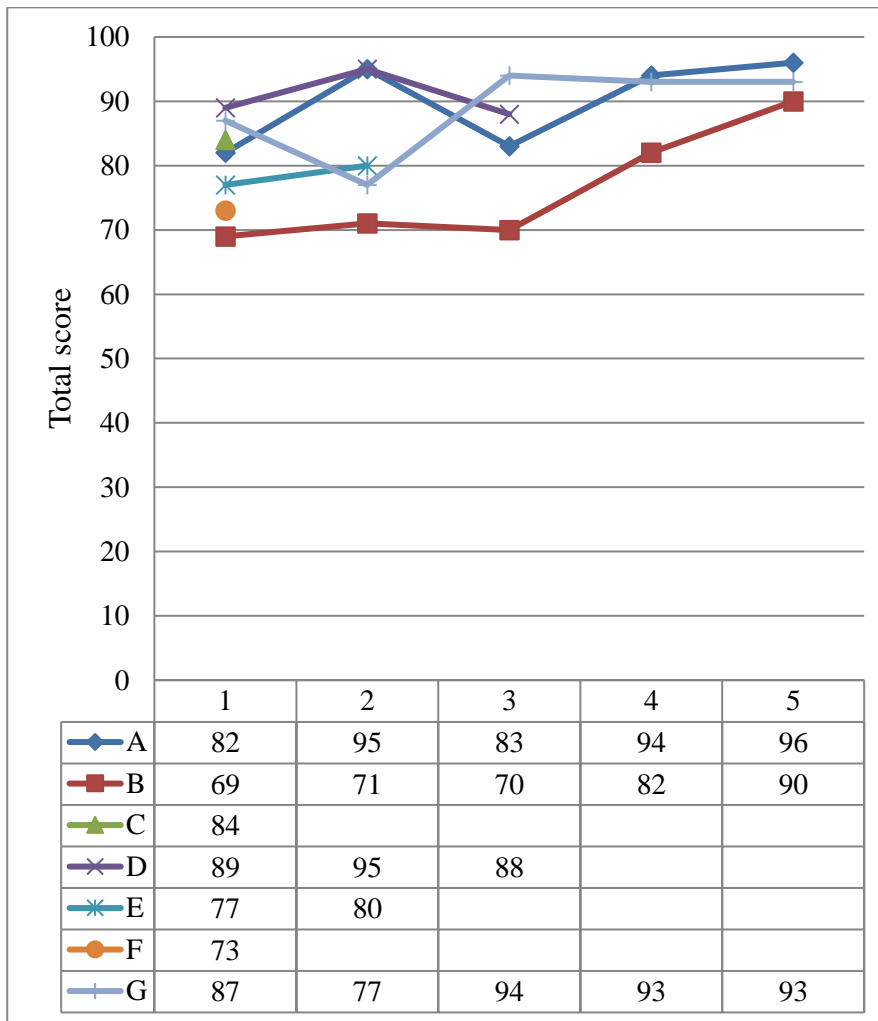
Figure 7.3 Participants' scores achieved during ACG sessions

7.5.3 Usability and acceptability

Data related to participants' perceptions of the usability and acceptability of the ACG system were collected following use of the system, using the SUS and AFRIS, and participants' ratings of difficulty and enjoyment collected by the system immediately following each use. Qualitative data collected during semi-structured interviews explored factors influencing perceptions of usability and acceptability of the ACG system.

7.5.3.1 SUS scores

Participants' SUS scores are presented in Figure 7.4. In general, SUS scores suggested high levels of usability. The median (IQR) SUS score of n=22 sessions completed was 85 (75.6-92.5), which is considered excellent (Figure 5.5; Bangor et al. 2008; Vaziri et al. 2016). Of the three participants who completed the greatest number of ACG sessions, Particpants B and G showed a trend toward increased usability with repeated use of the system; Participant A had lower perceptions of usability from session 1, and these declined further by session 5. One session was scored < 50, indicating poor usability; reflecting on this session (Participant A visit 4), problems with calibration meant that additional instruction was required for set-up before each mini-game. Additionally, following use of the ACG system some of the participant's comments suggested feelings of frustration despite achieving high scores in all games, "I don't know what I was doing wrong," and, "My balance is not good, simple as that".

7.5.3.2 AFRIS scores

Participants' AFRIS scores are presented in Figure 7.4. In general, AFRIS scores suggested high levels of acceptability and positive attitudes from visit 1 to visit 5. The median (IQR) AFRIS score of n=22 sessions completed was 36 (35-39) out of 42. Individual items scored similarly or higher than normative values on all visits (Table 5.8; Yardley & Donovan-Hall 2007; Illiffe et al. 2014). Looking more closely at the three participants that completed five ACG sessions, AFRIS scores increased from visit 1 to visit 5 for participants A and G, while participant B reduced slightly following visit 1 then reported unchanged perceptions of acceptability with increased uses of the ACG system.
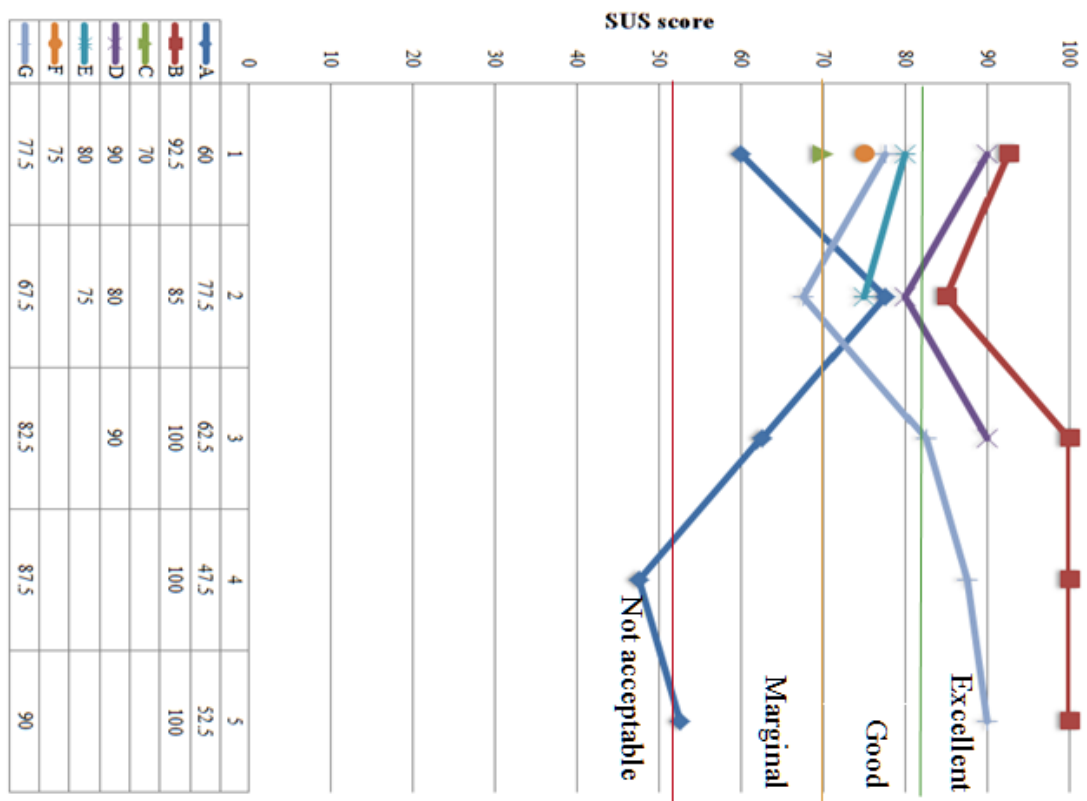
Figure 7.4 Participants' change in total SUS scores over sessions

	1	2	3	4	5
A	60	77.5	62.5	47.5	52.5
B	92.5	85	100	100	100
C	70				
D	90	80	90		
E	80	75			
F	75				
G	77.5	67.5	82.5	87.5	90
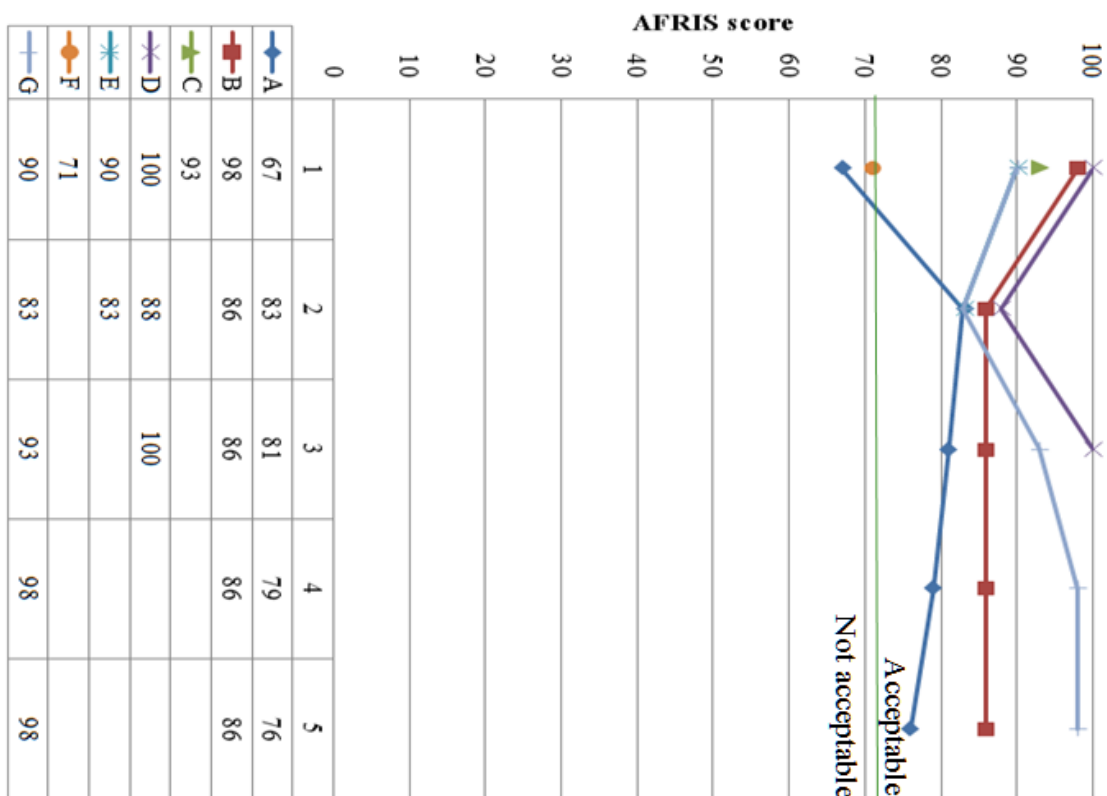
Figure 7.5 Participants' change in AFRIS scores over visits (converted)

	1	2	3	4	5
A	67	83	81	79	76
B	98	86	86	86	86
C	93				
D	100	88	100		
E	90	83			
F	71				
G	90	83	93	98	98

7.5.3.3 Enjoyment and difficulty ratings

Participants most frequently rated that they were "very happy" (n=10) or "happy" (n=6) following their use of the system. Enjoyment ratings are presented in Figure 7.6. Participants generally experienced low to moderate levels of difficulty with their ACG sessions; n=11 were rated from "not at all" to "easy", and n=8 were rated "moderate". Difficulty ratings are presented in Figure 7.7. Participant A rated "unhappy" following their third use of the system and on this visit rated the difficulty of the session as "hard"; notes made from observation of this session indicated that a technical difficulty during One Leg Stand had meant that, although Participant A had raised his foot correctly, the system did not recognise this due to a problem with the Kinect tracking. The participant stated they were "disappointed" and on viewing their score for One Leg Stand said, "See, that's much worse than I've had up to now!"

	1	2	3	4	5
A	4	6	2	4	5
B	4	5	5	5	5
C	6				
D	6	6	5		
E	6	4			
F	6				
G	6	6	6	6	4

Figure 7.6 Variance in enjoyment ratings over sessions

Enjoyment was rated from 1-6 with a higher score indicating greater enjoyment

Figure 7.7 Variance in difficulty rating over sessions

Difficulty was rated from 1-9 with a higher score indicating greater difficulty

7.5.3.4 Relationship between usability and acceptability

Shapiro-Wilk tests indicated that the data for the SUS, AFRIS and other outcomes related to usability and acceptability were not normally distributed, and scatter plots showed a non-linear relationship; therefore, Spearman's rho (r) was used and showed no significant correlation between usability, measured with the SUS, and acceptability, measured with the AFRIS (r = -0.025; p=.912; Figure 7.8). While the SUS and AFRIS shared some similar items, such as those related to confidence and ease of use, it is possible to suggest a number of explanations for this result. The SUS items addressed participants' individual perceptions of the ACG system during each particular use, while some of the AFRIS items asked questions related to future intentions and perceived behavioural control. Additionally, the AFRIS items addressed a number of

different components of acceptability of the ACG system as a falls related intervention, including attitudes and beliefs about using the system, and social norms. Additionally, all the AFRIS items were worded positively, using terms such as "good for me" and "a good idea", while the SUS had an equal number of negatively and positively phrased items, for example it uses terms "well integrated" and "cumbersome/awkward to use".
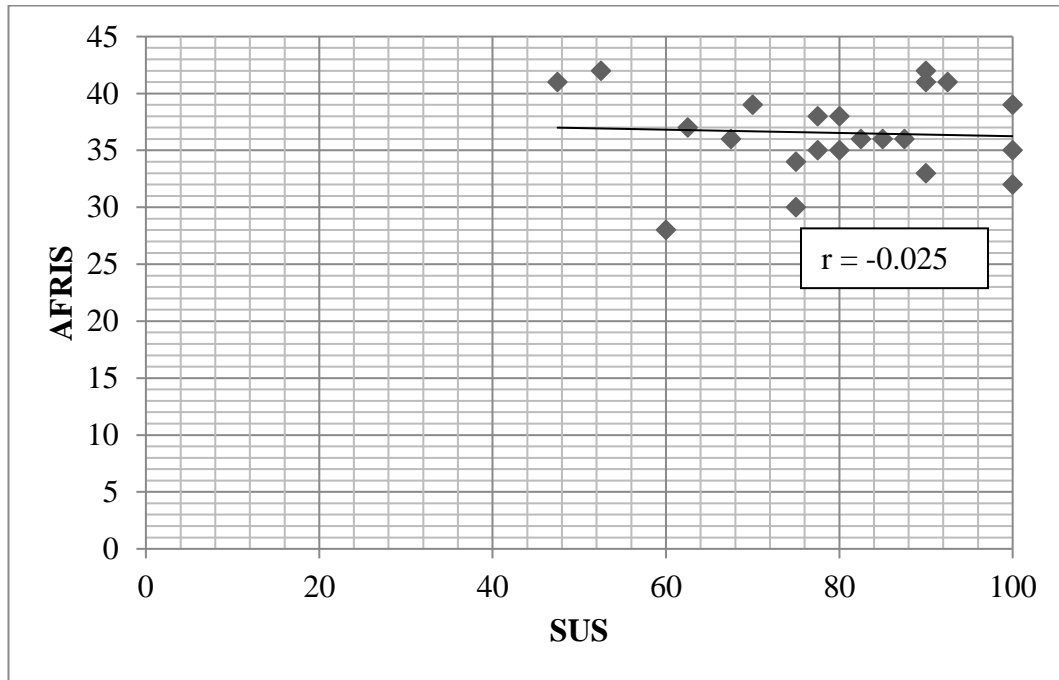
Figure 7.8 Scatter plot of correlation between SUS and AFRIS

The maximum score for the SUS was 100, while the maximum score for the AFRIS was 42.

Correlations between SUS and AFRIS scores and other usability and acceptability outcomes, such as instruction required, score and user ratings indicated no statistically significant correlations. However, there were small to moderate significant correlations between other usability and acceptability outcomes. A higher score was associated with lower difficulty rating (r = -0.596, p=0.003; Figure 7.9). Higher level of instruction was associated with a lower difficulty rating (r = -0.477, p= 0.025; Figure 7.10) and a higher enjoyment rating (r = 0.426, p=0.048; Figure 7.11).
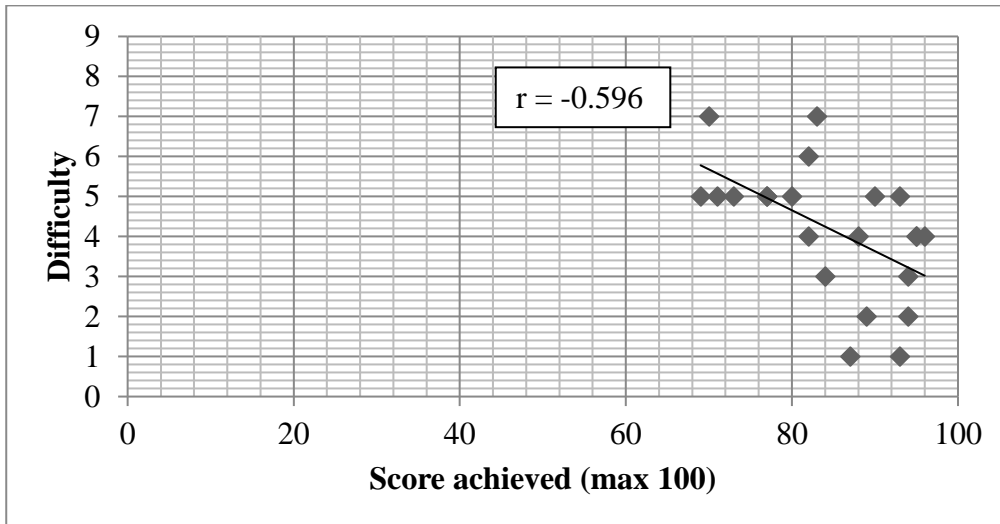
Figure 7.9 Scatter plot of correlation between score and difficulty rating
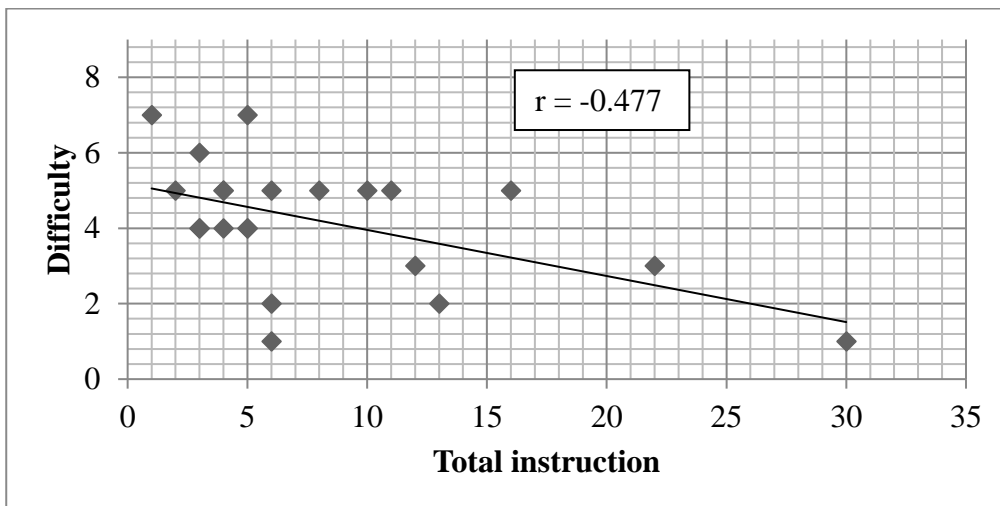
Figure 7.10 Scatter plot of correlation between instruction and difficulty rating
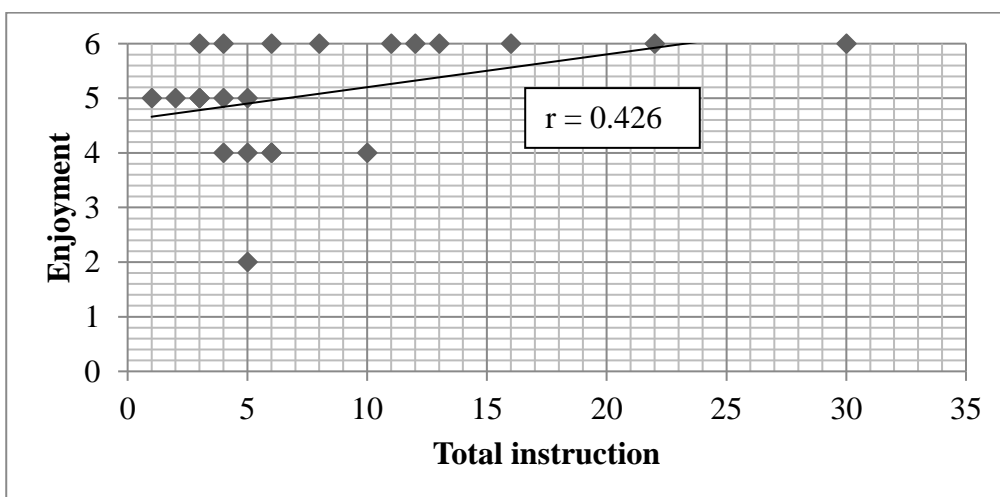
Figure 7.11 Scatter plot of correlation between instruction and enjoyment rating

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7.5.3.5 Qualitative findings

Findings from semi-structured interviews conducted with n=7 participants following their last use of the ACG system along with comments made during use of the system suggested that a number of factors influenced participants' experience of using the system. These factors could be categorised into three over-arching themes: salience to current health; previous exercise/therapy experience sets the precedent; and, engagement with the system. All quotes could be coded into one of these themes. A summary of themes, sub-themes, category groups and participant quote examples are included in Table 7.3 to support the detailed description in the main text.

7.5.3.5.1 Salience to current health

During the semi-structured interviews, participants described their experience of their health through ageing, including changes and the capabilities and limitations they experience:

> "So, I find that most things, actually, getting in and out of a car is a classic example. When I get into the car in the mornings, David's car, I can get in and lift that leg in. Invariably when I am going home in the evening David has to lift that leg into the car because I've been on it all day and it does get very, very tired." (Pt: B, M, 78 years)

> "But me, I couldn't walk, say, to that church. That's me in a sense. Walking is one of my problems today. I couldn't walk as far without an assistance, without being assisted." (Pt: D, M, 86 years)

> "You get to a certain stage, and I know I have fallen back a bit over this last, I felt my fitness just wasn't what I would have liked it to have been, so it still is a battle." (Pt: G, M, 73 years)

This also included how their current capabilities and limitations affected their experience of the using the ACG system, such as games they had difficulty completing and how, in some instances, their health had contributed to missed ACG sessions or reasons for stopping use of the system:

> "I think the main benefit it will get from the game is the fact that I will know now that there are some things that I can do quite easily, and yet

there are other things like the balancing one or the one leg thing that I can't do. It makes you aware of that for your own benefit." (Pt: A, M, 81 years)

"Unfortunately, I didn't maybe measure up to the regime because of the leg but I enjoyed it." (Pt: B, M, 78 years)

"See there's a thing I couldn't do, I couldn't stand on one leg, while that ball was coming out you know, I had to hold on. I would have lost my balance, things like that." (Pt: D, M, 86 years)

"I did learn from it actually, I realised I am not quick enough. That was one thing I did realise." (Pt: E, F, 86 years)

"I'm not too well, you know. And the first time I done it I was great, but I wasn't well last week so that's why I'm not doing it." (Pt: F, F, 82 years)

Participants were asked what they hoped to get from using the system; amongst their reasons for using the ACG system, participants described a desire for health benefits from using the system:

"I thought the game would actually help achieve a bit of fitness for me, bit of maybe strength in my legs." (Pt: B, M, 78 years)

"Well I thought I would get better walking … But exercise does do you good." (Pt: F, F, 82 years)

"Well at least you're giving me something to fight against that pain. I'm doing exercises that you're giving to me, which I want, you know, to take the stiffness out of my leg or whatever." (Pt: G, M, 73 years)

Answers given during semi-structured interviews indicated that participants had an understanding that regular exercise and activity was important for health and that they had a responsibility for maintaining their health. Participants referred to the need to use the system regularly to get health benefits associated with use:

"I think you've got to dedicate yourself to do the exercise and you know there's no doubt about it." (Pt: B, M, 78 years)

"Well, I think in the matter of doing exercises, the main thing is to get them done." (Pt: E, F, 88 years)

"But, no, I think it would, if you did it religiously, on a regular basis it would help you." (Pt: B, M, 78 years)

However, two participants did not believe that using the system would benefit their health. For one participant, this was because he did not believe it was possible to improve balance:

"Well I don't think anything I have done here would benefit me health wise." (Pt: A, M, 81 years)

"No, I don't think, I don't believe it could actually improve your balance, but what it could do, it could make you aware that you don't have good balance." (Pt: A, M, 81 years)

Another participant (PtID: D, M, 86 years) did not believe he needed to use the ACG system:

PtD: That might suit some people, it could maybe help people but I can't see it helping me.

R: What kind of people could it help?

PtD: Oh, I don't know, people with more of a disability than mine. That's what them exercises is for more. Disabilities. Isn't it?

7.5.3.5.2 Previous exercise/therapy experience sets the precedent

During the semi-structured interviews, the participants reflected on their memories of other exercise when considering their experience of using the ACG system. Some participants compared use of the ACG system with sport or recreational exercise, while others likened it to exercises they may have completed during physiotherapy. Parallels were also drawn between use of the ACG system and playing other games:

"I think you have to enjoy it. It's like any sport you're doing; you have to do it with a smile on your face at least." (Pt:B, M, 78 years)

"Maybe I was anticipating something else that was on the physical end of the scale like you know… See when I was your age I would have been doing all the physical things going. You understand what I mean now. That's what I'm saying, handstands things like that, walking along a board. Now the two rails you could reach up, hold onto the rail, swing yourself 'til you came upright then swoop down" (Pt:D, M, 86 years)

"Well, as I told you before I still do a few exercises from physiotherapy and I try to do as much as I can. I think that those games, I'm not saying they'd make it brilliant, but it certainly would help eventually to get you to a level where you could move just that bit more freely." (Pt:B, M, 78 years)

"I don't know, I mean, I wasn't doing anything I hadn't done before. I found it quite good, you know. And sort of, it's less boring than doing a thing and doing it on your own." (Pt: E, F, 88 years)

"I suppose it's the element of the game because I think for most of your life you partake in games" (Pt: E, F, 88 years)

Participants reported some of their current barriers to exercise, suggesting that the system may help overcome some of these:

"It's very boring, you probably wouldn't know, but to sort of now, to make time to do exercises and to do them, with doing it on your own, it's very boring and it doesn't encourage you very much you know." (Pt: E, F, 88 years)

"It's hard to motivate yourself at home. It's much easier to motivate yourself there when you have the thing on the screen" (Pt: B, M, 78 years)

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"Aye, well, actually the thing is if you have to go somewhere to do something you are more inclined to go, if you have an aul thing set up at home you are going to put it off you see…. So, I think actually with the game, it would control your time keeping to a certain extent as well." (Pt: E, F, 88 years)

"I should have went for exercises when I got the stents in, but I couldn't manage…. And I would have liked to have went there for to do the exercises but I just gave it up because it was too far up there. I couldn't get a bus; I'd have to get a taxi." (Pt: F, F, 82 years)

"Well I would like to do it on a day I was here, but I wouldn't like to go anywhere else." (Pt: E, F, 88 years)

7.5.3.5.3 Engagement with the system

As described above, some of the barriers to engagement with traditional exercise, for example exercises prescribed by a physiotherapist, were related to motivation. Participants appeared to recognise their responsibility to adhere to exercise and the importance of personal, or intrinsic, motivation. It seemed that this was difficult to maintain; however, some participants suggested ways by which they believed exercise delivered using the ACG system could overcome this barrier and increase motivation:

"You're doing something because you want to do it." (Pt: A, M, 81 years)

"I think that is a failing in human nature anyway. I think you've got to dedicate yourself to do the exercise and you know there's no doubt about it." (Pt: C, M, 78 years)

"The game is probably different, I think if it's there you have a visual and you're trying to, as I say, what that visual is doing, and I think it's a better motivation to do the thing daily, on a daily basis even." (Pt: B, M, 78 years)

Participants described their interactions and experience with some of the system features, reflecting on their enjoyment using the system, with novelty and entertainment reported by some as their reason for using the system:

"See that's why I came in, more or less on a curiosity basis. To see what there was like." (Pt: D, M, 86 years)

"There is an element of entertainment with this as well, you know." (Pt: E, F, 82 years)

"That was totally new to me, I never seen that actually being put on screen sort of thing" (Pt: G, M, 73 years)

"No, just that I enjoyed the challenge, eh, I would like to try and improve what I have done. Again, if I was doing it again I would enjoy it, I thought it was great." Pt: B, M, 78 years)

Feedback provided by the ACG system influenced participants' experience and engagement with the system. Participants reported that visual feedback guided their use and improved motivation. Responses given during the semi-structured interviews also suggested that participants viewed achieving scores as motivating, as was competition, particularly with themselves:

"If you see the object on the screen, what you need to do, then I think it helps you too... You can see your result on the TV screen." (Pt: B, M, 78 years)

"It's probably because it's a bit more like a game and you're sort of watching yourself but at the same time you're watching this body thing, and it moves very quickly and so on, and eh I don't know. It gives it a bit of edge." (Pt: E, F, 88 years)

"That's right, I was looking at those marks for the other three things and I did well in them so I was happy with that." (Pt: A, M, 81 years)

"I think if you're competing with someone else it is that extra bit of motivation. Ok, you can gee yourself up to try and improve what you did, which Is what I was trying to do, but if you have that person that is achieving, I'm not saying it's a competition, it's just something you say

to yourself, there's a person that can achieve that sort of level, why can't I?" (Pt: B, M, 78 years)

Excerpt from semi-structured interview with Pt: B, M, 78 years:

R1:   How important is achieving a score to you?

PtB   I think that's really what it's all about. A score shows, a good score shows that you are capable of participation of the game and, you know, you can maybe try and increase it.

Other factors influencing participants' attitudes towards use of the ACG system were simplicity and suitability:

"It wasn't complicated, it was simple…. Aw it has to be, the simpler, if you simplify the game it actually helps people." (Pt: B, M, 78 years)

"Very good, I thought it was easy to understand so it was, yea, I liked it." (Pt: F, F, 82 years)

Excerpt from semi-structured interview with Pt: E, F, 88 years:

R: So, what type of person would be fit for that game?

PtE: Well, I think nearly anyone. Now a young person would be better doing the game, but whether they would need to do it... but I think they would take to that better.

R: In what way?

PtE: Well, just usage really. They're sort of used to you know screens on computers and so on.

Participants tended to infer that they required a longer learning and familiarisation in getting to know the system:

"At first I wasn't sure what I had to do and then when I got into it, you know, I concentrated on it." (Pt: C, F, 76 years)

"Nearly like learning a thing from new, like if you were teaching me to do something you wouldn't just be shooting it through." (Pt: E, F, 88 years)

"As you get older, we don't think as quickly as you younger folk and with the apparatus changing so quickly, all coming off a screen it's different someone saying do this now or that or the other, but eh when it's coming at you, you've only so many seconds to do that. You have to try and get your mind and your body working to suit that." (Pt: G, M, 73 years)

"Yes, I think that's right because if you are looking at any of them really, after you've done it you can anticipate what is going to happen. The first time you don't know, the second time you probably haven't familiarised yourself with it yet, but after that you sort of know what is going to happen next so you are prepared." (Pt: A, M, 81 years)

Some non-game related factors seemed to be important facilitators to engagement with the ACG system by the participants. These included the use of chairs for hand support, having supervision, and having another older person present:

"Because you were here and we were comfortable doing the things, you know, the chairs and all." (Pt: F, F, 82 years)

"I had to hold on. I would have lost my balance, things like that." (Pt: D, M, 86 years)

"You had someone there to help and to try and tell you if you were doing something wrong, or if, maybe, you should be trying it this way or, I think that is a great help to people." (Pt: B, M, 78 years)

"It's company, isn't it? Although you're company; but somebody nearly the same as yourself, you know." (Pt: F, F, 82 years)

"I just thought it was good. Sometimes you feel embarrassed going in somewhere on your own." (Pt: C, F, 76 years)

Both during and following use of the system, participants suggested things they felt would improve the system. Suggestions included different levels of difficulty, modifications to be able to complete the games more than once or in a different order and completion of the ACG with peer support:

> "Well, I thought it was, again, it gets back to what I've said about levels. If you can increase say different levels up from what you have, for anyone who is capable of achieving that it has to be a plus." (Pt: B, M, 78 years)

> "The only thing I could suggest, if they could slow it down a bit at first and have it gradual, and if it started the first couple of times at a slower pace and then speeded it up to what would be the correct speed, just so you would really get into the way of doing it properly and so on." (Pt: E, F, 88 years)

> "If you do the difficult ones first you then go on to the ones you feel you can achieve a high score in and you can then look at it and say, what if I could try that one again or those two games again, and try and concentrate really to build up a better method and trying to achieve a better score." (Pt: B, M, 78 years)

> "I was hoping if this thing was here there would be a core of people who would use it on a regular basis. And those core of people would be a spur to each other to try and achieve the best they possibly could." (Pt: B, M, 78 years)

Table 7.4 Themes, sub-themes, categories and example quotes

Themes	Sub-themes	Categories	Examples
Salience to current health	Understanding own capabilities and limitations	Changes associated with ageing	"I always did have reasonable health and fitness but over this last, I suppose, this last four or five years, you know, things have just deteriorated." (PtID:G, M, 73 years old) "See there's a thing I couldn't do, I couldn't stand on one leg, while that ball was coming out you know, I had to hold on. I would have lost my balance, things like that." (PtID: D, M, 86 years)
		Limitations to participation	"I wasn't good at the wall one, you know the wall coming down, I was too slow moving. I seemed to do the other ones all right, you know, lifting your knee." (PtID: F, F, 82 years) "The water one, I don't know, I just find it very, very hard to keep that leg up and it would probably continue that way." (PtID:B, M, 78 years)
		Barriers to participation	"I think it would if you were well enough, but I'm not too well, you know. And the first time I done it I was great, but I wasn't well last week so that's why I'm not doing it." (PtID:F, F, 82 years)

			"Although I don't suppose you could do much to improve your balance, I don't think so anyway." (PtID:A, M, 81 years)
	Beliefs about health	Responsibility for health	"I think you've got to dedicate yourself to do the exercise and you know there's no doubt about it." (PtID:B, M, 78 years)
			"Well as you get older you probably maybe don't think you could walk as far as you would like but you can't be giving into that because you have to keep your legs moving too." (PtID:G, M, 73 years old)
		Importance of regular participation	"If you're doing it regularly, you get onto the thing quite quickly but then when you stop, you seem to forget that. I don't know whether that's typical of people my age or not, but certainly that's the case for me anyway." (PtID:A, M, 81 years)
			"I think if you achieved that twice a week, and then again it's down to the participant that they can put themselves into that sort of regime, fine. I would say it would be more beneficial." (PtID:B, M, 78 years)
			"Especially if it was having an effect, and I know that you have to do it and do it and do it, but if you were starting to feel an effect that would encourage you more, you know, to keep at it." (Pt ID:E, F, 88 years)

	Beliefs about the system	Effects of the system on health	"Well I don't think anything I have done here would benefit me health wise" (PtID:A, M, 81 years)

"It wouldn't be important. Would it be helpful, would it be helpful for me to do that?" (PtID:D, M, 86 years)

"I thought the game would actually help achieve a bit of fitness for me, bit of maybe strength in my legs." (PtID:B, M, 78 years)

"I like to do things myself, or try and do them…But you feel useless sometimes, so I thought it was good doing the exercises." (PtID:F, F, 82 years) |
| | | Usefulness of the system for health | "You'd near try anything, you know… That's why I played it last week." (PtID:F, F, 82 years)

"But it's not really of any benefit, not to me, I don't know, I hope I am wrong in the way people have set up it like you know. What they think. That might suit some people, it could maybe help people but I can't see it helping me." (PtID:D, M, 86 years)

"Oh, I don't know, people with more of a disability than mine. That's what them exercises is |

			for more; disabilities, isn't it?" (PtID:D, M, 86 years)
Previous exercise experience sets the precedent	Comparison with other exercise	Recreational	"It's like any sport you're doing; you have to do it with a smile on your face at least." (PtID:B, M, 78 years)
			"We do chair exercises sometime in the centre and they're completely different to what you were showing us. Well you sat in your chair and you just done different exercises with your arms and lifted your legs up, but not as the way it was, looking at it." (PtID:C, F, 76 years)
		Sport	"Maybe I was anticipating something else that was on the physical end of the scale like you know." (PtID D, M, 86 years)
			"See you don't have a set of weights. See if you can lift that bar from the ground see if you can lift it and put it above your head, you know what I mean. There's none of that in it." (PtID: D, M, 86 years)
		Therapy	"Well, as I told you before I still do a few exercises from physiotherapy and I try to do as much as I can. I think that those games, I'm not saying they'd make it brilliant, but it certainly would help eventually to get you to a level where you could move just that bit more freely… And same here, you're trying to, if you see the object on the screen, what you need to do, then I think it helps you to. It's better than actually doing it at home, say trying to walk along a table or that. You can see your result on the TV screen." (PtID:B, M, 78
		Physiotherapy	

			years)
			"Em, I think we all, I am guilty of it as well at home. You know, you have to say yourself, I'll do extra tomorrow but you never do. The game is probably different, I think if it's there you have a visual and you're trying to, as I say, what that visual is doing, and I think it's a better motivation to do the thing daily, on a daily basis even. I think it's much, much harder to, as I say, to just do a set regime at home set by a physiotherapist. I always find it hard." (PtID:B, M, 78 years)

"I don't know, I mean, I wasn't doing anything I hadn't done before. I found it quite good, you know. And sort of, it's less boring than doing a thing and doing it on your own… No I think it would be very beneficial." (PtID:E, F, 88 years) |
| | | Games | "I suppose it's the element of the game because I think for most of your life you partake in games, from a very young age to a very old age if you're fit for it, you know, and eh, it makes it more interesting generally." (PtID:E, F, 88 years) |
| | Barriers to other exercise | Travel | "What made me come in was… I should have went for exercises when I got the stents in, but I couldn't manage. It was up in Dundonald Hospital, I went one day but I couldn't manage the next day because I was on antibiotics. And I would have liked to have went |

			there for to do the exercises but I just gave it up because it was too far up there. I couldn't get a bus; I'd have to get a taxi. … A taxi was about £11 up and £11 down, there's £22. Like you couldn't... and I couldn't get the bus because I couldn't get on the bus with that [rollator], cos you know the way the bus would shake." (PtID:F, F, 82 years)
		Boredom Motivation	"Em, I think we all, I am guilty of it as well at home. You know, you have to say yourself, I'll do extra tomorrow but you never do." (PtID:B, M, 78 years) "That's all right following the guidelines something like I mean, if you thought about it you wouldn't do it in the house, you're already busy doing something else." (PtID:D, M, 86 years) "It's very boring, you probably wouldn't know, but to sort of now, to make time to do exercises and to do them, with doing it on your own, it's very boring and it doesn't encourage you very much you know." (PtID:E, F, 88 years)
		Health	"And then it leaves me very tired" (PtID: E, F, 88 years) "But as I say when you've soreness there" (PtID:G, M, 73 years)

Engagement with the system	Personal motivation	Barrier Overcoming barriers	"It's hard to motivate yourself at home. It's much easier to motivate yourself there when you have the thing on the screen" (PtID:B, M, 78 years) "It is, it is, because you sort of say that's ok I'll do it in the morning and I'll do it at night, but then the morning seems to go in and you find yourself doing them at a quarter to one which is daft, absolutely. No, so I think actually with the game, it would control your time keeping to a certain extent as well." (PtID:E, F, 88 years) "Em, I think we all, I am guilty of it as well at home. You know, you have to say yourself, I'll do extra tomorrow but you never do. The game is probably different, I think if it's there you have a visual and you're trying to, as I say, what that visual is doing, and I think it's a better motivation to do the thing daily, on a daily basis even." (PtID:B, M, 78 years)
	Facilitators to engagement	Social support Practical support	"The fact was that you were there, and if I needed a chair I could get one." (PtID:A, M, 81 years) "Because we were in with you, we knew you were there and you had the chairs set up to hold on to. I'm no good if I haven't anything to hold onto." (PtID: F, F, 82 years) "I think someone there is a help, you know. I couldn't see myself enjoying it as much, possibly, on my own as I did when you were here when I was doing it…. You had someone

			there to help and to try and tell you if you were doing something wrong, or if, maybe, you should be trying it this way or, I think that is a great help to people. And that applies to anyone, I mean if you've anyone in the room at all. If you've two people doing it, one encouraging the other. Encouragement is a great thing." (PtID: B, M, 78 years) "No they're a great help, they're a great aid, and yea they're a great aid in many ways. And probably too, it would probably mean too, unfortunately, they would maybe use less staff, which would not be good, because it's nice to have a person helping you." (PtID: E, F, 88 years) "See there's a thing I couldn't do, I couldn't stand on one leg, while that ball was coming out you know, I had to hold on. I would have lost my balance, things like that." (PtID: D, M, 86 years)
	System features	Enjoyment Novelty Entertainment	"I found it quite good, you know. And sort of, it's less boring than doing a thing and doing it on your own." (PtID: E, F, 88 years) "There is an element of entertainment with this as well, you know." (PtID: E, F, 88 years) "Well while I'm doing it, that's the real world isn't it?" (PtID: D, M, 86 years) "See that's why I came in, more or less on a curiosity basis. To see what there was like…. I

			wondered what it was about. I just wanted to see what it was about, curious." (PtID: D, M, 86 years)
			"I was doing things there that I wouldn't have done at home, now I would definitely have went out for a walk with the dog but you put a bit more into it by giving me those exercises to do. You know they're not things you'd meet up with every day." (PtID: G, M, 73 years)
		Simplicity	"It wasn't complicated, it was simple…Aw it has to be, the simpler, if you simplify the game it actually helps people. You know, when you go into something and it's over complicated, I think you soon lose interest in it." (PtID: B, M, 78 years)
		Competition	"There was no strain, no pressure. You're not doing it competitively, it's not a competition. You're doing something because you want to do it. Not at all. I wasn't interested because I didn't care how I did. And that's sometimes the best way. When I say I didn't care how I did, I did care but against myself." (PtID:A, M, 81 years)
			"I think if you're competing with someone else it is that extra bit of motivation. Ok, you can gee yourself up to try and improve what you did, which Is what I was trying to do, but if you have that person that is achieving, I'm not saying it's a competition, it's just something you say to yourself, there's a person that can achieve that sort of level, why can't I? Maybe not

			get it, but get close to it, you know." (PtID:B, M, 78 years)
		Score	"That's right, I was looking at those marks for the other three things and I did well in them so I was happy with that, but I'm not so happy with the balance thing but I don't think that there is anything I can do short-term about that." (PtID:A, M, 81 years) "Well, I think, em, as I said harping back to sports, if you can achieve a level, say in this game, you have a high level of participating, a high level of scoring, I mean that is leadership in itself." (PtID:B, M, 78 years) "I think the character on the screen is actually the help to you, you know, if the character on the screen is doing it you're trying to copy and imitate sort of thing. So, it's there for you to focus on and to relate to, you know. I think it's much easier than doing an ordinary physio thing at home, much, much, easier." (PtID:B, M, 78 years)
		Visual feedback	"It probably helps to do the things when you're sort of watching yourself doing it, you know, I think it's beneficial that way…. Especially with the character, you're watching the character and you can follow it. Nearly like learning a thing from new," (PtID: E, F, 88 years)

			"Well, if you had an arm stuck out the wrong way or a leg or something, you'd be more aware of it and eh try to remedy it. Or for instance the one with the water appearing, you have to be quite quick off the mark, you know, to get changes from one to the other, you know. So I think it probably speeds up your sort of observation and so on." (PtID: E, F, 88 years)
	Suitability	Appropriateness for older people	Excerpt PtID: E, F, 88 years. PT E: Well, I think nearly anyone. Now a young person would be better doing the game, but whether they would need to do it... but I think they would take to that better. R: For what reasons? PT E: Well, just usage really. They're sort of used to you know screens on computers and so on, and there are games. Like I remember when they started having games, and I remember my sister standing on nights throwing and doing things when these games started. This was a grown woman; it wasn't a child you know. So I think you people in particular would like it, or old people like me probably. And I don't know about the sort of middle group, they maybe wouldn't have the patience for it.

			R: So it seems games and computers are traditionally associated with young people.
			Pt E: Still they are but that will change so it will. It's nearly changed now, you know. And eh, no they're a great help, they're a great aid, and yea they're a great aid in many ways. And probably too, it would probably mean too, unfortunately, they would maybe use less staff.
	Learning and familiarisation	Repeated use Learning in ageing	"As you get older, we don't think as quickly as you younger folk and with the apparatus changing so quickly, all coming off a screen it's different someone saying do this now or that or the other, but eh when it's coming at you, you've only so many seconds to do that. You have to try and get your mind and your body working to suit that." (PtID: G, M, 73 years) "After you've done it you can anticipate what is going to happen. The first time you don't know, the second time you probably haven't familiarised yourself with it yet, but after that you sort of know what is going to happen next so you are prepared. And in that particular one leg stand I think that should mean that you would improve because you know what is going to happen and you're kind of ready for it." (PtID: A, M, 81 years) "It would take me to be doing it. We've only been two days at it. But I was bad at it." (PtID: F, F, 82 years)

	Suggestions to improve system	Ability to skip and repeat games	R1 During one of the sessions when you were using the game, you had suggested could you change the order of the games to do the ones you found more difficult first. Is that something you would stand by? Pt B Well yes I would, because, em, if you do the difficult ones first you then go on to the ones you feel you can achieve a high score in and you can then look at it and say, what if I could try that one again or those two games again, and try and concentrate really to build up a better method and trying to achieve a better score. Pt B: Again, I think it's, the, if you're doing the exercise that you can try it again immediately. You can go forward but you can't go back, is that what it is? Pt B: Well I would rectify that. If you're there and you know what you did wrong, then I think if you could try it again immediately, to try and put that right, you know. I think that would be advantageous really.
		Levels	"If you get to a position where you're level 1, level 2, level 3, say, if you go well on level 1 and 2, you know, you can't be expected to stay there all the time, you have to have some new goal. So I do think it would be advantageous if you had different levels. (PtID:B, M, 78 years)

		Peer support	Pt E: The only thing I could suggest, if they could slow it down a bit at first and have it gradual, and if it started the first couple of times at a slower pace and then speeded it up to what would be the correct speed, just so you would really get into the way of doing it properly and so on. "And that applies to anyone, I mean if you've anyone in the room at all. If you've two people doing it, one encouraging the other. Encouragement is a great. I think it would a spur really. I was hoping if this thing was here there would be a core of people who would use it on a regular basis. And those core of people would be a spur to each other to try and achieve the best they possibly could." (PtID:B, M, 78 years)

7.6 Discussion

7.6.1 Summary of findings

This study explored older adults' experience with repeated use of an ACG system designed to deliver strength and balance exercises based on the OEP. Participants were invited to use the ACG system up to six times. Seven participants used the system at least once, and 22 out of 42 scheduled sessions were completed. None of the participants completed all six ACG sessions. Data collected during and following each session suggested high levels of usability and acceptability. The level of additional support and instruction required varied between participants. While the level of hand support used by participants appeared to remain unchanged with repeated use of the system, the level of additional instruction required tended to decrease with repeated use. Participants perceptions of the system seemed to be influenced by factors related to their beliefs about how using the system met their own current health needs, how it compared to their previous experience of exercise, and their engagement with the ACG system including features embedded within the system as well as external facilitating factors.

7.6.2 Usability

Overall, participants' ability to complete the games and their SUS scores indicated good usability of the system. However, completion of ACG sessions was low (52.3%) in comparison to n=17 studies included in the systematic review (Chapter 2) that had reported data related to completion, the mean adherence rate across which was 78.8%. A recent RCT comparing adherence to exercise in older adults in an inpatient rehabilitation setting found higher levels of dropouts and lower adherence in the ACG group in comparison to the self-regulated exercise using instruction leaflets (Oesch et al. 2017). The RCT reported comparable adherence, based on minutes completed per day, between the two groups on the first day that gradually decreased in the ACG group, and while enjoyment and motivation ratings were initially higher for the ACG group, they decreased during the treatment period of ten days. The findings of this study suggested that older people in an inpatient rehabilitation setting preferred paper-based instructions over ACG for rehabilitative exercise (Oesch et al. 2017). The majority of reasons reported for non-completion of sessions during the current study were not directly

related to the system. Many barriers to use of the system mirrored barriers to traditional exercise faced by older people. A systematic review and qualitative synthesis of 132 studies investigating older adults' engagement with physical activity identified six major factors influencing older adults' participation in physical activity: social influences; physical limitations; competing priorities; access difficulties; personal benefits of exercise; and, motivation and beliefs (Franco et al. 2015). During the semi-structured interviews, participants reiterated the barriers they had faced to traditional exercise, in line with those presented in Franco et al. (2015). Some participants described the ways in which they thought the ACG system could help overcome barriers, for example by improving motivation to exercise or providing easier access without the need for additional travel or expense. However, despite reporting beliefs that ACG may overcome barriers to participation, corresponding high levels of adherence were not observed.

When considering the reasons for non-completion of sessions by the seven participants, as well as the additional three individuals who did not complete any ACG sessions, described in section 7.5.1., the two main reasons reported for non-completion of ACG sessions were due to health and other activities scheduled at the day centre. Despite a desire to improve their health being reported as one of the reasons for using the ACG system, participants' health seemed to limit their participation. Education about the benefits of strength and balance exercise may be one way to encourage older people to use the system. During recruitment, a presentation giving information about the project provided potential participants with information about falls in older adults and falls prevention. Nevertheless, two participants did not believe it was possible to improve their balance, or did not think the system would be effective. An education component delivered via the ACG system, for example, providing falls prevention information may improve users' knowledge of the evidence in the area, thus promoting adherence. Application of the Behaviour Change Wheel (Michie et al. 2014) suggests that improving knowledge may contribute to older adults' beliefs about the benefits of ACG, developing reflective motivation to promote behaviour change. As such, the BCTTv1 (Michie et al. 2013) suggests BCTs including *5.1 Information about health consequences* to improve knowledge.

While participants reported that they felt that ACG would make exercise more enjoyable, non-completion of some ACG sessions was due to alternative activities that were scheduled in the day centre. Integration of ACG into the routine of the day centre would reduce conflict of priorities, perhaps contributing to increased participation. Additionally, during the semi-structured interviews, responses suggested that ACG in a group setting would be favourable to older adults. A social influence was important for all participants, of which peer support from similar people was also important to a few. Application of the Behaviour Change Wheel (Michie et al. 2014) suggests that social opportunity is an important component for behaviour change, with the BCTTv1 (Michie et al. 2013) suggesting BCTs related to practical and emotional social support to provide an individual with the opportunity for behaviour change.

Participants were able to complete most or all of the games during each use of the system; however, additional instruction and support was frequently required. The categorisation of additional instruction into that required for set-up and that required during play facilitated a number of ways to reduce the amount of instruction required. Additional instruction required for set-up was higher during sessions when there were problems with calibration of the Kinect tracking; this was not related to the number of sessions completed by participants. Modifications to the system to improve the consistency of the Kinect tracking would reduce the requirement for additional instruction guiding the participants through successful calibrations. Alternatively, modification to the system to allow it to identify when there had been a problem with calibration, followed by instruction how to overcome this issue provided by the system would reduce the need for input by a therapist or researcher. For example, the avatar was displayed on screen frozen at the beginning of the game and displayed the users' bodily movements if calibration had been successful and the Kinect had detected the user; therefore, if this did not happen, SH was able to identify unsuccessful calibration and restart the game, instructing the user to alter their posture, by standing upright and positioning their upper limbs to the side, to aid successful calibration. Increased sensitivity to detect the user, alongside an instruction guiding the user to attain the posture required for calibration would reduce the requirement for input by a therapist or researcher. Additionally, the ACG system performed a countdown to the game if the user was standing in the correct place, and if the countdown did not begin when

expected SH identified that the user was not correctly positioned and guided them to the appropriate position to allow the game to begin. Increasing the area that the user could be positioned to play, or an additional verbal instruction informing the participant that the game had not begun as they were not positioned correctly, would reduce the requirement for input by a therapist or researcher. Improved user control, via remote, arm as mouse or voice control, would also allow the participant to restart the game should an error occur.

The second type of additional information was related to play, including correction of technique. This appeared to reduce with repeated use of the system, as participants became more familiar with the system. In line with guidance (Ijsselsteijn et al. 2007, Fisk et al. 2009, Gerling et al. 2012), attempts were made to ensure the game was intuitive and that instruction provided by the system was short and clear. Modification to the system to detect common errors during use and prompt correction of them was one way suggested to overcome this problem; this could not be implemented for this prototype due to time and resources. Even if this had been possible, older adults are less familiar with being instructed by a computer screen (Gerling et al. 2012). A positive relationship was observed between additional instruction provided and enjoyment rating; it seemed surprising that older adults may have preferred sessions during which they required more instruction, but may suggest that they enjoyed the social support provided. During use of the system, it was observed that participants tended to turn to support available for reassurance, suggesting computer anxiety and low self-efficacy remained with repeated use of the system (Czaja et al. 2006; Ijsselsteijn et al. 2007; Fisk et al. 2009). It is not clear whether this would have reduced with further use of the system. Additionally, during the semi-structured interviews, participants spoke about the importance of social support as a facilitator to use of the system. For some participants, company and encouragement was more important than the provision of additional instruction. As suggested by one participant, participation of ACG in a group setting would potentially provide the social support preferred by participants.

While user scores tended to increase and the need for additional instruction tended to decrease with repeated use of the system, suggesting that participants were learning and becoming more familiar with use of the system, the amount of hand support used by participants did not tend to change with repeated use. As per protocol, chairs were

placed at either side of the participants and they were instructed to use the hand support they required; however, participants often used two hand support as it was available, even if they had used no hand support on previous uses of the system. Reducing upper limb support is a guideline for best practice in exercises to prevent falls (Sherrington et al. 2011). It is one of the ways in which the OEP progresses the difficulty of its exercises (Campbell et al. 1997). Implementing structured goal-setting or instruction or prompts related to reducing hand support within the game is one way to encourage older adults to reduce their level of hand support. An example of this may be, if a participant gets full marks in a game with two hand support, they can progress to one hand support. Creating a series of levels within the game was suggested by participants as a way to improve the system; progression towards reduced hand support could also be included in the structure of levels within the game.

7.6.3 Acceptability

Scores from the AFRIS suggested high levels of acceptability of the ACG system as a falls related intervention; these were generally supported by user data collected by the system related to participant enjoyment. Additionally, qualitative findings from participant comments and semi-structured interviews reinforced that participants viewed the ACG system as an acceptable way to deliver strength and balance exercise that may help overcome some of the barriers to traditional modes of exercise faced by older people. Factors reported in the semi-structured interviews that influenced older adults' experience of using the ACG system could be mapped to components of the TAM (Davis 1989), previously described in Chapter 3 (Figure 3.1).

One of the emerging themes, salience to current health, included sub-themes related to participants identifying their health and limitations, their beliefs about improving their health and their beliefs about the effectiveness of the system to contribute to improved health. The acceptance of the ACG system depended on the extent to which participants believed they needed to use it alongside the extent to which they believed using it would be effective. This maps to the perceived usefulness component of the TAM (Davis 1989). Enhanced education about the benefits of using technology has been suggested as a way to increase adoption and usage in older adults (Mitzner et al. 2010). Findings from the semi-structured interviews suggested that maintaining or improving health was

important to older adults, and that they understood their responsibility to do so. Providing more information about the health benefits associated with participating in ACG may be a way to improve acceptance and engagement with it.

Perceived ease of use is another component of the TAM (Davis 1989). AFRIS item 4 referred to participants' perceptions of the ease of use of the system; positive responses to this item were supported by qualitative findings from the semi-structured interviews. The importance of ease of use in terms of simplicity was reported during semi-structured interviews. Participants were satisfied with their use of the system and its ease of use; however, as use of the system was facilitated by a researcher, it is not clear how participants would have perceived the ease of use of the system if they had to manage the set-up and navigation of the system independently. Participants commented that use of technology was not familiar to them, but they were willing to try it and felt that using technology was becoming acceptable for them. Guidelines for design of technology appropriate to older people should be adhered to in order to ensure ease of use of such interventions in this population. Previous exercise experience also contributed to participants' attitudes towards the system. Particularly participants that had previous physiotherapy commented that they perceived using the system as easier than completing home exercise programmes.

Aside from for health benefits, entertainment and enjoyment were other important factors contributing to participants' engagement with the system. Qualitative findings suggest a number of ways in which the ACG system features, as well as non-game features improved enjoyment, influencing older adults' attitudes towards the acceptability of the system and engagement with ACG. As well as guiding participants through their use of the system, feedback by the system was often a motivating factor for participants. Participants were often observed comparing their scores to previous uses of the system, some requesting to replay games to try and improve their scores. Participants used their score to compete with their previous performance, and expressed some interest in competing with others. Competition to motivate use of the system could be implemented through leader boards (Snyder et al. 2012; Mattaloui et al. 2017), or through ACG in a group setting (Meekes et al. 2017).

7.6.4 Limitations

While this study provides valuable insight into older adults' perceptions of the usability and acceptability of a specifically designed ACG system using both quantitative and qualitative methods, there are a number of limitations to its findings. Primarily, the small number of participants recruited and poor completion rates of scheduled ACG sessions meant limited ability to perform statistical analysis of usability and acceptability with repeated use. Additionally, as the study design did not include a comparison group, we are unable to make assumptions about this population in terms of their adherence to another exercise programme.

Table 7.5 Table summarising suggested changes to the system following user testing phase 2

Summary of suggested changes
Improve the consistency of the Kinect tracking, less errors during calibration
System identifies problem with calibration and provides appropriate instruction
Improve user control, via remote, arm as mouse or voice control
System detects common errors during use and prompts correction
Peer support; ACG in a group setting
Education component; falls prevention education; benefits of ACG
Goal-setting, instruction or prompts related to reducing hand support
Levels of difficulty
Leader boards

7.7 Conclusion

Findings from this study suggest good usability of this system in older adults, with a trend towards a reduced requirement for additional instruction with repeated use of the system, suggesting learning with increased exposure to the system. Additionally, older adults viewed ACG as an acceptable way to engage with strength and balance exercises. Findings from this study have been used to identify ways to improve the usability and acceptability of the current system (Table 7.5). A desire to obtain health benefits and enjoyment were the participants' two main reasons for engaging with the system. Their attitudes towards the system were often shaped by their previous exercise experience; system features, including feedback, improved motivation to continue engaging with the system; and, non-gaming features such as hand support and social support were important facilitators of use of the system. Positive attitudes towards the system did not ensure high levels of participation with the ACG system, suggesting that acceptance does not equate adoption.

8 Discussion

8.1 Chapter overview

This chapter reflects on the main findings of this research. More detailed discussion of specific findings of each study, and their implications can be found in the discussion section in Chapters 2, 5 and 7. However, during the conduct of this PhD, a number of factors were identified as playing a key role throughout the design, development and evaluation of the ACG system. These are discussed in this chapter.

8.2 Overall summary of findings

This PhD consisted of a number of strands that contributed to the iterative development of an ACG system designed, by an interdisciplinary team, to deliver evidence based strength and balance exercises to older adults. Development of the system involved consultation of the available evidence; this included conducting a comprehensive systematic review and meta-analysis of the physical and cognitive health benefits of ACG in older adults. Findings from this, presented in Chapter 2, suggested small to moderate positive effects for balance, functional exercise capacity and cognitive function; however, GRADE analysis indicated that the majority of data came from low quality studies. Data collected from the studies also provided information about the delivery of ACG interventions, suggesting that many were delivered to generally healthy older people in a clinical setting with supervision and assistance. One driver behind this project was to explore the possibility of developing a system that could be used safely and autonomously to meet the needs of more frail older adults who perhaps were unable to attend falls prevention therapy outside of their home. To this end, each

prototype was evaluated in terms of its safety, usability and acceptability in older adults, including those at risk of falls.

Feedback from older adults, including those with physical limitations and those at risk of falls, was used throughout the development process, as presented in Chapter 3, contributing to the design and modification of the ACG system, described in Chapters 4 and 6. Involving users early in the development process has been recommended by a number of research teams involved in the development of ACG systems for health (Uzor et al. 2012; Proffitt and Lange 2013; Brox et al. 2017). While it was possible to learn from and apply some of their processes to refine the user-centred design methods used in this thesis, there was limited guidance available to inform the effective interdisciplinary collaboration required to successfully develop an ACG system. Interdisciplinary collaboration formed the key stone of the development process, enabling user-centred design and bridging the gap between developers, clinicians and clinical populations, to develop an interesting and fun ACG system that met the clinical needs of older people. The interdisciplinary collaboration is reflected upon below.

The two phases of user testing, presented in Chapters 5 and 7, suggested that ACG was a safe way to deliver strength and balance exercise to older people, including those at risk of falls who would benefit from the system. No AEs were reported during use of the system. Participants unanimously preferred viewing the system displayed on flat screen rather than using a VR headset. While during both phases participants reported high levels of usability according to the SUS, they also required high levels of additional support to use the system. Support was also identified as an important factor influencing participants' ability to engage with the system as well as their perceptions of it. The requirement of additional instruction did, however, reduce with repeated use of the system. Nonetheless, support was identified as an important factor influencing participants' ability to engage with the system; additionally, support influenced their perceptions of the system. Both quantitative and qualitative findings suggested that the system was not suitable for autonomous use by older people in its current format. In both study phases, additional instruction was required, and observation of sessions suggest that older people tended to seek support that was available. This observation was supported by responses given in semi-structured interviews suggesting that the social support and interaction with the therapist influenced participants' experience of

using the system and their perceptions of it. Furthermore, although AFRIS scores and enjoyment ratings indicated high levels of acceptability of the ACG system, low levels of completion of ACG sessions suggest poor adoption of the system. Older adults may require external support to continue engagement with an ACG system, similarly to the need for follow-up to review their adherence to a traditional exercise programme provided by a therapist. This chapter (see Section 8.4.1) suggests a number of proposed changed to the ACG system and its delivery that may improve its usability and acceptability, aiming towards long-term engagement and adoption.

8.3 Interdisciplinary collaboration

An interdisciplinary team of clinicians and developers was involved in the iterative development process. Effective interdisciplinary collaboration was imperative for the successful development and modification of the ACG system to meet the needs of the target population. As described in Chapter 3, healthcare research and system development tend to use different frameworks and processes to develop interventions and systems (Pagliari et al. 2007). Both disciplines bring invaluable knowledge and skills to the development of ACG systems for health, facilitating optimum design and development to meet users' needs. While consultation with other disciplines has been used and reported in trials to inform the development of ACG systems for health (McNaney et al. 2015; Perez et al. 2017), there is limited information or guidance for interdisciplinary ACG system development teams. Interdisciplinary collaboration was central to this project, and a number of strengths and challenges have been identified, and lessons learned, through three years of engagement within an interdisciplinary team during the development of the ACG system.

8.3.1 Strengths of interdisciplinary collaboration

The three main strengths of interdisciplinary collaboration on this PhD were a shared vision, the potential to draw knowledge and expertise from different disciplines, and the use of communication in gathering and sharing knowledge across disciplines to optimise the development of the ACG system.

As described in Chapter 3, the benefits of multidisciplinary working are often referred to in health care (Royal College of Nursing, 2006). Literature from other fields, such as

business and education, identifies important components of collaboration including consultation, co-operation and co-ordination (Idol et al. 1995; Economist Intelligence Unit 2008; Williamson et al. 2016). Reflecting on this PhD, one characteristic of collaboration was a shared vision, contributing to high levels of motivation and commitment from all team members. During this project, trust was developed within a team comprised of different disciplines with the same goals and eagerness to contribute to the project goal. Team members from both disciplines engaged in the project with the intrinsic desire to develop an intervention for health and rehabilitation.

One of the greatest benefits of interdisciplinary collaboration is its ability to draw together the knowledge and expertise of more than one discipline. This interdisciplinary collaboration provided the potential to draw knowledge and expertise from health science and computer science disciplines to develop an intervention for health and rehabilitation. Clinician researchers were able to define the requirements of the system to meet clinical aims based on research and best evidence, while developers in the research team were able to identify ways in which to implement them in an interesting way. Given their understanding of the needs and potential impairments associated with health conditions, clinicians are often involved in the development of ACG for clinical populations (McNaney et al. 2015; Perez et al. 2017). During this PhD, the clinician members of the research team were able to apply available design guidelines (Czaja et al. 2006; Ijsselsteijn et al. 2007; Fisk et al. 2009; Gerling et al. 2012) to their understanding of the target population, including potential physical and cognitive limitations that may have affected usability of the ACG system by older people. Additionally, rather than assuming older adults' preferences and requirements for an ACG system, efforts were made by clinician research team members, early in the design and development phase, to engage with the target population to gather information about their preferences and requirements. These were communicated to the developers to optimise the development of the ACG system to meet the needs of end users. Effective collaboration meant that the system could be modified prior to user testing to reduce the risk of these potential challenges to engagement with the ACG system.

Interaction between clinical and development teams has been recognised as having the potential to maximise adoption of ACG systems in clinical populations (Pirovano et al. 2016); involvement of clinicians in the design and development of an ACG system may

help identify and overcome any barriers faced by clinicians in the adoption of novel technologies for health. Effective communication is imperative for successful integration of different disciplines (O'Rourke et al. 2013). Communication within this interdisciplinary team occurred regularly; as described in Chapter 3, communication within the interdisciplinary team included regular face-to-face team meetings to review the development of the ACG system, as well as ongoing communication, via video call and email, to share progress and discuss issues. During this project, efforts were made to break down jargon and terminology specific to one discipline to facilitate effective communication. There was a need to be prepared to ask questions in order to avoid assumptions and ambiguities. In the early stages of this project, efforts were made to communicate requirements of the system clearly and thoroughly. Clinician members of the research team were able to share information and expertise about the evidence base, target population and ACG system requirements from a clinical perspective. This information was delivered to the team via a presentation, including images and visual demonstrations of the movements required within the OEP, to aid understanding by team members unfamiliar with some of the terminology. As the development progressed, the team continued to communicate their progress, and accepted and responded to feedback to further advance the development of the system. Following the first user testing phase, results were fed back to the team, using video clips of participants using the technology alongside a presentation of the qualitative feedback plus written reports, to aid the modification of the ACG system for development of prototype 2. Information was communicated to the team by developer members through demonstration of the game design ideas with the opportunity to discuss and further develop these ideas, with respect to improving interaction with the system and changes to its presentation and aesthetics. As well as facilitating the development and modification of the ACG system, effective communication provided all the necessary information about game design and game features to enable the clinician researcher to plan the content and issues to be discussed at meetings with older people to ensure that the most valuable feedback could be collected and used to further develop the system.

8.3.2 Challenges of interdisciplinary collaboration

Challenges encountered during the interdisciplinary collaboration for this PhD included bringing together the different methods used by each discipline, and working with limited time and resources to develop the system.

As previously described in Chapter 3, research in health science and computer science uses different frameworks and processes to guide their methods. One challenge of working collaboratively is the necessity to combine these. From the earliest team meetings it was possible to draw several parallels between the different disciplines. An example of this was the value of involving patients or users in the development of the intervention or system. Another similarity in the disciplines was the use of features with a psychological underpinning, within the intervention or system, specifically to increase adherence or use. As the research team gained a greater understanding of each discipline it was possible to extract processes from each discipline to optimise the development process. One such process was the use of smaller study phases to trial the ACG system and iteratively pilot each modification made prior to roll out. It is identified in the MRC framework (Campbell et al. 2000; Craig et al. 2008) that feasibility and piloting should be included prior to evaluation of an intervention; however, the focus is about broad acceptability of an intervention, evaluating outcomes such as recruitment and retention. On the other hand, games development models describe a process of testing in a smaller sample of users to optimise factors such as usability, efficacy and safety of specific components of the intervention (Henderson et al. 1999). Guidance from these models provides more information about game design factors to consider when developing an ACG system using novel technology, particularly for a clinical population. A series of testing of the ACG system by clinicians and non-gamers within the research team and other healthy adults reduced the resources and time required, as well as overcoming any usability issues, prior to testing in the target population.

The expectations of the ACG system from the different disciplines within the team were observed early in the development process. Clinician members of the team defined the requirements from a clinical perspective and with consideration for appropriate level of challenge for older people, ensuring safety and accounting for potential limitations experienced by the target population, as well as appropriate dose for clinical effect and

ways to progress based on participants' level of function as traditional therapy would be progressed. As well as considering how the ACG system could be developed to meet the clinical goals discussed, game developer members of the research team thought about ways to make the game interesting, aesthetically and in terms of enjoyment, to encourage repeated use. Game developer members tended to be gamers and were familiar with and enjoy the fast paced nature of action games. They had the skills to react to these games and be successful during play. This was not necessarily reciprocated in clinician members of the team, with games features that were appealing to the developers and speed and difficulty levels chosen by developers not always being appropriate for optimal interaction by non-gamers, who did not intuitively understand commands. Clinician testing during interdisciplinary meetings was used to identify features of the system that did not meet the ability of non-gamers. It could be anticipated that if a game feature was not appropriate for a non-gamer that it would not be appropriate for an older person who was also unfamiliar with gaming.

Limited time and resources with which to develop and test the ACG system meant that the team relied on junior team members to develop the software. System development was mainly by an Erasmus student (GC) and an undergraduate computing student (CB), with the support of a PhD student (DH). Iterative modification to the ACG system was completed based on the knowledge and skills of the junior team members; due to this, a number of games features were not implemented. Some of the suggestions to improve usability and acceptability of the system would not have been possible to implement within the available timeframe of this PhD without input from a more experienced software developer. Additionally, while the research team were able to draw on their clinical and software development knowledge to support the development of an ACG system to deliver strength and balance exercise to older adults, it did not have a strong history of the chosen study methodology of user-centred design. This methodology was identified, through literature searching and discussion within the interdisciplinary team, as a way to include best practice from both disciplines. As described in this thesis, it was necessary to consider ways to use methods and measures used by both disciplines in order to gather rich data related to the safety, usability and acceptability of the ACG system in older adults. As an example of this learning process, the initial study protocol had outlined that usability would be evaluated through observation of older adults'

ability to use the ACG system, including additional verbal and physical assistance required. Extensive literature searching identified the SUS as a way to measure older adults' perceptions of the usability of the system. An amendment was made to the ethics application to include this as an outcome measure. Identifying this additional measure enabled collection of quantitative data to support observations of ACG system use.

8.3.3 Lessons learned through interdisciplinary collaboration

Developing effective communication has been imperative to the success of this interdisciplinary team to meet its goals, and is a common thread through all of the lessons learned through interdisciplinary collaboration on this project:

1) Preparation and planning are necessary when collaborating across different disciplines. Prior to the initial meetings for this project, research team members from the different disciplines prepared content and knowledge to be shared at the meeting. Documents were sent to all team members to allow them to read prior to the meeting so that any queries could be discussed and resolved during the meeting.

2) A clear understanding of project goals and roles within the interdisciplinary team is important. The research team agreed consensus on a task list with specific tasks assigned to individual team members; this involved discussion to prioritise the requirements of the ACG system based on the potential to achieve them within the timeframe and with available resources.

3) Regular communication is necessary. This included communication to review progress to date, discuss issues and make decisions; this included regular face-to-face team meetings and more regular progress reports.

4) Measures should be taken in order to ensure transparency of processes, including a log of changes made to the system, with reasons for decisions; testing regularly by the team to review the system. This allows both disciplines to be involved in identifying, reporting and resolving any usability issues.

8.4 Bespoke versus commercial ACG

The bespoke ACG system developed through this PhD was developed for use with a commercially available platform. The Kinect sensor, described in Chapter 4, tracks user

body position and movements to control an avatar displayed on-screen, permitting controller-free active gaming. This makes it ideal for rehabilitative exercise; however, many commercial games for the Kinect are developed for entertainment of young, healthy adults. Consequently, they do not meet the needs of some clinical populations, in terms of delivering appropriate exercise and permitting optimal interaction when physical and cognitive limitations are present. To optimise the usability and acceptability of ACG in older adults, it was necessary to develop software that would accommodate the physical limitations of the target population and deliver exercise to meet their needs.

A bespoke ACG system can be developed to include specific movements to train the therapeutic goal; in this study the ACG system was developed to deliver strength and balance exercises from the evidence-based OEP. Each OEP exercise was considered in terms of its potential to be implemented within the system. The development of the system was influenced by available guidelines for the design of technology for older people (Czaja et al. 2006; Ijsselsteijn et al. 2007; Fisk et al. 2009, Gerling et al. 2012). The range and speed of movement required to be successful was adapted to suit the physical capabilities of older people, including permitting the use of walking aids, and calibrated to individuals where possible, for example, leg abductions calibrated for range of movement prior to play. Displays were designed to provide the appropriate amount of information to guide older people through use without increasing the cognitive load. Information was also presented clearly on screen, and where possible presented in more than one way to accommodate vision or hearing impairment. The aim of system design was to increase older people's self-efficacy and improve levels of enjoyment and engagement with the system.

There were, however, some challenges experienced in relation to the development of a bespoke ACG system. An initial protocol developed to meet the overall aim of this system included the use of a piece of novel technology that had been pre-ordered for use in this project. It was anticipated that it would enable older adults to complete walking practice and balance exercises, and that safety features in the design of the product may have reduced some barriers to exercise faced by older adults, therefore increasing participation. However, shipping of the product was delayed and eventually cancelled (Appendix 26). Technology advances quickly, and products can be obsolete before

evidence has established their effectiveness. In order to overcome this, the system had been pre-ordered and the protocol planned to enable its prompt evaluation upon arrival; however, other obstacles prevented the use of the system for this project. Another obstacle to developing a bespoke system was overcoming bugs in the system during development. As such, there were a number of features that were not possible to implement in the ACG system, due to technical difficulties implementing them with the time and resources available. For example, efforts were made to implement a progress bar, but this caused problems in collecting participant scores. Other features that were not implemented are described in detail in the description of each prototype of the system (Chapters 4 and 6).

8.4.1 Suggestions to improve engagement

Findings from both study phases suggested that older people were satisfied with the presentation and content of the ACG system; however, additional changes can be proposed based on reflection and on participant feedback. The following changes to the system could improve usability, enjoyment and self-efficacy to facilitate long-term engagement with the system:

1) Provision of a video demonstration of the movement required, played during the audio instruction, would provide additional instruction immediately prior to playing each game; this may reduce cognitive load for older people, reducing their need to rely on memory for a visual demonstration of the movement required (Charness et al. 2009). This may improve system usability. On-screen demonstrations have previously been suggested to provide clear explanation to older adults (Gerling et al. 2012).

2) User choice, in terms of the choosing the games to play and the order to play them, may provide more autonomy and freedom of choice which can be an important motivator in some game users (De Schutter and Malliet 2014).

3) The current ACG system collected data related to scores, and provided users with feedback on the outcome of their movement; this was knowledge of results. Had the system collected performance data, it could have rewarded improved quality of movement, for example improved range of movement or accurateness, rather than just score based on results; this would have been knowledge of

performance. Additional feedback on the quality of movement during use of the system may have improved older adults' self-efficacy to improve engagement with the ACG system. Also, it would have better mirrored how an exercise intervention would be delivered by a therapist in clinical practice.

4) Adding a social component to delivery of ACG was a suggestion for future use of the system. While older people seemed to rely on the support of the therapist during use of the system, during user testing of prototype 2, they reported beliefs that presence of a clinician was not necessary, and that peer support would be sufficient to support use of the system. Games features to encourage group play would provide social interaction that has been considered as important to older adults in other ACG interventions (Meekes et al. 2017).

8.5 Relating games features to BCTs

During the systematic review in Chapter 2, data related to BCTs from the BCTTv1 (Michie et al. 2013) aimed at increasing adherence to ACG was extracted from the included studies. In comparison with a study that coded BCTs directly from games (Lyons et al. 2013), the systematic review coded fewer BCTs from papers describing ACG interventions, suggesting an underreporting of within-game BCTs. The most frequently used BCTs were related to *Feedback and monitoring*, delivered by ACG via instantaneous visual feedback and scoring. However, it is possible to draw parallels between a number of games features and BCTs.

8.5.1 Reflecting on this thesis

In the concept development for this ACG system, the research team considered how games features implemented to increase engagement with the system mirrored BCTs to promote health behaviour change in healthcare interventions (Table 4.1). The implementation of features, underpinned by psychological theory, to promote repeated use is well established in game design; while healthcare intervention design is catching up in this respect. Many of the games features implemented mirrored the role of the therapist in delivering traditional exercise, for example, *4.1 Instruction on how to perform a behaviour* and *2.2 Feedback on behaviour*; these could lead to autonomous use of the system by older adults. The uses of scoring and visual display, both coded as

2.2 Feedback on behaviour, are games features that are not necessarily a component of traditional therapy; these may improve motivation and engagement.

There were also a number of ACG system features that could not be coded using BCTs from the BCCTv1 (Michie et al. 2013):

1) Delivery of exercise through tasks within the ACG system was coded as *2.2 Feedback on behaviour;* however, it did not meet *6.1 Demonstration of the behaviour* due to the exercise not being displayed on screen, although tasks presented within the virtual environment cued the desired movement to be performed.

2) User profiles, that collected data related to each use of the system such as users' scores, could not be coded as a BCT. Information collected within the user profiles could be used to provide users with a record of their uses of the system; this could be used as a log to monitor progress and promote accountability, and be coded as *2.3 Self-monitoring of behaviour*. Implementing user profiles, in the game design, is viewed as a personal feature of that may provide users with continuity and a sense of belonging; however, this did not correspond to any of the BCTs.

3) Achievements, a game feature included in prototype 2 of the ACG system (Chapter 6), were gained through completion of specific tasks, for example, an achievement was awarded for entering the game. Achievements were not necessarily related to performance; they were implemented to reward effort and to provide positive feedback, to increase participants' sense of mastery and self-efficacy to improve engagement with the ACG system (Hamari and Eranti 2011).

4) Participants reported that they would be more likely to remember to use the ACG system than to do traditional exercise, potentially because they would be reminded when they saw the equipment; however, due to the system not delivering reminders for use, this would not be coded as *7.1 Prompts/cues*.

There were a number of additional components of the intervention delivery that mapped to BCTs; these were not all delivered directly by the ACG system (Table 8.1). Additionally, reflecting on the findings from the user testing, including components of

the ACG intervention that were not delivered by the system, a list of suggestions of games features to improve engagement and long-term adherence were proposed (Table 8.1). Table 8.1 summarises the components of the ACG intervention that were not delivered by the system and suggestions to improve the system. It also summarises the BCTs to which they map. From this table it is possible to suggest that some of the components of the ACG intervention that were not delivered by the current system could be implemented to improve engagement with a future ACG system.

Table 8.1 Table summarising components of the ACG intervention that were not delivered by the system and suggestions to improve the system, both mapped to corresponding BCTs

Components of intervention not delivered by the current ACG system	BCTs	Suggestions to improve engagement with the ACG system
Presentation delivered by a clinician member of research team. Content included: risk of falling; physical activity/exercise; the use of ACG to deliver exercise	9.1 Credible source 5.1 Information about health consequences 5.2 Salience of consequences	Education component delivered via the ACG system. Content including: ageing; risk of falling; falls prevention; physical activity/ exercise guidelines
Agreed schedule of ACG sessions (participant and researcher scheduled twice weekly ACG sessions on days the participant attended the day centre)	1.1 Goal-setting (behaviour) 1.4 Action Planning	Goal-setting related to performance or results at the beginning of each session

Components of intervention not delivered by the current ACG system	BCTs	Suggestions to improve engagement with the ACG system
Introduce ACG system. Content included: overview of technology, set up and overcoming technical issues; demonstration of use of the ACG system; instruction on how to perform the exercises; opportunity to try ACG system/ information about ACG system feedback during and following play	4.1 Instruction on how to perform a behaviour 6.1 Demonstration of the behaviour 8.1 Behavioural practice/ rehearsal	Video demonstration or virtual instructor
Reflected on previous score prior to each use of ACG system	1.5 Review outcome goals 2.7 Feedback on outcome of behaviour	System encouraging reflection on previous scores/ performance
Additional instruction and assistance provided as necessary.	3.2 Social support practical	System detects common errors during use and prompts correction
	3.1 Social support (unspecified)	Social component. Features include: multiplayer

Components of intervention not delivered by the current ACG system	BCTs	Suggestions to improve engagement with the ACG system
	3.2 Social support (practical) 3.3 Social support (emotional) 6.1 Demonstration of the behaviour 6.2 Social comparison	setting, leader boards, peer leader, peers provided encouragement and feedback
	2.2 Feedback on behaviour 2.3 Self-monitoring of behaviour	Scoring based on quality of movement
	8.7 Graded tasks	Progressing levels of difficulty
Provided chair close by to sit on, chairs to either side to reach for hand support	12.5 Adding objects to the environment	

8.6 Acceptance does not equate adoption

In line with available guidelines recommending user involvement early in the design process (Fisk et al. 2009; McLaughlin et al. 2012; Uzor et al. 2012; Proffitt and Lange 2013), this study involved older adults throughout the development process to improve users' perceptions of the usability and acceptability of the ACG system. Changes were made to the system to optimise its usability and acceptability, and it was anticipated that repeated use of the ACG system would increase usability and acceptability of the system to promote ongoing motivation and engagement. Despite this, during testing of the repeated use of the system, while results from the SUS and AFRIS showed high levels of acceptability and usability, low levels of completion of ACG sessions were observed. This may suggest that acceptance would not necessarily lead to long-term adoption of the system by this population.

In the TAM (Davis, 1989), perceived usefulness and perceived ease of use are factors contributing to the acceptance and ultimate adoption of a technology. During the two user testing phases, perceived usefulness seemed to be the most important of these factors to the older adults participating in this study. In user testing phase 1 (Chapter 5), participants described their perceptions of the general usefulness of the system, and whether they believed it could be useful to them personally. In user testing of prototype 2 (Chapter 7), participants' perceptions of the system were influenced by their beliefs about their need to improve their balance and their beliefs about the effectiveness of using the ACG system to improve balance. Findings suggested that some participants found the system of potential value to their health and as superior to traditional exercise, but others did not believe that the system could be effective to improve health outcomes. Therefore, as described above, providing health education through the ACG system may be one way to increase engagement by increasing users' perceptions of its usefulness.

Physical limitations and poor health were often provided as reasons for not participating or stopping use of the ACG system. The physical function, in terms of BBS and SPPB, of participants in each study phase was different; older adults with a lower level of physical function agreed to participate in testing a single use of prototype 1 of the ACG system. Furthermore, during user testing of repeated use of prototype 2, those with

higher physical function, in terms of BBS and SPPB, tended to complete a greater number of ACG sessions; and, one participant identified by a BBS score <40 as at risk of falls, completed the fewest ACG sessions. Older adults with physical limitations were willing to try the system, but it could be suggested that they were more likely to try something once than commit to a longer block of sessions. Perhaps they were concerned that they would not be able to use the system. Adaption of the system to match the capability of the individual could facilitate use by a wider range of older people, and could increase older adults' self-efficacy to improve uptake and adherence to ACG interventions.

Social interaction seemed important to participants; some did not want to miss the group activities contributing to reduced engagement with the ACG system. A number of social factors could be manipulated to increase engagement with the ACG system. These include: changing the gaming environment so that ACG can be done in a group setting rather than in a separate room; including use of the system within the centre activity schedule; inclusion of features to encourage group ACG, such as multiplayer and leader boards, or peer support (Snyder et al. 2012; Mattaloui et al. 2017; Meekes et al. 2017). Future research could look at the feasibility of a peer-led ACG intervention in this population.

8.7 Strengths and limitations of this thesis

The main strength of this thesis is the collection of both qualitative and quantitative data to provide greater insight into older adults' experience of using the ACG system (Greene et al. 1989). The integration of data collected concurrently through observation, quantitative measures and qualitative feedback provided by participants during and after use of the system provided an understanding of the safety, usability and acceptability of the ACG system, alongside the factors influencing older adults' perceptions.

This PhD project has a number of limitations, one of which was the involvement of the researcher (SH) during all stages of user testing. Through visiting the day centres to collect information related to the preferences and requirements of older adults for the development of the system, and study recruitment and delivery of the intervention, participants may have built a relationship with the researcher (SH). This may have led

to their desire to please, therefore providing more positive responses. While efforts were made to reduce the risk of bias from this source when developing the semi-structured interview schedule, it is possible that participants' responses may have been influenced by their relationship with the researcher.

Another compromise required to collect such observational, quantitative and qualitative data within the confines of a PhD project is the reduction of sample size. As such, the main limitation of this research is its exploratory nature; small sample sizes in both study phases limited potential to draw conclusions of their findings. Additionally, low completion rates during study phase 2 limited the value of performing inferential statistics to measure change in outcomes with repeated use of the ACG system. However, research on the number of participants required for usability testing indicates the 5-10 participants are sufficient (Faulkner et al. 2003; Virzi et al. 1992); with some suggestion that multiple small tests are more valuable in allowing iterative changes to be made based on findings with smaller numbers of users (Nielson et al. 2000).

8.8 Conclusion

This research has two main outputs: the development of an ACG system designed specifically to deliver strength and balance exercise to meet the requirements and preferences of older people at risk of falling; and the evaluation of the safety usability and acceptability of the ACG system through observation and feedback from older adults' use of the ACG system.

The ACG system was developed iteratively and collaboratively by an interdisciplinary team to deliver strength and balance exercises based on the evidence based OEP. The interdisciplinary collaboration described in this thesis is a strength both in terms of system development and the knowledge gained about how to optimise collaborative working within a team of clinicians and developers. This thesis reports on this process of collaborative working in terms of communication and organisation to ensure understanding, management of tasks and resolution of usability issues. Additionally, older adults were actively involved from the early stages of the development of the system. Thus, development of the system has drawn on the expertise of clinicians and

developers, and on the experience of older people, with the aim of optimising its design to meet the needs of older people and its usability in this population.

Evaluation of the system, through observation of use and quantitative and qualitative feedback from older adults following use, has indicated that it is a safe, usable and acceptable way to deliver exercise to older people. However, the preference or need for additional instruction, even with repeated use of the ACG system, suggests that the system may not be suitable for autonomous use in older adults. While feedback suggested high levels of usability and acceptability, low completion rates of ACG sessions could be interpreted to mean that more is required for adoption of ACG for strength and balance exercise in this population.

Overall findings of this thesis highlighted that maintaining and improving health was important to older people and that they were willing to try novel technologies, both for health benefits and enjoyment. Based on the findings from user testing, a number of suggestions have been made to improve long term engagement with the system in older adults. These suggestions were based on feedback from older people and reflect their individual motivations for using the system and unique experience and perceptions of using the system. Novel technology, such as ACG, shows promise for developing individualised interventions to meet the needs and preferences of our ageing population.

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10 APPENDICES

APPENDIX 1 – SEARCH STRATEGIES FOR MEDLINE, EMBASE, PSYCINFO AND CENTRAL IN THE COCHRANE LIBRARY

Database: Ovid MEDLINE(R) <2011 to current>

Search Strategy:

1 Aging/ or Aged/ or "Aged, 80 and over"/ or Geriatrics/ or older adults.mp.

2 Computer-Assisted Instruction/ or Computers/ or User-Computer Interface/ or Computer Simulation/ or interactive computer$.mp. or Software/

3 Video Games/ or Games, Experimental/ or gam$.mp.

4 Virtual reality exposure therapy/ or virtual reality.mp.

5 Therapy, Computer-Assisted/ or visual feedback.mp.

6 exergam$.mp or serious gam$.mp. or computer gam$

7 Postural Balance/ or balance.mp.

8 Muscle Strength/ or strength.mp.

9 Range of Motion, Articular/ or flexibility.mp.

10 Exercise/ or Physical Fitness / or Health status/ or aerobic fitness.mp. or physical activity.mp.

11 Accidental falls/ or fall prevention.mp.

12 Motivation/ or motivation.mp.

13 Patient compliance/ or adherence.mp.

14 Mental Health/ or psychological well being.mp.

15 Cognition/ or memory/ or cognitive function.mp.

16 "Quality of life"/

17 Health behavior/ or behaviour change.mp. or Self-efficacy/

18 2 or 3 or 4 or 5 or 6

19 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17

20 1 and 18 and 19

21 Limit to yr="2011- Current"

Database: Ovid EMBASE(R) <2011 to current >

Search Strategy:

1 Aging/ or Aged/ or very elderly/ or "Aged, 80 and over".mp. or Geriatrics/ or older adults.mp.

2 Computer/ or Computer-Assisted Instruction.mp. or Computers.mp. or Computer interface/ or Computer Simulation/ or interactive computer$.mp. or Computer program/ or Software.mp.

3 Game/ or Video Gam$.mp. or Games, Experimental.mp. or gam$.mp.

4 virtual reality/ or virtual reality.mp.

5 Computer assisted therapy/ or visual feedback.mp.

6 exergam$.mp. or serious gam$.mp. or computer gam$

7 Body equilibrium/ or balance.mp.

8 Muscle Strength/ or strength.mp.

9 Joint mobility/ or flexibility.mp.

10 Falling/ or fall prevention.mp.

11 Exercise/ or Fitness/ or aerobic fitness.mp. or Physical activity/ or Physical mobility/

12 Motivation/ or motivation.mp.

13 Patient compliance/ or adherence.mp.

14 Mental Health/ or psychological well being/

15 Cognition/ or memory/ or cognitive function.mp.

16 Quality of life"/

17 Behavior change/ or Health behaviour/ or Self-concept/ or self-efficacy.mp.

18 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17

19 2 or 3 or 4 or 5 or 6

20 1 and 18 and 19

21 Limit to yr="2011- Current"

Database: Cochrane <2011 to current>

Search Strategy:

1 Aging/ or Aged/ or "Aged, 80 and over"/ or Geriatrics/ or older adults.mp. or Frail elderly/

2 Computer-Assisted Instruction/ or Computer/ or User-Computer Interface/ or Computer Simulation/ or interactive computers.mp. or Software/

3 Video Games/ or Games, Experimental/ or games.mp.

4 Virtual reality exposure therapy/ or virtual reality.mp.

5 exergam$.mp or serious gam$.mp. or computer gam$.mp.

6 Computers/ or Therapy, Computer-Assisted/ or video capture.mp.

7 balance.mp. or Postural Balance/

8 strength.mp. or Muscle Strength/

9 flexibility.mp. or Range of Motion, Articular/

10 Exercise/ or Physical Fitness/ or walking/

11 Accident prevention/ or Accidental falls/ or Health status/

12 Motivation/ or motivation.mp.

13 adherence.mp.

14 Mental Health/

15 Cognition/ or Learning/

16 "Quality of life"/

17 Health behavior/ or Behavior/ or behavior change.mp. or Self-efficacy/ or Self-concept/

Database: PsycInfo < July Week 2 2011 to current 2014>

Search Strategy:

1. Aging/ or Aged.mp. or "Aged, 80 and over".mp. or Geriatrics/ or older adults.mp. or Elder Care/

2. Computer-Assisted Instruction/ or Computers/ or User-Computer Interface.mp. or Human computer interaction/ or Computer Games/ or Computer Simulation/ or interactive computer$.mp. or Software.mp. or Computer software/

3. Video Games.mp. or Computer games/ or Experimental games.mp. or games/ or gam$.mp. or Games theory/

4. Virtual reality/ or virtual reality.mp.

5. Computer-Assisted Therapy/ or visual feedback.mp.

6. exergam$.mp or serious gam$.mp. or computer gam$.mp.

7. balance.mp.

8. Physical strength/ or strength.mp.

9. "Range of motion"/ or flexibility.mp.

10. Exercise/ or Physical Fitness/ or Activity level/ or Health/ or aerobic fitness.mp.

11. Falls/ or Physical mobility/ or fall prevention.mp.

12. Motivation/ or motivation.mp.

13. Compliance/ or adherence.mp.

14. Mental Health/ or Well being/

15. Cognitive ability/ or Learning/ or MEMORY

16. Quality of life/

17. Health behavior/ or Behavior change/ or Readiness to change/ or Self-efficacy/ or Self-concept/

APPENDIX 2 – FORMS FOR DATA EXTRACTION AND BCT CODING

Study ID *(surname of first author and year first full report of study was published e.g. Smith 2001)*		
Date form completed *(dd/mm/yy)*		
Name/ID of person extracting data		
Reference citation		
Notes:		

Methods

	Descriptions as stated in the report/paper	Location in text or source *(pg & ¶/fig/table/other)*
Aim of study		
Study Design		
Duration of study, start/end date		
Notes:		

Participant Characteristics

	Description	Location in text or source
Total no. participants *(Male/female)*		
Mean age +/- SD		
Inclusion criteria		
Exclusion criteria		
Co-morbidities/ general health		
Method of recruitment of participants		
Notes:		

Other Information

Study funding sources		
Possible conflicts of interest *(for authors)*		
Notes:		

Intervention groups

Copy and paste table for each intervention and comparison group

	Description as stated in report/paper	Location in text or source
Group name		
No. in intervention group		
No. of dropouts (reasons)		
Description of the intervention		
Dose/duration of the intervention		
Delivery Setting		
Providers		
Co-interventions		
Description of control		
No. in control group		
No. of dropouts (reasons)		
Baseline differences		
Adverse events		
Notes:		

Outcomes

	Description as stated in report/paper	Location in text or source
Outcome name		
Time points measured		
Person measuring		
Scales: Measurement range of the tool *(indicate if high or low score is good)*		
Is outcome/tool validated?	☐ Yes ☐ No ☐ Unclear Notes:	
Notes:		

	Description as stated in report/paper						Location in text or source
Time points measured							
Post-intervention or change from baseline?							
Results	Intervention			Comparison			
Outcome Measure	Mean (SD) Time point 1	Mean (SD) Time point 2	Mean (SD) Time point 3	Mean (SD) Time point 1	Mean (SD) Time point 2	Mean (SD) Time point 3	
Any other results reported *(e.g. mean difference, CI, P value)*							
Imputation of missing data (e.g. assumptions made for ITT analysis)							

		Location in text or source
Statistical methods used and appropriateness of these		
Key conclusions of study authors		
References to other relevant studies		
Notes:		

Study ID	
Reviewer & Date	
ACG Intervention	
Adherence reported (Y/N)	
Description of ACG	
BCTs coded	

BC LABEL	EXCERPT	Pg&Para
1.1. Goal setting (behaviour)		
1.2. Problem solving		
1.3. Goal setting (outcome)		
1.4. Action planning		
1.5. Review behaviour goal(s)		
1.6. Discrepancy between current behaviour and goal		
1.7. Review outcome goal(s)		
1.8. Behavioural contract		
1.9. Commitment		
2. Feedback and monitoring		
2.1. Monitoring of behaviour by others without feedback		
2.2. Feedback on behaviour		
2.3. Self-monitoring of behaviour		
2.4. Self-monitoring of outcome(s) of behaviour		
2.5. Monitoring of outcome(s) of behaviour without feedback		
2.6. Biofeedback		
2.7. Feedback on outcome(s) of behaviour		
3. Social support		
3.1. Social support (unspecified)		
3.2. Social support (practical)		
3.3. Social support (emotional)		
4. Shaping knowledge		
4.1. Instruction on how to perform the behaviour		
4.2. Information about antecedents		
4.3. Re-attribution		

4.4. Behavioural experiments		
5. Natural consequences		
5.1. Information about health consequences		
5.2. Salience of consequences		
5.3. Information about social and environmental consequences		
5.4. Monitoring of emotional consequences		
5.5. Anticipated regret		
5.6. Information about emotional consequences		
6. Comparison of behaviour		
6.1. Demonstration of the behaviour		
6.2. Social comparison		
6.3. Information about others' approval		
7. Associations		
7.1. Prompts/cues		
7.2. Cue signalling reward		
7.3. Reduce prompts/cues		
7.4. Remove access to the reward		
7.5. Remove aversive stimulus		
7.6. Satiation		
7.7. Exposure		
7.8. Associative learning		
8. Repetition and substitution		
8.1. Behavioural practice/rehearsal		
8.2. Behaviour substitution		
8.3. Habit formation		
8.4. Habit reversal		
8.5. Overcorrection		
8.6. Generalisation of target behaviour		
8.7. Graded tasks		
9. Comparison of outcomes		
9.1. Credible source		

9.2. Pros and cons		
9.3. Comparative imagining of future outcomes		
10. Reward and threat		
10.1. Material incentive (behaviour)		
10.2. Material reward (behaviour)		
10.3. Non-specific reward		
10.4. Social reward		
10.5. Social incentive		
10.6. Non-specific incentive		
10.7. Self-incentive		
10.8. Incentive (outcome)		
10.9. Self-reward		
10.10. Reward (outcome)		
10.11. Future punishment		
11. Regulation		
11.1. Pharmacological support		
11.2. Reduce negative emotions		
11.3. Conserving mental resources		
11.4. Paradoxical instructions		
12. Antecedents		
12.1. Restructuring the physical environment		
12.2. Restructuring the social environment		
12.3. Avoidance/reducing exposure to cues for the behaviour		
12.4. Distraction		
12.5. Adding objects to the environment		
12.6. Body changes		
13. Identity		
13.1. Identification of self as role model		

13.2. Framing/reframing		
13.3. Incompatible beliefs		
13.4. Valued self-identify		
13.5. Identity associated with changed behaviour		
14. Scheduled consequences		
14.1. Behaviour cost		
14.2. Punishment		
14.3. Remove reward		
14.4. Reward approximation		
14.5. Rewarding completion		
14.6. Situation-specific reward		
14.7. Reward incompatible behaviour		
14.8. Reward alternative behaviour		
14.9. Reduce reward frequency		
14.10. Remove punishment		
15. Self-belief		
15.1. Verbal persuasion about capability		
15.2. Mental rehearsal of successful performance		
15.3. Focus on past success		
15.4. Self-talk		
16. Covert learning		
16.1. Imaginary punishment		
16.2. Imaginary reward		
16.3. Vicarious consequences		

APPENDIX 3 – COCHRANE RISK OF BIAS TOOL

Cochrane Risk of Bias Tool for RCTs		
Study ID		
Reviewer initials		
Date reviewed		
Selection Bias	Description	Reviewer's judgement
Adequate sequence generation?	Quote: Comment:	
Allocation concealment?	Quote: Comment:	
Blinding of participants, personnel and outcome assessors	Quote: Comment:	
Attrition bias - Incomplete outcome data?	Quote: Comment:	
Free of selective outcome reporting?	Quote: Comment:	
Free of other sources of bias?	Quote: Comment:	
Reviewer's overall judgment (L/U/H)	Comment:	

Appendix 4 – BCTs coded

A - Summary of behaviour change techniques coded in included studies

Study ID	BCTs
Anderson-Hanley 2012	3
Barcelos 2015	8
Bateni 2011	0
Bieryla 2013	1
Chao 2014	13
Chow 2015	2
Daniel 2012	0
Duque 2013	2
Eggenberger 2015	3
Franco 2012	6
Fu 2015	3
Gschwind 2015	8
Hagedorn 2010	4
Haslinger 2015	2
Heiden 2010	6
Hughes 2014	4
Jorgensen 2013	0
Kahlbaugh 2011	0
Karahan 2015	0
Kim 2013	3
Laver 2012	2
Lee 2014	0
Lee 2015	3
Maillot 2012	3
Padala 2012	1
Pichierri 2012	6
Pluchino 2012	4
Rendon 2012	0
Sato 2015	1
Schoene 2013	4
Schoene 2015	7

Szturm 2011	2
Toulotte 2011	0
Whyatt 2015	2
Wolf 1996	3

B – Summary of behaviour change techniques coded by category

BCT	Total
1. Goals and planning	8
2. Feedback and monitoring	29
3. Social support	13
4. Shaping knowledge	10
5. Natural consequences	0
6. Comparison of behaviour	9
7. Associations	4
8. Repetition and substitution	13
9. Comparison of outcomes	0
10. Reward and threat	16
11. Regulation	0
12. Antecedents	4
13. Identity	0
14. Scheduled consequences	0
15. Self-belief	0
16. Covert learning	0

APPENDIX 5 - EFFECT OF ACG ON OUTCOMES OF INTEREST

Balance - Standardised mean difference (SMD) 0.52, 95% confidence interval (CI) 0.24, 0.79, 17 studies, n=743

Balance subgroup according to control
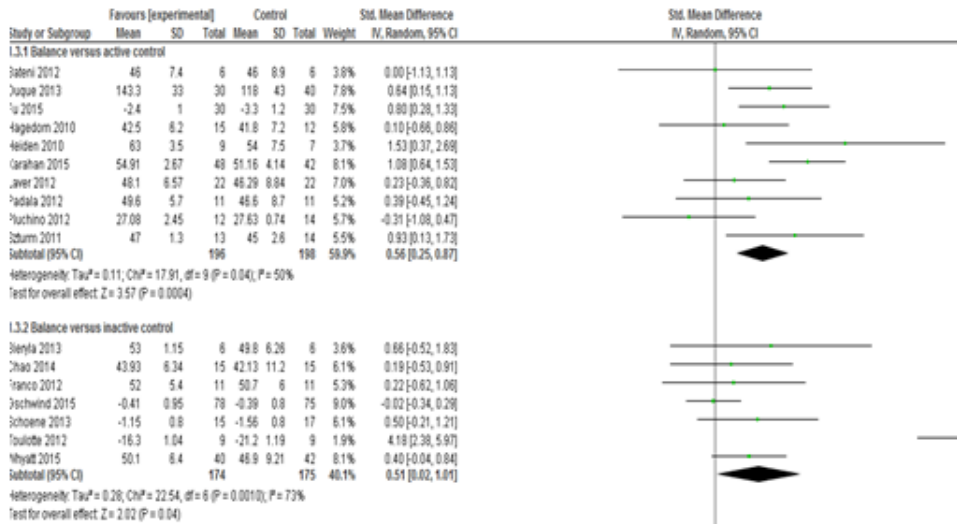
Sensitivity analysis

SMD 0.55, 95% CI 0.19, 0.91; 11 studies, n=555
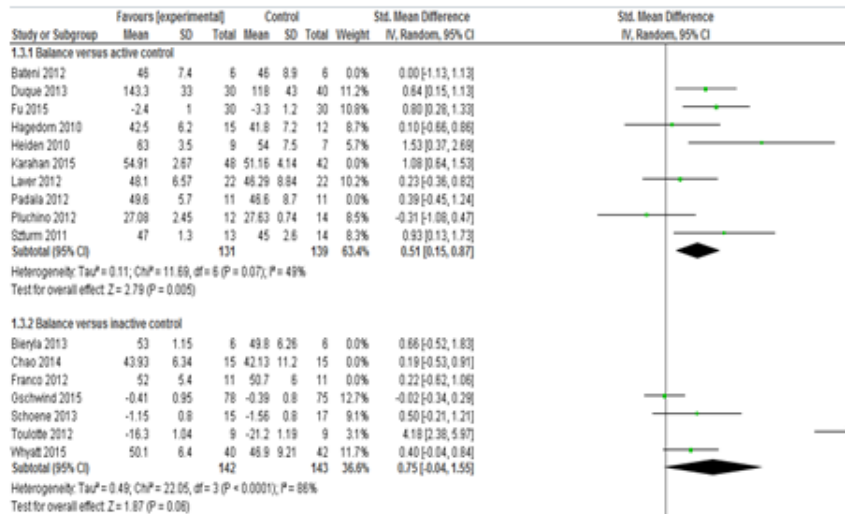
Balance sub-group according to dose

1.3.3 Dose <120 mins/week

Study	Mean	SD	Total	Mean	SD	Total	Weight	Std. Mean Difference [95% CI]
Bateni 2012	46	7.4	6	46	8.9	6	2.8%	0.00 [-1.13, 1.13]
Bienyla 2013	53	1.15	6	49.8	6.26	6	2.7%	0.66 [-0.52, 1.83]
Chao 2014	43.93	6.34	15	42.13	11.2	15	4.5%	0.19 [-0.53, 0.91]
Duque 2013	143.3	33	30	118	43	40	5.8%	0.64 [0.15, 1.13]
Franco 2012	52	5.4	11	50.7	6	11	4.0%	0.22 [-0.62, 1.06]
Schoene 2013	-1.15	0.8	15	-1.56	0.8	17	4.6%	0.50 [-0.21, 1.21]
Szturm 2011	47	1.3	13	45	2.6	14	4.1%	0.93 [0.13, 1.73]
Toulotte 2012	-16.3	1.04	9	-21.2	1.19	9	1.5%	4.18 [2.38, 5.97]
Whyatt 2015	50.1	6.4	40	46.9	9.21	42	6.0%	0.40 [-0.04, 0.84]
Subtotal (95% CI)			145			160	36.0%	0.61 [0.20, 1.01]

Heterogeneity: Tau² = 0.20; Chi² = 19.57, df = 8 (P = 0.01); I² = 59%
Test for overall effect: Z = 2.95 (P = 0.003)

1.3.4 Dose >120 mins/week

Study	Mean	SD	Total	Mean	SD	Total	Weight	Std. Mean Difference [95% CI]
Fu 2015	-2.4	1	30	-3.3	1.2	30	5.5%	0.80 [0.28, 1.33]
Gschwind 2015	-0.41	0.95	78	-0.39	0.8	75	6.7%	-0.02 [-0.34, 0.29]
Hagedorn 2010	42.5	6.2	15	41.8	7.2	12	4.3%	0.10 [-0.66, 0.86]
Heiden 2010	63	3.5	9	54	7.5	7	2.8%	1.53 [0.37, 2.69]
Karahan 2015	54.91	2.67	48	51.16	4.14	42	6.0%	1.08 [0.64, 1.53]
Laver 2012	48.1	6.57	22	46.29	8.84	22	5.2%	0.23 [-0.36, 0.82]
Padala 2012	49.6	5.7	11	48.6	8.7	11	3.9%	0.39 [-0.45, 1.24]
Pluchino 2012	27.08	2.45	12	27.63	0.74	14	4.2%	-0.31 [-1.08, 0.47]
Subtotal (95% CI)			225			213	38.7%	0.44 [0.03, 0.85]

Heterogeneity: Tau² = 0.23; Chi² = 25.78, df = 7 (P = 0.0006); I² = 73%
Test for overall effect: Z = 2.11 (P = 0.03)

1.3.5 Dose >150 mins/week

Study	Mean	SD	Total	Mean	SD	Total	Weight	Std. Mean Difference [95% CI]
Fu 2015	-2.4	1	30	-3.3	1.2	30	5.5%	0.80 [0.28, 1.33]
Gschwind 2015	-0.41	0.95	78	-0.39	0.8	75	6.7%	-0.02 [-0.34, 0.29]
Hagedorn 2010	42.5	6.2	15	41.8	7.2	12	4.3%	0.10 [-0.66, 0.86]
Heiden 2010	63	3.5	9	54	7.5	7	2.8%	1.53 [0.37, 2.69]
Karahan 2015	54.91	2.67	48	51.16	4.14	42	6.0%	1.08 [0.64, 1.53]
Subtotal (95% CI)			180			166	25.3%	0.63 [0.05, 1.21]

Heterogeneity: Tau² = 0.33; Chi² = 22.16, df = 4 (P = 0.0002); I² = 82%
Test for overall effect: Z = 2.14 (P = 0.03)

| **Total (95% CI)** | | | 550 | | | 539 | 100.0% | 0.54 [0.30, 0.78] |

Heterogeneity: Tau² = 0.20; Chi² = 68.54, df = 21 (P < 0.00001); I² = 69%
Test for overall effect: Z = 4.39 (P < 0.0001)
Test for subgroup differences: Chi² = 0.44, df = 2 (P = 0.80), I² = 0%

Favours control Favours ACG
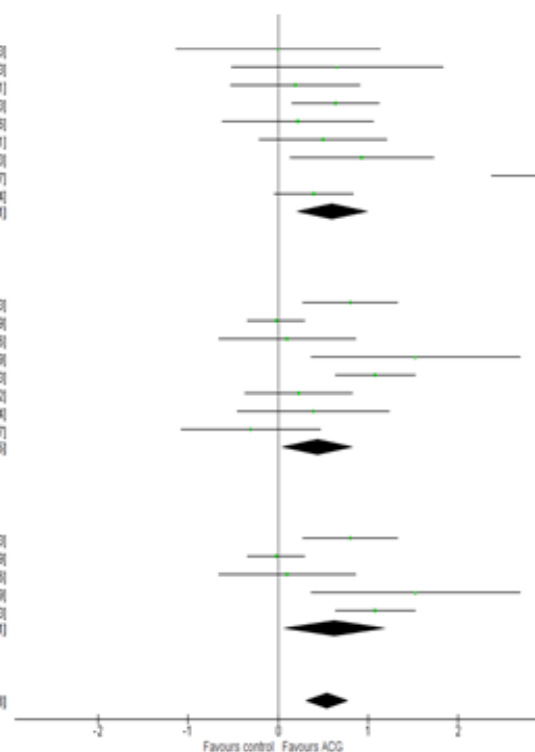
Functional exercise capacity - SMD 0.29, 95%CI 0.04, 0.55; 7 studies, n= 248 participants

Functional exercise capacity sub-group analysis according to control

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Std. Mean Difference IV, Fixed, 95% CI
1.5.1 6MWT versus active control									
Eggenberger 2015	560	81.33	15	538	81.33	15	12.4%	0.26 [-0.46, 0.98]	
Hagedorn 2010	333	76	14	257	74	10	8.5%	0.98 [0.11, 1.84]	
Heiden 2010	517	25	9	492	45	7	6.1%	0.68 [-0.35, 1.70]	
Subtotal (95% CI)			38			32	27.0%	0.58 [0.09, 1.07]	
Heterogeneity: Chi² = 1.58, df = 2 (P = 0.45); I² = 0%									
Test for overall effect: Z = 2.34 (P = 0.02)									
1.5.2 6MWT versus inactive control									
Chao 2014	262.86	103.07	15	216.22	104.05	15	12.2%	0.44 [-0.29, 1.16]	
Daniel 2012	632	228	8	425	236	8	6.0%	0.84 [-0.19, 1.88]	
Maillot 2012	469.22	125.14	15	439.91	88.12	15	12.4%	0.26 [-0.46, 0.98]	
Wolf 2003	0.58	0.08	50	0.58	0.11	52	42.5%	0.00 [-0.39, 0.39]	
Subtotal (95% CI)			88			90	73.0%	0.19 [-0.11, 0.48]	
Heterogeneity: Chi² = 2.94, df = 3 (P = 0.40); I² = 0%									
Test for overall effect: Z = 1.23 (P = 0.22)									

Sensitivity analysis - SMD -0.34, 95% CI -0.79, 0.10; 4 studies, n=172

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Std. Mean Difference IV, Fixed, 95% CI
1.5.1 6MWT versus active control									
Eggenberger 2015	560	81.33	15	538	81.33	15	0.0%	0.26 [-0.46, 0.98]	
Hagedorn 2010	333	76	14	257	74	10	12.3%	0.98 [0.11, 1.84]	
Heiden 2010	517	25	9	492	45	7	8.8%	0.68 [-0.35, 1.70]	
Subtotal (95% CI)			23			17	21.1%	0.85 [0.19, 1.51]	
Heterogeneity: Chi² = 0.19, df = 1 (P = 0.66); I² = 0%									
Test for overall effect: Z = 2.52 (P = 0.01)									
1.5.2 6MWT versus inactive control									
Chao 2014	262.86	103.07	15	216.22	104.05	15	0.0%	0.44 [-0.29, 1.16]	
Daniel 2012	632	228	8	425	236	8	0.0%	0.84 [-0.19, 1.88]	
Maillot 2012	469.22	125.14	15	439.91	88.12	15	17.8%	0.26 [-0.46, 0.98]	
Wolf 2003	0.58	0.08	50	0.58	0.11	52	61.1%	0.00 [-0.39, 0.39]	
Subtotal (95% CI)			65			67	78.9%	0.06 [-0.28, 0.40]	
Heterogeneity: Chi² = 0.40, df = 1 (P = 0.53); I² = 0%									
Test for overall effect: Z = 0.34 (P = 0.73)									

Functional exercise capacity sub-group analysis according to dose

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI	Std. Mean Difference IV, Fixed, 95% CI
1.5.3 Dose <120 mins/week									
Chao 2014	262.86	103.07	15	216.22	104.05	15	10.6%	0.44 [-0.29, 1.16]	
Wolf 2003	0.58	0.08	50	0.58	0.11	52	37.1%	0.00 [-0.39, 0.39]	
Subtotal (95% CI)			65			67	47.7%	0.10 [-0.24, 0.44]	
Heterogeneity: Chi² = 1.09, df = 1 (P = 0.30); I² = 8%									
Test for overall effect: Z = 0.56 (P = 0.58)									
1.5.4 Dose >120 mins/week									
Daniel 2012	632	228	8	425	236	8	5.2%	0.84 [-0.19, 1.88]	
Eggenberger 2015	560	81.33	15	538	81.33	15	10.8%	0.26 [-0.46, 0.98]	
Hagedorn 2010	333	76	14	257	74	10	7.4%	0.98 [0.11, 1.84]	
Heiden 2010	517	25	9	492	45	7	5.3%	0.68 [-0.35, 1.70]	
Maillot 2012	469.22	125.14	15	439.91	88.12	15	10.8%	0.26 [-0.46, 0.98]	
Subtotal (95% CI)			61			55	39.6%	0.53 [0.15, 0.90]	
Heterogeneity: Chi² = 2.50, df = 4 (P = 0.64); I² = 0%									
Test for overall effect: Z = 2.76 (P = 0.006)									
1.5.5 Dose >150 mins/week									
Hagedorn 2010	333	76	14	257	74	10	7.4%	0.98 [0.11, 1.84]	
Heiden 2010	517	25	9	492	45	7	5.3%	0.68 [-0.35, 1.70]	
Subtotal (95% CI)			23			17	12.8%	0.85 [0.19, 1.51]	
Heterogeneity: Chi² = 0.19, df = 1 (P = 0.66); I² = 0%									
Test for overall effect: Z = 2.52 (P = 0.01)									
Total (95% CI)			149			139	100.0%	0.36 [0.13, 0.60]	
Heterogeneity: Chi² = 8.94, df = 8 (P = 0.35); I² = 10%									
Test for overall effect: Z = 3.02 (P = 0.002)									
Test for subgroup differences: Chi² = 5.15, df = 2 (P = 0.08), I² = 61.2%									

Favours control   Favours ACG

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Functional mobility - SMD -0.13, 95% CI -0.36, 0.09, 16 studies, n= 670 participants

Functional mobility sub-group according to control

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Std. Mean Difference IV, Random, 95% CI
1.7.1 Up&Go versus active control									
Hagedorn 2010	14.6	5.8	14	18.1	6.4	10	2.0%	-0.56 [-1.39, 0.27]	
Karahan 2015	8.04	1.47	48	8.6	1.83	42	4.1%	-0.34 [-0.75, 0.08]	
Laver 2012	27.9	10.44	22	28.86	11.71	22	3.0%	-0.08 [-0.68, 0.51]	
Lee 2015	5.38	0.47	26	5.07	0.63	28	3.3%	0.55 [0.00, 1.09]	
Padala 2012	13.9	7.9	11	12.8	3.2	11	2.0%	0.18 [-0.66, 1.01]	
Pluchino 2012	8.18	2.44	12	9.44	1.49	14	2.1%	-0.62 [-1.41, 0.18]	
Subtotal (95% CI)			133			127	16.6%	-0.12 [-0.48, 0.25]	

Heterogeneity: Tau² = 0.10; Chi² = 9.86, df = 5 (P = 0.08); I² = 49%
Test for overall effect: Z = 0.64 (P = 0.53)

1.7.2 Up&go versus inactive control									
Bieryla 2013	11.2	1.5	6	10.1	2.7	6	1.2%	0.46 [-0.69, 1.62]	
Chao 2014	15.27	4.68	15	18.11	15.81	15	2.4%	-0.24 [-0.96, 0.48]	
Chow 2015	12.8	4.3	10	10.9	3	10	1.8%	0.49 [-0.40, 1.38]	
Daniel 2012	7.3	1.1	8	6.4	2	8	1.5%	0.53 [-0.48, 1.53]	
Gschwind 2015	9.5	2.7	78	9.2	2.1	75	4.9%	0.12 [-0.19, 0.44]	
Haslinger 2015	5.08	0.84	20	6.93	1.92	19	2.5%	-1.23 [-1.93, -0.54]	
Hughes 2014	7.14	2.16	10	7.46	1.69	10	1.9%	-0.16 [-1.04, 0.72]	
Jorgensen 2013	9	3.2	28	10.9	5.1	30	3.4%	-0.44 [-0.96, 0.08]	
Maillot 2012	6.48	2	15	7.1	2.69	15	2.4%	-0.25 [-0.97, 0.46]	
Schoene 2013	9.1	1.4	15	9.3	1.8	17	2.5%	-0.12 [-0.81, 0.58]	
Subtotal (95% CI)			205			205	24.6%	-0.14 [-0.45, 0.17]	

Heterogeneity: Tau² = 0.12; Chi² = 18.28, df = 9 (P = 0.03); I² = 51%
Test for overall effect: Z = 0.90 (P = 0.37)

1.7.3 Dose <120mins/week									
Bieryla 2013	11.2	1.5	6	10.1	2.7	6	1.2%	0.46 [-0.69, 1.62]	
Chao 2014	15.27	4.68	15	18.11	15.81	15	2.4%	-0.24 [-0.96, 0.48]	
Haslinger 2015	5.08	0.84	20	6.93	1.92	19	2.5%	-1.23 [-1.93, -0.54]	
Hughes 2014	7.14	2.16	10	7.46	1.69	10	1.9%	-0.16 [-1.04, 0.72]	
Jorgensen 2013	9	3.2	28	10.9	5.1	30	3.4%	-0.44 [-0.96, 0.08]	
Schoene 2013	9.1	1.4	15	9.3	1.8	17	2.5%	-0.12 [-0.81, 0.58]	
Subtotal (95% CI)			94			97	14.0%	-0.37 [-0.77, 0.03]	

Heterogeneity: Tau² = 0.11; Chi² = 8.89, df = 5 (P = 0.11); I² = 44%
Test for overall effect: Z = 1.80 (P = 0.07)

Functional mobility sub-group according to dose

1.7.3 Dose <120mins/week									
Bieryla 2013	11.2	1.5	6	10.1	2.7	6	2.1%	0.46 [-0.69, 1.62]	
Chao 2014	15.27	4.68	15	18.11	15.81	15	4.1%	-0.24 [-0.96, 0.48]	
Haslinger 2015	5.08	0.84	20	6.93	1.92	19	4.3%	-1.23 [-1.93, -0.54]	
Hughes 2014	7.14	2.16	10	7.46	1.69	10	3.2%	-0.16 [-1.04, 0.72]	
Jorgensen 2013	9	3.2	28	10.9	5.1	30	5.8%	-0.44 [-0.96, 0.08]	
Schoene 2013	9.1	1.4	15	9.3	1.8	17	4.3%	-0.12 [-0.81, 0.58]	
Subtotal (95% CI)			94			97	23.9%	-0.37 [-0.77, 0.03]	

Heterogeneity: Tau² = 0.11; Chi² = 8.89, df = 5 (P = 0.11); I² = 44%
Test for overall effect: Z = 1.80 (P = 0.07)

1.7.4 Dose >120mins/week									
Chow 2015	12.8	4.3	10	10.9	3	10	3.1%	0.49 [-0.40, 1.38]	
Daniel 2012	7.3	1.1	8	6.4	2	8	2.6%	0.53 [-0.48, 1.53]	
Gschwind 2015	9.5	2.7	78	9.2	2.1	75	8.2%	0.12 [-0.19, 0.44]	
Hagedorn 2010	14.6	5.8	14	18.1	6.4	10	3.4%	-0.56 [-1.39, 0.27]	
Karahan 2015	8.04	1.47	48	8.6	1.83	42	7.0%	-0.34 [-0.75, 0.08]	
Laver 2012	27.9	10.44	22	28.86	11.71	22	5.2%	-0.08 [-0.68, 0.51]	
Lee 2015	5.38	0.47	26	5.07	0.63	28	5.6%	0.55 [0.00, 1.09]	
Maillot 2012	6.48	2	15	7.1	2.69	15	4.1%	-0.25 [-0.97, 0.46]	
Padala 2012	13.9	7.9	11	12.8	3.2	11	3.4%	0.18 [-0.66, 1.01]	
Pluchino 2012	8.18	2.44	12	9.44	1.49	14	3.7%	-0.62 [-1.41, 0.18]	
Subtotal (95% CI)			244			235	46.2%	-0.01 [-0.25, 0.24]	

Heterogeneity: Tau² = 0.05; Chi² = 13.97, df = 9 (P = 0.12); I² = 36%
Test for overall effect: Z = 0.07 (P = 0.94)

1.7.5 Dose >150 mins/week									
Chow 2015	12.8	4.3	10	10.9	3	10	3.1%	0.49 [-0.40, 1.38]	
Daniel 2012	7.3	1.1	8	6.4	2	8	2.6%	0.53 [-0.48, 1.53]	
Gschwind 2015	9.5	2.7	78	9.2	2.1	75	8.2%	0.12 [-0.19, 0.44]	
Hagedorn 2010	14.6	5.8	14	18.1	6.4	10	3.4%	-0.56 [-1.39, 0.27]	
Karahan 2015	8.04	1.47	48	8.6	1.83	42	7.0%	-0.34 [-0.75, 0.08]	
Lee 2015	5.38	0.47	26	5.07	0.63	28	5.6%	0.55 [0.00, 1.09]	
Subtotal (95% CI)			184			173	29.9%	0.09 [-0.25, 0.44]	

Heterogeneity: Tau² = 0.09; Chi² = 10.56, df = 5 (P = 0.06); I² = 53%
Test for overall effect: Z = 0.52 (P = 0.61)

| Total (95% CI) | | | 522 | | | 505 | 100.0% | -0.07 [-0.25, 0.12] | |

Heterogeneity: Tau² = 0.08; Chi² = 40.48, df = 21 (P = 0.007); I² = 48%
Test for overall effect: Z = 0.70 (P = 0.48)
Test for subgroup differences: Chi² = 3.16, df = 2 (P = 0.21), I² = 36.7%

Favours ACG   Favours Control

Cognitive function - SMD -0.48, 95% CI -0.80,-0.17,

Cognitive function sub-group according to control

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
3.1.1 Executive function tracking task versus active control								
Anderson-Hanley 2012	39.26	29.84	38	85.34	65.65	41	6.7%	-0.88 [-1.35, -0.42]
Barcelos 2015	2.05	0.41	15	2.92	1.62	15	3.0%	-0.70 [-1.71, 0.32]
Eggenberger 2015	72.81	37.64	24	87.6	52.16	25	5.8%	-0.32 [-0.88, 0.25]
Subtotal (95% CI)			70			74	15.4%	-0.65 [-1.03, -0.28]

Heterogeneity: Tau² = 0.02; Chi² = 2.30, df = 2 (P = 0.32); I² = 13%
Test for overall effect: Z = 3.43 (P = 0.0006)

3.1.2 Executive function tracking task versus inactive								
Gschwind 2015	60.2	34.6	70	56.8	33.8	75	8.1%	0.10 [-0.22, 0.42]
Hughes 2014	0.02	0.01	10	0.03	0.01	9	3.2%	-0.96 [-1.92, 0.01]
Maillot 2012	-15.42	20.27	15	3.7	28.54	15	4.4%	-0.75 [-1.50, -0.01]
Schoene 2013	43	15	15	74	61	17	4.6%	-0.66 [-1.38, 0.05]
Schoene 2015	74.9	35.5	39	90.5	58.5	42	6.9%	-0.32 [-0.76, 0.12]
Subtotal (95% CI)			157			158	27.2%	-0.40 [-0.79, 0.00]

Heterogeneity: Tau² = 0.11; Chi² = 9.73, df = 4 (P = 0.05); I² = 59%
Test for overall effect: Z = 1.94 (P = 0.05)

Sensitivity analysis – SMD -0.38 [-0.69, -0.06], 7 studies, n= 444 participants

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
3.1.1 Executive function tracking task versus active control								
Anderson-Hanley 2012	39.26	29.84	38	85.34	65.65	41	14.0%	-0.88 [-1.35, -0.42]
Barcelos 2015	2.05	0.41	8	2.92	1.62	8	0.0%	-0.70 [-1.71, 0.32]
Eggenberger 2015	72.81	37.64	24	87.6	52.16	25	12.1%	-0.32 [-0.88, 0.25]
Subtotal (95% CI)			62			66	26.1%	-0.63 [-1.18, -0.07]

Heterogeneity: Tau² = 0.09; Chi² = 2.30, df = 1 (P = 0.13); I² = 57%
Test for overall effect: Z = 2.22 (P = 0.03)

3.1.2 Executive function tracking task versus inactive								
Gschwind 2015	60.2	34.6	78	56.8	33.8	75	16.7%	0.10 [-0.22, 0.42]
Hughes 2014	0.02	0.01	10	0.03	0.01	9	6.9%	-0.96 [-1.92, 0.01]
Maillot 2012	-15.42	20.27	15	3.7	28.54	15	9.4%	-0.75 [-1.50, -0.01]
Schoene 2013	43	15	15	74	61	17	9.8%	-0.66 [-1.38, 0.05]
Schoene 2015	74.9	35.5	39	90.5	58.5	42	14.4%	-0.32 [-0.76, 0.12]
Subtotal (95% CI)			157			158	57.2%	-0.40 [-0.79, 0.00]

Heterogeneity: Tau² = 0.11; Chi² = 9.73, df = 4 (P = 0.05); I² = 59%
Test for overall effect: Z = 1.94 (P = 0.05)

Cognitive function sub-group according to dose

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
3.1.3 Dose >120mins								
Anderson-Hanley 2012	39.26	29.84	38	85.34	65.65	41	11.5%	-0.88 [-1.35, -0.42]
Barcelos 2015	2.05	0.41	8	2.92	1.62	8	5.5%	-0.70 [-1.71, 0.32]
Eggenberger 2015	72.81	37.64	24	87.6	52.16	25	10.2%	-0.32 [-0.88, 0.25]
Gschwind 2015	60.2	34.6	78	56.8	33.8	75	13.6%	0.10 [-0.22, 0.42]
Maillot 2012	-15.42	20.27	15	3.7	28.54	15	8.0%	-0.75 [-1.50, -0.01]
Subtotal (95% CI)			163			164	48.8%	-0.46 [-0.93, 0.01]

Heterogeneity: Tau² = 0.19; Chi² = 14.17, df = 4 (P = 0.007); I² = 72%
Test for overall effect: Z = 1.93 (P = 0.05)

3.1.4 Dose <120mins/week								
Hughes 2014	0.02	0.01	10	0.03	0.01	9	6.0%	-0.96 [-1.92, 0.01]
Schoene 2013	43	15	15	74	61	17	8.3%	-0.66 [-1.38, 0.05]
Schoene 2015	74.9	35.5	39	90.5	58.5	42	11.9%	-0.32 [-0.76, 0.12]
Subtotal (95% CI)			64			68	26.1%	-0.48 [-0.83, -0.13]

Heterogeneity: Tau² = 0.00; Chi² = 1.71, df = 2 (P = 0.42); I² = 0%
Test for overall effect: Z = 2.71 (P = 0.007)

3.1.5 Dose >150 mins/week								
Anderson-Hanley 2012	39.26	29.84	38	85.34	65.65	41	11.5%	-0.88 [-1.35, -0.42]
Gschwind 2015	60.2	34.6	78	56.8	33.8	75	13.6%	0.10 [-0.22, 0.42]
Subtotal (95% CI)			116			116	25.1%	-0.38 [-1.34, 0.59]

Heterogeneity: Tau² = 0.44; Chi² = 11.76, df = 1 (P = 0.0006); I² = 91%
Test for overall effect: Z = 0.77 (P = 0.44)

| Total (95% CI) | | | 343 | | | 348 | 100.0% | -0.46 [-0.75, -0.16] |

Heterogeneity: Tau² = 0.14; Chi² = 29.09, df = 9 (P = 0.0006); I² = 69%
Test for overall effect: Z = 3.02 (P = 0.002)

Favours ACG   Favours control

Fear of falling - SMD 0.18, 95% CI -0.16, 0.53, 16 studies, n= 816 participants

Fear of falling sub-group according to control

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI	Std. Mean Difference IV, Random, 95% CI
2.4.1 Fear of falling versus active control									
Duque 2013	67.5	8.75	30	30	13.75	40	6.0%	3.12 [2.41, 3.83]	
Eggenberger 2015	19.2	2.71	15	20.7	3.87	15	5.9%	-0.44 [-1.16, 0.29]	
Hagedorn 2010	10.6	4.1	14	11.3	2.9	10	5.6%	-0.18 [-1.00, 0.63]	
Laver 2012	47.22	18.62	22	46.29	18.95	22	6.5%	0.05 [-0.54, 0.64]	
Lee 2014	88	1	40	88	1	42	7.1%	0.00 [-0.43, 0.43]	
Pichierri 2012b	65.9	7.8	11	70.3	6.4	11	5.4%	-0.59 [-1.45, 0.26]	
Pluchino 2012	59.6	10	12	60.7	5	14	5.7%	-0.14 [-0.91, 0.63]	
Szturm 2011	58.52	20.46	13	51.71	15.91	14	5.8%	0.36 [-0.40, 1.12]	
Subtotal (95% CI)			157			168	48.1%	0.28 [-0.50, 1.05]	

Heterogeneity: Tau² = 1.12; Chi² = 73.47, df = 7 (P < 0.00001); I² = 90%
Test for overall effect: Z = 0.70 (P = 0.49)

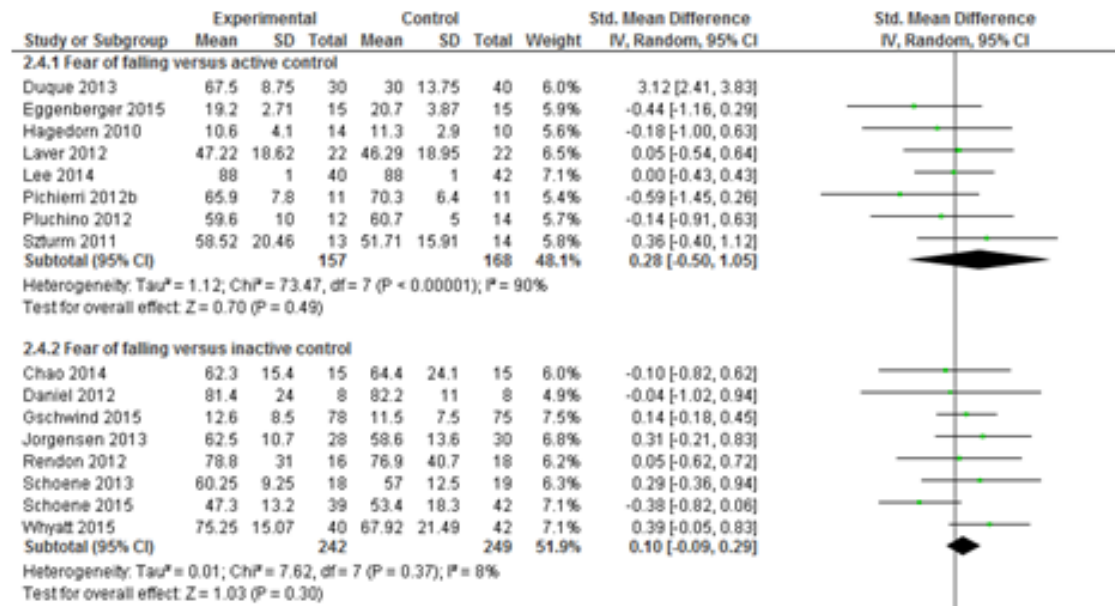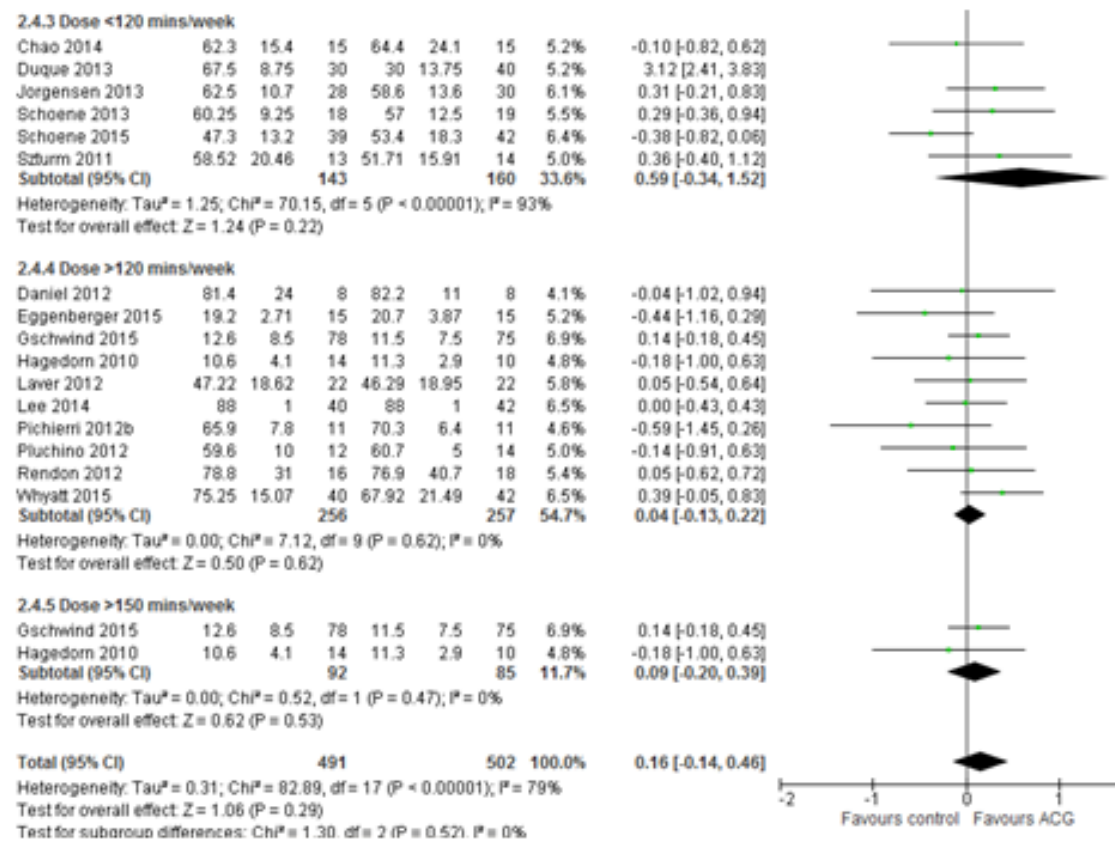|									
2.4.2 Fear of falling versus inactive control									
Chao 2014	62.3	15.4	15	64.4	24.1	15	6.0%	-0.10 [-0.82, 0.62]	
Daniel 2012	81.4	24	8	82.2	11	8	4.9%	-0.04 [-1.02, 0.94]	
Gschwind 2015	12.6	8.5	78	11.5	7.5	75	7.5%	0.14 [-0.18, 0.45]	
Jorgensen 2013	62.5	10.7	28	58.6	13.6	30	6.8%	0.31 [-0.21, 0.83]	
Rendon 2012	78.8	31	16	76.9	40.7	18	6.2%	0.05 [-0.62, 0.72]	
Schoene 2013	60.25	9.25	18	57	12.5	19	6.3%	0.29 [-0.36, 0.94]	
Schoene 2015	47.3	13.2	39	53.4	18.3	42	7.1%	-0.38 [-0.82, 0.06]	
Whyatt 2015	75.25	15.07	40	67.92	21.49	42	7.1%	0.39 [-0.05, 0.83]	
Subtotal (95% CI)			242			249	51.9%	0.10 [-0.09, 0.29]	

Heterogeneity: Tau² = 0.01; Chi² = 7.62, df = 7 (P = 0.37); I² = 8%
Test for overall effect: Z = 1.03 (P = 0.30)

Fear of falling sub-group according to dose

2.4.3 Dose <120 mins/week									
Chao 2014	62.3	15.4	15	64.4	24.1	15	5.2%	-0.10 [-0.82, 0.62]	
Duque 2013	67.5	8.75	30	30	13.75	40	5.2%	3.12 [2.41, 3.83]	
Jorgensen 2013	62.5	10.7	28	58.6	13.6	30	6.1%	0.31 [-0.21, 0.83]	
Schoene 2013	60.25	9.25	18	57	12.5	19	5.5%	0.29 [-0.36, 0.94]	
Schoene 2015	47.3	13.2	39	53.4	18.3	42	6.4%	-0.38 [-0.82, 0.06]	
Szturm 2011	58.52	20.46	13	51.71	15.91	14	5.0%	0.36 [-0.40, 1.12]	
Subtotal (95% CI)			143			160	33.6%	0.59 [-0.34, 1.52]	

Heterogeneity: Tau² = 1.25; Chi² = 70.15, df = 5 (P < 0.00001); I² = 93%
Test for overall effect: Z = 1.24 (P = 0.22)

2.4.4 Dose >120 mins/week									
Daniel 2012	81.4	24	8	82.2	11	8	4.1%	-0.04 [-1.02, 0.94]	
Eggenberger 2015	19.2	2.71	15	20.7	3.87	15	5.2%	-0.44 [-1.16, 0.29]	
Gschwind 2015	12.6	8.5	78	11.5	7.5	75	6.9%	0.14 [-0.18, 0.45]	
Hagedorn 2010	10.6	4.1	14	11.3	2.9	10	4.8%	-0.18 [-1.00, 0.63]	
Laver 2012	47.22	18.62	22	46.29	18.95	22	5.8%	0.05 [-0.54, 0.64]	
Lee 2014	88	1	40	88	1	42	6.5%	0.00 [-0.43, 0.43]	
Pichierri 2012b	65.9	7.8	11	70.3	6.4	11	4.6%	-0.59 [-1.45, 0.26]	
Pluchino 2012	59.6	10	12	60.7	5	14	5.0%	-0.14 [-0.91, 0.63]	
Rendon 2012	78.8	31	16	76.9	40.7	18	5.4%	0.05 [-0.62, 0.72]	
Whyatt 2015	75.25	15.07	40	67.92	21.49	42	6.5%	0.39 [-0.05, 0.83]	
Subtotal (95% CI)			256			257	54.7%	0.04 [-0.13, 0.22]	

Heterogeneity: Tau² = 0.00; Chi² = 7.12, df = 9 (P = 0.62); I² = 0%
Test for overall effect: Z = 0.50 (P = 0.62)

2.4.5 Dose >150 mins/week									
Gschwind 2015	12.6	8.5	78	11.5	7.5	75	6.9%	0.14 [-0.18, 0.45]	
Hagedorn 2010	10.6	4.1	14	11.3	2.9	10	4.8%	-0.18 [-1.00, 0.63]	
Subtotal (95% CI)			92			85	11.7%	0.09 [-0.20, 0.39]	

Heterogeneity: Tau² = 0.00; Chi² = 0.52, df = 1 (P = 0.47); I² = 0%
Test for overall effect: Z = 0.62 (P = 0.53)

Total (95% CI)			491			502	100.0%	0.16 [-0.14, 0.46]	

Heterogeneity: Tau² = 0.31; Chi² = 82.89, df = 17 (P < 0.00001); I² = 79%
Test for overall effect: Z = 1.06 (P = 0.29)
Test for subgroup differences: Chi² = 1.30, df = 2 (P = 0.52), I² = 0%

Favours control   Favours ACG

APPENDIX 6 – TROUBLESHOOTING DOCUMENT

Date	Problem	Measures taken and outcome
7/10/16	Single leg stand is very difficult with the VR headset on – difficult to balance.	Tried to find point of focus within game (for example, the wooden beam down middle) but this did not facilitate balance. Plan to have at least one chair close by for reference point/hand support for users.
	Side stepping outside area tracked by Oculus.	Plan to test and mark area prior to users in day centre participating. Also, ensure one researcher on either side of the area to ensure user safety with headset on.
13/10/16	Set up in university with Kinect placed on top of monitor - Problem detecting user led to altered ROM required to be successful in games.	Advised to set Kinect on desk in from of computer – do not solve problem. Height of Kinect and tilt angle need to be same as set-up during development of game. Acquired tripod stand and measured height of original stand to be able to replicate this– able to adjust height and angle to correct this problem.
	No music in screen condition Game 1	Music works during all other games. Technical problem.
	Mismatch in volume of instructions (quiet) compared to background music (loud).	Manually increasing and decreasing volume during game play.
	Journey between games is very quick in the VR condition.	Warn users. Reassure that a chair is right behind them, and encourage user to sit down if they feel it necessary.

Date	Problem	Measures taken and outcome
19/10/16	In VR condition, unable to skip from "Side Stepping" to "one leg stand" – problematic as side stepping is the only exercise during which participants cannot have chair support.	Explain to users that this is a technical fault and try to manage as best as possible. Unable to correct this; however, usually can progress to one leg stand by waiting through the whole "side stepping" exercise.
	Difficulty finding "X" spot in VR	Advising participants to look down and step forward and back until they are on the X
	Kinect tracking/detection of user very difficult (however detecting research assistant easily) – unable to complete 2 of the games (screen condition)	Considered participant clothing – removed scarf. Clothing colour grey – would this affect? Consider body composition – indefinite joints causing problem? Consider posture – forward lean could be causing problem? Distraction from assistant being too close – positioned assistant far from camera view during detection period, no change.
21/10/16	Oculus error – cannot connect "invalid library". Error 1971018 OVR27912674	Google numbers – found no information online. Un-plugged and re-plugged wires, switched PC off/on. We were able to click exit and game would open, but this was done by eye gaze and handset. This was required every time the headset was put on and was quite difficult to co-ordinate with users.

Date	Problem	Measures taken and outcome
	"Side-stepping" in VR condition not working; had to stop testing as we are unable to skip this game to get to "one leg standing" as mentioned above	Restarted whole game, still unable to get this game to work. Closed game and re-opened, unable to get this game to work. Worked fine next time we tried to play in UU. Query, busy background area in day centre compared with green screen in university.
25/10/16	Motion sickness -	Unable to find another game that involved walking and turning and did not require hand gestures.
	Assessed whether connect could detect user whilst in ROVR	Kinect detects user. Difficulty tracking some leg movements due to vertical support legs. Able to turn ROVR to ensure best visibility of users' limbs for tracking.
28/10/16	Game 4 – difficulty positioning Kinect so that calibration is successful. Either user's food never collides with rising water or constantly colliding even when foot is raised.	Adjust height and angle of Kinect and recalibrate
4/11/16	VR condition – sidestepping would not calibrate	Close and restart Adjust angle of tilt of Kinect on tripod Outcome:

Date	Problem	Measures taken and outcome
		Jumping during play but can still use to do side-stepping
	Recognising chair leg as user's leg – not recognising collision with ball for abduction	Recalibrate – no change Move chair – no change
	For abduction recognising user's foot as behind the ball – query due to hand position across body	Recalibrate – no change
18/11/16	Meeting at Coleraine	
	Problem – VR journey causing users to feel unsteady/motion sickness	Slow journey/remove journey between mini-games; give an opportunity for a break between exercises
	Some users unable to complete Sideways Walking due to physical limitation.	In pilot and pre-testing the Kinect seemed to track user even with Zimmer frame in front – many users used rollator, with which the same was not possible. Potential to use parallel bars for hand support – this would overcome any problems that arose with calibration due to having chairs placed at sides for hand support. Query access to parallel bars. Would need to test Kinect with parallel bars prior to intro to older people.

Date	Problem	Measures taken and outcome
	Additional instruction required	1- Embed **video demo** of the exercise to show users how to correctly perform the exercise 2- Identify common problems: missed instructions, incorrect performances, try to identify ways that Kinect could detect these and if they were detected an **additional instruction** would be provided. For example, during Leg Abduction, if the user was raising leg in front rather than to the side an additional pre-recorded instruction about correct technique would be played such as "lift your leg out to the side"; or, if the user was tending to lean to the side during One Leg Stand, the Kinect would detect the altered body position and the instruction would be provided to maintain correct posture "try to stand tall and keep looking ahead".
	Feedback on performance	Currently tick or X on screen – could include a sound effect "ping" or other visual rewards – consider sparkles or fireworks for successful performance. Consider collecting stars. Measure the effect of feedback on motivation/user experience
	Timing of feedback	Currently only tick/X at time of performance then all scores provided at the

Date	Problem	Measures taken and outcome
		end. If more repetitions of each game it may be useful to have the scores displayed after each mini-game.
	Conditions	*** if playing each mini-game >1 time then could have **different feedback conditions** randomised. For example, standard tick/X versus stars + visual + sound effects + verbal + scores at end. *** I like this idea. Or randomise on different study visits
	Problems with calibration mean it is necessary that a researcher is close by in order to press start button etc	Could a hand gesture be used to start each game? Could arm movement be like a mouse on screen to choose options? Voice control?
	Continuing play	If arm movement could be used as a mouse on screen at the end of each game could users report their borg score (exertion 1-10) on a scale and choose whether they would like to "play this game again", "move to another game", "take a break" or "stop play"

APPENDIX 7 - INFORMATION ABOUT SKAINOS BUILDING AGE NI DAY CENTRE

Skainos Building, Age NI day centre	
Client Group	Older adults 65+ Referred via social worker, GP, District Nurse, Self-referral Mostly living in community alone Isolated No dementia referrals – if develops can usually remain as client unless unsafe
Sessions available	2 groups attend per day Group 1 ~11-2 – get lunch, pudding, tea Group 2 ~12.45-3 – get finger food and tea Clients mostly attend 1-3 sessions per week Some attend every day – if particularly vulnerable
Staff	Manager, cook/day care worker, driver/day care worker, day care worker, volunteers Limited staff due to charitable organisation
Assessment	Home visit prior to starting at day centre Previous medical history from referral Transport risk ax covers mobility/aids etc "Getting to know you" questionnaire completed Daily evaluation, Activity record, Medical records, Contact sheet completed regularly – all falls recorded All in line with RQIA Care plan reviews Surveys – twice per year Inspections – report available online

Activities available	Bowls/Boccia	Pool tournament
	Quoits	Skittles
	Netball	Tea dance
	Mental stimulation	Quizzes
	Reminiscence	Bingo
Popularity of activities	Bingo is particularly enjoyed by women – set up like actual bingo hall, prizes	
	Men enjoy chatting	
	Friendly competition in pool/boccia etc	
SONAS	Sensory stimulation designed for dementia – armchair exercises, sing a long, play instruments, memorable smells	
	This group did not respond well when SONAS was introduced. Wendy felt that they felt silly doing it.	

APPENDIX 8 - INFORMATION ABOUT ANNA HOUSE AGE NI DAY CENTRE

Anna House, Dunmurry, Age NI Day Centre		
Client Group	Older adults 65+ Referred via social worker, GP, District Nurse, Self-referral Mostly living in community alone Isolated No dementia referrals – if develops can usually remain as client unless unsafe Some clients in wheel chairs	
Sessions available	15 clients attend per day ~10-3pm 75 places per week 45 clients on books Clients mostly attend 1-3 sessions per week Transport by local taxis, family etc	
Staff	Manager, day care worker, volunteers Limited staff due to charitable organisation	
Assessment	Previous medical history from referral "Getting to know you" questionnaire completed Daily evaluation, Activity record, Medical records, Contact sheet completed regularly – all falls recorded All in line with RQIA Care plan reviews Surveys – twice per year Inspections – report available online	
Activities available	Bowls/Boccia	Pool tournament

	Quoits	Skittles
	Netball	Tea dance
	Mental stimulation	Quizzes
	Reminiscence	Bingo
Fracture and falls prevention class	Exercise and education Gillian previously trained through the trust Clients participate to own level Once per week during winter, different time each week so all clients get opportunity regularly Do SONAS (includes gentle exercise) during summer as would get too warm doing falls prevention exercises Chair exercises Standing exercises available for those who are able Music session Education – tips on safe sit-stand and stand-sit etc	
SONAS	Sensory stimulation designed for dementia Modified to suit current clients Not memory related Arm chair exercises Sing a long – change songs Hand cream/perfume/aftershave try new scent	
Popularity of activities	Friendly competition in skittles is enjoyed SONAS particularly enjoyed with this group but not in Skainos Building	
Older adult perspectives	Gillian feels clients are aware of benefits of the physical activities, and also that they see improvement in their fitness after taking part in falls prevention class. They report noticing the benefits of things like the tips on getting out of chair.	

	Physical health can be a barrier to physical activity, particularly as some take time off, for example after a heart attack. Advised to wait for a while then get letter from GP.
Use of computer games	Manager, Gillian, got Nintendo Wii for day centre. She demonstrated some of the games for the clients and was playing along with them Played skittles, darts etc. Although she considered herself active and quite fit, the following morning she was very sore from the physical activity involved. Following this she was afraid to use the games with the clients in case they experienced the same discomfort. None of the clients reported discomfort or pain after playing up until this point.

APPENDIX 9- HEALTHY PILOT

Older adults experience performing strength and balance exercises in standing whilst wearing a virtual reality headset

Introduction

Virtual reality (VR) allows users to interact with computer-generated environments. Traditionally this involved large screen displays; however, head-mounted displays (HMD), such as the Oculus Rift that is commercially available and affordable, can deliver a more immersive experience. As VR technology advances and becomes more accessible, it is becoming a more frequent adjunct to traditional rehabilitation. Emerging evidence supports the use of immersive VR headsets in stroke rehabilitation [Just et al. 2014; Laver et al. 2015]. VR can provide additional feedback to optimise both motor learning and motivation. Most of these interventions have been conducted with participants in sitting (Crosbie et al. 2008; Jannink et al. 2008)

Aims

1- Assess users' experience using the equipment
2- Identify issues and concerns

Methods

The ACG system (described in Chapter 3) was set up in Ulster University. Four adults, aged 21-28 years, who were not regular gamers and not familiar with the system, were invited to complete the two conditions (as per the methods described in Chapter 4). Users were instructed to "think aloud" and comment throughout. A handwritten record was made of users' comments along with a record of any problems encountered.

Results

Feedback on the system was positive with users commenting that they did not think the scene would be as realistic; however, some concerns were noticed during use of VR headset. It was identified that, in the virtual reality headset condition, the journey between games 1 and 2, Knee Bends and Leg Abduction, was very quick. One user became unsteady and, when questioned, she said she felt like she had to duck under

obstacles on the journey as she was during the game and that when she looked down whilst wearing the VR headset, it felt as though the ground was moving beneath her. The other three users also commented that it felt that they were going to fall or hit something and that the journey came to a very abrupt stop. These findings enabled the researcher to plan to warn users about the speed of the journey, provide additional instruction that it is not necessary to react to the scene and that they will pass through automatically. We made the decision to encourage users to sit down during break between games, although were unsure how this would affect the tracking of the user at the beginning of the next game, particularly if the user was slow from sit to stand. Comments from users about difficulty maintaining a straight line when performing Sideways Walking in the VR headset condition led to the decision to ensure that the researcher and a research assistant would stand on either side of the area to ensure participant safety. One user commented that they could not keep their balance during the One Leg Stand performed with the VR headset on; this enabled us to plan to have hand support available for all participants during participation in the study, particularly the VR condition.

Game feature	Notes made, including comments by users	Action
Healthy User 1 (female, 22 years)		
Knee bends	"When is it safe to come up again?"	Given additional instruction on completing game
Journey between games 1 and 2	Journey was very quick. User became unsteady. When questioned, stated she felt like she had to duck under obstacles on the journey as she was during the game. When she looked down with the VR headset on, the ground was moving beneath her.	Plan to warn users about the speed of the journey, provide additional instruction that it is not necessary to react to the scene and that they will pass through automatically. Decision made to encourage users to sit down during break between games, although unsure how this will affect the tracking of the user at the beginning of the next game, particularly if the user is slow from sit to stand.
Healthy User 2 (female, age 29)		

Side-stepping with VR condition	"it's difficult to keep straight."	Decision made to ensure that researchers will stand on either side of the area to ensure participant safety.
Journey between games 1 and 2	"I feel like I am going to fall."	See above
One leg stand	"I can't keep my balance at all"	User given a chair for hand support
Healthy User 3 (female, age 28)		
Journey between games 1 and 2	"That's an abrupt stop… It's the doors" "Oh, I am going through a tree"	See above
Healthy User 4 (female, age 21)		
On virtual environment	"This is so much fun" "I didn't think it would be this real" "You can see all around"	No action
Journey between games 1 and 2	"It feels like you're going to hit something".	See above

APPENDIX 10 – ETHICS AND GOVERNANCE DOCUMENTATION

HSC Business Services
Organisation

Office for Research Ethics Committees
Northern Ireland **(ORECNI)**

15 December 2015

Professor Suzanne McDonough
Director of Centre for Health and Rehabilitation Technologies
1F119, Ulster University Jordanstown
Shore Road, Newtownabbey
BT37 0QB

Dear Professor McDonough

Study title:	An evaluation of the safety, usability and acceptability of the Virtuix Omni Treadmill in the older adult population.
REC reference:	15/NI/0217
IRAS project ID:	187902

Thank you for your letter of 30 November 2015, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair of the October HSC REC A meeting and the Lead Reviewer for the application.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details. Publication will be no earlier than three months from the date of this opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to make a request to postpone publication, please contact the REC Manager, Kathryn Taylor, RECA@hscni.net.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a <u>favourable ethical opinion</u> for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Conditions of the favourable opinion

The REC favourable opinion is subject to the following conditions being met prior to the start of the study.

<u>Management permission must be obtained from each host organisation prior to the start of the study at the site concerned.</u>

Providing Support to Health and Social Care

HSC **Business Services Organisation**

Office for Research Ethics Committees Northern Ireland **(ORECNI)**

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www.orecni.hscni.net
HSC REC A

15 December 2015

Professor Suzanne McDonough
Director of Centre for Health and Rehabilitation Technologies
1F119, Ulster University Jordanstown
Shore Road, Newtownabbey
BT37 0QB

Dear Professor McDonough

Study title:	**An evaluation of the safety, usability and acceptability of the Virtuix Omni Treadmill in the older adult population.**
REC reference:	**15/NI/0217**
IRAS project ID:	**187902**

Thank you for your letter of 30 November 2015, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chair of the October HSC REC A meeting and the Lead Reviewer for the application.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details. Publication will be no earlier than three months from the date of this opinion letter. Should you wish to provide a substitute contact point, require further information, or wish to make a request to postpone publication, please contact the REC Manager, Kathryn Taylor, RECA@hscni.net.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a <u>favourable ethical opinion</u> for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Conditions of the favourable opinion

The REC favourable opinion is subject to the following conditions being met prior to the start of the study.

<u>Management permission must be obtained from each host organisation prior to the start of the study at the site concerned.</u>

Providing Support to Health and Social Care

Management permission should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements. Each NHS organisation must confirm through the signing of agreements and/or other documents that it has given permission for the research to proceed (except where explicitly specified otherwise).

Guidance on applying for NHS permission for research is available in the Integrated Research Application System, www.hra.nhs.uk or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of management permissions from host organisations

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database within 6 weeks of recruitment of the first participant (for medical device studies, within the timeline determined by the current registration and publication trees).

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to contest the need for registration they should contact Catherine Blewett (catherineblewett@nhs.net), the HRA does not, however, expect exceptions to be made. Guidance on where to register is provided within IRAS.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Ethical review of research sites

NHS sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Covering letter on headed paper [OREC cover letter]	1	10 September 2015
Covering letter on headed paper [OREC cover letter]	2	30 November 2015
Evidence of Sponsor insurance or indemnity (non NHS Sponsors only) [Statement of sponsorship and indemnity]	1	30 September 2015
GP/consultant information sheets or letters [GP letter]	2	10 November 2015
IRAS Checklist XML [Checklist_30092015]		30 September 2015
IRAS Checklist XML [Checklist_09122015]		09 December 2015

Letter from sponsor [Statement of sponsorship and indemnity]	1	30 September 2015
Non-validated questionnaire [AFRIS]		
Other [Recording pro-forma]	2	10 July 2015
Other [Adverse events record]	2	10 July 2015
Other [CV supervisor KP]	1	25 September 2015
Other [Response table]	1	30 November 2015
Participant consent form [Consent form]	3	10 November 2015
Participant information sheet (PIS) [PIS]	3	10 November 2015
REC Application Form [REC_Form_30092015]		30 September 2015
REC Application Form [REC_Form_09122015]		09 December 2015
Referee's report or other scientific critique report [UU Internal Review Documents]		
Research protocol or project proposal [Protocol]	3	10 November 2015
Summary CV for Chief Investigator (CI) [Summary CV for CI SMcD]		
Summary CV for student [Student S Howes CV]		
Summary CV for supervisor (student research) [Supervisor D Charles CV]		04 August 2015
Validated questionnaire [revised physical activity questionnaire]		
Validated questionnaire [Mini mental state examination]		
Validated questionnaire [Short Physical Performance Battery]		
Validated questionnaire [Berg balance scale]		
Validated questionnaire [Falls Efficacy Scale]		
Validated questionnaire [Geriatic Depression Scale]		
Validated questionnaire [36-item Short Form]		

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document *"After ethical review – guidance for researchers"* gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The HRA website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

User Feedback

The Health Research Authority is continually striving to provide a high quality service to all applicants and sponsors. You are invited to give your view of the service you have received and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website: http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance/

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HRA Training

We are pleased to welcome researchers and R&D staff at our training days – see details at
http://www.hra.nhs.uk/hra-training/

15/NI/0217	Please quote this number on all correspondence

With the Committee's best wishes for the success of this project.

Yours sincerely

Kathryn Taylor.

pp Dr Alastair Walker
Vice-Chair – Chair of the HSC REC A October meeting
Email: RECA@hscni.net

Enclosures: "After ethical review – guidance for researchers"

Copy to: *Nick Curry, Ulster University*

HSC **Business Services**
Organisation

Office for Research Ethics Committees
Northern Ireland *(ORECNI)*

Customer Care & Performance Directorate
Unit 4, Lissue Industrial Estate West
Rathdown Walk
Moira Road
Lisburn
BT28 2RF
Tel: 028 95361400
www.orecni.hscni.net
HSC REC A

21 June 2016

Prof Suzanne McDonough
Professor of Health and Rehabilitation
Ulster University
School of Health Sciences, Jordanstown campus,
Room 01F118, Shore Road
Newtownabbey, BT37 0QB

Dear Prof McDonough

Study title:	An evaluation of the safety, usability and acceptability of exergaming, virtual reality and the Virtuix Omni treadmill in the older adult population
REC reference:	15/NI/0217
Amendment number:	Substantial Amendment 1 - May 2016
Amendment date:	25 May 2016
IRAS project ID:	187902

The above amendment was reviewed at the meeting of the Sub-Committee held on 21 June 2016 in correspondence.

Ethical opinion

The members of the Committee taking part in the review gave a <u>favourable ethical opinion</u> of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Notice of Substantial Amendment (non-CTIMP)	Substantial Amendment 1 - May 2016	25 May 2016
Participant consent form	4	03 May 2016
Participant information sheet (PIS)	4	03 May 2016
Research protocol or project proposal	4	03 May 2016

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.

Providing Support to Health and Social Care

Office for Research Ethics Committees
Northern Ireland **(ORECNI)**

Customer Care & Performance Directorate
Unit 4, Lissue Industrial Estate West
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HSC REC A

13 October 2016

Prof Suzanne McDonough
Professor of Health and Rehabilitation
Ulster University
School of Health Sciences, Jordanstown campus,
Room 01F118, Shore Road
Newtownabbey, BT37 0QB

Dear Prof McDonough

Study title:	**An evaluation of the safety, usability and acceptability of exergaming, virtual reality and the Virtuix Omni treadmill in the older adult population**
REC reference:	**15/NI/0217**
Amendment number:	**Amendment 2, 29/09/2016**
Amendment date:	**05 October 2016**
IRAS project ID:	**187902**

Thank you for Ms Howe's email of 07 October 2016, notifying the Committee of the above amendment to add Mr Nathan McKenna to the research team.

The Committee does not consider this to be a "substantial amendment" as defined in the Standard Operating Procedures for Research Ethics Committees. The amendment does not therefore require an ethical opinion from the Committee and may be implemented immediately, provided that it does not affect the approval for the research given by the R&D office for the relevant NHS care organisation.

Documents received

The documents received were as follows:

Document	Version	Date
Notice of Minor Amendment [Form authorised by CI and Sponsor]	Amendment 2, 29/09/2016	05 October 2016
Other [N McKenna CV]		

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics

Providing Support to Health and Social Care

31 October 2016

Prof Suzanne McDonough
Professor of Health and Rehabilitation
Ulster University
School of Health Sciences, Jordanstown campus,
Room 01F118, Shore Road
BT37 0QB

Dear Prof McDonough

Study title:	An evaluation of the safety, usability and acceptability of exergaming, virtual reality and the Virtuix Omni treadmill in the older adult population
REC reference:	15/NI/0217
Amendment number:	Amendment 3
Amendment date:	10 October 2016
IRAS project ID:	187902

The above amendment was reviewed at the meeting of the Sub-Committee held on 25 October 2016.

Ethical opinion

The members of the Committee taking part in the review gave a <u>favourable ethical opinion</u> of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Notice of Substantial Amendment (non-CTIMP) [Notice of Substantial Amendment Form]	Amendment 3	10 October 2016
Other [Appendix 11- SUS]		07 October 2016
Research protocol or project proposal [Protocol]	Version 5	07 October 2016

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.

Providing Support to Health and Social Care

Our Ref: NC:GOV

30 September 2015

Professor S McDonough
Room 01F119
School of Health Sciences
Ulster University
Jordanstown Campus

Dear Professor McDonough

SPONSORSHIP FOR PROJECT REFERENCE 15/0098

Full Project Title: Feasibility of the Virtuix Omni Treadmill in an Older Adult Population

Chief Investigator	Professor S McDonough (Ulster)
Other investigators	Prof D Waters, Prof L Hale (both University of Otago), Dr K Pedlow (Brain Injury Matters), Dr D Charles, S Howes (both Ulster)

I confirm that the Ulster University will act as sponsor for the above research project as required by the Research Governance Framework for Health and Social Care.

Please refer to the accompanying documentation for more information and to note the outline requirements placed upon investigators. In particular, you must seek appropriate ethical review and confirm that approval is in place before commencing the study.

Please do not hesitate to contact me should you require any further information.

Yours sincerely

Nick Curry
Senior Administrative Officer
Research Governance
028 9036 6629
n.curry@ulster.ac.uk

ULSTER UNIVERSITY

RESEARCH GOVERNANCE

University Sponsorship of Research involving Human Participants and conducted in collaboration with:

- **HSC/NHS trusts or other bodies**
- **Other organisations requiring the University to act as equivalent to Sponsor**

Please find attached the University's letter confirming that it will act as Sponsor for this study.
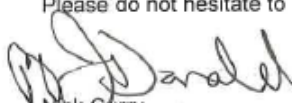
The role of Sponsor includes the following requirements:

- Confirming that arrangements are in place for the research to begin, including arrangements to manage and, where appropriate, fund the study
- Ensuring that the research protocol, the investigators and the environment are appropriate
- Confirming that ethical approval and other authorisations have been obtained before a study begins
- Ensuring that good practice arrangements are maintained for the duration of the study in relation to the conduct of the study, monitoring and reporting (including the immediate reporting of suspected unexpected serious adverse events or reactions)

In practice, the role of sponsor might be divided between the University and the HSC/NHS organisation hosting the research, but the requirements upon the investigators generally remain the same and these are: to conduct the study in line with the approved protocol, to maintain records, to provide reports as required during and at the end of the study and to report any adverse occurrences/seek approval for amendments to the protocol. You should also note that audits of compliance with procedures will be carried out by the HSC/NHS and the University from time to time.

In addition to complying with the University's requirements, you must also familiarise yourself with Trust (or equivalent organisation) policy in this area, including the requirement for honorary contracts or placement agreements to be in place.

Please do not hesitate to contact me should you require any further information.

Nick Curry
Senior Administrative Officer
Research Governance

ULSTER UNIVERSITY

RESEARCH GOVERNANCE

Project Reference Number: 15/0098

Project Title: Feasibility of the Virtuix Omni Treadmill in an Older Adult Population

Statement on indemnity for staff and students conducting research on human subjects

The University is indemnified, through its insurance policies (and subject to the terms and conditions of these policies), for its staff and students engaged in the pursuit of research involving human subjects where the research is being conducted for and on behalf, and with the prior knowledge and consent of, the University.

However, the University is not indemnified through its insurance for non-negligent harm. Legal liability does not arise where a person suffers harm but no-one has acted negligently. The University cannot offer advance indemnities or, generally, insure against non-negligent harm, although such indemnity can be applied for in specific cases and where it is considered to be an essential element of the study.

Participants in research studies (research subjects) should be made aware in the information provided to them of the University's position.

This statement is only valid if it is on headed paper, is signed and bears the Research Governance stamp.

NICK CURRY
SENIOR ADMINISTRATIVE OFFICER
RESEARCH GOVERNANCE

DATE: 30 September 2015

2015 V1

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Physical Activity Readiness Questionnaire (PAR-Q)

If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you significantly change your physical activity patterns. If you are over 69 years of age and are not used to being very active, check with your doctor. Common sense is your best guide when answering these questions. Please read carefully and answer each one honestly: check YES or NO.

		Yes	No
1.	Has your doctor ever said you have a heart condition and that you should only do physical activity recommended by a doctor?	☐	☐
2.	Do you feel pain in your chest when you do physical activity?	☐	☐
3.	In the past month, have you had a chest pain when you were not doing physical activity?	☐	☐
4.	Do you lose you balance because of dizziness or do you ever lose conciousness?	☐	☐
5.	Do you have a bone or joint problem (for example, back, knee, or hip) that could be made worse by a change in your physical activity?	☐	☐
6.	Is your doctor currently prescribing medication for your blood pressure or heart condition?	☐	☐
7.	Do you know of any other reason why you should not do physical activity?	☐	☐

If yes, please comment: _____

YES to one or more questions:
You should consult with your doctor to clarify that it is safe for you to become physically active at this current time and in your current state of health.

NO to all questions:
It is reasonably safe for you to participate in physical activity, gradually building up from your current ability level. A fitness appraisal can help determine your ability levels.

I have read, understood and accurately completed this questionnaire. I confirm that I am voluntarily engaging in an acceptable level of exercise, and my participation involves a risk of injury.

Signature _____

Print name _____

Date _____

Having answered YES to one of the above, I have sought medical advice and my GP has agreed that I may exercise.

Signature _____

Date _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the 7 questions.

Mini-Mental State Examination (MMSE)

Patient's Name: _____   Date: _____

Instructions: Ask the questions in the order listed. Score one point for each correct response within each question or activity.

Maximum Score	Patient's Score	Questions
5		"What is the year? Season? Date? Day of the week? Month?"
5		"Where are we now: State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible. Number of trials: _____
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, ...) Stop after five answers. Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.)
30		TOTAL

(Adapted from Rovner & Folstein, 1987)

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APPENDIX 13 – POWERPOINT PRESENTATION FOR RECRUITMENT
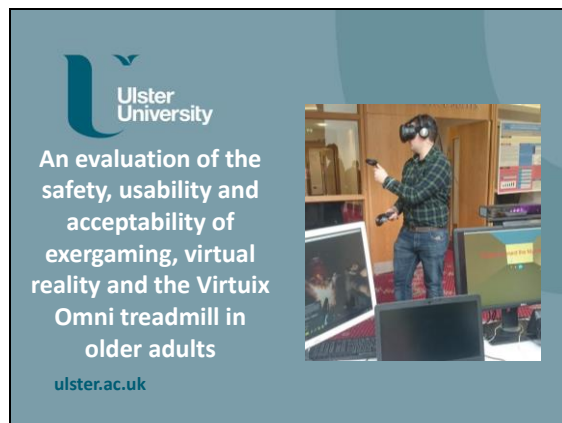
I am here today to talk to you about my research project, titled:

I will go on to explain more about this later.
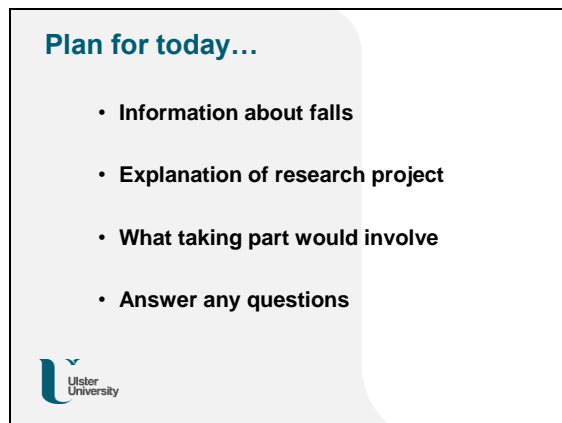
The research project is part of my PhD which is titled:

I am a physiotherapist by background, now completing a PhD at Ulster University at Jordanstown. I work as part of a team – my supervisors are:

THE FALL CYCLE

Fall → Fear of Falling Again → Less Activity → Decreased Muscle Strength & Balance → Increased Risk of Falling → Fall

Ulster University
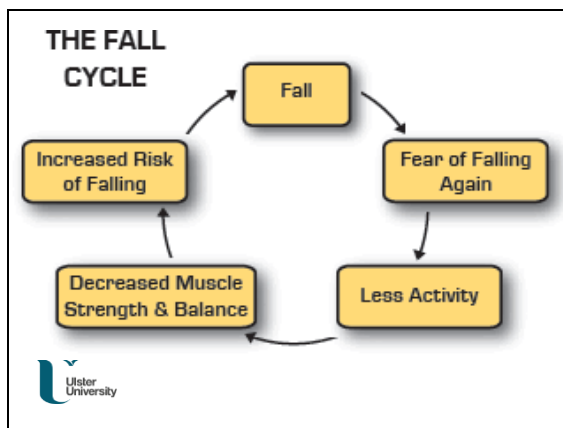
We will start with the good news!

Older adults are the fastest growing portion of the population!!

With falling there is a risk of injury… but people who fall may experience reduced confidence and a fear of falling -> limiting daily activities.

Falls in older adults

- Congratulations!!!

- Increased risk of falls

- Loss of mobility & independence

Every year, more than one in three (3.4 million) people over 65 suffer a fall that can cause serious injury, and even death.

Ulster University

Risk factors

- Muscle weakness
- Reduced balance
- Difficulty walking
- Slower reaction times
- Aches and pains
- Foot problems
- Problems with eyesight
- Medications
- Dizziness
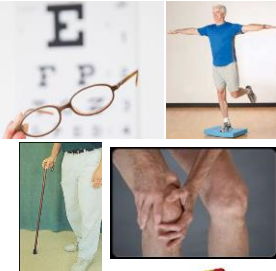
Ulster University

Perhaps some of you will have had a fall or noticed that you are more unsteady…

Looking at the pictures can you tell me what some of the reasons for falling are?

Here is a list of some of the risk factors for older adults that cause falls.

Risk factors
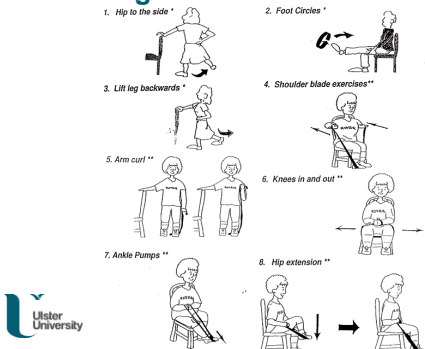
- **Muscle weakness**
- **Reduced balance**
- **Difficulty walking**
- **Slower reaction times**
- Aches and pains
- Foot problems
- Problems with eyesight
- Medications
- Dizziness

For some of these your GP may be able to help… But the ones highlighted in red can be improved with increasing your activity or exercise.

Preventing falls

1. Hip to the side *
2. Foot Circles *
3. Lift leg backwards *
4. Shoulder blade exercises**
5. Arm curl **
6. Knees in and out **
7. Ankle Pumps **
8. Hip extension **

Be more physically active

Exercises can improve strength and balance

Weight bearing exercise can improve bone strength, preventing fractures.

Strength and balance exercise

A supervised group program can help with balance and gait training.

This can lead to problems with access for some people.

I am here today to talk to you about my research project, titled:

I will go on to explain more about this later.

Exergames are digital games that involves movement or being active.

These can be used as exercise – we have developed a game that includes some balance exercises. It can be displayed on a screen or using a virtual reality headset (pictured). We are interested in how users feel about using the game with both the screen and the headset.
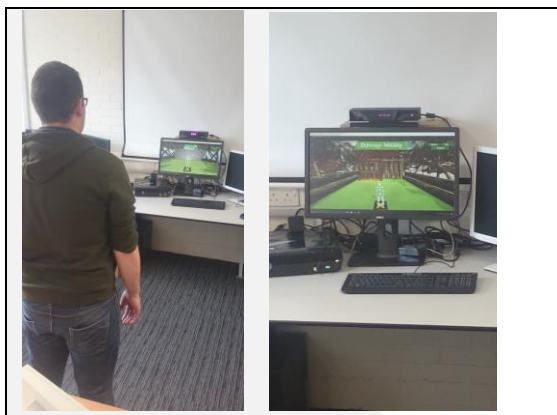
Video clips of demo

What we are testing

- **Safety**

- **Usability**

- **Acceptability**

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Safety - unlikely to cause danger, risk, or injury

Usability - ease of use and learnability

Acceptability – users find it acceptable… in terms of it delivering an exercise intervention

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What taking part would involve

- 20 participants
- Stable health
- Initially 2 visits (~1 hour each)
- At day centre
- Two members of the research team will be present at each visit
  - Supervise
  - Assist
- Feedback from user

Ulster University

We hope at least 20 people will try out the game. We will ask for your permission to check with your GP that they are happy for you to take part.

Who can take part?

	Inclusion Criteria
1	Males and females aged ≥ 65 years
2	Stable physical health as indicated by GP and according to PAR-Q
3	MMSE ≥18
4	Fluency in English (verbal and written)
5	Willing and able to consent
	Exclusion Criteria
1	Bed or wheel chair bound.
2	Significant cognitive impairment, unable to follow verbal or written instruction, MMSE <18
3	Current acute, or uncontrolled medical condition that would not tolerate physical activity
4	Unwilling or unable to consent.

Y
1. Has your doctor ever said you have a heart condition and that you should only do physical activity recommended by a doctor?

2. Do you feel pain in your chest when you do physical activity?

3. In the past month, have you had a chest pain when you were not doing physical activity?

4. Do you lose you balance because of dizziness or do you ever lose conciousness?

5. Do you have a bone or joint problem (for example, back, knee, or hip) that could be made worse by a change in your physical activity?

6. Is your doctor currently prescribing medication for your blood pressure or heart condition?

7. Do you know of any other reason why you should not do physical activity?

Ulster University

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rPAR-Q and inc/exc criteria –PIS & letter to notify GP

Recruitment – up to 2 weeks to allow GP to express concerns

What happens on each visit?

<u>Visit 1</u>
1. Initial assessment
2. Demonstration and instruction on how to use the game with display on screen
3. Your opportunity to use it

<u>Visit 2</u>
1. Demonstration and instruction on how to use the game with virtual reality headset
2. Your opportunity to use it
3. Questionnaire and short interview to get your feedback and views on using the game.

Ulster University

What happens on each visit

<u>Visit 1</u>
1. Initial assessment
2. Demonstration and instruction on how to use the game with display on screen
3. Your opportunity to use it

<u>Visit 2</u>
1. Demonstration and instruction on how to use the game with virtual reality headset
2. Your opportunity to use it
3. Questionnaire and short interview to get your feedback and views on using the game.

Ulster University

Additional information

Ulster University

Visits will be completed at least one day apart.

You can see that what we plan to do will be similar on both visits.

Initial assessment – general information, balance, physical function, quality of life

Use of the game will involve following a short demo which will be displayed on screen or on the headset. A written record will be made

Questionnaire and interview are to find out more about your views, any problems you had, whether you think it is something you would like to use in the future, etc

There will always be someone close by to ensure your safety.

For some of the exercises you will be able to use a walking aid. We will ensure your walking aid is close by, if you are not able to use it. As an alternative, you can use one or two chairs for extra support.

You will be able to pause, quit, or restart at any time.

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Participant information sheet
An evaluation of the safety, usability and acceptability of exergaming, virtual reality and the Virtuix Omni treadmill in the older adult population

Exergaming is a term used to describe video games with an exercise component. It can be combined with additional equipment, such as the Virtuix Omni treadmill and a virtual reality headset (see picture below) which may allow users to exercise safely in a virtual environment, for example in a park or forest. This research is to assess whether this is safe and usable for older adults, and if they find it an acceptable mode of exercise.

You are being invited to take part in a research study, which is being undertaken as part of a PhD. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives, carers and your GP if you wish. Please ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

What is the purpose of the study?
Exercise has been shown to make everyday tasks easier and prevent falls in older adults. However, many older adults do not complete enough exercise. New technology, such as the Xbox Kinect, Virtuix Omni treadmill and virtual reality headset, may provide the opportunity for older adults to exercise in their own homes, in a way that is safe and

enjoyable. Before conducting a large study, it is necessary to investigate older adults' experience of using the equipment and ensure it is safe to use. This study will test investigate older adults' experience of using the Xbox Kinect and Virtuix Omni treadmill *with* and *without* the use of a virtual reality headset, and ensure it is safe to use.

Why have I been chosen?
For this stage of the research, we aim to recruit 30 people aged over 65 with different levels of mobility and physical function. We are asking service users who use Age NI day centres to take part; however, attending a day centre is not necessary to take part in this study.

Do I have to take part?
It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason.

If you decide to take part we will send your GP a letter to inform them of the study. This will give them an opportunity to share any concerns about you taking part.

What will happen to me if I take part?
The study involves three visits; each will last approximately 2 hours, and be conducted within the day centre, in a separate room or partitioned off area to ensure privacy.

On Visit 1, you will be asked to answer some questions and complete some questionnaires and a balance test. If you have any problems in completing the questionnaire e.g. poor eyesight, the researcher can help you to complete it.

On each visit (1, 2 & 3), you will be shown how to use the equipment, and then have an opportunity to try the equipment out yourself. You can ask for assistance as required at any stage though each visit. All visits will be video recorded; this will only be viewed by members of the research team.

On Visit 3, you will complete one short questionnaire and answer some questions about your experience of using the equipment. This conversation will be recorded using a voice recorder. If you do not wish to have your session video recorded, you can still take part in the study.

What is being tested?

Xbox Kinect uses cameras to detect users, allowing them to use their body movements to control a game. The Virtuix Omni Treadmill includes a platform and specialised shoes which allow users to stand up and walk, and turn in a virtual environment. It features a support ring and safety harness, which are designed to improve safety. It can be used to display different environments, such as a park or forest, on a screen or using a virtual reality headset. During this study you will have a chance to try this equipment. A short demo, developed at Ulster University, will be used to provide you with direction whilst using the Omni treadmill. You will be asked to progress through the environment by walking and performing balance exercises; for example, to pass a low hanging branch you would bend your knees to duck beneath it.

What are the side effects of taking part?

We do not anticipate any serious side effects from taking part. You may feel muscle soreness, which is normal and associated with an increase in physical activity. If you suffer these or any other symptoms, during or in the days following participation in the study, please report them to the researcher, contact details can be found at the bottom of this information sheet. Alternatively, you can tell a member of staff at your day care centre who will contact the research team.

What are the possible benefits of taking part?

The information we get from this study will help us to modify the next stage of research, which is a larger study to develop an intervention for older adults to reduce the risk of falls. Participants will potentially benefit by learning more about new technology and research. If the Omni treadmill is found to be useful it may be introduced into day centres for people to use.

What if something goes wrong?

There is a very low risk of any harm associated with taking part in this research; however, the University has procedures in place for reporting, investigating, recording, and handling what are called adverse events.

Any complaints will be taken seriously and should be made, in the first place, to the Chief Investigator, contact details are below. Following this, the research office can also provide additional guidance, contact details below.

The University is insured for its staff and students to carry out research involving people. The University knows about this research project and has given permission for it to proceed. Further details can be found in

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the University's research indemnity statement which is available on request.

Confidentiality
All information which is collected about you during the course of the research will be kept strictly confidential. Any information about you will have your name and address removed so that you cannot be recognised from it. If you wish to withdraw from the study at any point, we will ask your permission to use any information already obtained.

What will happen to the results of the research study?
The results are likely to be published in a relevant medical journal within 12 months of testing. No participants will be identified in any report/publication. If you wish to obtain results, please contact the researcher.

Who has reviewed the study?
Ethical approval has been obtained from Office of Research and Ethics Committees Northern Ireland.

Contacts for Further Information

PhD Researcher: Sarah Howes
Email: Howes-S@email.ulster.ac.uk
Telephone: 028 9036 8778

Chief investigator: Prof Suzanne Mcdonough
Email: s.mcdonough@ulster.ac.uk
Telephone: 028 9036 6459

Research office: Nick Curry
Email: n.curry@ulster.ac.uk
Telephone: 028 9036 6629

Thank you for taking part in this study.

1 copy for participant; 1 copy for researcher

APPENDIX 15 – GP LETTER (PRINTED ON HEADED PAPER)

Dr Name
Address

Sarah Howes BSc MCSP
Room 1F125
School of Health Science
Ulster University – Jordanstown Campus
Shore Road
Newtownabbey
Tel:02890368778

DATE

Email: Howes-S@email.ulster.ac.uk

Dear Dr NAME

Re: PATIENT NAME
Date of birth: DOB

Your patient has been invited to take part in a research project to test the safety and usability of *a* new piece of technology that may provide the opportunity for older adults to exercise in their own homes, in a way that is safe and enjoyable. The *Virtuix Omni treadmill* includes a platform and specialised shoes which allow users to stand up and walk, and change direction in a virtual environment. It features a support ring and safety harness, which are designed to improve safety. It can be used to display different environments on a screen or using a virtual reality headset. Users can progress through the environment by walking and performing balance exercises; for example, to pass a low hanging branch the user should perform a squat to duck beneath it.

The testing will take place in the Age NI day centre at Skainos building where they attend weekly. PATIENT NAME will be asked to complete some questionnaires and balance tests then shown how to use the equipment. They will then have an opportunity to try the equipment out including stepping onto it and taking some steps. There will be two members of the research team supervising and providing assistance where required.

PATIENT NAME has met the eligibility criteria for inclusion in this study. They report being of stable health and have indicated that they do not have any medical condition that would contraindicate participating in physical activity. Testing will commence two weeks from the date of this letter to allow you the opportunity to share any concerns about PATIENT NAME's medical history that may affect their ability to participate in this study.

If you would like any further information about this project, or have any concerns about PATIENT NAME participating please contact me using the details above. This research project is supervised by Professor Suzanne McDonough, who can be contacted for more information via telephone on 02890366459 or email at s.mcdonough@ulster.ac.uk.

Kind regards,
Sarah Howes
(PhD Student)

APPENDIX 16 – CONSENT FORM

Consent form

Title of Project: An evaluation of the safety, usability and acceptability of exergaming, virtual reality and the Virtuix Omni treadmill in the older adult population

Name of Chief Investigator: Professor Suzanne McDonough

	Please initial
• I confirm that I have been given and have read and understood the information sheet for the above study and have asked and received answers to any questions raised	[ ]
• I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason and without my rights being affected in any way	[ ]
• I give my consent for my GP to be informed about my participation in the study.	[ ]

• I give my consent to allow recording during participation in this study, and for those records to be reviewed by persons involved in the study:

Video [   ]
Audio [   ]

• I understand that the researchers will hold all information and data collected securely and in confidence and that all efforts will be made to ensure that I cannot be identified as a participant in the study (except as might be required by law) and I give permission for the researchers to hold relevant personal data   [   ]

• I agree to take part in the above study   [   ]

_____ _____ _____
Name of Participant   Signature   Date

_____ _____ _____
Person taking consent   Signature   Date

_____ _____ _____
Name of researcher   Signature   Date

One copy for the subject; one copy for the researcher.

APPENDIX 17 – SAFETY PRO-FORMA

Pro-forma to measure safety components and practical aspects of using the equipment

Warm up	Task completed, yes/no	Type and level of assistance required, eg. verbal/physical Notes	Comments made by user during participation
Marching on the spot			
Gentle stretches for neck, shoulders, ankles			
Practical tasks	Task completed, yes/no	Type and level of assistance required, eg. verbal/physical Notes	Comments made by user during participation
Ability to carry out basic movements as instructed on Kinect	Task completed, yes/no	Type and level of assistance required, eg. verbal/physical Notes	Comments made by user during participation
Knee bends			
Abduction			

Side stepping				
One leg stand				
Cool down	Task completed, yes/no	Type and level of assistance required, eg. verbal/physical Notes	Comments made by user during participation	
Gentle stretches for calfs, thighs, shoulders, neck				
Adverse events	Yes/no	Details (including activity during which it occurred, description of AE, severity, outcome, follow-up)		

APPENDIX 18 – INTERVIEW SCHEDULE (USER TESTING PHASE 1)

How did you find using the system?
Did you find the game to be something that you would find useful?
Would you like to do this again in the future if you were offered the opportunity? Would this be a type of exercise you would like to do in the future?
What would prevent you doing exercises like this? Would there be any barriers that you would anticipate?
Do you feel that playing games would make exercise more or less enjoyable? If refers to other exercise they complete? What type of exercise do you currently do? How do these games compare to your usual exercise? What interests you in the exercise you do? Why do you do it?
Do you think it would be easy for you to use the system on your own? How long do you think it would take you to learn the system, and get used to it?
Is this something you think you would do by yourself? Or would you prefer to have someone with you?
What would be the most appropriate environment for you to use the games in?
If you were to do the exercises in the future, what do you think would be an appropriate duration to do them for?
How frequently do you think you would like to use it?

Game specific questions:
Which study condition did you prefer, viewing it on the screen or using the headset? Could you explain your answer?
Could you share some of the problems you might have had using the system, with either the screen or the headset?
Did you find it was easier or harder to be successful with one or the other?
Do you think the instructions that the game gave were sufficient?

APPENDIX 19 – DEMOGRAPHIC QUESTIONNAIRE

Study ID ....

Demographic Information

Name... .... Gender...

D.O.B.. Age ....

Living situation (co-habitants, type of house) ....

Medical conditions (receiving treatment? ....

Number of medications ....

Walking aid (at home) .... Walking aid (outside home) ....

Falls in last 12 months .... Injuries sustained ....

Health professional consulted............... Hospital admission ....

Eligibility screening

MMSE   _____/30

Baseline measures

Short Physical Performance Battery   _____/12

Berg Balance Scale   _____/ 55

FES-I   _____/64

Outcome measures

AFRIS   _____/42

APPENDIX 20 – SPPB

Short Physical Performance Battery

1- Repeated Chair Stands
   5 chair stands for time
   Number completed _____
   Time taken _____seconds

                             SCORE_____

2- A- 10 second semi-tandem stand
   Completed 10 secs _____
   <10 secs_____
   not done_____

   B- 10 second side by side stand
   Completed 10 secs _____
   <10 secs_____
   not done_____

   C- 10 second tandem stand
   Completed 10 secs _____
   <10 secs_____
   not done_____

                             SCORE_____

3- Timed 8 foot walk
   Completed _____
   Time taken _____seconds

                             SCORE_____

                      TOTAL SCORE_____/12

APPENDIX 21 – BBS

Berg Balance Scale

ITEM DESCRIPTION SCORE (0-4)

1- Sitting to standing _____

2- Standing unsupported _____

3- Sitting unsupported _____

4- Standing to sitting _____

5- Transfers _____

6- Standing with eyes closed _____

7- Standing with feet together _____

8- Reaching forward with outstretched arm _____

9- Retrieving object from floor _____

10- Turning to look behind _____

11- Turning 360 degrees _____

12- Placing alternate foot on stool _____

13- Standing with one foot in front _____

14- Standing on one foot _____

Total _____

APPENDIX 22 – FES-I

NYC **Health**

Falls Efficacy Scale-International

Below are some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity (for example, if someone does your shopping for you), please answer to show whether you think you would be concerned about falling IF you did the activity. For each of the following activities, please check the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

		Not at all concerned 1	Somewhat concerned 2	Fairly concerned 3	Very concerned 4
1	Cleaning the house (for example, sweep, vacuum or dust)	1 ☐	2 ☐	3 ☐	4 ☐
2	Getting dressed or undressed	1 ☐	2 ☐	3 ☐	4 ☐
3	Preparing simple meals	1 ☐	2 ☐	3 ☐	4 ☐
4	Taking a bath or shower	1 ☐	2 ☐	3 ☐	4 ☐
5	Going shopping	1 ☐	2 ☐	3 ☐	4 ☐
6	Getting in or out of a chair	1 ☐	2 ☐	3 ☐	4 ☐
7	Going up or down stairs	1 ☐	2 ☐	3 ☐	4 ☐
8	Walking around in the neighborhood	1 ☐	2 ☐	3 ☐	4 ☐
9	Reaching for something above your head or on the ground	1 ☐	2 ☐	3 ☐	4 ☐
10	Going to answer the telephone before it stops ringing	1 ☐	2 ☐	3 ☐	4 ☐
11	Walking on a slippery surface (for example, wet or icy)	1 ☐	2 ☐	3 ☐	4 ☐
12	Visiting a friend or relative	1 ☐	2 ☐	3 ☐	4 ☐
13	Walking in a place with crowds	1 ☐	2 ☐	3 ☐	4 ☐
14	Walking on an uneven surface (for example, rocky ground, poorly maintained pavement)	1 ☐	2 ☐	3 ☐	4 ☐
15	Walking up or down a slope	1 ☐	2 ☐	3 ☐	4 ☐
16	Going out to a social event (for example, religious service, family gathering or club meeting)	1 ☐	2 ☐	3 ☐	4 ☐
	TOTAL SCORE=	*add all 1's*	*add all 2's*	*add all 3's*	*add all 4's*

SCORING: Low Concern: 16–19; Moderate Concern: 20–27; High Concern: 28–64

Adapted from the Prevention of Falls Network Europe, Falls Efficacy Scale International Prof Lucy Yardley and Prof Chris Todd

Geriatric Depression Scale: Short Form

Choose the best answer for how you have felt over the past week:

1. Are you basically satisfied with your life? YES / **NO**

2. Have you dropped many of your activities and interests? **YES** / NO

3. Do you feel that your life is empty? **YES** / NO

4. Do you often get bored? **YES** / NO

5. Are you in good spirits most of the time? YES / **NO**

6. Are you afraid that something bad is going to happen to you? **YES** / NO

7. Do you feel happy most of the time? YES / **NO**

8. Do you often feel helpless? **YES** / NO

9. Do you prefer to stay at home, rather than going out and doing new things? **YES** / NO

10. Do you feel you have more problems with memory than most? **YES** / NO

11. Do you think it is wonderful to be alive now? YES / **NO**

12. Do you feel pretty worthless the way you are now? **YES** / NO

13. Do you feel full of energy? YES / **NO**

14. Do you feel that your situation is hopeless? **YES** / NO

15. Do you think that most people are better off than you are? **YES** / NO

Answers in **bold** indicate depression. Score 1 point for each bolded answer.

A score > 5 points is suggestive of depression.
A score ≥ 10 points is almost always indicative of depression.
A score > 5 points should warrant a follow-up comprehensive assessment.

Source: http://www.stanford.edu/~yesavage/GDS.html
This scale is in the public domain.

APPENDIX 24 – INTERVIEW SCHEDULE (USER TESTING PHASE 2)

Version 1

How would the system help you in the real world?
 	
  - What are the main benefits?
  - What are some of the reasons you agreed to take part in this study?
  - Did you find that the games challenged your balance?
  - What influence do you feel playing these games over time would have on your health?

What things were necessary for you to be able to use the system?
 	
  - What was the most difficult aspect of using the system?
  - How did you find using the system?
  - How did you own ability and limitations affect your use of the system?
  - What factors would influence your ability to play the game regularly in the future?

How important is it to feel safe when using the system?
 	
  - Did you feel safe/secure/confident when playing the games?
  - How did concerns about falling affect you when playing the games?
  - How did having social support (researcher/another service user) influence your experience?
  - What are some of the barriers to using the system in the future?
  - How do barriers compare to the barriers to general exercise?

Version 2
Often when people agree to participate in a study, they anticipate something they want to get from it. What benefits did you think you would get from using this system/game?

- Did that happen for you?
- How could this system help you in the real world?
- What are the main benefits? Pick words they have used and ask them to explain more.
- What are some of the reasons you agreed to take part in this study?
- Did you find that the games challenged your balance?
- What influence do you feel playing these games over time would have on your health?
- Confidence / balance / sociability

Based on previous responses given in interviews, it seems that feeling secure is important when using the system. Can you tell me what you think about that?

- How important is it to feel [safe] when using the system?
- Did you feel [safe/secure/confident] when playing the games?
- How did [concerns about falling] affect you when playing the games?
- How did having [social support (researcher/another service user)] influence your experience?
- What are some of the barriers to using the system in the future?
- How do barriers compare to the barriers to general exercise?

Is there anything we should know, or is there anything we should take on board and try if we were planning to set this system up again somewhere else?

- What things were necessary for you to be able to use the system?
- What was the most difficult aspect of using the system?
- How did you find using the system?
- How did you own ability and limitations affect your use of the system?
- What factors would influence your ability to play the game regularly in the future?

APPENDIX 25 – NOTES ON VIDEOS

Pt A visit 1 14-04-17		
Game	Instruction related to set up	Instruction related to play
Knee Bends	1 – query about position on X	1- timing
Leg Abductions	1- position on x	0
Sideways Walking	1- position on x	0
One Leg Stand	0	1 - timing

Comments

Knee bends

PT21: "I'm pretty well on that, isn't that right"

"you need to go back a bit"

Pt21 (missed first one): "where's the wall, is that the wall? I'm waiting for the wall to move"

"the brown log"

"good job you put the chairs there" (two hand support)

No further instruction

"it's no problem as long as I have the chairs"

Leg abductions

"you might need to step back a bit"

Knee slightly out in front with knee bent a little – not corrected

"never scored a single goal…there you are that's not bad for an old fellow"

Sideways walking

"I think that's pretty well ok on the X"

"if it doesn't start counting you might need to move. … Step back"

"5/5 that's nearly perfect"

One leg stand

"this is going to be a disaster"

Continually switching legs "Just whatever side the water is on, then try and hold it"

"I couldn't have done that without the chairs"

Comments after

"Handy enough"

"I would have liked a test" – like a practice run.

"when you're my age you think there's an awful lot of things that I would have done automatically like getting on a roof or something and now I don't even do my own garden"

"you do things you think you can do and you really can't"

"That left leg, got that wrong at first. You don't know what's going to happen, takes you a few seconds to kick in"

Pt A   visit 2   26-04-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	0	1 – foot position
Leg Abductions	1 – reduce hand support	0
Sideways Walking	0	1 – number/length of steps
One Leg Stand	1 – Pt asked how much hand support they should use.	0

Visit 2 Comments before

No hearing aid

Knee bends

Reads instruction on screen

PtA: "I'll try it without the chairs I think"

Researcher: "Try your feet a bit wider"

"it's that single leg stand I think I have trouble with"

Leg abductions

Started no hand support then used two "it's the balance is the problem" able to reduce hand support when it was suggested.

Sideways walking

Followed verbal instruction given by game

Only taking 1 large step – instruction to take more smaller steps

One leg stand

"Do you want me to try and do this without holding on?" "I'll try it and see what happens" "You see, with the least touch I can do it, but without it I can't"

Comments after

Discussed reducing hand support

Pt A visit 3 28-04-17		
Game	Instruction related to set up	Instruction related to play
Knee Bends	1 - for calibration (countdown)	1 – foot position
Leg Abductions	0	2 - corrected technique
Sideways Walking	0	0
One Leg Stand	1 - for calibration (countdown)	0

Potential new participant observing this session

Knee bends

"Try to straighten your feet; a wee bit wider, hip width"

Leg abductions

Right side "I kicked that and it didn't move"   "you kicked out in front a bit"

Questioned as not successful with left side "your foot is in front; your foot needs to be in line with your body"

Sideways walking

Quite simple

One leg stand

Encouraged to reduce hand support from fingertips on two hands to one hand.

Did not start countdown to begin, assisted to get going

"See that's much worse than I've had up to now"

"disappointed" foot was raised and it didn't recognise.

Pt A visit 4 03-05-17		
Game	Instruction related to set up	Instruction related to play
Knee Bends	1 – for calibration (Kinect tracking)	0
Leg Abductions	1 – for calibration (countdown)	1 – corrected technique
Sideways Walking	1 – for calibration (countdown)	1 – corrected technique after an unsuccessful repetition
One Leg Stand	1 – for calibration (countdown)	0

Visit 4 comments before

"I'm determined to get full marks this time"

Knee bends

Reads instruction on screen

Instruction to put arms out to side for calibration – but this would not have been necessary if no difficulty calibrating.

Participant was able to try and wave etc for Kinect to recognise him.

Participant able to find position on X on instruction from game.

No further instruction during Knee Bends.

Participant used 2 hands today, hadn't used hands previously – Older adults likely to use the support available.

Abductions

Countdown did not start – Instruction to reposition on X – "you're maybe just not right on the centre"

Confusion over no ticks for calibration repetitions.

Removed one chair as kicking in front of it.

Instruction re direction of kick "Try and keep your leg straight"

Sideways walking

"If it doesn't start counting, you aren't right on the centre of the X. And if it stops counting, you're not on the centre of the x. Try back slightly."

One leg stand

Encouraged Pt to reduce hand support but he did not hear

Comments at the end

"I don't know what I was doing wrong"

"But that single leg stand is the one I've fallen down on every time"

"my balance is not good, simple as that. For me to do this a couple of times then never do it again, I don't notice my balance wrong any time. The difference is not enough to be obvious."

Pt A visit 5 12-05-17		
Game	Instruction related to set up	Instruction related to play
Knee Bends	0	0
Leg Abductions	0	1 – query about feedback
Sideways Walking	0	1 - timing
One Leg Stand	1 - calibration	

Knee bends

"Knee bends 10 out of 10, there you are!"

Chatting with

Leg abductions

"Now this is the one I was getting wrong, but I wasn't kicking the ball right. To the side!"

Reminded the first three are practice "I thought I was wrong you see"

One slight stumble – friend watching "Shut you up"

"Ten out of ten – perfect"

Sideways walking

"This walking sideways is alright, it's the single leg stand"

"Stepped back to soon"

Offered to replay

Chatting to friend

One leg stand

Trouble calibrating

"I didn't do too bad, that's the best I've done yet"

Comments after

"That sideways walking I must have come back too soon, racing ahead"

Pt B visit 1 25-04-17		
Game	Instruction related to set up	Instruction related to play
Knee Bends	0	0
Leg Abductions	2 – position on x (during play)	1 - technique
Sideways Walking	0	0
One Leg Stand	0	1 – query re game

Knee bends

Able to follow instructions provided without additional instruction from the researcher

Leg abductions

"Didn't like this one the first time" (Previous study phase)

Hitting target with no movement, instructed to reposition to fix problem

Kicking some out in front "when you go in front it doesn't get it, so try straight out to the side"

Pt22 "That was a disaster"

Sideways walking

Did not step far enough for first wall but corrected after with no instruction

"either I'm getting slower or that's getting quicker"

One leg stand

Pt 22: "Any leg?" – told it would be left leg lifted first

"This is a disaster." "Find it hard to lift that leg"

"That was a disaster" "Very disappointed with that one now" "It was much higher the

last time I did it"

right foot on ground was hitting water on left side causing lower score

Comments after

"good at some, not so good at others"

"happy with the game, not the result"

"I'm usually a competitive animal"

Pt B   visit 2   28-04-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	0	0
Leg Abductions	1 – problem tracking	3 – correct technique
Sideways Walking	0	0
One Leg Stand	0	0

Knee bends

"Quite easy to do"

Leg abductions

"It's hard to figure out whether it's forward or back"

First repetitions in front, did not correct. Same on left calibration reps

"so each time it should be out to the side"

"your foot is a wee bit in front there; directly out to the side"

Tried leg raise while holding left arm as tracking slightly off

"keep it coming to the side, you are a bit in front again with your foot"

"disaster, that's the worst I've done in that"

Sideways walking

Very comfortable with that one

One leg stand

"that's hard"

"left leg is a killer so it is, the left leg needs the work"

"the leg abduction one, I can't seem to master that one with the ball"

"You think this is stupid, what am I doing here, and you try to adjust your foot. And it's getting into your mind what way to adjust your foot. Cos that means forward on the computer doesn't it"

"I would try and improve it. I think I did better in the first one."

PtB   visit 3   04-05-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	0	0
Leg Abductions	0	1 – technique
Sideways Walking	0	0
One Leg Stand	0	0

Comments

Asked pt22 to position left arm (affected by stroke) at side to see if it affected calibration. Worked for knee bends but unable to maintain for leg abduction.

Knee Bends

n/a

Leg abduction

Successfully hitting target without moving lower limb – restarted game

Participant noticed right hand and foot of character were jumping around

"try and keep your toe facing forward"

Pt22 kicking in front and behind; system seems inconsistent.

"consciously trying to keep the toes that way, what I'm trying to work out is if I'm playing the ball in front or at the heel" "I was trying to move my leg back and out or forward and out to try and find the ball" "I can't understand why on the screen the left foot appeared static but the right foot and hand were jumping about".

Pt22 keen to try it again, but unable to skip backwards to replay.

Sideways walking

Stepped back to quickly on first one, corrected on next without additional instruction, aware of mistake

"motivated to try and do as well as I possibly can"

One leg stand

Compensating by leaning back and to the right – no instruction provided re this

Comments after

"I don't know whether that's an increase or not… I think the one leg stand has improved"

"The leg abduction was quite hard, and the water I find it hard especially with this (L) left. It's a struggle, I try to keep it but it was hard"

"Happy enough, I think it's an improvement, well hopefully"

Pt B   visit 4   11-05-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	1 – hand support (reduce)	0
Leg Abductions	1 – position on x	0
Sideways Walking	0	0
One Leg Stand	1 – difficult to calibrate	0

Comments

Knee Bends

"only use that (hand support) if you need it"

Dancing to music at the end

Leg abduction

Kicking behind; successful; therefore instructed to step back a bit; improved.

Repeated game at end - got full marks – "I think I did a bit better that time!"

"If I move back this way, I'm at the front of the x and I find it easier to judge where the ball is, so I've worked that bit out"

Sideways walking

Stepped back to quickly on first one, corrected on next without additional instruction, aware of mistake

No further instruction required

One leg stand

Additional instruction as hard to calibrate

Some compensation left side

"if it's not the water it's the balls"   "when I get a bit tired it's very hard to keep that leg up"

Pt 22   visit 5   17-05-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	1 position on x	0
Leg Abductions	0	0
Sideways Walking	0	0
One Leg Stand	1 – position (R foot hitting water on left)	

Comments

Knee Bends

Experimenting with position on X; guidance given

"quite easy, I've no problems with it"

Leg abduction

Missed first ball on left side "Now, how did I miss that"; got next one without additional instruction "by moving back a wee bit"

Sideways walking

Stepped back to quickly on first one, "wanted to give you the stick" to progress to playing with no hand support.

One leg stand

"this is the one I don't like"

"I couldn't get that leg up"

Additional instruction "I think that's your right foot hitting water on left"

"I'm having to lean over to get that leg up"

"Boy that's hard today"

Score: "that's not too bad actually"

Pt C visit 1 26-04-17		
Game	Instruction related to set up	Instruction related to play
Knee Bends	1 – position for countdown	2 – timing 1 – foot position
Leg Abductions	1- hand support	1- technique 1- navigation of screen (L/R)
Sideways Walking		9- navigation of screen (L/R)
One Leg Stand		3 – technique 3- timing

Knee bends

Did knee bend when it said "knee bends" in verbal introduction to game

Feet wider

When you see it go red, go now

Bending forward rather than knee bend – no additional instruction given

Leg abductions

"what does that mean?" during verbal instruction by system; additional instruction and demo provided

PT has cataracts; Researcher orientates pt to ball position on left or right and ask if she can see to continue playing the game.

Sideways walking

"what does that mean?" during verbal instruction by system; additional instruction provided

Additional instruction to prompt every wall apart from two.

Query poor eyesight affecting ability to view screen.

"I wasn't sure what to do"

One leg stand

Started OLS during verbal instruction from system

Instruction to maintain OLS position

"Got the hang of it now"

Pt D   visit 1 26-04-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	1 - calibration	1 – timing 2 – additional instruction
Leg Abductions	0	3 – correct technique 1 - position
Sideways Walking	0	2 – direction and distance
One Leg Stand	1 - countdown	1 – hand support 1 – correct side

Knee bends

Step back for calibration, could not see feet

"You don't need to do it until you see the log, it hasn't started yet."

What am I supposed to do?" "bend your knees" "come up each time"

Leg abductions

Kicking behind

"try and keep your leg as straight as you can"

"I cheated there" showed cheat "try not to cheat"

"I think you've moved forward slightly, try a step backwards"

"Out to the side is what the aim of the exercise is"

Sideways walking

Able to follow verbal instruction by game re posture and position

"you need to go a wee bit further" "this way this time"

"It's just a matter of getting used to it"

One leg stand

"Are you supposed to hold on?" "If you need to"

Instruction re position for countdown to begin

"it's your other leg, so it is like a mirror"

Comments

Pt D   visit 2   12-05-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	0	1 – query re technique
Leg Abductions	0	1 - technique
Sideways Walking	0	1 - distance
One Leg Stand	0	0

Knee bends

Pt25: "have I just to bend my knees?"

Demo of correct movement

Pt25: "have I to do it now?" but did it without further instruction

No further instruction

Leg abductions

Bending knee to kick behind – successfully hitting targets anyway

"Try and keep your leg straight"

Pt25: "was I doing it wrong?" (unaware)

At end Pt25: "Did you ever kick a ball into the net without bending your knee?!"

Sideways walking

Did not step far enough on first one "What happened there?"

"You need to go a bit further"

No further instruction

One leg stand

Went to lift wrong leg initially but corrected without instruction

Comments

Pt D   visit 3   19-05-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	0	0
Leg Abductions	1 – query re technique	1 - technique
Sideways Walking	0	1 - distance
One Leg Stand	1 – position on x	1 - technique

Knee bends

"Is that is?" doing correct movement

Leg abductions

Asked what this game was and instructed to listen to instructions provided by game; these were sufficient – shows reliance on person for instruction; perhaps not natural to listen to the audio; would an avatar/character giving instruction be more engaging for this population?

Bending leg to kick target "Try to keep your leg straight" - corrected

Sideways walking

Did not step far enough on first one "wee bit further" - corrected

One leg stand

"step forward a wee tough"

First rep: "keep it up" – "so you've to do it until the water goes away?" corrected

"I didn't get on too well in that one" "It was too soon I let my foot down"

Pt E   visit 1 11-05-17

Game	Instruction related to set up	Instruction related to play
Knee Bends	1- timing	1 - timing
Leg Abductions	2- Position on x 1- Foot position	2 - technique
Sideways Walking	Chairs taken away and reassurance about stopping if necessary	2- direction 1- technique
One Leg Stand	2 Position on x 1 Foot position	2 – technique

Knee bends

Did knee bend when it said "squatting down" in verbal introduction to game

"Just wait until the game starts, when the music starts"

Missed first log "When it turns red duck"

Coming onto toes slightly – no correction given

Leg abductions

"Can you step back a bit"

"and feet a wider"

Kicking forwards at first "try a bit more out to the side"

"so you're a bit in front again, try out to the side"

Assisted to reposition on X for better success with this game

No further instruction required

Sideways walking

Followed instruction for set-up well

Rep 1" so you'll step towards me to avoid the wall"

Rep 2 "so the other way this time"

Rep 3 "Start making your way that way again"

Rep 4 "Just a little bit further this time"

Dancing to music

No further instruction required

One leg stand

"You're a bit forward, put your feet wider"

"it's not counting down very well. Just in the middle"

Rep 1 - Participant side stepped out of the water "Back into the middle, then lift your right foot up, a bit higher"

Rep 2 - "then change legs"

No further instruction required

Comments

"it stretches your legs"

"well it wasn't very, very hard and it wasn't very, very easy"

"the ones with the ball I think I preferred than the other ones"

"I think it's great, it's excellent it really is"

"I can feel that in my legs"

Pt E visit 2	19-05-17	

Game	Instruction related to set up	Instruction related to play
Knee Bends	0	2 - technique
Leg Abductions	0	0
Sideways Walking	1 – reminder of no hand support	4 - direction 2 - speed
One Leg Stand	1 – foot position	0
Knee bends Coming up onto toes "try to keep your heels down"		

"you came up too fast that one"

Pt26: "it was ok once I got everything sorted"

Leg abductions

Difficult to calibrate; one chair taken away

Sideways walking

First 1, 2 ,3 ,4 direction left/right

2 "Take your time" "Don't rush it"

Very close supervision required

"it wasn't too bad, but I've a problem with my balance you see

One leg stand

"you want to be able to see one foot on each side, try your feet a bit wider"

No further instruction required

Pt F	visit 1 11-05-17	

Game	Instruction related to set up	Instruction related to play
Knee Bends	1 – position on x	0
Leg Abductions	0	1 – query about feedback 2 - technique
Sideways Walking	Game not completed	Game not completed
One Leg Stand		2 – timing 1 - technique

Knee bends

Pt27 - "Are you allowed 2 chairs?" …. "trying to do it with one hand"

Assisted to find position on X - No further instruction

"I tried to start with one hand but then I had to put my hands onto the two chairs"… "I felt myself unsteady"

Leg abductions

"is that only one I've got" when first tick/audio feedback given - informed first 3 are practice and not counted

"try more out to the side rather than in front"

"you are a bit in front again, try more out to the side"

Sideways walking

Tried game but did not complete; close supervision

"am I on the X?"

"I'll stop that one"

One leg stand

Rep 1 "Keeping holding it up"

"Raise your right foot" "Now your left"

"I didn't do too good in that sure I didn't"

Comments: "The right leg seems to be stronger doesn't it"

Pt G visit 1		
Game	Instruction related to set up	Instruction related to play
Knee Bends	1 – position on X 1- foot position 2- use of chair	9- timing 3- technique
Leg Abductions	1- use of chair	1- timing 2- technique 1- orientating L/R on the screen
Sideways Walking	0	3- technique 1- timing
One Leg Stand	1 – use of chairs 1 - calibration	1 – timing 2 – technique/answer questions

Knee bends

right in the middle do you stand?"

"feet hip width apart"

"use the chair if you need to"

Later - "And can I use the chair?"

"do you want me to bend my knees now" during instruction provided prior to game; Researcher advised "wait until the game tells you"

Missed first log; "OK so when it turns red, duck below it"

"So I've to bend my knees, when it turns red I've to get down"

"so you don't need to go yet"

"You say when I've to go"

"you went too early"

"oh I've to follow that?"

Additional instruction given re timing.

"Brown, red, duck"

Restarted game as participant has not followed demo and instruction by researcher and instruction from game.

"So bend my knees now?"

"when the log turns red, now"

"Again?"

"Now"

Try and keep on your heels

You don't need to go just as low actually

Try and keep on your heels, you might need your feet a bit wider.

"Oh you have to keep your feet flat"

"I wasn't picking you up"

"It's getting to know it"

"I'm trying to get down as far as I can"

Leg abductions

"you decide which hand works best for you"

"Now?" during instruction; advised to wait

"I've to kick that?"

Kicking in front; "Out to the side"

"you're kicking a bit in front there"

"It's the other side now"

Pt28 questions "have I to get back in line now?"

"No that's fine just out to the side"

What's happening here"

"You're going in front a bit, to the side"

I'm a wee bit thick as champ sometimes you know"

"I'm only starting to grasp that"

"you have to learn these things"

"We didn't get these games when we were playing football so we didn't"

"It's like taking a penalty kick"

Sideways walking

"You don't turn?"

"What do I do?"

"Step that way"

"You go across. Oh sorry I didn't catch that"

"You just need to go a wee bit further"

"Oh so you daren't touch that at all"

"Try not to run, don't rush it"

"Right I know what you mean now. It's old age you see"

"Some article that"

"this technology"

"our grandchildren would love that. They'd have fun"

One leg stand

"Do I need to hold onto the chairs"

"up to you"

"You don't need to do it yet, listen to the instruction first"

"Then it goes to the other leg?"

"I can go on the 10?"

"I'll maybe get into it a wee bit better the next time, you know. It's just I was trying to get the thing"

Pt G   visit 2

Game	Instruction related to set up	Instruction related to play
Knee Bends	0	1- timing
Leg Abductions	0	3- technique
Sideways Walking	1- position on X	2 – technique 1- timing
One Leg Stand	0	1- timing 2- technique

Knee Bends

Reminded re timing "I can't remember everything"

Leg Abductions

"So if it comes of the left I've to go to the left?"   "Yes, it's like a mirror"

"so, to the side"

"Do I need to strike forward on any of them?"   no, always to the side

"I suppose people buy that system to use at home, do they?"

Sideways Walking

Did not commence game as first wall approached "So, you're stepping this way"

"you're starting a wee bit late, you need to start now really."

"Even if my arm touches will it get it"   "Don't risk it, there is enough room to come on

out"

One Leg Stand

"Down again?" "Wait until.. see the timer"

"You'll need to lift your foot higher. If it is not high enough you will see the splash in the water"

"Not just that high, it should still be comfortable"

Pt G	visit 3	

Game	Instruction related to set up	Instruction related to play
Knee Bends	1- calibration	1- timing 3- technique
Leg Abductions	0	3- technique
Sideways Walking	0	2- technique
One Leg Stand	0	1- timing 1- technique

Knee Bends

Bending during instruction

"what do you want me to do now"   "So when it turns red, bend your knees"

"Stay on your heels" – soreness in back, left knee, right hip – "take feet wider"

Leg Abductions

"To the side"

"You're still in front, it's to the side"

Sideways Walking

Asked for additional instruction – recap: "This is the one where the walls come and you

step the other way"

"Try 5 steps"

One Leg Stand

"Wait for the game"

"so I have to move to the" ; stepped to the side   "no lift it"

It's just getting into my head what I've to do

I'm getting the basis of what you're trying to teach me

I'm comfortable doing them

Pt G visit 4		
Game	Instruction related to set up	Instruction related to play
Knee Bends	0	1 - timing
Leg Abductions	1 - calibration	1- technique
Sideways Walking		2- technique
One Leg Stand	1- calibration	2- technique

Knee Bends

Not following timing

Leg Abductions

Kicking in front

"do you want me to kick out to the side"   "to the side, that's still out in front"

 Sideways Walking

Not stepping far enough – additional instruction

Taking large steps – additional instruction

One Leg Stand

"Any one of the legs?"

Lifted left before the water arose; did not change when water moved to right – additional instruction

Pt G visit 5		
Game	Instruction related to set up	Instruction related to play
Knee Bends	0	1- technique
Leg Abductions	0	3- technique
Sideways Walking	0	0
One Leg Stand	1- use of chair	1- technique

Knee Bends

You don't need to go just as low

Leg Abductions

"More to the side"

"You're a wee bit in front again" x2

Inclination to step to reposition, rather than to change direction of kick.

"it takes very little movement to knock you off"

Sideways Walking: No instruction required

One Leg Stand

"Do I need to hold the chair if I need to?"   "yes, if you need to"

Looked at researcher for further instruction at beginning of game "Lift your left foot"

Hi Sarah,

Here is the email. I then chased the refund and have been looking for a replacement. I think that we won't be able to get a treadmill at this time as the European equivalent is still in development.

Darryl

–

SH

Reply all

From: Virtuix <info=virtuix.com@mail236.atl101.mcdlv.net> on behalf of Virtuix <info@virtuix.com>

Sent: 05 December 2016 17:44

To: Charles, Darryl

Subject: Omni Refund Program - ACTION REQUIRED

Update on shipping and our Omni refund program.

Hello,

When we launched our Omni Kickstarter campaign in June 2013, our dream was to ship Omnis to our passionate VR community all over the world. At that time, the Omni was still in the form of a wooden prototype made in our garage. Over the last three years and with your support, we converted the Omni to a final product that can be produced and shipped in large quantities. The Omni has

become a beautiful and robust device that has all the functionality we deemed essential: accommodating players safely and comfortably up to 285lbs (130kg) and with a variable height of up to 6' 5" (195cm), easy assembly of the product with an updated one-piece base, and fully de-coupled locomotion tracking thanks to integrated sensors in the Omni shoes and ring.

As we focused on product quality and user-friendliness, the Omni transformed from a simple prototype to a complex machine with more than 200 custom parts, several printed circuit boards, an intricate height adjustment mechanism, and a durable form factor that increased the weight of the Omni to 175 pounds (80kg). The Omni's production cost grew to more than three times our initial estimate. Logistics became equally complicated. The Omni ships in a large 48" x 43" box (123cm x 110cm) on a wooden pallet and comes with additional packages for Omni shoes and other accessories. The hardest part of fulfilment is not the initial delivery of the Omni and various accessories (albeit costly and complicated), but complying with international regulations and the global shipping and storing of replacement parts necessary to effectively support a range of geographically diverse customers.

In the last few months we have explored cost effective options to get the Omni distributed and serviced worldwide, which has become increasingly difficult and expensive given the Omni's transformation to a high-end entertainment device. After much internal debate and soul-searching, we have concluded that as a small U.S. based startup, we unfortunately do not have the resources to deliver and service units in every country. Our dream of shipping the Omni to customers all over the world has proven naive and unfeasible. Therefore, we have made the difficult decision to only deliver units to our U.S. home market and issue refunds to our customers outside of the U.S. Internationally, our goal is to work with distributors for commercial markets such as VR arcades and family entertainment centers where logistics and customer support channels are more established.

We regret to inform you that we will not be able to deliver your Omni unit to you

at this time, and that we will offer you a full refund of your pre-order plus an interest amount of 3% per year, compounded monthly. We realize this offers little consolation after you committed financially and emotionally to the Omni for several years. No words can adequately express our appreciation for your generous and long-standing support, without which we would not be here today. We assure you that we have not given up on our dream. We will continue our efforts to expand our distribution markets, and we hope one day to be able to deliver an Omni to you. However, we do not deem it appropriate to hold on to your funds until that time. Along with our refund, please accept our sincere apologies.

To process your refund including interest, we require the email address that is linked to your PayPal account (PayPal is currently the only way we can refund). **Please reply to this message with your PayPal account's email address.** We will then process your refund right away. Because we have a long list to work through, the refund process will take several weeks to complete. Please keep in mind that we may not be able to get back to you for a while should you have any questions.

Our process from Kickstarter campaign to delivering a hardware product has been very humbling. At the start of any journey it's not always exactly clear where you might end up. We'd like to thank you for embarking on this journey with us and for all your support along the way. We are working hard to bring the Omni to your country, and we hope to see you again in the future.

Best regards,

The Virtuix Team