The Use of Interactive Game Technology to Improve the Physical Health of the Elderly: A Serious Game Approach to Reduce the Risk of Falling in Older People

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Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text. I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

The elderly population is growing dramatically both in Australia and globally. With age, the human body undergoes a series of changes that can lead to decline in mental and physical health. Decline in motor functions increases the risk of developing health problems such as postural instability, balance disorders or simply having a fall. Falling is the main cause of disability and fatality among the elderly. Statistics show that one in three older adults might experience a fall every year. This could be prevented with regular exercise. Exercises with a walking component have proven to reduce falls by 40%. However, compliance with physical activity is often poor due to the mode of delivery, which is often unattractive. One approach that might help alleviate this is the use of commercial video games to engage the elderly in physical exercise. However, this practice may have undesirable results as such games are not designed to provide therapeutic support for the elderly but instead to entertain a much younger audience.

This thesis aims to solve the above problem through the use of interactive game technology by testing that optimal results for the health of the elderly come from the combination of three elements:

- the integration of a formal method to assess progress towards and the achievement of the desired health outcomes,
- inclusion of meaningful tasks aligned with the specific health objectives
- an appropriate game design through the use of user-centred design methodologies.

Firstly, literature in the area of video games with health purposes for the elderly is reviewed to develop a clear understanding of the health issues and the research opportunities in the area. Secondly, a series of game prototypes is built and tested to investigate whether off-the-shelf game technology can be used to reliably perform a clinical test for fall risk assessment. Then a game is developed that aims to reduce the risk of falling by training a set of specific cognitive and physical functions that have been shown to be associated with falling. This prototype, known as the *StepKinnection* game, integrates the concept of an appropriate game design for the elderly, inclusion of meaningful tasks and the collection of stepping performance data. Thirdly, a series

of studies on independent-living people aged 65 years and over are conducted. These studies confirmed the ability to reliably perform a clinical test using off-the-shelf game technology, the acceptance and ease of use of the *StepKinnection* game, and the potential of *StepKinnection* to reduce the risk of falling in the elderly.

Finally, an analytical framework is developed for designing interactive games with health purposes for the elderly. This framework aims to assist the development of games aligned to particular health outcomes. This framework emphasises the importance of aligning the game goals to the expected health outcomes as well as the continuous assessment of progress and effectiveness.

Publications Supporting this Thesis

The following is a list of accepted refereed publications resulting from this thesis.

Journals

1. **Garcia, Jaime A**, Karla Felix Navarro, Daniel Schoene, Stuart T Smith, and Yusuf Pisan (2012), "Exergames for the elderly: Towards an embedded kinect-based clinical test of falls risk." *Stud Health Technol Inform*, 178, 51-7.

Conferences

1. **Garcia, Jaime A** and Karla Felix Navarro (2015), "Step Kinnection: A Fall Prevention Game Mindfully Designed for the Elderly." In *Australia's premier digital health, health informatics and e-health conference and expo, HIC2015*, HISA.

2. **Garcia, Jaime A**, Yusuf Pisan, Chek Tien Tan, and Karla Felix Navarro (2014), "Assessing the kinect's capabilities to perform a time-based clinical test for fall risk assessment in older people." In *Entertainment Computing - ICEC 2014*, 100-107, Springer.

3. **Garcia, Jaime A**, Yusuf Pisan, Chek Tien Tan, and Karla Felix Navarro (2014), "Step Kinnection: a hybrid clinical test for fall risk assessment in older adults." In *CHI'14 Extended Abstracts on Human Factors in Computing Systems*, 471-474, ACM.

4. **Garcia, Jaime A** and Karla Felix Navarro (2014) "The Mobile RehApp^{TM}: an AR-based mobile game for ankle sprain rehabilitation." In *3rd International Conference on Serious Games and Applications for Health, SeGAH 2014*, IEEE.

5. Pisan, Yusuf, **Jaime A Garcia**, and Karla Felix Navarro (2013), "Improving lives: using microsoft kinect to predict the loss of balance for elderly users under cognitive load." In *Proceedings of The 9th Australasian Conference on Interactive Entertainment: Matters of Life and Death* , 29, ACM.

6. Felix Navarro, Karla, Elaine Lawrence, **Jaime A Garcia**, and Christian Sax (2011), "A dynamic and customisable layered serious game design framework for improving the physical and mental health of the aged and the infirm." In *The Third International Conference on eHealth, Telemedicine and Social Medicine (eTELEMED 2011)*, 140-145.

7. Lawrence, Elaine, Karla Felix Navarro, **Jaime A Garcia**, and Christian Sax (2011), "Towards building health systems." In *ICONS 2011, The Sixth International Conference on Systems*, 109-114.

8. **Garcia, Jaime A.**, Karla Felix Navarro, and Elaine Lawrence (2011), "Serious games to improve the physical health of the elderly: A categorization scheme." In *CENTRIC 2011, The Fourth International Conference on Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services*, 64-71.

9. **Garcia, Jaime A** , Elaine Lawrence, Karla Felix Navarro, and Christian Sax (2011), "Heuristic evaluation for interactive games within elderly users." In *eTELEMED 2011, The Third International Conference on eHealth, Telemedicine, and Social Medicine*, 130-133.

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Chapter 1

Introduction

1.1 Introduction

This chapter presents an overview of the research and sets out the research questions along with the research justification and significance. The research rationale used for accomplishing the research objectives is also presented. Finally, the structure of the thesis is described at the end of the chapter.

1.2 Overview and Research Questions

The elderly population, defined as people aged 65 years and over, is increasing dramatically in both Australia and worldwide. As an example, in Australia the elderly population (65+ years old) increased by 94,800 people between June 2009 and June 2010, a 3.3% increase. In the last two decades the elderly population increased from 11.8% to 14.7% in Australia (Australian Bureau of Statistics, 2014).

These increases were also reflected in a 6.1% increase in people aged over 85 years and a 18.2% increase in people aged over 100 years. For that reason, the need to support this increasing population has become a concern for governments and health providers around the world. With increasing age there is a progressive decline in physical function leading to problems such as postural instability and falls (Stuck et al., 1999). Falls are associated with increased mortality, disability, fractures and fear of falling (Aschkenasy and Rothenhaus, 2006; Zijlstra et al., 2007a). About one third of community-dwelling older people have falls at least once every year, with many of them experiencing multiple falls (Blake et al., 1988; Campbell et al., 1990). Stepping is often the last resort in order to avoid a fall. Physical exercise has been shown to be the most effective intervention to improve balance, stepping behaviour and reduce fall risk in older people (Gillespie et al., 2009;

Howe et al., 2011; Sherrington et al., 2008). In fact, relatively strenuous exercise programs, without walking, could reduce the risk of falling by 40% (Barnett et al., 2003).

However, compliance with exercise interventions has been often poor, partly due to the mode of delivery of these programs as they are often perceived as boring and not motivating (Schneider et al., 2003). The use of video games in physical training and therapy has shown a positive impact on delivering exercise programs with higher levels of enjoyment and motivation for the elderly (Mubin et al., 2008; Poels et al., 2007; Sugarman et al., 2009). However, there are some negative impacts which are inherent to the use of video games due to the limitation of available commercial video games which have not been designed for the purpose of providing physiotherapy support for the elderly (Neufeldt, 2009; Ijsselsteijn et al., 2007). Current research projects seem to have an increased awareness of the needs of elderly users and limitations in gaming design for health purposes by keeping in mind the concept of accessibility (Kalapanidas et al., 2009; Nap et al., 2008). Guidelines and user-centred design methodologies showed favourable results in the area of games for health among elderly users (Abeele and Rompaey, 2006; Gamberini et al., 2006; Väätänen and Leikas, 2009).

Nevertheless, there are two main points that still require attention and further research. The first one is the requirement for special games to be mindfully designed for the elderly and aligned to specific health goals. The second area is the lack of built-in mechanisms in the game to clinically assess the effectiveness of the intervention (Garcia et al., 2011a). The research objective of this work is to investigate the feasibility of using video games as an effective tool for improving the physical and mental health of the elderly in order to prevent falls. This project also aims to assist other researchers and professionals in the game industry by providing an analytical framework for gaming design with specific health purposes to suit the elderly. The justification for this research is both economic and social imperatives such as assisting government initiatives towards building nationally consistent care systems to support the older population.

This work describes the evolution and validation of the *StepKinnection* system as a proof-of-concept example of an interactive game that was mindfully designed for the elderly by incorporating special age-related features, meaningful tasks aligned to the expected health outcomes and a tool to reliably assess the progress of the players. As a result of this work, a game design framework for the elderly was developed to guide other researchers and the game industry in this field.

1.3 Hypotheses

The issues that were identified from the literature review of the following: serious games for health, games for stroke rehabilitation, games for balance training and fall prevention, user-centred design methodologies and evaluation, guidelines for designing systems for older adults, clinical tests for fall risk assessment; led to refinement of the following research hypotheses:

- **H1.** that off-the-shelf game technology can be used to reliably perform a clinical test for fall risk assessment
- **H2.** that the collection of clinical data (such as stepping performance and motor inhibition) during gameplay can be used as a reliable indicator to determine health improvements
- **H3.** that a game mindfully designed for the elderly, with specific health alignments and an embedded health assessment tool can significantly reduce the risk of falling for the aged cohort

1.4 Research Purpose and Significance

According to recent studies, both Australia and the entire world are dealing with a dramatic increase of the aged population. As an example, the elderly population in Australia (65+ years) is expected to increase from 2.5 million people in 2003 to 5.7 million in 2031 (Hugo, 2007). This could be considered a crisis, if the problem is not addressed effectively and in a timely fashion. Therefore governments have led a move to encourage and support older citizens. In Australia, for instance, the Commonwealth is taking full policy and funding responsibility for aged care in most States, allowing for the building of a nationally consistent aged care system to enable people to seamlessly move from basic help at home through to residential care as their care needs change, assisted through improvements to aged care information and assessment services (Council of Australian Governments, 2014).

The use of interactive technologies such as video games has shown a positive impact in health outcomes for the elderly (Hanneton and Varenne, 2009). Research has been applied to find feasible methods to encourage and engage seniors with the use of these games. For instance, the use of Nintendo Wii has shown positive results in therapies for balance disorders and post-stroke rehabilitation (Deutsch et al., 2009; Sugarman et al., 2009). However, recent studies also state that these practices could result in undesirable consequences, even negative impacts, related to the usability of the video games (Neufeldt, 2009). The use of video games with health purposes for the elderly is a relatively new research area so it is important to contribute to the body of knowledge to ensure that the health objectives are achieved and the elderly perceive the benefits. The ultimate hope is that this approach will also improve the well-being and quality of life of the elderly as well as assist all the stakeholders in aged care.

The specific objectives of this research are:

- to study the academic literature to develop an understanding of the current status of this area and identify the issues that have not yet been addressed
- to understand the needs, preferences, capabilities and limitations of the elderly
- to investigate formal methods to clinically assess and validate the risk of falling in the elderly
- to utilise off-the-shelf gaming technology such as game consoles, remote controllers and input devices to illustrate a proof-of-concept as accurately as possible through prototyping, for instance:
  - Nintendo Wii Remote Controllers (Wiimotes) and Balance Board,
  - Microsoft Xbox 360 and Kinect Sensor Bar,
  - Microsoft Kinect SDK with Visual C#,
  - OpenNI Framework with C++,
  - Unity3D.
- to develop a fully functioning interactive video game prototype addressing the requirements found in the literature
- to verify the validity and responsiveness of the prototype
- to develop a generic analytical framework for designing interactive games with health purposes for the elderly.

1.5 Research Methodology

This research work was undertaken in the following series of steps:

- Phase 1: Literature review
  - Examination of the literature in a series of specific areas: guidelines for designing systems for older adults, user-centred design methodologies and evaluation, serious games, games for rehabilitation and games for balance training and falls prevention.
- Phase 2: Preliminary study on appropriate game design for the elderly

- Evaluation of several commercial balance games found in the literature, in order to identify the key usability aspects that must be taken into account when designing games for the elderly.

- Phase 3: Feasibility of performing a clinical test with off-the-shelf technology
  - Examination of the literature in clinical methods to assess the risk of falling in older adults.
  - Exploration of the existing game technology and game development tools.
  - Identification of requirements for performing a clinical test with off-the-shelf game technology.
  - Examination of a variety of clinical tests for balance assessment based on the suitability for the development of a game-like prototype.
  - Development of an initial prototype for balance assessment aligned to a clinical test.
- Phase 4: Determining the concurrent validity of the developed clinical assessment tool
  - Conduct of experiments to determine whether the developed clinical assessment tool can reliably assess the risk of falling in older people.
- Phase 5: Development of a game for the elderly that combines appropriate age-related features and a clinical assessment tool.
  - Development of a game with special age-related features based upon design considerations found in the literature and user-centred design approaches to gather user preferences and requirements.
  - Integration of mechanisms to collect clinical data during gameplay in order to assess user progress on an ongoing basis.
- Phase 6: Trials with the elderly to verify the effectiveness of the developed game
  - Execution of focus groups to assess the usability of the system.
  - Execution of a three month intervention feasibility study to determine whether the game can improve physical and cognitive functions associated with falling.
- Phase 7: Development of a game design framework for the elderly
  - Development of a generic gaming design framework with health purposes for older adults.
  - Analysis of results and conclusions.

1.6 Key Contributions

The key contributions of this research are:

- A comprehensive literature review of the emerging area of video games with health purposes for the elderly, including the area of post-stroke rehabilitation, fall detection and prevention, and clinical procedures to assess the risk of falling to ensure a comprehensive knowledge of the current issues and research opportunities in this field.
- The development and validation of a hybrid clinical test for fall risk assessment to illustrate the potential and applicability of utilising off-the-shelf game technology to collect clinical measures in a cost-effective and reliable manner.
- The *StepKinnection* Game - A Fall Prevention Game for the Elderly
- The development of an analytical game design framework to assist in the development of serious games with specific health outcomes for the elderly.

1.7 Thesis Structure

Chapter 1 introduces the study. Hypotheses, research questions and objectives are set out along with the justification, significance and key contributions of this work. Also, the research rationale that was followed to test the hypotheses is set out. Finally, the thesis chapter structure is presented.

Chapter 2 and **Chapter 3** establish the background to the thesis. Firstly, the problem of falling in the elderly is introduced as this health issue provides the underpinning for the research. Epidemiology and consequences of falling in the elderly community are presented. Then, the author discusses a series of risk factors that were found relevant in the literature followed by a discussion about the strategies to prevent falls in the elderly. Secondly, a comprehensive review is conducted giving special attention to research that aimed to improve the physical and mental health of the elderly population through the use of video games. The researcher also presents a categorisation scheme that focuses on the use of video games with health purposes for the elderly. This work aims to extend a previous categorisation in the area of video games for health. This review was crucial to identify the research gaps and opportunities in the field. One of the most relevant findings is that the majority of the research focused on assisting the rehabilitation process of older people after suffering a stroke. Also, most of the systems reviewed were developed with the purpose of either exercising or rehabilitating physical functions in the upper limbs. This highlighted the need for further research in the area of fall prevention through rehabilitation and training of lower limbs.

Chapter 4 presents a preliminary study to determine whether a set of commercial balance games widely used in the literature are appropriate or not for the elderly. Six health experts from both the traditional and alternative sectors participated in this evaluation. Their insights were vital to identify the key design aspects that needed to be addressed in order to make these games suitable for the elderly.

Chapter 5 describes the building of a hybrid clinical test for fall risk assessment using off-the-shelf game technology. This study aims to determine the feasibility of implementing a descriptive clinical test to assess the risk of falling in older people through the use of off-the-shelf game technology. Firstly, a literature review in the area of clinical testing for fall risk assessment is conducted. Then, selection criteria are developed based upon the technical advantages and limitations of the technology. The Choice Stepping Reaction Time (CSRT) task is then selected as it can reliably discriminate between fallers and non-fallers, and predict falls in the elderly. The design considerations are described along with the incorporation of complementary clinical measures in order to make this hybrid test a more descriptive and meaningful assessment tool.

Chapter 6 presents the results of a series of experiments to determine the concurrent validity of the developed clinical test with a well-established response time device, using a sample of 10 healthy people. This assessment is conducted in two parts. Firstly, participants are asked to use the developed system and the validated response time device simultaneously in order to determine the agreement of the measurements taken by these platforms. Then participants are asked to use both systems in a randomised order to determine the reliability and repeatability of the chosen clinical test. Statistical analyses show high correlation between the two systems implying that the hybrid clinical test developed by the researcher is reliable and potentially useful in the clinical setting.

Chapter 7 comprises the description, design, building and testing of the *StepKinnection* game, whose key features include, but are not limited to, an appropriate game design to suit the capabilities of the elderly and the ability to collect clinical measures during gameplay. The combination of these two aspects was crucial in order to increase the levels of motivation and adherence towards physical exercise, and to determine the effectiveness of the intervention in an unobtrusive but systematic manner. Usability studies were also conducted in order to identify the preferences, needs and limitations of the target audience. These studies were crucial to identify the hidden usability issues in the early prototypes of the system.

Chapter 8 presents the result of a three month feasibility study. A sample of 10 independent-living older adults was recruited. This study aimed to determine the acceptance of the *StepKinnection* game, whether this system could potentially improve the physical and cognitive functions that were found associated with falling, and the accuracy of the stepping performance data collected during gameplay, in order to determine whether this is a reliable indicator for health improvements. Qualitative data regarding the usability of the system was collected through the use of several questionnaires and interviews. An assessment protocol was designed in order to evaluate changes in functions such as gait speed, dynamic balance, stepping performance, processing speed, static balance and leg strength and endurance. This assessment was conducted in a systematic manner on a monthly basis throughout the study. The results indicate that participants showed significant and consistent improvements on all the dimensions described above.

Chapter 9 describes the development and components of the proposed analytical framework for game design for the elderly. This chapter also includes the research conclusions and outcomes, future research opportunities and challenges, and potential directions for the project.

1.8 Conclusion

This chapter presents the foundations for the research, including its significance and importance, followed by the research questions, hypotheses and research objectives. The methodology used for accomplishing the research objectives was presented. The following chapter presents the literature review, which is essential for the grounding of this work. It covers the evolution of the area of video games for health for the elderly along with a categorisation scheme of relevant work found in the literature.

Chapter 2

Falls in the Elderly Population: An Overview

2.1 Introduction

This chapter introduces the problem of falling in the elderly community. Firstly, the epidemiology and consequences of falling are presented. Then, a series of relevant risk factors found in the literature are discussed. Finally, strategies to prevent falls in the elderly are introduced.

As stated in Chapter 1, one of the main objectives of this work is to demonstrate the use of video game technology to improve the physical health of the elderly, more specifically, to reduce the risk of falling. The research has the potential to reduce the costs of health care and hospitalisation associated with fall-related injuries and the overall quality of life of the elderly. Therefore, it is imperative to understand how this health issue affects the aged community and the strategies that can be taken to alleviate this problem.

The next section in this chapter discusses the epidemiology and consequences of falling in the elderly.

2.2 Epidemiology and Consequences

As a consequence of ageing, the human body undergoes a series of changes that could lead to the decline of mental and motor capabilities. Furthermore, health problems such as postural instability, balance disorders and stroke are common at this age and are considered the main cause of disability among the elderly (Lloyd-Jones et al., 2010).

Falls are the main cause of injury and death in the elderly (Kannus et al., 2005). This is a major problem not only because it negatively affects the quality of life of the elderly, but also because it has a significant impact on public health systems. Recent studies show that 30% of the population aged 65+ experiences at least one fall every year (Masud and Morris, 2001). This rate is even higher for people with special conditions who require the assistance of a care giver to perform daily activities (Rubenstein, 2006). In fact, 50% of the people classified as recurrent fallers may experience two or more falls every year (Stalenhoef et al., 1997). Work done by Masud et al. (2001) proved that the risk of falling increases proportionally as people age. This is primarily due to a series of changes that the human body undergoes affecting several sensorimotor and cognitive functions (Maki and McIlroy, 2006).

In most cases, an individual might suffer numerous physical injuries as a consequence of falling. This includes bruises, cuts, sprains, fractures and even brain damage (Lord et al., 2007). Traumatic Brain Injury (TBI) is one of the most common injuries which often requires hospitalisation and may result in death for 13% of the cases.

Fall-related hospitalisations in older people often result in the loss of independence (Australian Institute of Health and others, 2012). Due to the functional declines suffered after falling, an individual might lose the ability to perform daily activities such as showering, dressing and cooking. In some cases, residential changes are required as the need for continuous care becomes imperative (Kiel et al., 1991).

From the psychological point of view, another major consequence that fallers experience is the development of a constant fear of falling. According to Aoyagi et al. (1998), 92% of the people who experienced a fall developed this condition. This leads to a permanent sense of restriction which limits the individual re-engaging in activities that might now be perceived as hazardous (Wijlhuizen et al., 2007). This becomes a vicious cycle which results in a continuous decrease of activity, loss of confidence and further development of the fear (Murphy et al., 2002).

For that reason, it is imperative to take preventive actions by implementing mechanisms that not only can detect the risk of falling in a timely fashion but can also reduce the risk of falling in an effective manner.

The next section presents a series of factors that have been found to be associated with falling in the elderly.

2.3 Risk Factors for Falling

2.3.1 Declines in Physical Health

2.3.1.1 Disturbed Balance and Coordination

Balance is often defined as the ability to maintain the line of gravity of a body within the base of support. In the human body, the ability to maintain a balanced position requires the integration of multiple sensory systems such as the vestibular, somatosensory and visual systems. According to Lord et al. (1991), the somatosensory system is the most important mechanism controlling standing balance in the elderly. This system uses senses of proprioception and kinesthesia of joints; information from skin and joints such as pressure and vibrations among others in order to detect changes of spatial orientation with respect to the base of support. Consequently, the disturbance of any of these mechanisms may result in losing stability and consequently falling (Shumway-Cook and Woollacott, 2007). Age-related changes may affect the sensory systems resulting in poor balance and an increased risk of falling.

2.3.1.2 Gait Disorders

Normal walking or gait requires an appropriate integration and functioning of several dimensions such as strength, sensation and coordination. Declines in the nervous and musculoskeletal systems may result in abnormalities in the ability to walk. According to recent studies (Deandrea et al., 2010; Lord et al., 2007), deficits in gait and balance are highly associated with falling in the elderly. Slow gait speed has been shown to be a good indicator and predictor of falls and fatality in older people living in the community (Fried et al., 2001; Kenny et al., 2011).

2.3.1.3 Poor Vision

Multiple sensory systems such as hearing and vision often deteriorate as people age (Shaffer and Harrison, 2007). Disturbed vision affects the ability to perceive depth and other functions related to sensing contrast. Consequently, an individual with disturbed vision might find it difficult to detect potential hazards in places with inappropriate lighting conditions, which increases the likelihood of tripping over obstacles or simply falling (Lord et al., 2007).

2.3.1.4 Muscle Weakness

Muscle strength is an important factor in the ability to maintain a balanced position. For example, rising from a chair and walking require power and muscle strength. However, with ageing there are significant declines in muscle mass and power (Young and Skelton, 1994). The lack of activity and little physical exercise can aggravate the situation resulting in further weakening of muscles, loss of joint position sense and loss of balance. All these factors are associated with an increased risk of falling in the elderly (Lord et al., 2007).

2.3.1.5 Poor Stepping

Stepping can be described as the ability that an individual has to change their base of support in relation to their centre of mass. This skill is essential to avoid obstacles and overcome perturbations where the individual loses their base of support, for example when slipping or tripping over objects (Shumway-Cook and Woollacott, 2007). Being able to respond appropriately to these potential threats can prevent an individual from falling.

Evidence demonstrates that being able to react given a sudden perturbation, or just to initiate an anticipated protective step, can reduce the impact of a fall on the pelvis by 22% (Feldman and Robinovitch, 2007). However, as people age, this ability deteriorates resulting in the inability to take reactive steps (Maki and McIlroy, 2006). Consequently, this increases the risk of falling as the individual is no longer able to recover from a postural perturbation (Maki and McIlroy, 1996)

2.3.2 Declines in Mental Health

2.3.2.1 Depression

Depression has been shown to be an important factor for falling in the elderly. Suffering a depression could increase by 50% the risk of having a fall (Kao et al., 2012). In fact, one in three older adults who reported depressive symptoms has also reported an incident related to falling (Kvelde et al., 2013). Research shows that depressive symptoms and the use of antidepressants can influence poorer balance as well as cognitive functioning, which at the same time increases the risk of falls in the elderly (Kvelde et al., 2010).

2.3.2.2 Deficits in Selective Attention

Inhibition or selective attention is defined as the ability to react given a relevant stimulus and suppress a dominant behavioural response. This ability is one of the multiple processes that decline with the ageing process (Liu et al., 2014a). One of the main consequences of poor selective attention is the inability to react adequately to sudden changes in the environment that put the individual at risk (Nagamatsu et al., 2013). For that reason, inhibition has been widely used as a descriptor and discriminator of potential fallers and non-fallers (Sparto et al., 2013).

2.3.2.3 Poor Task-Switching Abilities

Task switching is defined as the ability to change the allocation of attention in order to switch between different tasks. This ability has been shown to be an important factor in discriminating between fallers and non-fallers (Hsu et al., 2012) and this ability tends to decline as people age (Liu et al., 2014a). Poor task-switching affects the ability to perform cognitively demanding tasks which results in slower responses in individuals with higher risk of falling (Maki et al., 2001).

2.3.2.4 Reduced Cognitive Processing Speed

With ageing, there are declines in the ability to process information (Welford, 1977). This affects the ability to accomplish cognitively demanding tasks (Diggles-Buckles and Vercruyssen, 1990). This decline can be observed when an individual requires a longer period of time to complete a relatively complex task (Welford, 1977). Delayed cognitive processing affects directly the ability to physically respond, reducing gait speed and consequently increasing the risk of falling (Welmer et al., 2014). Research has shown that there is a strong association between reduced processing speed and falling (Martin et al., 2013).

2.3.2.5 Deficient Visuo-spatial Skills

This dimension refers to the ability to navigate through continuously changing spaces as well as the ability to identify oneself in space. For that reason this ability is essential for avoiding hazards such as obstacles and uneven surfaces. Before executing a corrective action, an individual must process information that has been visually perceived (Alichniewicz et al., 2012). For that reason, a diminished working memory might affect the ability to perceive environmental changes affecting the capacity to take a corrective step and subsequently avoid a fall (Alichniewicz et al., 2012).

2.4 Prevention of Falls

Although falls are unpredictable, it is important to take action to reduce the likelihood of suffering falls. Physical activity and structured exercise have been shown to reduce the risk of developing several chronic diseases (Chodzko-Zajko et al., 2009). For the purpose of preventing falls, exercising has also been shown to be the most effective intervention (Gillespie et al., 2009). Programs targeting the lower limbs have been demonstrated to improve several dimensions associated with falling such as gait speed and balance coordination (Howe et al., 2011). In fact, interventions that did not include a walking component but involved balance exercises proved to reduce the risk of falling by 42% (Sherrington et al., 2008).

However, the effectiveness of such exercise interventions also relies on the level of exertion as well as intensity and duration of the activity that is being executed. For instance in the work done by Sherrington et al. (2008), it is suggested that exercises should challenge balance through the inclusion of tasks that involve moving the centre of mass, reducing the base of support and reducing the use of upper limbs to maintain a balanced position (Sherrington et al., 2008). Howe et al. (2011) suggested that dynamic balance exercises should be conducted three times a week for 15 minutes in order to be effective (Thomas and Magal, 2014).

Research by Yau et al. (2013) showed strength and power exercises were a good strategy to counterbalance the loss of muscle mass suffered as a consequence of ageing. Muscle mass decreases with age affecting muscle strength and power which subsequently affects postural stability (Scott et al., 2014). Hence, training resistance can help to improve muscle strength (Liu and Latham, 2009), and conducting exercises at high speed with low intensity can improve muscular power (Tschopp et al., 2011).

Research by Zijlstra et al. (2007b), found that Tai Chi was beneficial not only as a form of physical exercise but also as a means to reduce the fear of falling, which is one of the risk factors that affects an individual's ability to re-engage with physical activity after suffering a fall. By suppressing this fear, an individual regains balance confidence and reduces the likelihood of falling again (Büla et al., 2010). More importantly, strength training and aerobic exercises have also been reported to improve brain functioning (Gregory et al., 2012) and to reduce depressive symptoms (Bridle et al., 2012), both major risk factors for falling in the elderly.

Finally, in the work done by Draganski and May (2008) and Bhatt et al. (2012), stepping exercises involving a series of induced slips were shown to be an effective method for reducing falls in a laboratory setting. Similarly, in the work done by Studenski et al.(2010), step training showed improvements in dynamic balance and balance confidence, both associated with falling. Stepping requires the integration of several dimensions such as sensory, central and neuromuscular systems. By taking a short proactive or reactive step an individual can increase their base of support regaining balance. Hence, training this ability is important because it could be the last resort to prevent a fall from happening.

2.5 Conclusion

This chapter has provided an overview of the problem of falling in the elderly community, a problem that affects one in three older adults every year which may result in disastrous consequences such as fractures, brain injuries and even death. A series of risk factors and preventive strategies have been presented in order to develop a better understanding of this issue. Research has demonstrated that physical exercise can improve several physical and cognitive functions that are associated with falling in the elderly and subsequently reduce this risk. More importantly, stepping is a strategy that has been shown to be effective in both the assessment and prevention of falls in the elderly. Stepping is used in Chapter 5 and 7 for the design and development of a fall risk assessment tool and a balance training game for the elderly.

The following chapter reviews video games with health purposes for the elderly, with special attention to research projects that aimed to assess as well as reduce the risk of falling in the elderly.

Chapter 3

The Use of Video Games to Promote Health in the Elderly

3.1 Introduction

This chapter provides an overview of video games with health purposes for the elderly. It reviews relevant research projects for stroke rehabilitation and for fall prevention for the elderly. Special attention was given to research where user-centred design methodologies were applied in order to accommodate the needs and capabilities of this audience. A classification of the most relevant work in this area is also provided along with a brief description of the platform, technology required and user-centred design principles applied.

In Chapter 2, epidemiology and consequences of falling in the elderly population were discussed. Then, the most relevant risk factors and strategies to prevent falls in the elderly were described. Chapter 2 also highlighted that physical exercise has been shown to be the most effective intervention to reduce the risk of falling in the elderly community. Exercise programs normally require the user to perform repetitive activities in order to improve muscle strength and power.

However, recent studies have shown that this practice is often perceived as boring for patients affecting their motivation and commitment to the program (Burke et al., 2009a).

Video games have become popular among the aged population during the last decade, especially since the release of the Nintendo Wii and the Microsoft Kinect. These systems introduced a revolutionary way of interaction where players are now required to perform movements in order to interact with such games (Theng et al., 2010). This natural way of interacting has the potential to deliver training programs since such movements can be perceived as a form of exercise.

Specialists and researchers have applied efforts to include interactive games in health treatments looking for a suitable method to keep their patients engaged. A significant number of studies have been conducted showing a positive impact among elderly users who increased their motivation and adherence to rehabilitation through the use of interactive games (Sugarman et al., 2009).

However, this could also result in undesirable consequences or poor outcomes for the elderly when the age-related changes are not considered throughout the game design process (Hanneton and Varenne, 2009; Neufeldt, 2009). Usability issues have been found mainly because these games are not designed for this audience leading to negative impacts for the elderly (Flores et al., 2008; Ijsselsteijn et al., 2007).

As the main interest of this work is the use of video games as an effective tool for improving the health of the elderly, one of the main goals of this research is to identify how the proper design could guarantee optimal health results.

This chapter provides a snapshot of the current status in the area through a literature review and categorisation of relevant work. Therefore, special attention is given to research projects that presented tested working prototypes and that incorporated user-centred design for the elderly.

In the next section the author introduces the term video game and describes the structure of a game.

3.2 Video Games

Video games are commonly defined as entertainment electronic systems where players interact with an user interface and receive visual feedback on a video device (or display) as well as auditory feedback through speakers or a headset (Definition: Video game, 2015).

These games often involve a mental or physical contest where the player is expected to achieve a goal (or objective) within the game itself. One of the main components is the input device or game controller. This is primarily used by the player to manipulate objects within the game.

According to Fullerton (2008), the structure of a game can be defined by the following components:

3.2.1 Players - *"You"*

This is defined as the person (or group of people) that voluntarily participates and consumes the entertainment offered by the video game. When a player joins or starts a game, they implicitly accept the rules and constraints of a game.

3.2.2 Objectives - *"Your goal"*

This can be described as the goal one must work towards in order to win a game. This is a key element, that can severely affect motivation and engagement. As mentioned above, when playing a game, players adopt a state of mind where reaching the goal becomes a need. However, when a game objective is not clearly defined, players lose interest and the experience loses much of its structure.

3.2.3 Procedures - *"What you can do"*

Procedures are by definition the actions and methods allowed by the rules and that a player can do to achieve the game objectives. These determine the players behaviour within the game.

3.2.4 Rules - *"What you can't do"*

Rules are a key structural element as without them a game would not function. These define game objects, describe principles and limit the player behaviour within the game. When a player agrees to participate in the game experience, he/she must respect the authority of the rules. Not following the rules implies that the player is not playing the game.

3.2.5 Resources - *"What you can use"*

Resources are known as the items or objects that can assist the player to achieve the goal. These are made valuable because they are often scarce and result of great utility. In some games, these can be even combined to make new items that can be later bought or sold in order to further advance towards the player aims.

3.2.6 Conflict - *"What won't let you reach the goal"*

Conflict can be simply defined as anything in the game what will not not let the player reach the goal directly. As mentioned above, rules and procedures dictate what the player can do in order to achieve the objectives, however, conflict is what the player needs to resolve that prevents him/her from reaching the goal like avoiding obstacles, defeating enemies or avoiding hazards.

3.2.7 Outcome - *"What happens when you reach the goal"*

This refers to the element of uncertainty that players experience on every play. Unlike books or movies, the ending of a gameplay cannot be anticipated. If players were able to predict the outcome of a game before playing, they would not play. This is hence considered a key motivator for gamers. This dimension also refers to the ability to determine whether a player wins or not a game. For instance, in multi-player games, all players can reach the objective of a game at certain point in time, making it crucial to determine who wins in a measurable manner. While rules and constraints dictate what players can and cannot do, this dimension refers to the factors used to find a satisfying resolution to determine which player wins the game.

3.2.8 Challenge - *"What keeps you engaged"*

As mentioned earlier in this section, conflict refers to all the elements that prevent players from reaching the goal of a game directly. This challenges gamers by creating tension as they try to find a solution to the problems that are presented while they play. Players can experience a great sense of achievement when winning a game, or a great sense of frustration when the challenge is greater than their skills. Finding the appropriate balance of challenge is key as is what keeps players engaged with the game.

3.2.9 Story - *"What plays with your emotions"*

Game stories are normally used to engage players in an emotional manner. A story adequately integrated with play can create powerful emotional results due to its narrative qualities, which help players to immerse even more into the gameplay experience. Also, it makes it easier for users to contextualise their choices within the game as they play a role in the story that unfolds through gameplay.

In other words, a game is *"a closed formal system that engages players in a structured conflict and resolves its uncertainty in an unequal outcome"* - Fullerton et al. (2008).

The next section introduces the term serious games and presents an overview of the area of video games with health purposes for the elderly.

3.3 Serious Games for Health

Over the last decade, video games have become popular among different audiences. However such video games have a huge potential as a tool for other purposes. Serious games is a relatively new field that could be described as the use of video games to help users to achieve a specific goal by playing a game (Rego et al., 2010). This concept has been used to develop games in a range of areas such as medicine, defence, education and health (Graafland et al., 2012; McDowell et al., 2006; Göbel et al., 2010).

In 2002, the Serious Games initiative was formed to establish a formal basis for this emerging industry (Serious Games Initiative, 2002). Two years later, the Games for Health project was founded (Games for Health Project, 2004). Its objective was to foster knowledge, and support the community and business development efforts to use games to improve health and health care. As a result of this movement, an annual Games for Health conference is held which covers topics such as exergaming, physical therapy, rehabilitation and training. In 2006, the ElderGames project started (The ElderGames Project, 2006). It was based on the use of entertainment in leisure time as a tool for rehabilitation and prevention of common diseases for the elderly. The project created an interactive-play board that aimed to maintain the cognitive abilities of the elderly through exercises (Gamberini et al., 2009).

In 2008, Sawyer and Smith (2008) presented a categorisation of serious games which establishes a snapshot of the state of this area at that time. The authors presented a general categorisation of games and the application fields as well as further details for each category. Within the range of games for health, they present a classification of existing games grouped by intended audience and purpose.

In 2010, Rego et al. (2010) extended this work presenting a taxonomy that focuses on games for rehabilitation which serve people with declines in motor and cognitive capabilities. They identified a set of criteria for the classification that focused on the following dimensions:

- the purpose of the game, as the game could be intended for cognitive rehabilitation or physical rehabilitation
- the way the user interacts with the game
- the game interface - either two dimensional or three dimensional
- if the game allows more than one simultaneous player
- if the challenge was dynamically adapted based on the patient performance
- if the system enables the patient to know their progress
- progress monitoring capability
- capacity of game portability.

In 2014, Hawley et al. (2014) presented a systematic review that investigates the older adults' perceptions of technologies that aimed to predict, monitor and prevent falls in the elderly. The researchers found that factors related to older adults' attitudes around control, independence and perceived need and requirements for safety were crucial for their motivation towards using such technologies. Also, they highlighted the importance of aspects such as usability, provision of appropriate feedback and cost-effectiveness as essential elements to support these attitudes and perceptions.

This study surveys serious games for health purposes for the elderly and extends previous classifications by presenting a categorisation scheme where the use of games for improving the physical health of the elderly is the focal point. Hence, the existing literature was surveyed focusing on games with this purpose. The inclusion of user-centred design as a key element of this survey was incorporated as a result of previous studies (Felix Navarro et al., 2011; Lawrence et al., 2011) as well as for its importance in existing literature in the area (Kalapanidas et al., 2009; Väätänen and Leikas, 2009; Abeele and Rompaey, 2006).

The following topics were incorporated in this survey:

- games for rehabilitation
- games for balance training and falls prevention
- user-centred design methodologies and evaluation
- guidelines for designing games for older adults
- the use of game technology to assess health outcomes.

It is worth noting that stroke rehabilitation and fall prevention prevail through the literature, as stroke and falls are the most common causes of disability among the elderly (Burke et al., 2009a; Lawrence et al., 2011). The next section sets out the methodology used for this classification and the most relevant findings in terms of usability and gaming design for the elderly.

3.4 Methodology for Game Categorisation

A comprehensive search was conducted in order to gather relevant information for the categorisation. Peer reviewed journal articles sourced from databases such as IEEE, ACM, EBSCO, Elsevier and SpringerLink were reviewed for this survey. The first phase of the search focused on identifying key points for a proper game design for the elderly which included the understanding of the ageing process and changes in the human body and common diseases at this age. Based on findings from this phase, the second phase of this work was oriented to technologies that included the entertainment factor to provide tools for physical and cognitive rehabilitation in patients who suffered stroke and games for fall prevention and balance training in older adults. As this review was of a heterogeneous nature, a concept matrix was created in order to ease the classification of the existing games for improving the physical health of the elderly. For each reviewed project, the following information was registered:

- **Audience:** Due to the focus on games for health and the elderly, one of the goals was to identify if the game was suitable for older adults. This includes design and testing phases with older users and design evaluation post-playing.
- **Goal:** This dimension is related to which area of the human body receives benefits from playing the game. It also aims to show if the game is designed as a training tool or for rehabilitation purposes, and if the main objective was to either improve physical functions or cognitive processes.

- **Interaction:** This dimension is the way the user interacts with the game. Some systems use commercial input devices such as a remote controller, keyboard or mouse whereas others developed their own input devices or ask the user to wear sensors that could be recognised by the platform.
- **Technology:** This includes a brief description of components and techniques that make it possible to run the game.
- **Special age appropriate features:** This refers to enhancements or mechanisms that make the game suitable for the elderly such as adapting the difficulty of the game dynamically.
- **Home-based (yes/no):** Many games are developed to be used at medical or rehabilitation centres, but games played at home have the potential to be more beneficial to users because this reduces the need to travel to rehabilitation centres.
- **Feedback:** This dimension is related to the type of feedback provided. Some games only use images and graphics on the screen to represent user actions (visual) while others emit sounds (audio) or use vibration alerts (haptics) to notify actions to the user.
- **Measurements:** This dimension is related to measurements that can be obtained during or after playing the game and could help specialists to determine improvements through clinical assessment.
- **Progress Records:** Records are game characteristics that record user results such as score or performance.

3.5 Inclusion Criteria for Game Categorisation

Overall, the reviewed literature showed that using games as a tool for rehabilitation and training has a positive outcome for the elderly. It was found that the main cause of frustration is usability issues related to changes in the human body over the years. Therefore, much effort has been applied to create guidelines in order to develop suitable games for this audience (Gamberini et al., 2006).

IJsselsteijn et al. (2007) presented a compilation of age-related changes that must be considered when designing digital games for elderly users. They state that, although each individual differs from others in terms of abilities and experience, the human body normally tends to undergo a series of changes in sensory-perceptual processes, motor abilities and cognitive processes when getting older. For these reasons, the elderly user may not find these games enjoyable or beneficial if the games are not properly designed for the user.

Flores et al. (2008) conducted a search of journals and databases as a methodology to gather information regarding the most important game design principles for post-stroke rehabilitation. The review was focused on finding a set of criteria for two purposes: designing effective therapy for post-stroke patients and entertainment for the elderly. It was found that most of the games for post-stroke rehabilitation did not include enjoyable content for the elderly. Flores et al. (2008) proposed a set of criteria that covered these two factors (Table 3.1).

Table 3.1: Gaming design criteria for stroke rehabilitation programs serving elderly users (Flores et al., 2008)

Criteria for Stroke Rehabilitation	**Criteria for Elderly Entertainment**
• Adaptability to motor skill level • Meaningful tasks • Appropriate feedback • Therapy-Appropriate Range of Motion • Focus diverted from exercise	• Appropriate cognitive challenge • Simple objective/interface • Motivational Feedback • Element of social activity • Appropriateness of genre • Creation of new learning following guidelines of experts • Sensitivity to decreased sensory acuity and slower responses

Based on these guidelines, key points for suitable design for the elderly were identified and used for classification. Thus, the concept matrix was used as a tool for filtering data and identifying the most relevant work in the area. The inclusion criteria used for this taxonomy are set out in Table 3.2.

Table 3.2: Criteria for including games in the categorisation

Parameter	**Value**
Audience	Elderly
Goal	Improve physical health (upper limbs, lower limbs, balance)
Interaction	Any of these: Shifting weight, Wearing Sensor (Image Recognition), Stepping on Surfaces, Touching Surfaces, and Grasping Objects.
Technology	Any of these: commercial platforms (Wii, PS, Xbox, Kinect), PC Games, Robot, Balance Board, commercial remote controller, Camera / WebCam, Dancing Pad, MultiTouch Tabletop.
Special Age Appropriate Features	Large visual instructions, audio assistance, mechanisms to dynamically adapt challenge, monitored by the Occupation Therapist .
Home-based	Preferable
Feedback	Any of these: Visual, Haptics, Audio
Measurement	Any of these: range of motion, user movements and trajectories, high scores, game results.
Progress Record	Preferable

3.6 Review of Games for Health for the Elderly

This section presents the research projects considered in this review. This survey was initially conducted in mid-2011 and continuously updated up to mid-2014. It reviewed the work developed in the area of serious games for health for the elderly, including a number of studies where commercial games were used as a tool to promote physical exercise, along with several custom-made video games found in the academic literature with the purpose of either training balance, preventing falls, engaging the elderly in physical activity or rehabilitating after having a stroke. Also, developments that aimed to assist the elderly in improving their physical health through the use of game technology were included. However, these were not considered games as such systems did not have any playable content. Instead, these projects use game technologies to either assess balance, assess risk of falling, detect falls, or simply deliver exercises without a game story.

A total of 159 articles were collected. After removing non-relevant items and duplicate entries, a total of 78 articles were relevant for this categorisation, with 38 catalogued as games and the remaining 40 as non-games. Three levels of classification were then utilised for a better presentation of the results. Firstly, articles were categorised by the adopted technological approach, resulting in six main categories: Camera and Webcams, Kinect, Custom-made Pads and Plate Forces, Wearable Sensor, Wii and Others. Secondly, these groups were classified by the purpose of the system, which resulted in nine sub-categories: Balance Assessment, Balance Training, Fall Assessment, Fall Detection, Fall Prevention, Fall Rehabilitation, General Training, Other Assessment and Other Training.

It is worth mentioning that in this classification, “Assessment” refers to the collection of some form of clinical data in order to determine health improvements or diagnose a medical condition. Likewise, “Prevention” and “Therapy” refer to systems that encourage players to perform a physical activity as a means to exercise in order to preclude an ailment, or a repetitive task to recover from an injury respectively.

Finally, the inclusion of playable content as explained in section 3.2, was utilised for the third level of the categorisation, which resulted in two main groups: games and non-games. Table 3.3 summarises the findings with respect to the proposed classifications.

Table 3.3: Summary of the surveyed systems with health purposes for the elderly

Platform	Purpose	No Game	Game
Camera	Balance Assessment	1	
	Fall Assessment	2	
	Fall Detection	2	
	General Training	2	
	Other Training		1
Computer Game	Balance Training		1
	Fall Assessment	1	
Kinect	Balance Training		2
	Fall Assessment	8	
	Fall Detection		1
	Fall Prevention	2	1
	General Training	3	3
	Other Assessment	1	2
Mobile Phone	Other Assessment	1	
Other	Fall Assessment	2	
	General Training		1
Pad	Balance Assessment	1	
	Balance Training		5
	Fall Prevention		3
	Fall Training		1
	General Training		2
PlayStation	Balance Training		1
Robot	General Training		2
SmartTV	Fall Prevention		1
	Other Training	1	
Touch Screen	General Training		1
	Other Training		1
Wearable Sensor	Balance Training		1
	Fall Assessment	4	
	Fall Detection	4	
	Fall Prevention	1	1
	Fall Training		2
	General Training	1	
Wii	Balance Assessment	1	
	Balance Training		3
	Fall Assessment	2	
	Fall Prevention		1
	General Training		1
Total		**40**	**38**

Table 3.4 collects the information of games that used camera-based input devices such as webcams or RGB cameras. Eight articles were reviewed in total, where only one met the selection criteria. Also, 23 Kinect-based platforms were also found and classified in a separate category, where nine were labelled as games and the rest as systems with health purposes for the elderly

Table 3.4: Camera-based systems with health purposes for the elderly

Purpose	**Author**	**Year**	**Game**
Balance Assessment	Wang et al.	2010	N
Fall Assessment	Cardiel et al.	2010	N
	Rueangsirarak et al.	2014	N
Fall Detection	Jiang et al.	2013	N
	Rougier et al.	2011	N
General Training	de Morais and Wickstrom	2011	N
	Rice et al.	2011	N
Other Training	Burke et al.	2009	Y

As showed in Table 3.5, there has been a significant increase in the number of Kinect-based systems that aimed to assist the elderly over the past two years, nevertheless, none met the selection criteria as most of the projects are still in very early stages (Webster and Celik, 2014).

Table 3.5: Kinect-based systems with health purposes for the elderly

Purpose	**Author**	**Year**	**Game**
Balance Training	Hsieh et al.	2013	Y
	Lange et al.	2011	Y
Fall Assessment	Banerjee et al.	2012	N
	Dubois and Charpillet	2014	N
	Ejupi et al.	2014	N
	Garcia et al.	2014	N
	Hassani et al.	2014	N
	Loncomilla et al.	2014	N
	Parajuli et al.	2012	N
	Yeung et al.	2014	N
Fall Detection	Davari et al.	2013	Y
Fall Prevention	Barelle et al.	2014	Y
	Hsieh et al.	2013	N
	Otanasap and Boonbrahm	2014	N
General Training	Gerling et al.	2012	Y
	Hauer et al.	2010	N
	Liu et al.	2014	Y
	Miyosawa et al.	2013	N
	Paredes et al.	2014	N
	Sato et al.	2014	Y
Other Assessment	Dutta and Banerjee	2013	N
	Kayama et al.	2013	Y
	Okamoto et al.	2014	Y

Table 3.6 presents the 11 systems that used pressure-based devices such as dance pads and force plates systems. Although a significant number of games were found in this category, only one was relevant for this survey.

Table 3.6: Pad / Plate force driven systems with health purposes for the elderly

Purpose	**Author**	**Year**	**Game**
Balance Assessment	Walsh et al.	2011	N
Balance Training	Chen et al.	2012	Y
	Lai et al.	2013	Y
	Lamoth	2011	Y
	Pichierri et al.	2012	Y
	Szturm et al.	2011	Y
Fall Prevention	Pichierri et al.	2012	Y
	Schoene et al.	2013	Y
	Smith et al.	2011	Y
Fall Training	Yamada et al.	2011	Y
General Training	Jessen et al.	2014	Y
	Lund and Jessen	2014	Y

In regards to the Nintendo Wii, a total of eight systems were found, where five were categorised as games due to the inclusion of playable content and one met the inclusion criteria (Table 3.7)

Table 3.7: Wii-based systems with health purposes for the elderly

Purpose	**Author**	**Year**	**Game**
Balance Assessment	Jorgensen	2014	N
Balance Training	Billis et al.	2010	Y
	Gerling et al.	2010	Y
	Sugarman et al.	2009	Y
Fall Assessment	Korostelev et al.	2014	N
	Koslucher et al.	2012	N
Fall Prevention	Hardy et al.	2013	Y
General Training	Abeele and De Schutter	2010	Y

As illustrated in Table 3.8, another commonly adopted approach found in the literature are the wearable sensors that can be attached to either the upper and lower limbs. Of the total of 14 articles surveyed, four were in the games category. Two out of the four met the selection criteria and are presented in the next section.

Table 3.8: Wearable sensor systems with health purposes for the elderly

Purpose	**Author**	**Year**	**Game**
Balance Training	Yaothak et al.	2011	Y
Fall Assessment	Brassard et al.	2012	N
	Jiang et al.	2011	N
	King et al.	2010	N
	Tmaura et al.	2013	N
Fall Detection	Bourke et al.	2010	N
	Karel et al.	2010	N
	Lan et al.	2012	N
	Tivatansakul et al.	2012	N
Fall Prevention	Kudoh et al.	2011	N
	Uzor and Baillie	2013	Y
Fall Training	Uzor and Baillie	2014	Y
	Uzor and Baillie	2013	Y
General Training	Wu et al.	2013	N

Finally, the remaining categories of Computer Game, Mobile Phone, PlayStation, Robot, SmartTV and Touch Screen were merged as these did not use any of the commercial interactive game technologies (Table 3.9). A total of 13 platforms were allocated into this group where only two met the selection criteria.

Table 3.9: Non-commercial game technology systems with health purposes for the elderly

Technology	Purpose	Author	Year	Game
PlayStation	Balance Training	Lee and Shin	2013	Y
Robot	General Training	Fasola and Mataric	2010	Y
		Okano et al.	2013	Y
SmartTV	Fall Prevention	Aal et al.	2014	Y
	Other Training	Diaz-Orueta et al.	2014	N
Touch Screen	General Training	Ishihara et al.	2014	Y
	Other Training	Annett et al.	2009	Y
Computer Game	Balance Training	Smith-Ray et al.	2014	Y
	Fall Assessment	Cattelani et al.	2014	N
Mobile Phone	Other Assessment	Oner et al.	2012	N
Other	Fall Assessment	Narayanan et al.	2010	N
		Phillips et al.	2012	N
	General Training	Leinonen et al.	2012	Y

3.7 Categorisation of Surveyed Health Games

This section focuses on providing a review of the games that were found relevant and met the inclusion criteria. This review includes: a brief description of the game(s), the range of technology used in this field, interactions with the games and usability studies as well as relevant results. Much attention was given to working prototypes that followed a user-centred design methodology. Some of the research projects that meet the inclusion criteria are discussed below.

3.7.1 Pad / Plate Force Driven Systems with Health Purposes for the Elderly

3.7.1.1 A Dance MAT Driven System for Stepping Exercises

The work of Smith et al. uses a modified version of the game Dance Dance Revolution (Smith et al., 2009). The main purpose of this game is to provide a tool to train the stepping abilities of the elderly, a common problem experienced by this population. In order to interact with the game, the player must step on a dance pad sensor that has eight arrows. A display on a TV or PC monitor provides step direction instructions to the player by scrolling arrows from the bottom to the top of the screen (see Figure 3.1). The game is adapted for the slower responses of the elderly. Smith et al. (2009) present a design for monitoring the user performance by using mobile technology. This aims to enhance cooperation among patients and therapists by sending information about user performance to the practitioner. Finally, the system is designed to be used at home.

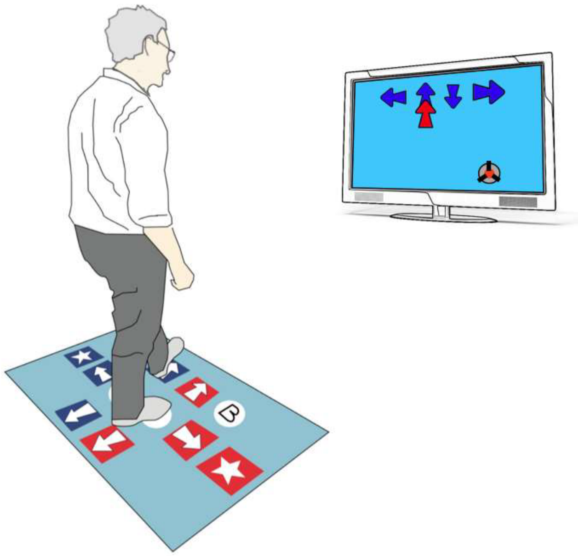


Figure 3.1: Modified version of the Dance Dance Revolution game developed by Smith et al. (2009)

3.7.2 Wearable Sensor Systems with Health Purposes for the Elderly

3.7.2.1 A Kinematic Sensor Driven Game for Balance and Strength Exercises

Doyle et al. (2010) developed a game to deliver balance and strength exercises. This project aims to help elderly users to improve the motor capabilities of their lower limbs in order to avoid falls. This system is made of a flash application running on a Laptop, a camera (webcam), a set of markers for upper and lower limbs and a SHIMMER kinematic sensor for walking exercises (see Figure 3.2). The game provides five exercises from the Otago exercise program (Accident Compensation Corporation New Zealand's , 2013). As the user performs the exercises, their performance is remotely monitored by the instructor in order to validate the correct completion of each exercise. Additionally, Doyle et al. conducted a series of usability tests in order to identify the user preferences to make the platform more attractive to the elderly users. These tests focused on evaluating visual and audio feedback, navigating through the application, providing instructions and measuring attitudes and motivation to the exercises. There were four key findings. Users are more likely to play games that use an avatar instead of seeing themselves on screen (visual feedback). With audio feedback, users prefer counters that emit single sounds (such as ding) instead of listening to number countdowns as the latter could be distracting for patients leading to lack of concentration. It was found that providing options to pause then resume the game or skip to the next exercise eases the navigation through the application. The notion of being under observation by a therapist increases the motivation of the patient (Doyle et al., 2010).

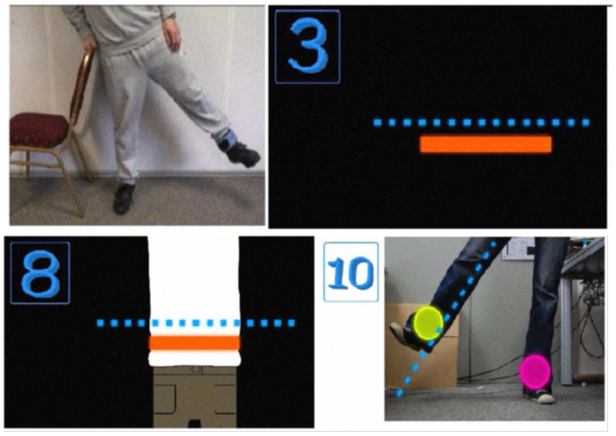


Figure 3.2: BASE game for balance developed by Doyle et al. (2010)

3.7.2.2 An Inertial Sensor Based Game for Fall Rehabilitation

Uzor et al (2013; 2014) developed a series of mini games with the purpose of rehabilitating older adults who experience a fall. The main input device used in this system is a pair of inertial sensors that are attached to the player's lower limbs in order to capture leg movements. Each mini game (or task) aims to train a specific function associated with the recovery of muscle strength and power. For instance in the Pigeon Express game the user is required to perform sit-to-stand and back-to-sit movements to control a pigeon that collects fruits that fall out of the back of a van (see Figure 3.3). In the *River Gems* Game, the player needs to perform side steps, while holding onto a chair for support, in order to collect coloured gems that come towards the player on the screen. In the *Panda Peak* game the user must make a panda walk across a log to the top of a hill by mimicking a marching-like movement. In the *Horse Hurdles* game, players bend their knees in order to control a racehorse that jumps over hurdles while galloping. Finally, this platform incorporates a virtual physiotherapist that delivers nine different exercises as a complement to the other games.

Figure 3.3: Game for fall rehabilitation developed by Uzor et al. (2013)

3.7.3 Wii-based Systems with Health Purposes for the Elderly

3.7.3.1 A Wii Balance Board Driven Game for Balance Training

Gerling et al. (2010) present a case study where they developed a game for balance training considering the needs of the elderly. Their prototype, called *SilverBalance*, uses the Wii balance board and consists of two single tasks with a simplistic graphic design. In task 1, a series of obstacles randomly appear aligned to the left or right and the user must shift weight to the opposite way in order to avoid the obstacles. The longer the user plays, the higher the speed, until the player is unable to achieve the goal (see Figure 3.4). In task 2, the obstacles cover the width of the screen and the user must jump to avoid collisions. At the end of each task, the system shows the user performance and saves the best scores. Both activities can be performed either sitting or standing, which is more accessible for this audience and allows people in wheelchairs to participate. The focus group test conducted by Gerling et al. was composed of nine older adults with average age of 84 years. After testing the usability of this prototype, it was found that simplistic designs allow the user to concentrate on the game encouraging them to perform the exercises. Also, this work shows that applying design principles has a positive outcome for elderly users.

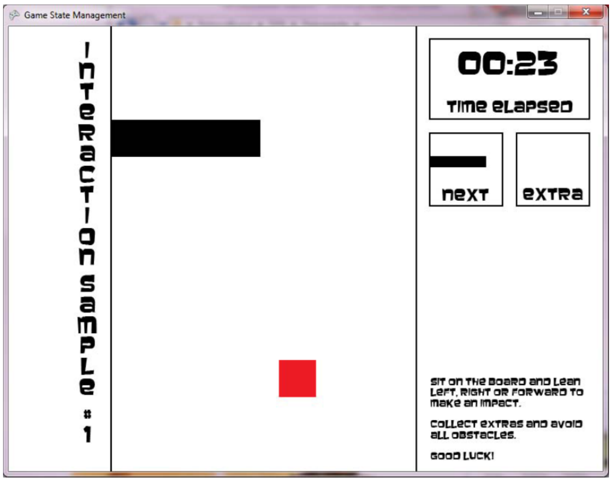


Figure 3.4: SilverBalance game for balance training developed by Gerling et al. (2010)

3.7.4 Camera-based Systems with Health Purposes for the Elderly

3.7.4.1 A Webcam-based Game for Upper Limb Rehabilitation

Burke et al. (2009a; 2009b) developed a series of webcam games considering the theory for design and rehabilitation set out in Table 3.1. This project aims to provide a low-cost tool for upper limb rehabilitation that can be used at home. This platform was developed using a commercial development kit and libraries and requires a webcam, a PC and coloured gloves in order to operate (see Figure 3.5).

Four games are provided. The *RabbitChase* game presents four holes and one rabbit. Eventually, the rabbit comes out of one hole, walks and gets in another hole, both randomly chosen by the game. The player must point at the hole hiding the rabbit. If the player is correct, encouraging visual/audio feedback is given. Also, these researchers developed a mechanism that automatically adapts the difficulty of the game based on patient success. In *Bubble Trouble* game, floating bubbles randomly appear on the screen, then after a short period of time they disappear. The user must touch the bubbles before they disappear, making them burst. *ArrowAttack* game shows two arrows that are coloured according to the user gloves or markers. One points to the left and the other to the right. Also four boxes are shown. The arrows move from one box to another and the user must imitate this movement with their hands as long as the arrows move. The system also includes a tool that analyses saved log files that are given to the therapist. Additionally, Burke et al. conducted two playability studies. It was found that the adaptive mechanism that increases and decreases the difficulty of the game was too aggressive when adjusting the challenges so it had to be refined to be more “gentle”.

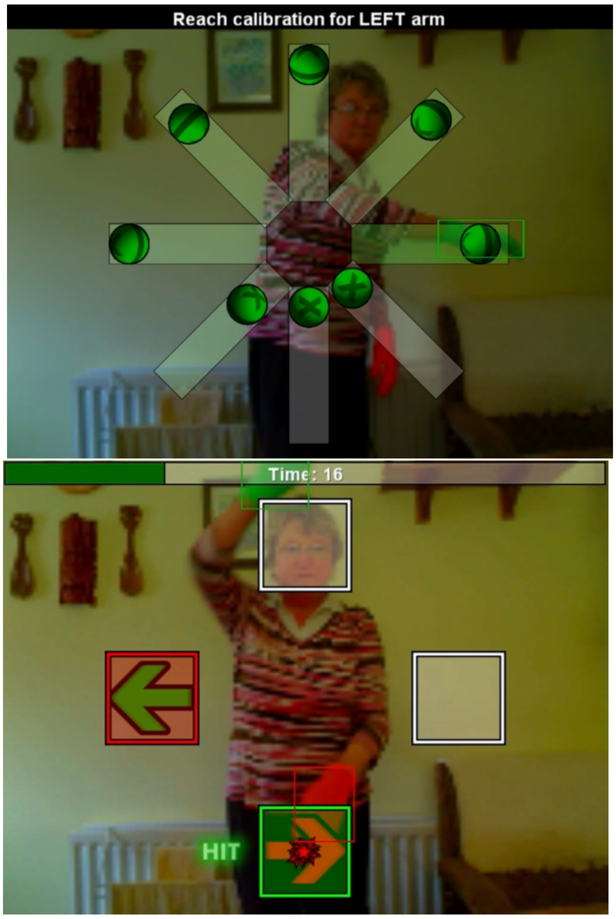


Figure 3.5: Webcam-based system that delivers Otago exercises (Burke et al., 2009a)

3.7.5 Non-Commercial Game Technology Systems with Health Purposes for the Elderly

3.7.5.1 A Robot-Based System for Arm Exercises

Fasola and Mataric (2010) implemented an assistive robot to deliver arm exercises for the elderly. The robot monitors the performance of the user and provides motivation to the player promoting an increased range of motion. In order to operate, the user must sit in front of the robot and three different games are given (see Figure 3.6). In *Workout* game the robot acts as a traditional instructor giving a series of exercise that the user must perform. In *Imitation* game, the player acts as the instructor and the robot imitates the user movements. In *Memory* game, the robot provides a sequence of arm gestures and the player must memorise them and repeat them. In order to capture the user movements, the research team developed a vision module that recognises the users' faces and determines hand location. In order to simplify the visual recognition, they installed a black curtain behind the user to provide a contrasting and static background. At the end of the trials, a survey was conducted to determine the participants' feeling and perceptions towards the robot. The results suggest that the participants perceive the robot as a trustworthy entity able to help them in exercise training.

Figure 3.6: Assistive robot to deliver arm exercises for the elderly (Fasola and Mataric, 2010)

3.7.5.2 A Multitouch-based Game for Upper-Limbs

Annet et al. (2009) developed a multi-touch table system to deliver training for upper limbs. This platform was built under the guidance of occupational therapists, specialists who normally work with patients to help restore or improve motor functions. Three objectives were established at the beginning:

- engage the user and provide easy to learn activities
- create repeatable activities, measure user performance and record it
- build on the therapist's expertise and knowledge of a patient.

The whole system is made of an existing multi-touch technology in conjunction with a set of applications for rehabilitation. Five games are given. In *Pop those balloons*, a landscape and a number of floating balloons are shown (see Figure 3.7). The user must touch the balloons in order to pop the balloons. Once the player touches the balloon, it disappears and increases the score. The therapist is able to modify the number of balloons and their speed while the patient is playing the game, in order to increase or decrease the difficulty of the activity. In *Drumhab*, the game presents a centre orb that emits beats from the middle of the screen to the four corners. Each corner has a drum that must be touched when a beat reaches its position. If the player hits the drum at the correct time, the beat disappears. The therapists can control the game by changing the number of beats and their speed as well as which drums are targets. In *Paint by number*, the game shows a group of paint buckets and an outline with numbers. Each paint bucket has a number and a different colour. The user must use their hand as a paintbrush and paint the image. In *Picture tracing game*, the therapist draws a pattern on the surface of the tabletop and the patient is asked to trace over the top of the pattern. In *Therapist Do-It-Yourself* game, the therapist creates a sequence of points (targets) and the user must reach them. Once the user touches a target, it disappears and the next one comes up.

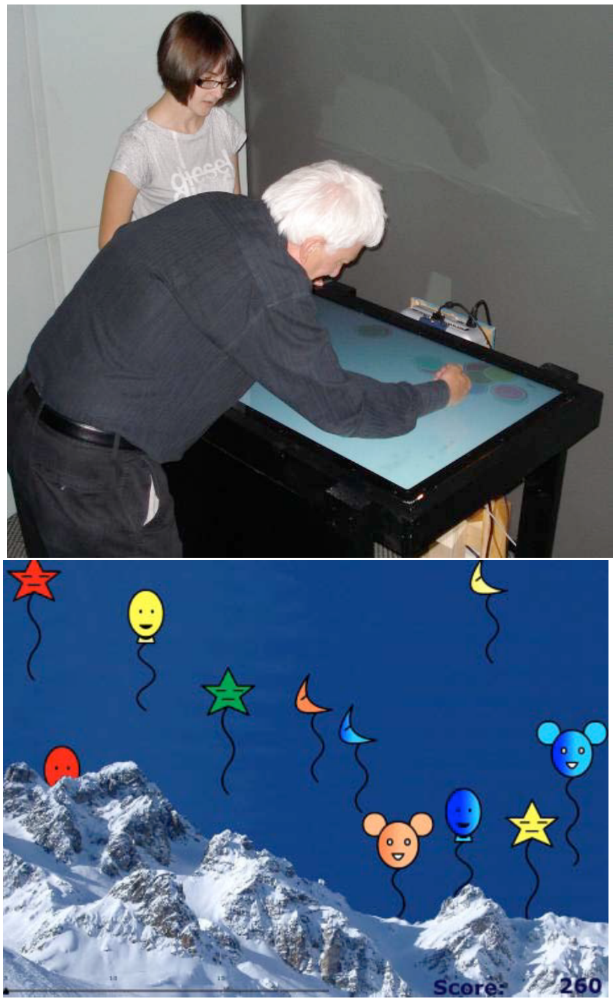


Figure 3.7: Multi-touch table system to deliver training for upper limbs (Annett et al., 2009)

The next section presents the most relevant findings of this survey and identifies the research opportunities in this field. Subsequently, the focus of this research is identified and set out.

3.8 Discussion and Results

Due to the lack of research across the area of the elderly and the use of serious games for health purposes, literature from other related disciplines such as the use of games for stroke treatment and games for improving balance function was reviewed to obtain more data. Some work was conducted in the late 1980s and early 1990s where some improvements in cognitive processes were observed after conducting trials with elderly patients and specifically selected computer games (Whitcomb, 1990).

Regarding the suitability of using commercial games, it was found that in several projects this approach was a success. However, there were a series of issues related to the poor usability of such games (Hanneton and Varenne, 2009; Neufeldt, 2009). These hidden usability issues could lead to negative results for the elderly, as their needs were not considered during the design process (Kalapanidas et al., 2009; Väätänen and Leikas, 2009; Abeele and Rompaey, 2006). For instance, the elderly could learn inappropriate movements in response to game actions, resulting in risks for their physical condition. Also, hearing impairments and sight problems were not properly addressed when providing rules and instructions, leading to confusion and frustration. Consequently, it was observed that rehabilitation techniques that applied user-centred design principles showed a higher acceptance by the older patients, especially when these systems involve a fun activity. This highlights the importance of appropriate design for this audience in order to obtain positive results. Additionally, it was noticed that much effort is applied to developing games for improving upper limb function rather than the lower limbs. Some of the reasons noted in the literature include:

- daily activities require the use of arms and hands such as grasping objects and brushing teeth (Cesqui et al., 2006; Giuffrida et al., 2008).
- a significant number of elderly users could require a wheelchair, so they would not be able to perform activities that require the whole body (Gerling et al., 2010; Herbelin et al., 2008; Zabaleta et al., 2007).

However, for the purpose of preventing falls in the elderly, the clinical literature suggests that stronger lower limbs and quicker stepping responses can reduce the risk of falling. Hence, this area of research requires further exploration. Furthermore, it is important to take into account that the use of webcams has become a popular low-cost input device solution. However, the nature of the device still imposes a series of inherent technological limitations to capture accurately the whole body. The costing of those games was not mentioned as the researchers developed extra items such as robots or mechanical arms and could employ programmers to assist in the games' construction.

Regarding the use of commercial platforms for this purpose, it was found that there is a tendency towards developing PC games that use commercial input devices such as remote controllers or balance boards, rather than developing games for such consoles. Although these innovative ways to interact increase the accessibility and motivation of patients, the coverage could be limited due to the lack of standardisation among platforms.

Finally, it was observed that even though most of the studied prototypes included the collection of game scores (Burke et al., 2009a; Smith et al., 2009), only a small number of these leverage on the collection of health data such as clinical measures that can be later used by a therapist to assess the effectiveness of the therapy (Annett et al., 2009). Future work on the inclusion of mechanisms to perform medical validation and assessment in real time could bring important benefits for both patients and therapists.

3.9 Focus of the Game Development Research

Based on findings of this literature review, the researcher identified the following five aspects as the focus of this project and the development of a game for fall prevention for the elderly:

- The inclusion of exercise routines to train the lower limbs rather than the upper limbs. As explained in Chapter 2, the ability to take a proactive or reactive step can prevent a fall from happening. Stepping has been shown to be one of the most effective strategies for preventing falls in the elderly. Subsequently a game should train this ability and incorporate relatively difficult cognitive tasks to complement the stepping activity.

- The promotion of a natural interaction. Throughout the literature a number of novel technological approaches were observed such as Nintendo Wii balance board, webcam-based games, force plates and mats. However, wearable sensors and the use of force plates or pads still impose an obstacle on the degree of freedom of the player. In fact, this can even put the player at risk of falling as they can trip over such devices and subsequently fall.

- Accessibility and cost-effectiveness. It was observed that many games found in the literature required a complex setup or required the use of expensive equipment in order to work. For instance the use of robots, electromyographic (EMG) sensors and custom-made controllers restrict the accessibility and coverage of these systems making it difficult for the elderly to adopt such technology as a home-based training tool. Hence, it is recommended that such games should be affordable and use standardised game technology that is easy to acquire.

- Collection of clinical parameters for the determination of health improvements. Game technologies have a notable potential to deliver exercises and collect data. In most cases, it was found that the games surveyed were programmed to store games scores, but the potential to acquire clinical data to assess the effectiveness of the therapy was not being fully exploited. Although game scores can be used as an indicator to determine health improvements, the use of a valid clinical assessment component is essential to determine progress and the achievement of the expected health outcomes. There were a few cases of the use of game technology to assess motor and/or cognitive functions but as the systems did not have any playable content, they were not considered games.

- The inclusion of appropriate playable content to meet the needs of the elderly. Usability and suitability are crucial to guarantee the acceptance of the players. The aged community is very heterogeneous and special design considerations must be taken into account in order to suit their needs, limitations, capabilities and motivations. Interfaces should be easy to use and the levels of exertion must be customisable. Also, the use of user-centred design methodologies throughout the design process including focus groups, participatory designed sessions and evaluations is recommended.

3.10 Conclusion

This chapter reviewed and classified the existing academic literature in serious games for the elderly according to their specific goal and key design elements for improving the physical health of the cohort. This categorisation was crucial to identify the current status of serious games for health and the major needs in this new field of research. It was found that research projects have an increased awareness of elderly user needs in gaming design for health purposes. Yet, little effort has been made to take into account the limitations of the elderly in the entire design process. This could be attributed to the favourable results that have been obtained in the past from the incorporation of elderly specific human-centred design guidelines to assist the design process. However, the theoretical nature of the guidelines could not be sufficient to guarantee optimal results, so testing phases and usability evaluation are needed. As a final point, the use of modern input devices has allowed specialists to determine patient performance in terms of motor functions. Nevertheless, the potential use of this capability to accurately perform medical assessment as a tool to guarantee effectiveness was not found to be fully exploited. This has been identified as an important direction for future research which is further explored in this research project.

Chapter 4 presents a preliminary study on the Nintendo Wii where the usability of four commercial games is assessed in collaboration with six health experts. This study was conducted in order to determine the suitability of utilising commercial games with health purposes for the elderly.

Chapter 4

Effects of Commercial Games on the Physical and Mental Health of the Aged

4.1 Introduction

This chapter presents an evaluation that focuses on assessing the suitability of four commercial games for balance in order to determine whether an elderly person may benefit from playing with such technology. Since the main interest of this study is to determine the effects that commercial games may have on the physical and mental health of the elderly, a group of six health experts participated in this evaluation.

As mentioned in Chapter 3, the use of interactive games as a method to keep and/or improve the health condition of the elderly has shown a positive impact and acceptance by the elderly. However, it was also found that commercial games may not always be suitable for the mental and physical health of the elderly as such games are designed to entertain a younger audience rather than providing therapeutic support for the elderly. In fact, several studies revealed that the elderly perceived game playing as an unpleasant experience mainly due to the occurrence of usability issues related to age-related changes (Neufeldt, 2009).

The results of the evaluation of four Nintendo Wii balance games, under the observation of six experts in health and well-being techniques, are presented. For this study, a series of recorded and transcribed structured interviews were conducted in order to assess the suitability of the games for physical and mental health of the elderly. This chapter provides an overview of previous studies related to this topic, a description of the games assessed and the scenario of the interviews, followed by the factors assessed and the analysis and conclusions of the obtained results.

4.2 Background

With ageing, the human body undergoes a series of changes in sensory-perceptual processes, motor abilities and cognitive processes that often lead to decline in physical and mental health (Ijsselsteijn et al., 2007; IJsselsteijn et al., 2007). For that reason it is crucial to understand the needs, capabilities and preferences of the elderly when designing video games for them. Youth-oriented interfaces feature sounds, flashing lights and colours which create enjoyable experiences for young players, but could also lead to negative feelings for an elderly user. Some of the most notable problems include confusion caused by pressing or releasing buttons in the appropriate time or anxiety and stress caused by the inability to reach the game goals (Neufeldt, 2009). Because of the above adverse effects, efforts have been made to establish formal methods and techniques to assess the suitability of video games. Some methods focus on technical issues such as the game aesthetic, sound events and programming errors instead of evaluating game interfaces, the mechanics of the game and how enjoyable it could be. For instance, the ISO 9241 standard of usability uses effectiveness, efficiency and satisfaction as basic metrics of suitableness (Pinelle et al., 2008).

An approach that has shown to be more effective to assess the usability of an interface is the heuristic evaluation of video games (Pinelle et al., 2008). Heuristic evaluation is an inspection technique where a set of usability principles is established and used by evaluators to explore an interface. These principles are called heuristics. Due to its flexibility and adaptability, heuristic evaluation has become popular in the evaluation of interfaces (Papaloukas et al., 2009).

The heuristic evaluation process divided into five stages:

- Identification of usability problems as well as their categorisation
- Observation of players while interacting with the video games under the observation of evaluators; recording facial expressions, verbal reactions, etc; looking for new problems which could be missed from the first stage
- Re-categorisation of usability problems
- Description of the ways to resolve problems encountered previously by the creation of heuristics
- Testing of heuristics applying the methodology of user logging combining the thinking aloud protocol.

For that reason, the heuristic evaluation technique was adopted as a tool to evaluate four Nintendo Wii balance games with the collaboration of six health experts. This study aims to determine the suitability of such games for the elderly regarding the ease of use of such systems as well as potential health benefits or drawbacks related to playing with the games.

4.3 Evaluation of Four Wii Fit Balance Games

For this preliminary study, six health professionals participated, with three representing traditional medicine and three representing alternative health techniques (Table 4.1).

Health professionals were invited to this study as the main purpose of this experiment was to find out the potential benefits/drawbacks that such games could have in the physical and mental health of the elderly. While the ease-of-use and intuitiveness of an interface are essential aspects in the game design process, this chapter rather focuses on the health outcomes that commercial games may have in the aged cohort.

Table 4.1: Description of six health experts used for evaluation of commercial games

Mainstream	**Pseudonym**	**Description**
Traditional Medicine	Expert 1	Professor Aged Care, Sydney Hospital Researcher and director of Health and the Aged Centre.
	Expert 2	Physiotherapist at an large Aged Care Facility in Sydney.
	Expert 3	Associate Professor Chronic Care at a Sydney university.
Alternative Health Techniques	Expert 4	Certified Feldenkrais Movement Practitioner in Sydney.
	Expert 5	Certified Alexander Technique Practitioner in Sydney. Own Practice.
	Expert 6	Expressive Arts & Music Therapy Specialist at a university in Sydney as well as having a Sydney private practice.

A series of recorded and transcribed structured interviews were conducted focusing on assessing the suitability of the games for the elderly. Overall, these sessions were conducted as follows:

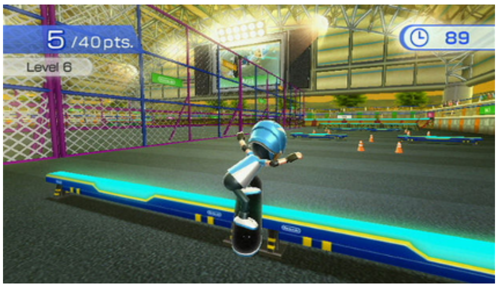
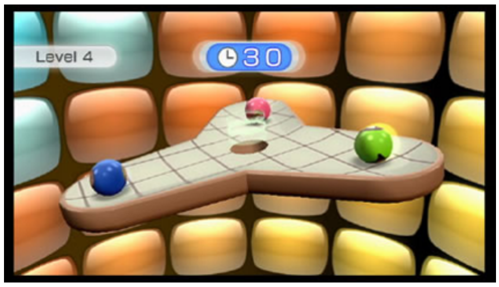
- A semi-structured interview with each health professional concerning the procedures which each one performed with the patients over 65, as well as their experience, if any, involving interactive technologies within their practices.

- A demonstration of the four Wii balance games from the Wii Fit Plus suite: Skate Board Arena, Tightrope Walk, Balance Bubble, and Table Tilt (Table 4.2). These demonstrations were performed by one of the researchers. In one interview, the interviewee offered to perform the activity. During all the demonstrations, the interviewees provided oral feedback by remarking on the strengths and weaknesses of the video games. They offered suggestions to make the games much more enjoyable and suitable for their elderly patients.

- This material was transcribed and analysed using Leximancer (Leximancer, 2015) , a specialised analytics technology for unstructured, qualitative, textual data.

A copy of the health experts' observations is in Appendix A.

Table 4.2: Description of the four Wii balance games

Skateboard Arena	**Tightrope Walk**
 **Objective**: Show off your technique with a skateboard. **Procedure**: Turn the balance board through 90 degrees clockwise, push off with your back foot to start and jump when obstacles appear. **Rules**: Ramps, half-pipes, etc. **Conflict**: The scoring depends on your tricks on ramps or half-pipe.	 **Objective**: Walk a rope strung between two buildings. **Procedure**: Walk across the rope, jump when biting machines appear. **Rules**: Biting machines, obscured view, and wind. **Conflict**: Leaning, falling off the rope, unbalanced jumps, time limit.
Balance Bubble	**Table Tilt**
 **Objective**: Navigate it along a river to the rainbow finish line. **Procedure**: Shift weight to propel the bubble along the river. **Rules**: Hazards such as rocks and river banks, and bees. **Conflict**: Reach the goal avoiding hazards and respecting the time limit.	 **Objective**: Tilt the tables so that the balls drop into the hole(s). **Procedure**: Shift weight to tilt the table. The table could have at least one hole in it; the balls must be guided into the hole(s). **Rules**: Hazards such as: unguarded edges, slopes and blocks. **Conflict**: Dropping balls could lose more balls as well as causing delays, time limit.

Based on previous studies on the heuristic evaluation, the initial heuristics for this study were defined focusing on the usability of video games for elderly users including factors such as engaging with the game, avoiding mental distress and physical damage by controlling extreme emotions as well as considering age-related changes such as the loss of cognitive and motor abilities.

After following the heuristic evaluation methodology, the author developed the following list which contains a general categorisation of the problems found:

(A) Customisation issues: User cannot modify the game settings according to their needs

(B) Inability to avoid non-playable content: User cannot skip introductory videos or parts of the game which are repetitive.

(C) Control of actions: Excess or deficiency of sensitivity of controllers.

(D) Training: The video game does not provide training practices before playing the real game.

(E) Goal feasibility: Extreme difficulty to avoid hazards within the time limits, with too many obstacles and limited time periods.

(F) Correspondence between user movements and display: The game must respond according to the user movements, mirroring the real world, with a connection between what the users see and do.

(G) Provision of rules, information and instructions: Lack of explanation, inadequate timing, content and/or format of the provided information such as the inappropriate usage of language.

(H) Mental health: Feelings of stress, anxiety and/or disturbance due to excessive memorisation, inadequate concentration requirement and dealing with the conflict of the game.

(I) Physical health: Physical issues caused by tightening up, falls, loss of balance, excessive requirement of workout, coordination and flexibility.

(J) Engagement: Lack of commitment and/or engagement due to the theme, challenges and/or diversion factors of the video game.

After the categorisation a set of heuristics was developed. A number of categories were deleted due to their lack of occurrence (Category A, B and C) and one resulted in the union of related categories (Category H and I which became Heuristic V). The final game heuristics are listed below:

(I) Provide training phases: The game should have training phases before the real game starts, allowing the users to become familiar with the technology. Additionally, these training stages must be easy to skip when they are not required any more.

(II) Create feasible goals: The goals must be reachable by adapting the difficulty of hazards to take into account the physical abilities of the elderly.

(III) Establish appropriate relationship between movements and display: The game must respond according to the user movements.

(IV) Provide rules, information and instructions in an adequate way: The information regarding rules, suggestions and instruction should be given before and during the game, so the user does not have to read instructions and operate at the same time. Also, this information should be provided by audio.

(V) Consider the mental and physical condition of the player: The player should not feel frustrated and upset because of hard goals. The objective of a game is to entertain the player, so practices involving excessive memorising must be avoided. Avoid unnecessary requirements for workouts involving coordination and flexibility outcomes. If possible, preclude the need for complex movements so elderly users do not require walking frames to maintain their balance.

(VI) Engage the user: The theme of the video game must be in accordance with the audience's interests to avoid lack of commitment.

4.4 Findings

After conducting the evaluation and categorising the problems found, a total of 26 unique usability problems were found. Each health professional found around four problems on average and the number of problems from each specialist ranged between one and eight (see Figure 4.1 and Table 4.3). The author then mapped the appropriate heuristic to address each particular problem that had been identified.

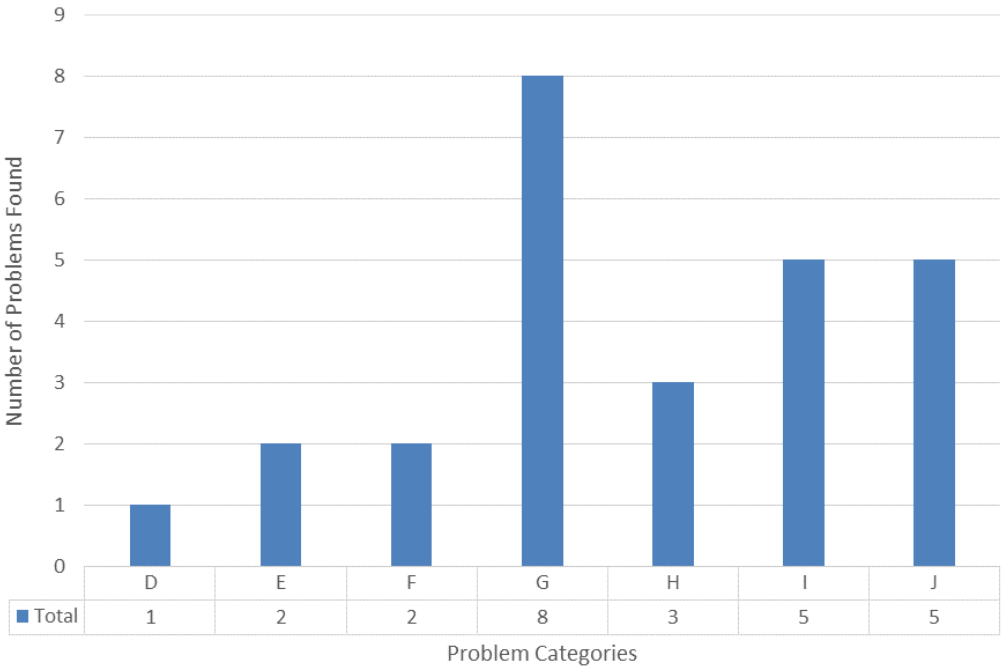


Figure 4.1: Frequency of the problems identified by the six health experts

Table 4.3: Usability problems found by six health experts

Usability problem	**E1**[a]	**E2**[a]	**E3**[a]	**E4**[b]	**E5**[b]	**E6**[b]	**Total**
(D) Training	1						1
(E) Goal feasibility	1				1		2
(F) Correspondence between user movements and display				1		1	2
(G) Provision or rules, information and instruction	1	1			3	3	8
(H) Mental health	1				1	1	3
(I) Physical health		1			2	2	5
(J) Engagement	2	1	1			1	5
Total	6	3	1	1	7	8	26

[a] Traditional Medicine.

[b] Alternative Health Techniques.

Figure 4.1 shows the frequency of problems found for each category ordered by their occurrence. It was found that the main problems were related to the provision of rules, information and instructions. One participant mentioned *that reading instructions spread across the screen may be confusing and less compatible with kinaesthetic awareness than auditory feedback*. Such games require a variety of instruction mechanisms such as text and audio together (Heuristic IV). The next three most common problem categories were concerned with the physical health, engagement and mental health of the user. One of the experts stated *that falling from a tightrope between two skyscrapers is an anxiety-producing stimulus, which makes people tighten their necks and shoulders and sabotages their balance reflex* resulting in risks for the physical condition of the elderly. Additionally, when playing the *Balance Bubble* game, one of our interviewees said *If the elderly are learning from this game to lean back in response to wanting to slow down it could actually lead to falling backwards*, that is potentially dangerous for the aged (Heuristic V). Also, some of the evaluators believed that providing a balance frame could be useful for older people when playing this kind of game, so they could hold onto it to gain confidence and avoid getting injured. During the evaluation of the *Skate Board* game, some of the experts stated that elderly people could reject playing this game because it was outside their own experiences and more suited to a younger audience. This supported the idea that the theme of a video game is a relevant factor when trying to engage an elderly user (Heuristic VI). The remaining categories D, E and F concern problems relating to the correspondence between the user movements and display, goal feasibility and training. Games like *Tightrope could be a bit confusing for the user as the picture is opposite to what they do e.g. the picture shows one foot in front of the other; however, on the board, the feet are apart* (Heuristic III). Although game theory points out that the conflict of the game creates a challenge which is the main reason to engage the user (Fullerton et al., 2008), one of the experts claimed that activities should not be *impossible to achieve as it becomes too distressing for people and they just give up*, losing their commitment to the game (Heuristic II). Consequently, it was found that some games could require preliminary training as well as customisation allowing the aged user to become familiar with the activities provided by the video game. Regarding the above, it was suggested that *they could pick up speed over time: Start very slowly until they get used to these things* (Heuristic I).

4.5 Conclusion

This chapter used the heuristic evaluation to assess the suitability of four commercial health games for the elderly. The insights of the six health specialists revealed some unexpected results about the mental and physical health of the elderly. Although video games can have a positive impact for the elderly, poor usability and inappropriate playable content can also result in drawbacks for them if their mental and physical conditions are not taken into account. For instance, a disconnect between what is on the screen and what the user is actually doing may cause confusion for the player, resulting in feelings of anxiety and frustration while also affecting their balance reflex and mental satisfaction. As users age, their sight and hearing often deteriorate making it difficult for them to read or listen to instructions while the game is running. For that reason, testing the usability and suitability of video games is critical to obtain the improvements expected. This preliminary study was critical to understand the importance of a proper design regarding the inclusion of appropriate exercise routines and meaningful tasks to ensure the elderly benefit from such games.

The next chapter presents the development of an initial prototype for a balance game. This prototype addresses the problems found in this study and establishes whether game technology can be used to perform a clinical test for fall risk assessment.

Chapter 5

The *StepKinnection* Test: Building a Hybrid Clinical Test for Fall Risk Assessment

5.1 Introduction

This chapter presents the development of the *StepKinnection* Clinical Test for Fall Risk Assessment, a Kinect-driven system that performs the Choice Stepping Reaction Time (CSRT) task, a clinical test that has been shown to prospectively predict falls in older people (Lord and Fitzpatrick, 2001). While this system has some similarities to interactive games, the design differs significantly as the main goal is the ability to assess the risk of falling in older people in a non-obtrusive way utilising game technology. Entertainment is a distant goal from this section but it is later explored and addressed in Chapter 7.

Chapter 3 presented the literature relevant to this research with a categorisation of the most relevant work in the area of serious games to reduce the risk of falling in older people. This review showed that the use of interactive games had a positive impact on delivering exercise programs with higher levels of enjoyment and motivation for the elderly. Also, it was found that input devices available in commercial games introduce a new mode of interaction in which the player is required to perform certain physical moves in order to operate the game. This natural mode of interaction has the potential to engage older users in physical activity as this can be considered a form of exercise.

However, the review also highlighted that commercial games had little alignment to health outcomes and lack of formal methods to assess progress and the achievement of health improvements.

Hence, the use of traditional clinical tests is still required to determine the effectiveness of this intervention.

Since the main interest of this project is the use of video game technology as an effective tool to improve the physical health of the elderly, the ability to accurately assess health outcomes is considered essential to promote optimal results in the elderly.

This chapter then explores the potential of using this technology to perform a clinical test for fall prevention as a tool to assess the effectiveness of an intervention on an ongoing basis. This not only allows for the monitoring of the user performance, but will also help to determine health improvements in an accurate and unobtrusive manner.

Later in Chapter 7, the core components of this system are then utilised for the building of a fall prevention game that delivers stepping exercises and embeds the above described test for fall risk assessment.

The chapter commences with a brief summary of related work, followed by the methodology used to build this system, then the design process and the aspects considered for both clinical assessment and suitability for elderly users. Finally, discussion and conclusions are at the end of the chapter.

5.2 Background

As stated in Chapter 3, game input devices such as the Nintendo Wii balance board, Nintendo Wii Motes, and webcams among others, are now commonly used to enable older adults without much or any computer experience to interact with games as well as to evaluate their performance while playing. For instance, Doyle et al. (2010) utilised a series of motion trackers and a webcam to deliver balance and strength exercises. The aim of this work is to improve the motor function of the lower limbs, which is essential to avoid falls. In this project, five exercises from the Otago Exercise Program (Accident Compensation Corporation New Zealand's , 2013) are delivered and the user performance is remotely monitored by the instructor. This feature allows the instructor to validate the correct completion of each exercise despite being remotely located from the participant.

In the work done by Jorgensen et al. (2014), the Nintendo Wii balance board was used to assess postural balance in community-dwelling older adults. In this work, the researchers used the stillness test available in the Nintendo Wii Fit suite to assess postural balance in 30 older adults. For this test, participants were asked to stand on the Nintendo Wii balance board (see Figure 5.1) and maintain a balance position for 30 seconds. The main outcome from the test is given in per cent ranging between 0 and 100% where 100 is the best score. One of the problems with this approach is that the use of the Wii balance board still imposes an obstacle on the degree of freedom to be able to perform a wider range of balance exercises suitable for the elderly and can potentially put the elderly at risk of falling.

Figure 5.1: Nintendo Wii Balance Board

Yeung et al. (2014) developed a Kinect-based system to assess body sway in the elderly. In this system, a person is asked to face a camera-based sensor and stand as still as possible for a certain period of time. Through the collection of spatial data, the amount of displacement in relation to the centre of mass is then calculated and used for diagnosis. Although this system tackles an important risk factor for falling in the elderly, this approach lacks the fun component that engages users to interact with these systems.

In the work done by Schoene et al. (2011), a flat dance pad was used to deliver stepping exercises in the form of a dancing game. Its main purpose was to provide a tool to exercise the stepping abilities of older adults. Unlike the commercial game, this version has been adapted to a range of stepping speeds including slow responses. Also, this system allows for the collection of stepping performance data that can potentially predict falls in the elderly. While this system trains an important strategy for preventing falls, the mat potentially exposes the older person to an increased risk of falling.

On account of the above, the author develops a Kinect-based system that delivers individually adaptable stepping exercises and simultaneously measures stepping performance.

The main motivation for choosing the Kinect as the primary input device is that it allows for a wider range of freedom for the user; an intuitive and natural interaction with the game as no controllers or wearable sensors are required for its operation; and a better provision of feedback allowing the display of a full body avatar to mirror the user movements. All these features are ideal for elderly users with minimal or no computer literacy.

More importantly, this system focuses on assessing the ability that an individual has to take a proactive step as this has been shown to be one of the most effective strategies to prevent falls (Feldman and Robinovitch, 2007). By taking a proactive or reactive step a person can increase their base of support and subsequently regain balance. Hence, training this ability is crucial as it deteriorates as people age (Maki and McIlroy, 2006).

The following section sets out the methodology used for building this system and the most relevant aspects that were considered through the design process.

5.3 Methodology

Based on the literature review in Chapter 3 and an evaluation on the suitability of four Nintendo Wii games for the elderly in Chapter 4, the author proposed a set of design aspects to address the most common issues found regarding the usability and suitability of such systems for the elderly. Hence, the following design criteria were utilised for the development of the *StepKinnection* system:

1. The game should promote physical exercises targeting the lower limbs as muscle strength and power are important factors in the risk of falling in the elderly.
2. Exercises should have direct alignment to the specific health outcomes in order to train specific functions associated with the problems of falling in the elderly.
3. The system should allow the determination of health improvements through the incorporation of a clinical test for fall risk assessment.
4. The platform should promote a natural interaction as this enhances the operability and engagement with the system.
5. The system must be accessible and cost-effective by utilising affordable game technology and a simple setup.
6. The platform needs to include appropriate age-related features in order to suit the age-related changes that affect the playability and enjoyment of such games.

On account of the above, the Microsoft Kinect for the Xbox 360 game console was selected as the main input point for the proposed system (see Figure 5.2).

Figure 5.2: Microsoft Kinect Sensor

This device is capable of capturing depth and video without the need to use a game controller or use additional wearable sensors to operate (Criteria 4 and 5). This feature makes the Kinect ideal for older people not only because they can focus on the exercise rather than the technology, but also because freeing their hands lowers the risk of falling by enabling them to grasp onto something or to reduce the impact with the arms in case of a fall (Criteria 6). Then, the technology was explored in order to assess its capabilities and limitations. The resulting criteria were determined according to the following technical aspects:

1. for skeletal recognition the users should stand between 1.2 m and 3.5 m depth from the sensor
2. the built-in skeleton tracking feature in the Kinect could be affected by the presence of objects such as support frames or chairs

Regarding the inclusion of a clinical test for fall risk assessment (Criteria 3), a literature review on existing performance-based tests for predicting falls risk in older people was conducted. The review was aligned to the technical specifications with the purpose of identifying a viable key set of parameters that could be measured. A number of tests that could be performed without utilising expensive equipment were found; however, many of them were not suitable to be used with the Kinect. The tests that were initially considered along with a brief description and the reasons for non-selection are described below.

- Walking tests such as the Dynamic Gait Index (Whitney et al., 2000), Functional Gait Assessment (Wrisley et al., 2004) and Time Up & Go (Shumway-Cook et al., 2000) are designed to test walking functions and speed where the subject is normally required to walk from one point to another within a range of time. On some occasions they are asked to avoid obstacles or move other limbs. The main limitation is that these tests require a distance that exceeded the 1.2 m - 3.5 m range that the Kinect is able to cover. Furthermore, measuring speed and gait would not be accurate or even plausible.

- Questionnaire-based tests such as the Rivermead Mobility Index (Collen et al., 1991), Falls Efficacy Scale (Hauer et al., 2010) and Barthel Index (Stone et al., 1994) do not require the user to perform any form of physical activity. They are intended to assess the level of confidence to perform daily activities or situations where balance is crucial to avoid falls and injuries; therefore, these cannot be adapted as an exergame.

- Balance tests such as the Berg Balance Scale (Muir et al., 2008), Romberg Test (Black et al., 1982), Clinical Test of Sensory Interaction and Balance (Cohen et al., 1993), Push and Release Test (Jacobs et al., 2006), L/E Chair Stand Test & U/E Arm Curl Test (Powell and Myers, 1995), Multi-Directional Reach Test (Newton, 2001) are more likely to be incorporated in the prototype. However, some of them require the assistance of the physiotherapist or the use of support frames in order to avoid risks of falling. This could be considered a problem as the Kinect could misunderstand the presence of two people or a supporting frame affecting the game input and the measurement.

- Stepping tests include the Four Step Square Test (Whitney et al., 2007) which is a simple test where the user is required to step on a square that is divided into four sections. The goal is to pass over the four sections, one by one, and then come back as quickly as possible. As this test does not require either much space or special equipment to be performed, it was found to be suitable for an initial prototype, however, the Choice Stepping Reaction Time task (CSRT) (Lord and Fitzpatrick, 2001) was found feasible to measure the required parameters with the Kinect and suitable for translation into a video game. This test has been validated in more detail in older populations including large prospective cohort studies with falls follow-up (Pijnappels et al., 2010). Also it has been shown to reliably discriminate between groups of recurrent fallers and non-fallers (Schoene et al., 2011). More importantly, stepping is one of the most effective strategies to prevent falls in the elderly, so the inclusion of this task is highly relevant and directly aligned to the health issue of falling in the elderly (Criteria 1 and 2).

The CSRT test is described in the following section

5.4 The Choice Stepping Reaction Time (CSRT) Test

The Choice Stepping Reaction Time (CSRT) task is a composite measure of sensorimotor functions, such as balance and strength, as well as cognitive functions such as attention and central processing speed (Lord and Fitzpatrick, 2001). It is through these composite metrics that the test is able to combine several dimensions of falls risk. In its original version the CSRT involves the person standing on the two central step panels of a wooden board (See Figure 5.3). One of four surrounding panels (front left or LF, front right or RF, left or LL, right or RR) lights up randomly and the person has to step on this panel as quickly as possible and then return to the centre. The sequence is presented randomly as well as the time varied between trials so that the user is unable to anticipate the time and location of the next stimulus. The mean reaction time of 20 trials is then measured and analysed for clinical diagnosis.

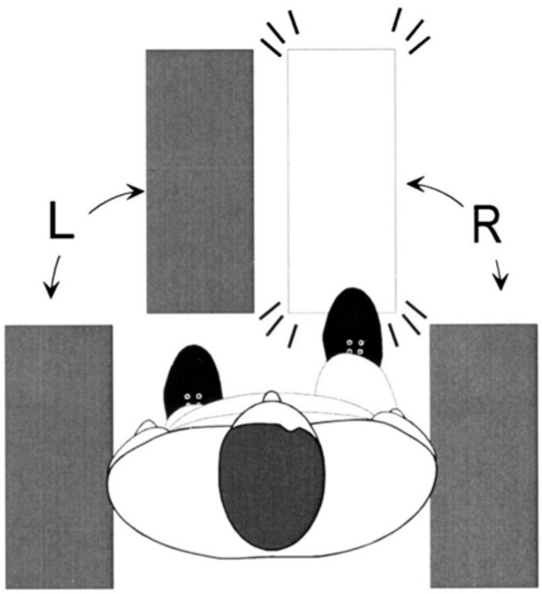


Figure 5.3: Original Choice Stepping Reaction Time (CSRT) test (Lord and Fitzpatrick, 2001)

5.5 Design Considerations

In the *StepKinnection* system, the person stands in front of a computer screen or TV connected to a Kinect PC (see Figure 5.4). The representation of the player in the system is a pair of shoes mirroring the person's feet movements.

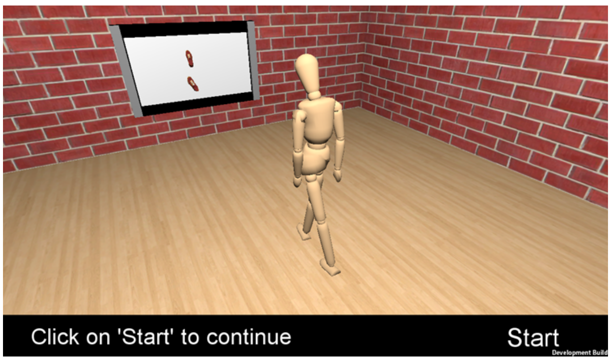


Figure 5.4: Interacting with the *StepKinnection* test (Garcia et al., 2014a)

Six symmetrically distributed square-shaped virtual panels are drawn on the screen representing the step panels surrounding the person (see Figure 5.5). The mechanics of the test are the same as the original version of the CSRT with the exception that the person steps in space.

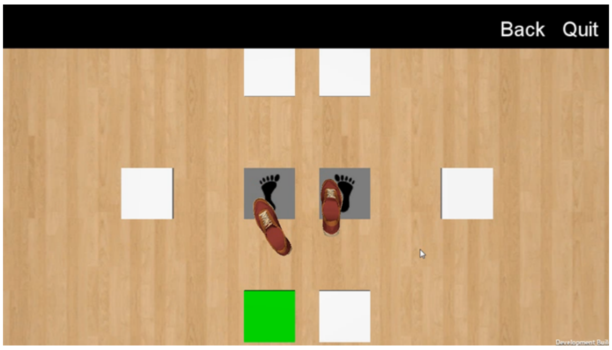


Figure 5.5: The *StepKinnection* Test for fall risk assessment (Garcia et al., 2014a)

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In addition to the stepping task, a "Go/No Go" task was incorporated (Schoene et al., 2013). This is to assess the ability that an individual has to inhibit responses. As explained in Chapter 2, one of the many processes that decline with age is Selective Attention, which can severely affect our ability to react adequately to unexpected changes in the environment. Consequently, this task includes a response selection component which uses the "Go/No-Go" test paradigm. During "Go" trials (indicated by the green colour) individuals are required to step as quickly as they can. However, during "No-Go" trials (indicated by the red colour) subjects are required to remain with both feet on the centre panels. The mean reaction time of the "No-Go" trials is compared to mean reaction time of the "Go" trials in order to assess the interference of the increased cognitive demand.

For this task 25% of trials appear in a red colour signalling the user to remain centred without stepping. The remaining 75% of trials are conducted as previously described.

This new Kinect-based test of CSRT also eliminates a limitation of the original CSRT task, where the distance between the player and the sectors is fixed. In the developed system, such distance is determined by the user's height which is measured by the Kinect. This feature is important as the adaptation of the test to the user dimensions is significant in terms of step length and fall risk. The user's actions such as a *step* or a *foot lift-off* are recognised by translating the user's lower limb movements obtained by the Kinect's depth sensor into the game-like platform. The system continuously retrieves spatial data (or skeleton frames) to determine whether a foot is intersecting one of the virtual panels. When the intersection of a foot and one panel is detected, the system records this action along with a timestamp.

These actions are subsequently used for the calculation of the following time-based variables which are essential for the fulfilment of the CSRT test (Schoene et al., 2011):

- **Decision Time (DT):** time elapsed between the instance where the sector turns green and the player lifts their foot off the central panel

- **Movement Time (MT):** time it takes for the user to step on a coloured sector once leg movement is initiated
- **Response time (RT):** Decision Time (DT) + Movement Time (MT).

Following a review of guidelines for building entertainment systems for older adults and the results of an evaluation on the Nintendo Wii (Chapter 4), the aspects that were considered during the design process are set out in Table 5.1.

Table 5.1: Elderly-appropriate game features, adapted from Flores et al. (2008) and Garcia Marin et al. (2011b).

Dimension	Description	Implemented Feature(s)
Cognition	While attention and executive functions are risk factors for falls, ongoing high levels of attention, memorisation and learning could cause difficulties when playing, leading to stop activity (Ijsselsteijn et al., 2007)	**Inhibitory Stepping Task:** Selective attention and response inhibition is assessed by the "Go/No Go" task **Number of stimuli:** The number of stimuli per trial was restricted to one.
Feedback	Provide accurate feedback for motivation of player (Burke et al., 2009a)	**Game Views:** the feature to select between three different camera views of the user onto the game is provided as well as a score after finishing.
Challenge vs. Player Skills	Provide the appropriate challenge to allow the player to perform activities according to their capabilities (Flores et al., 2008)	**Radius of the circle:** This is defined as the distance between the user foot when located at the initial point and the sectors surrounding the user. The larger the radius the more challenging it is for the user to make an appropriate step. For the game, this value ranges from 10-50% of the body height to enable frailer and fitter individuals to play. For the purpose of testing a step length of 20% was deemed appropriate. **Between-Trials time:** This is defined as the time that the user waits after touching the target sector and a new sector appears. This is randomly selected between 1.5 and 2.5
Control	Establish appropriate relations between movements and display. The elderly player could erroneously learn and adapt movements in real life (Garcia et al., 2011b)	**Use of an Avatar:** The user is represented by a pair of shoes that mirrors the user movements and the tasks the user is instructed to perform are totally aligned to what the user sees on the screen.

5.6 Enhancements to the Original CSRT Test

Advanced technical features of the Kinect allowed for the incorporation of the following spatial measures as a complement to the original parameters:

- **Active Foot Positioning (AFP):** Three-dimensional coordinates of the user's foot when stepping on a panel
- **Observed Step Length (SL):** Distance between left and right foot while stepping on a panel
- **Stepping Accuracy Coefficient (SAC):** Difference between expected step length and observed step length
- **Validation of "Go / No Go" Activity:** A "Go/No Go" activity is successful when the user meets the "Go" condition (green) and inhibits his/her response during "No Go" trials (red)
- **Validation of Expected Direction vs. Observed direction:** As each sector is strategically located surrounding the player in all directions (front-left, front-right, left, right, back-left and back-right), the user is expected to touch them accordingly.

The initial version of this system is intended to be used in a lab environment and be operated by a clinician or researcher for the setup of the initial parameters (see Figure 5.6).

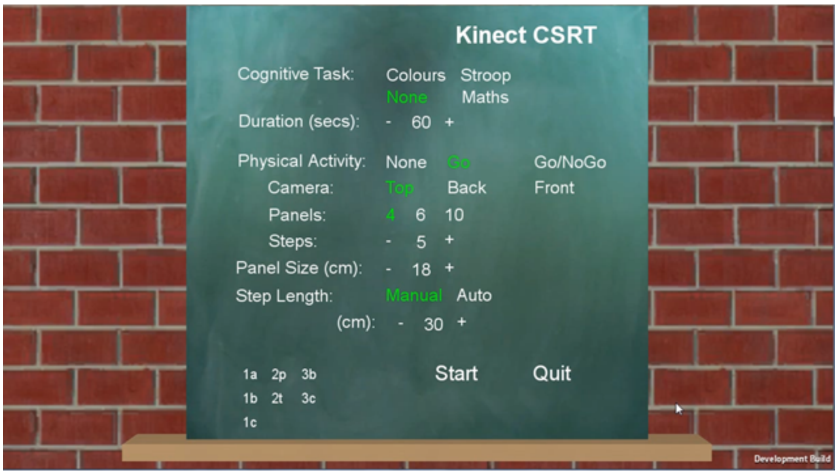

Figure 5.6: Parameters the therapist can select and tune in *StepKinnection* test (Garcia et al., 2014a)

The parameters to be selected and tuned by the therapist are the following:

- step length in percent of body height or in centimetres

- the activity to perform ("Go", "Go/No Go")
- the number of steps to execute per sector
- the visual perspective (camera view) the user has onto the game.
- number of panels
- panel size
- cognitive test and its duration

5.7 Refinements to the *StepKinnection* Test

A comparative review of the available gaming technology was carried out in order to select a suitable developing platform to implement the system. The Microsoft XNA Platform and the Kinect Software Development Kit (SDK) were initially chosen for two reasons.

1. Skeleton tracking and the process of gathering information of joint points are more accurate than the current open source alternatives.
2. The wider deployment of the game for the Xbox 360 platform for trial purposes makes the prototype exposed and available to a larger audience. Nevertheless, a refined prototype was built utilising the Unity3d engine (version 3.5.2) which speeds up the development process allowing for the incorporation of new features in a faster manner.

In addition to this the following features were incorporated for a more descriptive and accurate assessment.

5.7.1 Data Acquisition Accuracy

To minimise bias in data collection due to uneven surfaces or placing the Kinect on a slightly tilted table, a short calibration sequence was incorporated to determine the orientation of the actual floor plane or ground. Although the floor clip plane determination is a property built into the Microsoft Kinect SDK, experimentation suggested that this measurement might not be sufficiently accurate for research purposes. This is achieved through the collection of five points strategically located within an area of 1 m^2 which are then presented in a sequence (see Figure 5.7). Once this information is obtained, the relevant adjustments (mainly rotations) are applied to the game objects (if any). This helps to obtain more precise information about the positioning of the player's feet in order to accurately determine the exact instance when a foot hits the target.

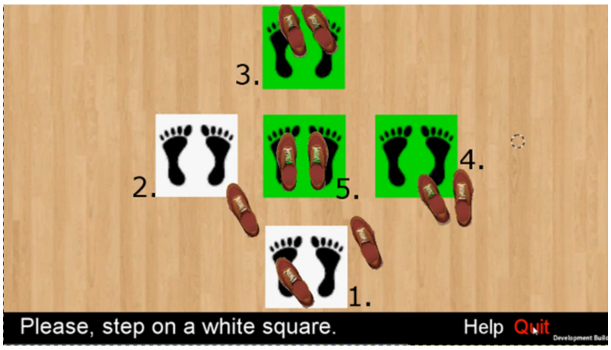

Figure 5.7: Calibration stage incorporated into the *StepKinnection* system (Garcia et al., 2014a)

5.7.2 Incorporation of Complementary Balance Measures

An alternative way to measure balance is by calculating the amount of postural sway of an individual while being asked to maintain a balanced position over a period of time, normally 30 seconds (Black et al., 1982). The slight postural movements made by the person are used to determine the total displacement of the centre of mass relative to the base of support. The literature suggests that falls in the elderly are primarily caused by their inability to adapt their balance given a change in the sensory information and this can be perceived when the subject experiences an increased sway in the anterior-posterior and medio-lateral directions.

On account of the above, the measurement of postural sway was also incorporated into the system as a complementary dimension of fall risk assessment (see Figure 5.8). By the end of the calibration stage, the user is asked to maintain a balanced position for 30 seconds. During this period of time, the system uses the skeletal information obtained by the Kinect and determines the total amount of displacement of the centre of mass relative to the base of support in order to fulfil the Sway Test.

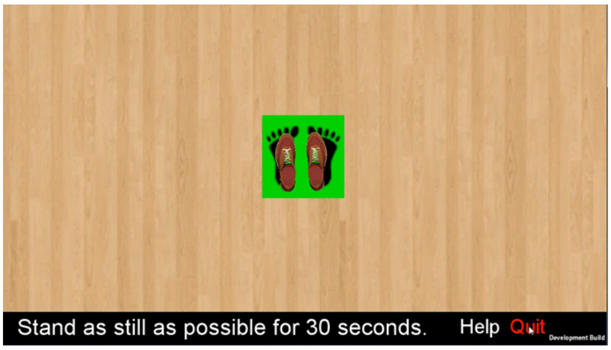

Figure 5.8: Implementation of the postural sway measure (Garcia et al., 2014a)

5.7.3 Adaptability to User Skills

One of the main limitations of the original CSRT test is that the distance of the stepping panels are fixed. This makes the stepping task less challenging for tall users but more difficult for short users. For that reason a feature was incorporated into the system in order to make the system more adaptable to the user. To achieve this, the participant's height is measured during the calibration phase and later used to determine the distance of the panels. This makes the test equally challenging for all users as panels are dynamically located based on the user's height.

5.7.4 Ability to Assess Stepping under the Dual-Task Paradigm

Assessing the disability and decline in the elderly is often difficult. Physical performance tests are often used in conjunction with self-reports from patients to reach a determination. In some cases, cognitive state is assessed using the Mini-Mental State Examination (Cockrell and Folstein, 2002); immediate and delayed recall of brief stories, which measures episodic memory; and the Symbol Digit Modalities Test, which measures the domains of perceptual speed and executive function (Smith, 2002). The results of the cognitive tests are evaluated as a contributing factor to decline in physical function, but there is currently no good model of the interplay between cognitive and physical functions in leading to falls. A recent study (Martin et al., 2013) showed that the risk of multiple falls increased with poorer function in the Stroop test. However, in all of these tests the physical test and cognitive test are separate. On account of the above, three voice-controlled concurrent cognitive activities were incorporated to assess the performance of the patient under differing cognitive and motor conditions concurrently. The increased cognitive load affects the user performance while stepping, resulting in noticeably slower reaction times for users that are likely to fall. The three integrated activities in the system are: read the word task, name the colour task and the maths workout task.

5.7.4.1 *Read the Word* Task

This is a simplified version of the Stroop test. During this task the user is required to say the colour out loud while performing the stepping exercises. As the colour of the word and its semantic meaning are identical, this task creates a minimally increased cognitive load for the user (see Figure 5.9).

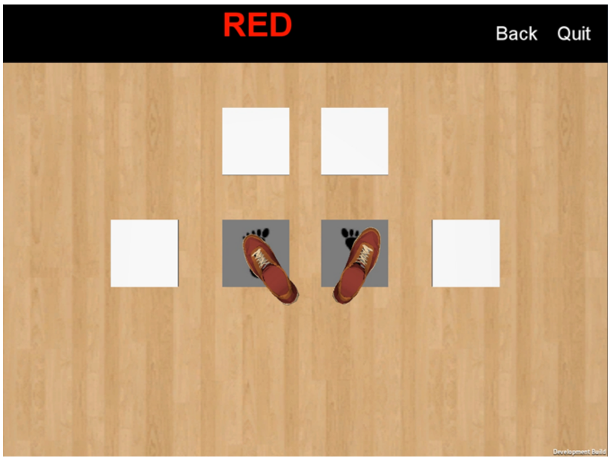

Figure 5.9: Simplified version of the Stroop test: the word matches the colour the word was written in (Garcia et al., 2014a)

5.7.4.2 *Name the colour* Task

For this task the semantic meaning of the word and the colour of the word do not match. Once again the user has to say the colour out loud, but in this case there is interference between the meaning and the colour of the word. While the mind automatically determines the meaning of the word, the player actually needs to identify the colour that the word is written in. This means the player needs to consciously re-evaluate their instinctive response. This interference, also known as the Stroop interference, results in a delay and the extra processing required normally results in a slowing down of the stepping test performance as it requires more cognitive effort than the previous task (see Figure 5.10).

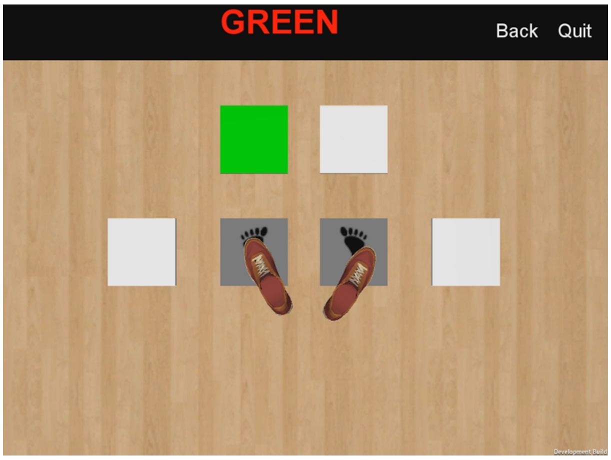

Figure 5.10: Implementation of the Stroop test: the word does not match the colour the word was written in (Garcia et al., 2014a)

5.7.4.3 *Maths Workout* Task

This task requires the user to answer a maths question that is read by the system. While there is no interference effect as with the Stroop test, the user is still required to interpret what they have heard to answer the question (see Figure 5.11).

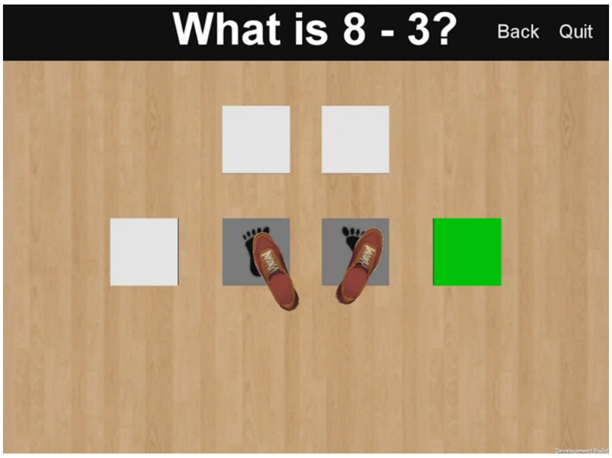

Figure 5.11: Maths workout activity: the system reads out a maths question and the user replies verbally (Garcia et al., 2014a)

For all the above tasks, the accuracy of the answer is automatically processed by the voice recognition system pre-built into the Kinect.

5.8 Conclusion

This chapter describes the development of the *StepKinnection* test for fall risk assessment, a system that uses the Microsoft Kinect depth and motion capture technology to deliver step training to older adults. The game-based system builds on Kinect's advanced features to allow continuous real time skeletal tracking and feedback. This implementation enhances the user interaction as no game controllers or wearable sensors are required for operation allowing older users with no computer experience to play. A set of parameters that can be obtained with the Kinect in order to fulfil the requirements to simultaneously measure clinical data has been identified, making this game potentially useful in clinical practice. This version of the system is intended to be operated in a clinical environment in the presence of a therapist. In addition to this, this system also allows for the collection of spatial information such as postural sway and stepping accuracy. More importantly, the assessment of stepping performance under the dual task paradigm can also be achieved through the incorporation of a series of cognitive activities. Poor dual tasking has been frequently associated with falls and balance impairments in older people, providing evidence for the importance of specific cognitive functions in postural stability (Yogev-Seligmann et al., 2008).

While the dual task system was not used in further experiments as the voice-enabled features lacked the reliability of a robust voice recognition engine to function accurately, the developed feature is still considered potentially useful in actual clinical practice to evaluate various dimensions involved in the diagnosis of fall risk in older people.

The next chapter presents a technical validation where the step parameters captured by the Kinect are compared to a validated response time device. This is to assess the reliability of the *StepKinnection* system and address Hypothesis 1.

Chapter 6

Assessing the Validity of the *StepKinnection* Test for Fall Risk Assessment

6.1 Introduction

In Chapter 5, the author described the development of the *StepKinnection* test, a hybrid clinical test for fall risk assessment in the elderly that performs the Choice Stepping Reaction Time (CSRT) task. This system builds on Kinect's advanced features to allow continuous real time skeletal tracking and feedback.

While this prototype demonstrated that off-the-shelf game technology has the potential to collect clinical parameters for the fulfilment of a clinical test for fall risk assessment, the accuracy of the system has not been yet established.

Consequently, this chapter focuses on assessing the capabilities of the developed system to reliably compute the CSRT test. Firstly, the author evaluates whether the Kinect can reliably collect time-based variables. Then, the author compares the Kinect measure of the CSRT test with a validated reaction time device in order to assess the validity of the developed system.

The reaction time device utilised for this comparison is a Dance MAT that has been shown to reliably perform the CSRT test as well as discriminate between recurrent fallers and non-fallers (Schoene et al., 2011).

Results showed a favourable correspondence and agreement between the two systems, suggesting that the Kinect platform could potentially be useful in actual clinical practice.

The chapter commences with a brief summary of related work in the field of fall risk assessment and describes the Choice Stepping Reaction Time test, then sets out the methodology used for this evaluation. Results and discussion conclude the chapter.

6.2 Background

Since the release of the Microsoft Kinect in mid-2011, both research communities and the industry have been actively investigating its potential use in the area of aged care and rehabilitation. This is mainly due to its capability to track real time full body movements in 3D, a characteristic that was not available in early consumer game technologies such as the Nintendo Wii or the Play Station 3 (PS3). In the area of fall prevention and safety for the elderly, the Kinect has also gained much interest. Kinect-based applications range from health and home monitoring systems (Parajuli et al., 2012), through unobtrusive fall detection platforms (Kepski and Kwolek, 2012); coaching, rehabilitation and therapeutic tools (Chen et al., 2012b), fall prevention training systems (John et al., 2012), to fall risk assessment tools (Stone and Skubic, 2011). Kinect-based serious games, being one of the most popular approaches, have shown a positive acceptance among seniors (Gerling et al., 2012). The fun factor inherent in such games and their ability to promote physical movements are ideal to encourage the elderly to exercise (Ganesan and Anthony, 2012).

From a clinical perspective, the capabilities of the Kinect also have the potential to implement low-cost methods to assess fall risk in older adults. This is achieved through the collection of measurements that fulfil the requirements of certain clinical tests such as posture control (Dutta and Banerjee, 2013), gait (Stone and Skubic, 2011), dual tasking ability (Kayama et al., 2012), and mobility (Lohmann et al., 2012), among others. Overall, these methods rely on the Kinect to obtain information on the human body positions in real time, which is shown to be fairly accurate. For instance in the work done by Dutta (2012), the Kinect demonstrated the ability to validly assess kinematic strategies of postural control. This work suggests that the Kinect could be considered an effective tool for collecting position-based measurements. However, for time-based measurements the Kinect introduces an additional challenge as it is a camera-based device restricted to processing up to 30 skeleton frames per second.

Consequently, this study focuses on evaluating the capabilities of the Kinect to reliably collect timing variables to fulfil the requirements of the Choice Stepping Reaction Time (CSRT) test, a time-based test that was incorporated into the *StepKinnection* test developed in Chapter 5. This evaluation is crucial because it addresses Hypothesis 1, that off-the-shelf game technology can be used to reliably perform a clinical test for fall risk assessment, and confidently incorporate this assessment tool into a video game for fall prevention.

For this study, the author evaluates the capabilities of the Kinect sensor to reliably collect timing variables to fulfil the requirements of the time-based test. Then, the validity of the Kinect measure of the CSRT test is compared with a validated choice reaction time device.

The next section describes the methodology for this evaluation.

6.3 Equipment for Evaluation

6.3.1 Mat-based Reaction Time Device

In the current version of the Choice Stepping Reaction Time task, the test is achieved through the use of a custom-made dance mat (or MAT) paired with a LCD monitor (see Figure 6.1). The person stands on the two central step panels of the MAT while facing the LCD monitor. Visual stimuli are presented on the LCD monitor and the user is expected to step accordingly on respective positions on the MAT. For this test, one of four surrounding panels illuminates on the LCD display and the person is required to step on this panel as quickly as possible and then return to the centre on the MAT. The sequence is presented randomly as well as the time between trials so that the user is unable to anticipate the time and location of the next stimulus. The mean reaction time of 20 trials is then measured and analysed for clinical diagnosis.

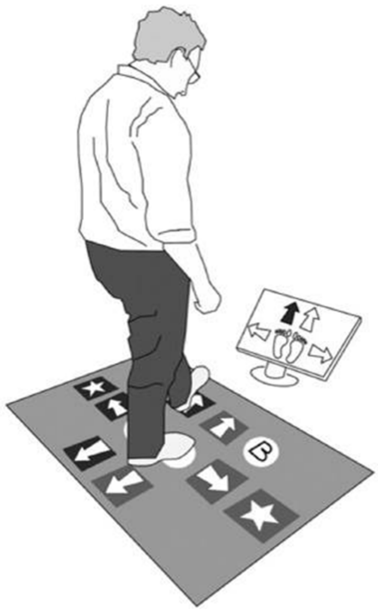

Figure 6.1: MAT version of the CSRT Test (Schoene et al., 2011)

6.3.2 Kinect-based Reaction Time Device

In the *StepKinnection* system, the person stands in front of a computer screen or TV connected to a Kinect PC (see Figure 6.2). The representation of the player in the system is a pair of shoes mirroring the person's feet movements. Six symmetrically distributed square-shaped virtual panels are drawn on the screen representing the step panels surrounding the person. The mechanics of the test are the same as the MAT version of the CSRT with the exception that the person steps in space.

Figure 6.2: Interacting with the *StepKinnection* System

Actions performed on both systems are used for the calculation of the following time-based variables which are essential in the completion of the CSRT test:

- **Decision Time (DT):** time elapsed between the instance where the sector turns green and the player lifts their foot off the central panel
- **Movement Time (MT):** time it takes for the user to step on a coloured sector once leg movement is initiated
- **Response time (RT):** Decision Time (DT) + Movement Time (MT).

While the MAT-based device has been shown to reliably compute the CSRT test, the Kinect-based version of the test still needs further evaluation as this camera-based device is restricted to process 30 skeleton frames per second, which could compromise the accuracy of the mentioned time-based measurements.

6.4 Participants for Evaluation

A sample of 13 individuals was recruited, consisting of research students and lecturers from the University of Technology Sydney. The eligibility criteria are described as follows:

- had not contributed to the design of these instruments
- able to walk independently without assistance

- fluent in the English language.

As mentioned earlier in this chapter, this evaluation focuses on assessing the accuracy of the Kinect-based system by comparing it with an well-established reaction time device. Hence, the recruitment of participants of all ages enabled the researcher to assess whether the system could reliably measure faster and slower reaction times.

Testing was performed in two occasions in a laboratory setting. The room was prepared to ensure the precision of the test results by avoiding visual or auditory distraction that could affect the performance of the participant throughout the tests (see Figure 6.3). On the first occasion, the consistency of the Kinect time-based measurements was assessed with the collaboration of a subset of 13 participants. To minimise bias on the data collection due to fatigue or acquaintance with the devices, a second testing phase was conducted five weeks later. On this occasion, the validity of the Kinect measure of the CSRT was evaluated with the collaboration of a sample of 10 participants.

Figure 6.3: mHealth Laboratory at the University of Technology Sydney

6.5 Evaluation 1: Consistency of the Kinect to Collect Time-Based Measurements

6.5.1 Procedures

In order to assess the correspondence of the time measurements taken by the Kinect, this test was designed to allow for the collection of data on both systems simultaneously. The CSRT task was delivered by the Kinect system while measurements were taken by both devices at the same time.

The six-panel layout on the MAT was fully simulated on the Kinect system by keeping the appropriate length proportions. This was to guarantee a full correspondence between the player movements and the avatar movements within the game. Throughout this experiment, the MAT was primarily used as a step logger.

In order to assure the integrity of the experiment, this device was attached to a Linux computer, which was merely dedicated to recording kernel events associated with the interaction with the MAT.

Prior to formal testing, each participant went through a calibration process in order to determine the proper floor plane and the participant's height. Then, the participants were asked to practise two trials on each panel. This procedure was to allow them to become familiar with the mechanics of the test and also to confirm their full understanding of the instructions. No data was recorded at this stage.

Once the calibration and practice trial were completed, each participant was instructed to complete the full test which consisted of a random sequence of 20 steps (four panels, five repeats per panel). The execution of this test was recorded by the Kinect and the MAT simultaneously.

Upon the completion of the previous stage, the subject was asked to complete a second trial under the same conditions (four panels, five repeats per panel) to confirm the repeatability of the test.

In both experiments, the Kinect and the MAT systems independently recorded stepping events, such as lifting a foot or stepping on a sector, along with a timestamp in milliseconds and microseconds accordingly. Timestamps in both systems were recorded as time values relative to the start-up time of the software programs.

6.5.2 Statistical Analysis

Stepping events recorded by both systems were analysed to assess the consistency of the Kinect time measurements. Pearson Correlation Coefficient *(Pearson's r)* was calculated in order to measure the strength of linear correlation between the two timing variables (Derrick et al., 1994). Finally, an Intraclass Correlation Coefficient model 3,1 *(ICC3,1)* was used to assess the consistency and agreement of the quantitative measurements taken by the two different systems, Kinect and MAT, when measuring the same parameter (time) (Shrout and Fleiss, 1979).

Samples of the collected data and statistical results are in Appendix B.

6.5.3 Results

Individually calculated Pearson Correlation Coefficients showed high association between the stepping data logged by the Kinect and the MAT systems throughout all the sessions (Table 6.1). Intraclass Reliability Coefficient was also performed individually and globally confirming both consistency and absolute agreement between the two systems *(Single Measures = 0.994, Average Measures =*

0.997 Significance = 0.000, Cronbach's Alpha = 0.997, N = 2).

Table 6.1: Evaluation 1: Correlation of stepping events (per panel)

Device	**Outcome**	**Panel**	**Pearson r**
Kinect vs. MAT	Time	LF	.994
		LL	.995
		RF	.994
		RR	.994

6.5.4 Findings

Stepping actions recorded by both systems were shown to be similarly distributed, thus confirming that the Kinect and MAT's variability was equivalent across the samples. Also, correlations between the two systems was high indicating strong association and agreement in the time-based measurement taken by both platforms. This suggests that the Kinect can be used as a reliable tool to measure timing events related to human movements, which is the foundation of the CSRT test for fall risk assessment.

6.6 Evaluation 2: Validity of the Kinect measure of the CSRT Test

6.6.1 Procedures

Participants were asked to perform the CSRT test on both systems. The order was randomised to counterbalance order effects. Prior to testing on the Kinect, each participant went through a calibration process in order to determine the proper floor plane and the participant's height. For both systems, participants were given a practice trial in order to become familiar with the mechanics of the test and to confirm their full understanding of the instructions. Later, they were instructed to complete a full CSRT task where execution of the test was recorded by the corresponding controlling software. Once the test was completed, they were asked to complete a practice trial and a full CSRT task on the other platform. In this experiment, the software that controls the MAT and the Kinect were run on the same computer to minimise bias in the measurements due to variability in computational power. As instructed in the original version of the CSRT test, the mean Reaction Time (RT) of 20 trials is measured and analysed. Also, the mean Decision Time (DT) and Movement Time (MT) were examined for a more descriptive assessment.

6.6.2 Statistical Analysis

In order to determine the validity of the Kinect-based CSRT, this evaluation was conducted in two steps. Firstly, the consistency and association of the three parameters (DT, MT and RT) per participant per panel was assessed. The Shapiro-Wilk test was utilised to assess the distribution of the time-based variables (Royston, 1992). The consistency and association of the three parameters (DT, MT and RT) were assessed by calculating the Pearson Correlation Coefficient and the Intraclass Correlation Coefficient model 3,1 *(ICC3,1)*. Secondly, the RT values were used to compute the CSRT test for both the Kinect and MAT and a similar analysis was then conducted.

6.6.3 Results

Regarding the consistency of the Reaction Times (RTs), the Shapiro-Wilk test showed normality across the log transformed time-based measures of the CSRT. The Pearson Correlation Coefficient showed high association between the values collected by Kinect and the MAT *(Pearson's r = 0.746)* (Table 6.2). Likewise, the ICC model 3,1 confirmed the consistency and agreement of the RT values across the samples *(ICC Single Measures = 0.657, Average Measures = 0.793, Significance = 0.000)*. Regarding the consistency of the Decision Times (DT) and Movement Times (MT), complementary parameters computed on the MAT version of the CSRT test; the Pearson correlation analysis determined that the DT values were highly correlated; however, the MT values reported a poor association (Table 6.2). Finally, the Choice Stepping Reaction Time (CSRT) test was calculated for both the Kinect and MAT as instructed in its original version. The Pearson r analysis showed high association between the CSRT values obtained by the Kinect and the MAT (Table 6.3). Similarly, the ICC model 3,1 confirmed the consistency and agreement between the CSRT measures computed with the Kinect and the MAT *(ICC Single Measures = 0.645, Average Measures = 0.784, Significance = 0.016)*.

Table 6.2: Evaluation 2: Correlation of timing variables (per panel)

System	Panel	Measure	Pearson r
Kinect vs. MAT	LF	DT	.6110
	LF	MT	.2100
	LF	RT	.7320
Kinect vs. MAT	LL	DT	.4350
	LL	MT	.1230
	LL	RT	.7550
Kinect vs. MAT	RF	DT	.7930
	RF	MT	.7060
	RF	RT	.7980
Kinect vs. MAT	RR	DT	.7030
	RR	MT	.1570
	RR	RT	.7680

Table 6.3: Evaluation 2: Correlation of CSRT, MT and DT

Device	Outcome	Panel	Pearson r
Kinect vs. MAT	CSRT	LF	.7875
	MT	LL	.3329
	DT	RF	.6430

6.6.4 Findings

This study shows that the Kinect-based system is able to compute the Choice Stepping Reaction Time (CSRT) task. Timing variables such as Decision Time (DT), Movement Time (MT) and Reaction Time (RT) were analysed to assess the capabilities of the Kinect to reliably perform a time-based clinical test. The variability of the reaction times was assessed and reported to be equivalently distributed in the Kinect and the MAT. Correlations between the Kinect and the MAT were high for RT suggesting that the Kinect could fulfil the requirements of the CSRT Test. In regards to the DT and MT values, the former showed high correspondence between the two systems whereas the latter reported a poor correlation. It is likely that the MT value did not agree completely due to the lack of precision in detecting the initiation of the user's leg movement (Webster and Celik, 2014). In the MAT this is determined by absence of pressure on the step panels whereas in the Kinect it is determined by the location of the foot in relation to the virtual panel, making it difficult to detect such a fine movement. In spite of this, the RT values were utilised to compute measures of the CSRT task. Statistical analysis and correlation demonstrated that the Kinect measure of the CSRT confidently agreed with the CSRT values computed by the MAT. In addition to this, the data presented shows that RT for the Kinect was overall shorter than for the MAT as shown in Figure 6.4, suggesting that this test might be slightly less cognitively demanding. It is likely that the immersive nature of this system and the appropriate provision of real time feedback removes the extra processing time required to operate with the MAT where stimuli are presented on the screen and the execution is expected to happen on the dance mat. Alternatively, participants may have felt more confident to step faster in space due to the absence of wearable sensors or a physical apparatus.

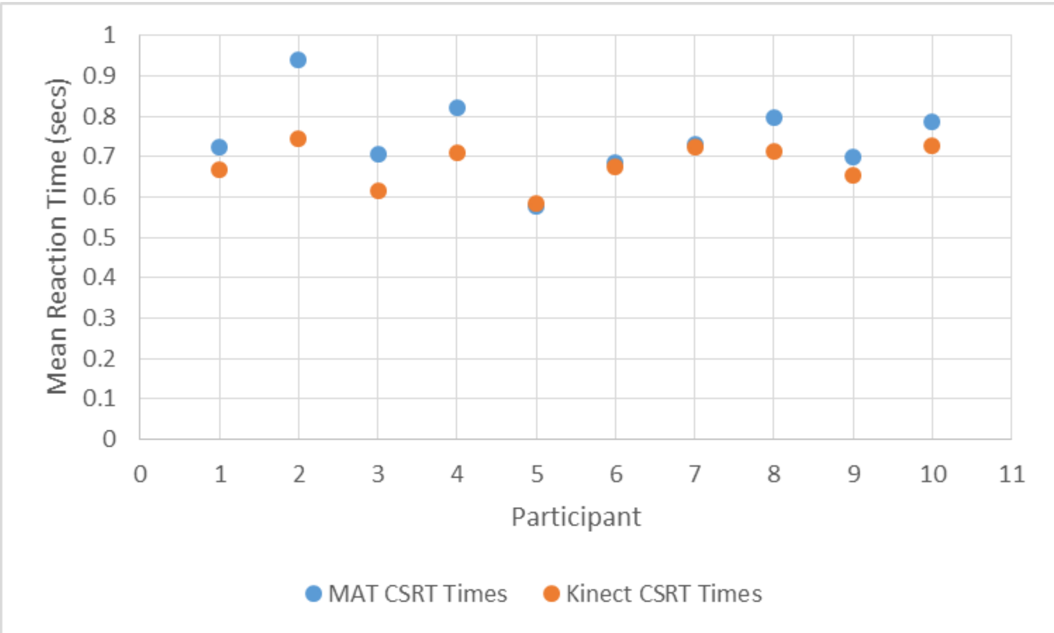

Figure 6.4: Comparison between average reaction times obtained with the Kinect and the MAT per participant per panel

6.7 Conclusion

As explained in Chapter 3, one of the main limitations in the available commercial games is the lack of mechanisms to reliably determine the improvement of mental and physical health. Although high scores have been linked to higher cognitive and physical functioning, observation has shown that players are very skilful and resourceful and always find a way to cheat within the game. Hence, the ability to measure clinically validated parameters during gameplay was identified as one of the aspects that required further research.

Subsequently, this study focused on comparing the developed Kinect-based system with a validated MAT-based version of the CSRT test. Firstly, the researcher evaluated the Kinect's capabilities to collect time-based measurements by collecting stepping responses with the two systems simultaneously. The results of this comparison showed high association between the Reaction Times (RT) and Decision Times (DT) values obtained in both systems, suggesting that the Kinect can measure time-based parameters in order to fulfil the requirements of the CSRT test. Secondly, the RT values were utilised to compute the CSRT test in order to assess the accuracy of the hybrid clinical test. Statistical analysis showed that both systems correlate favourably, suggesting that the Kinect version of the CSRT test is valid and reliable.

While the limitations in the sample size make it difficult to generalise the findings of this study and to determine the system's ability to differentiate between fallers and non-fallers, the findings are still considered relevant as the outcome measures are in agreement with the CSRT time measures of a well-established CSRT device.

This assessment was crucial for this project as it tested Hypothesis 1, that off-the-shelf game technology can be used to reliably perform a clinical test for fall risk assessment. Now this assessment tool can be confidently incorporated into a video game for fall prevention. This functionality not only allows for the validation of the correct exercise movements, but also allows for the assessment of physical and mental functions to determine progress and health improvements on an ongoing basis.

Chapter 7 presents the building of a fall prevention game mindfully designed for the elderly that delivers stepping exercises and has embedded the above described time-based test for fall risk assessment. The purpose of embedding the test is that it allows for the assessment of fall risk to determine the effectiveness of the intervention in an unobtrusive manner.

Chapter 7

The *StepKinnection* Game: Developing a Fall Prevention Game for the Elderly

7.1 Introduction

This chapter describes the development of the *StepKinnection* game, a Kinect-driven system mindfully designed to prevent falls in the elderly. This system combines three elements: appropriate age-related features, meaningful tasks aligned with the specific health outcomes, and an embedded clinical test for fall risk assessment. To develop this system, a series of evaluations were conducted to determine the playability and suitability of the game with the collaboration of 10 independent-living older adults. The results obtained during these studies highlighted the importance of utilising user-centred design techniques and running usability assessments in order to identify the key design aspects to suit the needs, preferences and capabilities of the elderly.

As stated in Chapter 3, the use of video games has become a popular approach to engage the elderly in physical exercise. The entertainment factor inherent in video games increases levels of motivation and enjoyment. However, the suitability of such games for the mental and physical health of the elderly is primarily determined by the design considerations that are taken into account throughout the development process (Gamberini et al., 2006). For that reason, it is important to incorporate special elderly-related features such as the inclusion of simple tasks, the use of large fonts and contrasting game graphics, in order to make these games more suitable for the elderly (Gerling et al., 2012). Game design guidelines have been developed in order to assist game designers and developers by presenting a set of general design considerations that have shown to be effective in previous studies on the use of games for health for the elderly (Ijsselsteijn et al., 2007; Gerling et al., 2012). However, as the aged community is not a homogeneous population, generalisations may not always be effective when it comes to designing video games with specific health purposes for the elderly.

Subsequently, two studies were conducted with the collaboration of two groups of independent-living older adults. The first study evaluates the usability of an initial version of the game that was developed following the design guidelines available in the literature. User-centred design methodologies are used to determine the acceptance and ease of use of the system. In the second study, several refinements are applied to the game and the usability of the system is again evaluated. The results showed fewer usability issues suggesting a favourable reception by the participants not only as a tool to entertain but as an alternative way to exercise.

The next section presents a brief summary of the related work in the area of game design for the elderly along with a compilation of the most relevant guidelines found in the literature.

7.2 Background

One of the main factors that determines the acceptance of a video game among the elderly is the inclusion of age-related features in order to satisfy their needs, preferences and capabilities. Several studies have shown that commercial games, which are originally designed for much younger audiences, might not always be perceived as enjoyable by the elderly (Neufeldt, 2009). The main reason lies in usability issues which relate to changes in the human body over the years. In Chapter 4, the usability of four balance games was assessed in order to determine whether these were suitable for the physical and mental health of an older person. The findings showed a set of hidden problems in such games, which could put an aged player at risk as these games do not accommodate their needs. For example, a disconnect between what is on the screen and what the user is actually doing may cause confusion for the player, resulting in feelings of anxiety and frustration while also affecting their balance reflex and mental satisfaction. Also, as people age, sight and hearing often deteriorate making it difficult for them to read or listen to instructions while the game is running.

In the work done by Ijsselsteijn et al. (2007), the researchers presented a compilation of age-related changes that should be considered when designing digital games for elderly users. Also, it is stated that, although each individual differs from others in terms of abilities and experiences, the human body tends to undergo a series of changes in sensory-perceptual processes, motor abilities and cognitive processes when getting older. In the work done by Flores et al. (2008), a similar study was conducted but focusing on finding a set of criteria for both; a) designing effective therapy for post-stroke patients and b) entertainment for the elderly. It was found that the most of the games for post-stroke rehabilitation did not include enjoyable content for the elderly.

In 2009, Gamberini et al. (2009) introduced a set of guidelines to assist the development of interactive tools for preserving cognitive functions that often decline with age. The work by Gerling et al. (2012) extends previous gaming design guidelines by developing a set of design principles regarding the use of full-body motion controls. It is relevant to mention that the latest generation of interactive games do not require players to press buttons in order to interact with the games, instead they encourage them to perform full-body movements which could be considered a form of exercise. Furthermore, these new guidelines aim to assist the development of gesture-based video games in order to ensure a wider accessibility and enjoyment for the elderly.

Since the main interest of this project is the use of video games as a tool to reduce the risk of falling in older people, this study focused on evaluating the usability and playability of a custom-made Kinect-driven game for fall prevention. Firstly, an interactive stepping game was developed following the most relevant design considerations found in the literature. Then the usability of this initial prototype is evaluated revealing hidden design issues. Based on the feedback obtained in the first evaluation, the game is rectified and a second assessment is conducted.

The next section presents a compilation of the most relevant guidelines that were utilised to build the first prototype as well as the methodology followed to conduct the usability assessment.

7.3 Game Design Guidelines Based On Age-Related Changes

In order to gather relevant design principles for the development of the Kinect-driven game a comprehensive search regarding game design guidelines for the elderly was conducted. This section presents a brief compilation of the most relevant aspects that were found that aim to assist the development of games for the elderly, and the design and evaluation of enjoyment in games. The guidelines were categorised based on the findings from Chapter 4.

7.3.1 Guideline 1: Concentration

As a consequence of ageing, the mental health suffers a series of changes that involve detriments in some cognitive processes such as: attention and vigilance, memory and learning, problem solving and reasoning among others (Gamberini et al., 2006; Gerling et al., 2012; Flores et al., 2008; Ijsselsteijn et al., 2007). Consequently, older players could find some difficulties when playing games that require a high load of memorisation such as remembering information from one screen to another one (Ijsselsteijn et al., 2007). Hence, having single tasks helps the user to keep their concentration and enjoyment in the game (Gerling et al., 2010). Also, incorporating a mechanism that assists the user in the navigation of the game reduces the memory load (Doyle et al., 2010).

7.3.2 Guideline 2: Challenge

Due to changes in motor abilities and cognitive processes, the user may experience slower response times that could lead to frustration due to the inability to reach the goal (Flores et al., 2008; Ijsselsteijn et al., 2007). Furthermore, providing the appropriate challenge allows the player to perform activities according to their abilities. Additionally, providing different levels of difficulty allows the user to start performing basic tasks to get familiar with the game and then perform more complex activities in advanced stages within the game (Lawrence et al., 2011), which could help to define the appropriate difficulty level for each individual.

7.3.3 Guideline 3: Player Skills

Although there is a belief that elderly users are not likely to use modern technology, recent studies have shown that this statement could be erroneous. Older adults use modern apparatus in daily activities such as mobile phones, microwaves, computers and the internet. In fact, they are willing to interact with new technologies when its use is properly taught (Gamberini et al., 2009). Thus, these games should have training phases before the real game starts, allowing the users to become familiar with the technology (Garcia et al., 2011b). Additionally, these training stages must be easy to skip when they are not required anymore (Doyle et al., 2010). Information regarding rules, suggestions and instruction should be given before and during the game, so the user does not have to read instructions and operate at the same time (Garcia et al., 2011b).

7.3.4 Guideline 4: Control

This dimension is related to establishing appropriate relations between movements and display as this could be confusing for the elderly player (Sweetser and Wyeth, 2005). They could learn erroneous reflexes in response to what they perceive from the game, which is potentially dangerous for the aged (Garcia et al., 2011b). Also, handling failure adequately could help the user to avoid feelings of frustration. It is highly recommended to avoid punishments within the game. Instead the game should reward the player's achievements (Ijsselsteijn et al., 2007).

7.3.5 Guideline 4: Feedback

The game must provide accurate feedback helping the player to focus on performing the activity (Flores et al., 2008). Appropriate feedback would also allow the therapist to know how well the patient is doing and identify improvements and progress. Additionally, providing redundant information through multi- modal interfaces (aural, visual, haptic) could be crucial to increase motivation, especially for elderly users who may suffer weakness in their sensory perceptual processes (Ijsselsteijn et al., 2007; Flores et al., 2008).

The next section describes the development of an initial prototype based on the design guidelines explained above.

7.4 Building a Game for Fall Prevention: Prototype 1

Based on these design guidelines, an interactive video game was created for the elderly that aims to improve balance and reduce the risk of falling. This game delivers balance training exercises and simultaneously measures stepping performance through the use of an embedded clinical test for fall risk assessment.

The following set of requirements were defined for the development of this system:

1. The game should require concentration and the player should be able to concentrate on the game.
2. The game should be sufficiently challenging and match the player's skill level.
3. The games must support player skill development and mastery.
4. The players should feel a sense of control over their actions in the game.
5. The player must receive appropriate feedback at appropriate times.

Similarly to the system described in Chapter 5, the Kinect was selected as the main input device as it facilitates the interaction with the game as no remote controllers are used. This is ideal for the elderly as minimal computer literacy is required.

In this system, the person stands in front of a computer screen or TV connected to a Kinect PC. Shortly after a stickperson (or avatar) mirroring the player's movements is presented. (Guideline 4: Control). In the main title screen, users get to select from four main locations by pointing at them with either hand. These are a garden, a desert, the South Pole and a Halloween theme. When the player makes their choice, visual and auditory feedback are presented to confirm the user's selection (Guideline 5: Feedback).

Once the location is selected users get to choose the level the wish to play in. Eight levels are available and each is represented by a number that is shown in a highly contrasting set of tiles (see Figure 7.1). (Guideline 2: Challenge)

Figure 7.1: Prototype 1: First version of the main menu

Once the level is selected, the main stepping task is then presented. During this task, the representation of the player is changed from the avatar to a pair of shoes mirroring the user's foot moves. This allows the user to concentrate on the task as it imitates what the user would see if they were stepping on the ground (see Figure 7.2). (Guideline 1 and 4: Concentration & Control)

Figure 7.2: Prototype 1: First version of the stepping task

The main task is to collect mushrooms that will appear on the screen. In order to collect a mushroom the user is required to step on them. Auditory feedback is presented to assist the player (Guideline 5: Feedback). The main motivation to include a stepping routine is that this ability has been shown to be one of the most effective strategies to prevent a fall from happening (Feldman and Robinovitch, 2007). By taking a proactive or reactive step a person can increase their base of support and subsequently regain balance. Hence, training this ability is crucial as it deteriorates as people age (Maki and McIlroy, 2006).

The score is primarily based on the number of mushrooms that the user collects and this will determine whether the user moves to a higher level or stays in the current one (Guideline 3: Player Skills). Initially, only the first level is available to play. Upon the completion of a level, the next level is then unlocked and the user is free to choose between playing the same level or moving to a higher one (see Figure 7.3). This allows the player to become familiar with the task and master it before the player moves onto a more difficult one (Guideline 3: Player Skills).

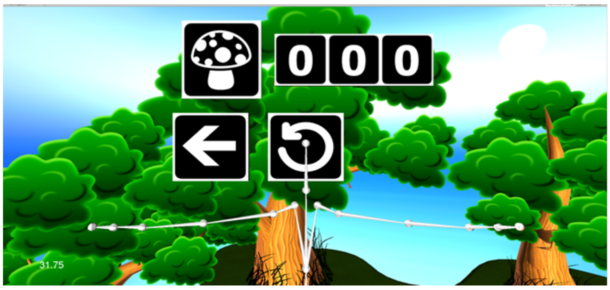

Figure 7.3: Prototype 1: First version of the “Results” screen

The game structure of Prototype 1 is presented in Table 7.1.

Table 7.1: Structure of Prototype 1, based on “Structure of a Game” by Fullerton et al. (2008)

Component	**Description**
Story	-NA
Player	-The player is represented by a pair of shoes mirroring the person movements
Objective	-Collect as many mushrooms as possible over a defined period of time
Procedures	-Step in space to collect a virtual mushroom
Rules	- The player must stay in the centre of the play area at all times - When a mushroom appears, only one leg can be moved - After collecting a mushroom, the player must return to the centre
Resources	-NA
Conflict	- Only one mushroom can be collected at the time - A mushroom disappears if not collected in a certain period of time
Outcome	- A level is completed when the player collects certain number of mushrooms - The player wins the game when passing all the levels
Challenge	-The speed at which mushrooms appear and disappear increases as the player moves through the game

7.5 Evaluation of Prototype 1

7.5.1 Procedures

This research assessed the usability of the interactive video which was conceived by following game design guidelines. A sample of five participants were recruited from a retirement village in Sydney.

The eligibility criteria are described as follows:

- had not contributed to the design of these instruments
- able to walk independently without assistance
- fluent in the English language
- aged over 65
- no vision impairments of colour-blindness

The researcher demonstrated and then evaluated the Kinect-based game for fall prevention with the cooperation of the managing staff and five residents of the Mirrabooka Village in Little Bay, Sydney. Firstly, an introductory session was conducted to present the project and let the participants interact with the first version of the game. This session started by explaining relevant facts regarding the positive impact that regular exercise has on preventing falls. Then, each participant had the chance to play with the game with the guidance of the researcher. After this, they were invited to participate in a one-to-one assessment with the purpose of evaluating the ease of use of the system in a personalised manner. Overall, these sessions were conducted as follows:

1. Participants were taught how to navigate through the menus and play the stepping task.
2. They played the game for a few minutes with the guidance of one of the researchers in order to become familiar with the game and confirm their full understanding of the instructions.
3. Later, they were tasked to switch between the four locations provided in the game as well as play three different levels of the main stepping task. This was to assess the intuitiveness and friendliness of the system.
4. Finally, a set of questionnaires were given to participants in order to assess the following aspects: Usability of the System (SUS Scale) (Brooke, 1996), Level of Exertion and Enjoyment (PACES Scale) (Kendzierski and DeCarlo, 1991), Challenge and Immersion (FSS) (Jackson and Marsh, 1996)and Gameplay Experience (PES Scale) (Pavlas et al., 2012).
5. Finally, the session was concluded with a semi-structured interview where participants were given the chance to express their feeling and attitudes towards the game in a more relaxed manner.

Participants were encouraged to provide oral feedback by remarking on the strengths and weaknesses of the game. Also, these sessions were video recorded for subsequent analysis. A copy of the participants' responses is included in Appendix C.

Written informed consent was obtained from the five participants prior to their participation in this evaluation. Also, this study was approved by the University of Technology Sydney Human

Research Ethics Committee, UTS Creativity and Cognition Studios two-page Ethics Approval Application HREC 2013000135 2013-7*.

7.5.2 Results

The questionnaires revealed that the game was perceived as easy to use, enjoyable and invigorating. Three of the five of the participants strongly agreed that:

1. they enjoy playing the game
2. the game is easy to use
3. the instructions of how to use the game were clear
4. they thought the avatar responds accurately and consistent to their movement.

When asked if they felt that time seemed to alter while playing the game, four out of five participants said that time seemed to pass by quicker than usual. When they were questioned about their attitudes and feelings towards the game, three of the five participants agreed that:

1. the game was appealing
2. they never felt frustrated while playing the game
3. they felt that playing the game was useful for improving their overall health
4. they would like to continue playing the game frequently.

Also, the majority answered favourably to questions concerning challenge or level of exertion, sense of control and ability to play without assistance. More importantly, when asked if they would consider using the system as means to exercise, all participants responded positively. Table 7.2 presents descriptive statistics regarding the most relevant aspects of the evaluation. Then again, the semi-structured interview revealed other aspects that the questionnaires did not show. For instance, three of the five participants stated that playing music during the stepping task would have made the game more enjoyable: *music will make it more fun* one lady said. Musical content was avoided intentionally as one guideline suggested that certain songs might affect the feelings of the participant by bringing up unpleasant memories. When questioned regarding the challenge of the workouts, participants had some contrasting opinions. Most of them stated that the game was suitable for their abilities: one subject even said *just be ready for what it comes!*. However, two participants did not agree with the rest of the interviewees. While a competitive participant expressed that he found the game *easy*, a 91 year old female thought the game was *quite challenging*. Also, two participants expressed that they found it difficult to see the *mushrooms* as the *wooden board* shown in the background was not contrasting enough. Surprisingly, when asked what features they would incorporate in the game, most participants said *it's good as it is*.

In regards to the potential benefits for mental and physical health, all the participants had favourable opinions. A male participant stated this *is good for the mind* while a female participant said *good for balance*. Two male participants said *it made me focus*. Finally, when asked if the game would motivate them to do their exercises, participants gave encouraging opinions. One 84 year old female said *at this age I hate physical exercise* but *this is fun and it's challenging it's fabulous*. Another female participant added *I'm lazy, but this... I'd use it every day*.

Table 7.2: Descriptive statistics for the perceived ease of use and suitability of the Prototype 1 game

Scale	Item	Mean	SD
Usability of the System (SUS) *1-to-5 rating scale, where 5: Strongly Agree.*	I felt very confident using the system	4.40	0.80
	I think that I would like to use this system frequently	4.00	0.71
	I thought the system was easy to use	4.60	0.80
Physical Activity Enjoyment Scale (PACES) *1-to-10 rating scale, where 10: Strongly Agree.*	I felt as though there was nothing else I would rather be doing	8.80	1.47
	I am not at all frustrated by it (the game)	9.8	0.40
	I enjoyed using the game as a means to exercise	7.00	0.00
	I am very absorbed in this activity	9	0.00
	I feel good physically while doing it	9.2	1.60
Flow State Scale (FSS) *1-to-5 rating scale, where 5: Strongly Agree.*	I really enjoyed the experience	4.60	0.49
	My goals were clearly defined	4.40	0.49
	I knew clearly what I wanted to do	4.20	0.40
	I loved the feeling of the performance and want to capture it again	4.40	0.80
	I felt I was competent enough to meet the high demands of the situation	4.00	0.89
	It felt like time went by quickly	4.20	0.75
	I made the correct movements without thinking about trying to do so	4.0	0.63
Play Experience Scale (PES) *1-to-5 rating scale, where 5: Strongly Agree.*	I was able to make the game do what I wanted it to	4.2	0.75
	I am able to use the game without help from anyone else	4.20	0.75

7.5.3 Observation

Observations and subsequent analysis of the recorded material showed that most of the participants were able to play with the game in an enjoyable way. In a few cases, additional explanations were provided regarding the use of the menus. Also, it was noticed that although most participants managed to change levels and switch locations, there was some difficulty interacting with screens that presented more than three options. In one case, an expression of frustration was observed when a female participant in her early 90s was attempting to select the level she wished to play but accidentally selected a different one.

7.5.4 Findings

Based on the results, the questionnaires showed that the participants had positive attitudes and feelings towards the game. This suggests that the guidelines used to conceive this prototype were helpful. Overall, participants found the game pleasant, easy to use and enjoyable. However, while the questionnaires showed that the game was appealing to the cohort, video recordings revealed some hidden problems regarding the usability and challenge of the system. There were some issues concerning the inability to select menu options due to inaccurate movement capture. Also, it was found that the level of exertion was not equally challenging for all the participants. Since the main interest of the game is to improve balance, the game needs to align to the expected health outcomes. Although the guidelines were shown to be beneficial, observation and user-centred design techniques play an important role in the development of a serious game for the elderly. The next section describes the development of a second prototype that takes into account the aspects mentioned above.

7.6 Building a Game for Fall Prevention: Prototype 2

As a result of the usability study described above, the requirements for the development of an enhanced prototype were refined, using the heuristic evaluation technique on the usability of the newly developed system. The next section presents a categorisation of the problems found concerning the following aspects: engagement with the game, avoidance of mental distress, and prevention of physical damage.

(A) Engagement: Lack of commitment and/or engagement due to the theme, challenges and/or diversion factors of the video game.

(B) Control of actions: Excess or deficiency of sensibility of controllers.

(C) Goal feasibility: Extreme difficulty to avoid hazards within the time limits, with too many obstacles and limited time periods.

(D) Mental health: Feelings of stress, anxiety and/or disturbance due to excessive memorisation, inadequate concentration requirement and dealing with the various menu choices of the game.

(E) Physical health: Physical issues caused by tightening up, falls, loss of balance, excessive requirement of workout, coordination and flexibility.

(F) Personalisation: User cannot modify the game settings according to their abilities.

(G) Alignment to health outcomes: Although the game was shown to engage the participants in a form of physical exercise, the stepping task by itself might not be sufficient to train other aspects linked to falls.

Based on these issues, the following set of heuristics were defined for the refinement of the game:

(I) Engagement: As requested by the participants, the game should play music during the stepping tasks. This music should also be aligned with the level of exertion to motivate participants and make the game more enjoyable.

(II) Control of actions: The gesture detection needs to be smoothed when actions are being translated into the game. Although the avatar responded according to the user actions, selecting menu options was difficult as the detection was too sensitive.

(III) Goal feasibility: In the higher levels, participants found it extremely difficult to play as there were too many obstacles and limited time periods. The pace of the game and the difficulty of the workouts should allow the player to operate without distress.

(IV) Mental health: Observation suggested that participants liked the idea of having different locations, but at the same time found it quite irrelevant and complex to use. The game should be intuitive and easy to use to avoid distress and frustration due to unnecessary memorisation.

(V) Physical health: Although the purpose of the game is to deliver relatively difficult exercise in order to train specific motor and cognitive functions, observation suggested that the level of exertion was not increased consistently. The game should allow the user to become familiar with the task and move on through the levels without being put at risk of falling.

(VI) Personalisation: The game should be customisable in order to accommodate the user abilities making it equally challenging for all the players.

(VII) Alignment to the health outcomes: The difficulty of the game should be aligned to the health purpose for which the game is being developed. Also it should stimulate and train the cognitive and motor functions associated with the problem that it aims to prevent.

On account of the above, the following design considerations were taken into account. Special attention was given to the inclusion of features and tasks that were aligned to the health issue of falling in the elderly. Hence, the fall prevention strategies presented in Chapter 2 were considered for the development of this prototype.

The entire game story was re-designed to make this game more appealing to this audience. In the new version of the game, the player is an explorer who travels around the globe visiting colourful countries, hunting for treasures and seeking different adventures (Heuristic I: Engagement). Each country presents an exciting challenge where the player gets to move to their traditional music and collect exotic fruits (Heuristic I: Engagement). Completing each challenge takes the player one step closer to winning a trophy. However, the further they travel the trickier it gets (Heuristic III: Goal Feasibility). Gameplay starts with a series of basic levels where players have the chance to become familiar with the game. Once they have finished these levels, players can move up to more challenging ones (Heuristic V: Physical health).

In order to play with the game, the player needs to stand in front of the TV facing the Kinect. Shortly after, the main menu is presented (see Figure 7.4).

Figure 7.4: Prototype 2: Interacting with the redesigned game

On this screen players can select from a list of countries to visit. Navigating through the menu is controlled by the player, using either hand to move the cursor (see Figure 7.5). An avatar mirroring the movements of the player is still shown on the screen. An algorithm to soften the hand movement detection was also incorporated making it easier for the user to select objects in the menu (Heuristic II: Control of actions).

Figure 7.5: Prototype 2: Navigating through the main menu

Once the level is selected the user moves to the main stepping task. Every now and then fruits appear on the screen, and the player is expected to collect them. In order to collect the fruits, the player needs to reach the fruits by stepping on them (see Figure 7.6).

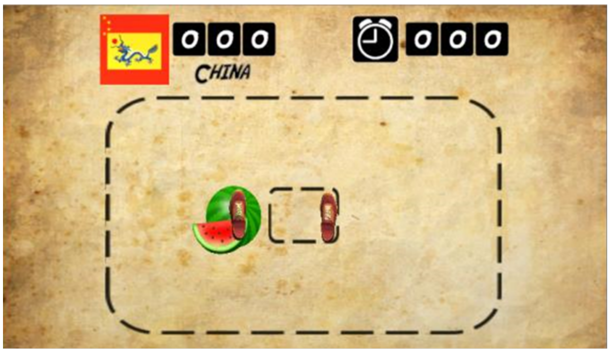

Figure 7.6: Prototype 2: Refined stepping tasks

The game guides the player through a series of stepping exercises which increase in speed and difficulty (Heuristic V and VII: Physical health and Alignment to health outcomes). For instance, in the mid-levels, a lady bug might randomly appear on the screen (see Figure 7.7). Stepping on a lady bug will take two penalty points off their current score reducing their chances of winning. However, if the player remains in position, one point will be awarded.

Figure 7.7: Prototype 2: Training motor inhibition

This augments the difficulty of the game by slightly increasing the cognitive demand through the use of a motor inhibition task. As mentioned in Chapter 2, adequate motor inhibition plays an important role in avoiding falls (Potocanac et al., 2014). Training this ability is ideal for hazardous situation where avoiding an obstacle can prevent a fall from occurring (Heuristic VII: Alignment to health outcomes).

In the higher levels, dollar coins also randomly appear on the screen for a split second (see Figure 7.8). These are bonus points that help players to move faster in the game, but they must step fast. For each dollar coin that they collect, two bonus points are added to their score.

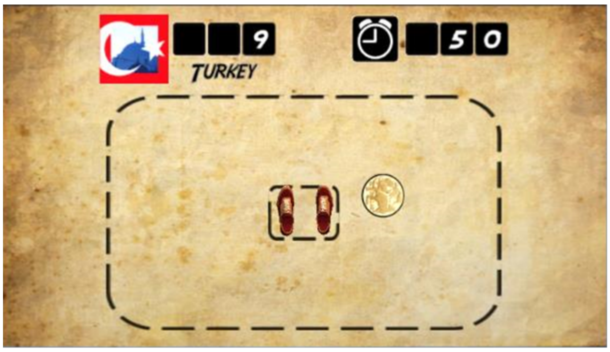

Figure 7.8: Prototype 2: Rewarding the player for taking rapid reactive steps

This is to reward the player as an incentive for taking reactive steps. This trains the ability to respond quickly to a hazardous situation (Pavol et al., 2004) which is ideal for circumstances where the person is put at risk due to a sudden changes in the environment such as stepping on a slippery surface. (Heuristic VII: Alignment to Health Outcomes).

Once a level is completed, a results screen is displayed showing the player's achievements and their next goal (see Figure 7.9). The system determines whether the player deserves a reward for outstanding performance (gold medals).

Figure 7.9: Prototype 2: Result presentation

Also, a pause pose is incorporated in order to allow the player to stop the game in case they feel fatigued or just wish to take a break (Heuristic II: Control of actions). By positioning both arms at the side, then moving the left arm straight out at a 45 degree angle from the player's body, the game can be stopped. A pause sign appears on the screen for a few seconds indicating that the game will stop (see Figure 7.10).

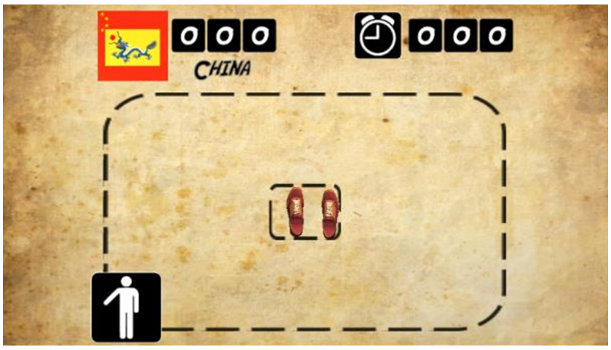

Figure 7.10: Prototype 2: The "Pause" Pose

At the beginning all the levels are locked, but these can be unlocked by increasing the accumulated score. As soon as the player increases their score, the system assesses whether to unlock a new country (or level) (Heuristic V: Physical health). This is to increase motivation as the game sets incremental goals for the player keeping them engaged with the activity. Also, this allows the player to become familiar with the task and master it before they move to higher levels avoiding potential injuries due to inability to cope with the exercise (Heuristic I and VI: Engagement and Physical health).

The speed of appearance and the size of the fruits changes as the user moves through the levels. This is to encourage players to perform quicker and more accurate steps while playing. The ability to take proactive steps can help an individual to regain balance and avoid a fall. Also, as the stepping area decreases, they need to be more coordinated to be able to step on the fruit (Heuristic VII: Alignment to health outcomes).

More importantly, the ability to customise the game to accommodate the player needs was incorporated (see Figure 7.11). For instance, the distance of the panels can be adapted as a percentage of the user height making the stepping task equally challenging for tall and short players. Also, the ability to turn on and off music and auditory feedback was incorporated. One participant wearing hearing aids mentioned that music could be disturbing due to her hearing impairments, therefore she preferred to exercise in silence.

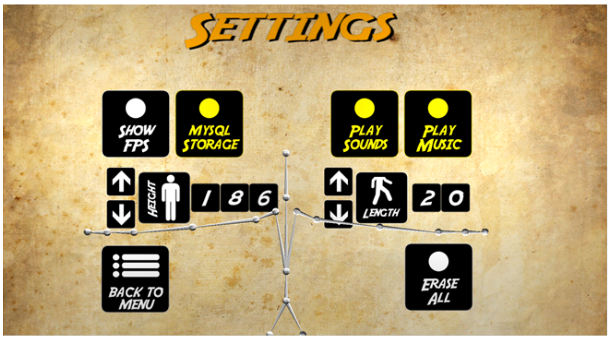

Figure 7.11: Prototype 2: Personalisation settings

Finally, since the game aims to reduce the risk of falling in older people, the Choice Stepping Reaction Time test described in Chapter 5 was incorporated into the game as a tool to clinically validate progress and improvement (Lord and Fitzpatrick, 2001). More importantly, Chapter 6 validated that the Kinect can consistently perform time-based tests, enabling this measure to be confidently used to assess the effectiveness of the game (Heuristic VII: Alignment to health outcomes).

The game structure of Prototype 2 is presented in Table 7.3.

Table 7.3: Structure of Prototype 2, based on "Structure of a Game" by Fullerton et al. (2008)

Component	**Description**
Story	- The player is an explorer who travels around the globe collecting exotic fruits
Player	- The player is represented by a stick-man during menus and a pair of shoes during gameplay
Objective	- Collect as many fruits as possible on each level - Win the *StepKinnection* trophy
Procedures	- Step in space to collect fruits - Take quick steps to collect coins - Stay still when a lady bug appears - Use "pause pose" to stop the game
Rules	- The player must stay in the centre of the play area at all times - When a fruit or coin appears, only one leg can be moved - After collecting a fruit or coin, the player must return to the centre - The player must not leave the play area - Game money will be given when collecting the target number of fruits
Resources	- Players earn game money after passing a level - Game money can be used to travel and unlock new levels - Collecting a coin results in two bonus points
Conflict	- Only one fruit can be collected at the time - Fruits and Coins disappear if not collected in a certain period of time - Stepping on a Lady Bug results in one penalty point - No game money is given when failing to collect the required number of fruits - Collected fruits are disregarded if game is stopped
Outcome	- A level is completed when the player collects certain number of fruits - The player is awarded with the *StepKinnection* trophy when passing the highest level and earning certain amount of game money
Challenge	As players move through the levels: - the speed at which Fruits and Coins appear and disappear increases, requiring faster reaction times - the chance of stepping on a Lady Bug increases, demanding higher levels of attention - the size of the fruits decreases at higher levels, increasing the need to accurately step on the fruits

The next section presents the results of an evaluation to determine the suitability of the new game for the physical and mental health of the elderly.

7.7 Evaluation of Prototype 2

7.7.1 Procedures

This second assessment was conducted to determine the usability, friendliness and responsiveness of the enhanced and more robust version of the developed stepping game.

Four participants from the same retirement village were recruited for this assessment. Two of them were part of the first study and had the chance to play with the first version of the game. The session started by presenting the project and explaining the importance of keeping active in the third age (65+ years old). The researcher then demonstrated the game and each participant played the game. After this, questionnaires on the usability of the system were handed out. On this occasion a unified questionnaire was used that combined the most relevant aspects found in the previously used scales to speed up the collection of data as some participants expressed that there were too many repetitive questions in the previous questionnaires. Finally, a semi-structured interview was conducted to identify hidden issues.

7.7.2 Results

The questionnaire revealed that the game was perceived as intuitive, enjoyable and very relevant. When asked about their experience with the new version of the game, a female participant stated that it was *exciting and positive, it is very relevant, acting and thinking simultaneously.* A man who was in the first study said *this [is] definitely much better that the one (game) you brought last time.* When questioned about the features they like about the game, three out of four participants agreed that it was easy to use, simple, clear and most importantly *doable.* Also, it was mentioned that music made it more fun and even *relaxing.* Questions regarding the challenge of the workouts showed that the game met their expectations. One participant said it is *not very hard* but *at a high level it could be challenging.* When they were asked if the game would motivate them to do their exercises, 3 of the 4 participants answered positively. One person even said *(the game) would get me moving those muscles that I rarely use, (this will) help me with my balance. Trying to improve score would be (an) incentive*, added another participant. When asked if they would like to use the game as a means to exercise in the future, all of them answered positively. One lady even stated that she would like to play it because it would *keep her moving and keep her focused.* Regarding the possibility of using the system in their own home, there were some contrasting opinions. While one participant was very excited because *it could be done in the home*, another participant stated *this is good, but in community environment.*

7.7.3 Findings

Based on the results and observations, the questionnaire and the semi-structured interview showed that the acceptance of the second game was higher than the first prototype. Overall, participants found the system easier to use and the menus were very intuitive. Participants seemed to like the simplicity and clarity of the game as a whole. Also, presenting less menu choices at once and the smoothed avatar actions made it easier for them to navigate through the menus. This gave them a higher sense of control allowing them to concentrate on what they want to achieve. Regarding the level of exertion, the ability to adapt the length of the steps to the user height made a significant difference for two players. While they struggled to play with the first version of the game, on the second version they were able obtain higher scores when the appropriate settings were applied. In regard to the cognitive tasks added to train specific functions related to the risk of falling, participants found the lady bug and the coins were an interesting feature for the game story. However, the impact these might have on their health outcomes still requires further evaluation.

7.8 Discussion

As explained earlier in this chapter, the use of video games to engage the elderly in physical exercise requires a deep analysis to guarantee optimum results on health practices. The evaluation of the first prototype showed that design guidelines concerning the age-related changes are extremely useful when building interactive games for the elderly. However, there are always hidden usability issues that will arise. User-focused methods such as the thinking aloud protocol and the heuristic evaluation can help to uncover these issues. These techniques can not only assess the usability of new systems but can also discover potential threats to the mental and physical health of the cohort. The elderly is a heterogeneous population and generalisations cannot be applied. Testing stages and conducting focus groups to assess the suitability of new games are always advisable.

Based on the first evaluation, the game was refined and the usability and acceptance of the second prototype was assessed. The main usability issues were the excessive sensitivity of the controls and the existence of meaningless content. The results showed fewer usability issues suggesting a higher acceptance by the participants. This confirms that the game is appealing to the cohort. Participants found the second version of the system clearer, more intuitive and more pleasant.

In regards to the level of exertion and challenge, the cognitive demanding activities and the ability to adapt the step length to the user height seemed to suit the user abilities. Since the game aims to improve certain motor and cognitive functions associated with falling, these tasks need be aligned to train coordination, muscle strength, attention, motor inhibition and the ability to respond quickly to hazardous situations. The game challenge was determined by the incorporation of tasks that were aligned to the problem of preventing falls, not just by increasing the number of obstacles in a linear way. Participants thought these were more meaningful and were a good complement to the game story.

7.9 Conclusion

As discussed earlier in this chapter, the favourable reception of interactive games often relies on the adequate inclusion of age-related features to accommodate the abilities of the cohort. Generalised game design guidelines have been developed in order to assist the development of such systems. However, as the elderly population is very heterogeneous, generalities may not always be applicable, especially when building games that are aligned to a particular health outcome.

Two evaluations were conducted to determine the suitability of a Kinect-based game that aims to reduce falls in the elderly. The first study focused on assessing the responsiveness of a game that was developed by utilising design guidelines. The results of this study were then used to refine the game and a second evaluation was conducted. According to the results, the second prototype presented fewer usability issues as it was easier to use and had clearer goals.

The analysis of the results also highlighted that, although design guidelines were shown to be helpful throughout the design process, these might not necessarily be connected with the specific health outcomes of the project. Furthermore, this study was important as it showed that user-centred design and usability assessment are vital to identify the key design aspects to suit the needs and preferences of the elderly.

The next chapter presents the result of a study to determine the effects that incorporating special age-related features might have on the physical and mental health of the elderly and whether this system has the potential to prevent falls in the elderly.

Chapter 8

Investigating the Long-Term Effects of Playing with the *StepKinnection* Game

8.1 Introduction

This chapter presents the results of a 12 week intervention to evaluate the effects of playing with the *StepKinnection* game, a stepping game mindfully designed for the elderly that aims to reduce the risk of falling. Since the main interest of this research is to determine the effects that this game may have on the physical and mental health of the elderly, 10 independent-living older adults were recruited for this pilot study.

As explained in Chapter 3, the use of interactive games available in the market has shown positive results in engaging the elderly in physical exercise and rehabilitation. However, there are some negative impacts which restrict the use of such games such as the limitation of available commercial video games which have not been designed for the purpose of providing therapeutic support for the elderly. The research objective of this work is to investigate the feasibility of using video games as an effective tool for improving the physical health of the elderly, more specifically, reducing the risk of falling. Based on the literature review and the research gaps that were identified, a fall prevention game for older adults should have three elements: integrate appropriate age-related features to suit the needs and preferences of the elderly, include meaningful tasks and exercise routines that are aligned to this health problem, and collect stepping performance data to validate the effectiveness of the intervention.

Chapter 4 reported an evaluation to assess the usability of four commercial games that were found to be relevant and widely used in the literature surveyed in Chapter 3. The results from this study suggested that, although video games can have a positive impact for the elderly, poor usability and inappropriate playable content can also result in drawbacks for them if their mental and physical conditions are not taken into account. This study highlighted the importance of a proper design regarding the inclusion of appropriate exercise routines and meaningful tasks to ensure the elderly benefit from such games.

In order to validate the proposed hypotheses, a proof-of-concept prototype was built that consists of a Kinect-based version of the Choice Stepping Reaction Time (CSRT) test. This system aims to illustrate that it is feasible to use off-the-shelf technology to perform a clinical test for fall risk assessment (refer to Chapter 5). A series of technical experiments were conducted in order to determine the concurrent validity of this system with an already validated response time device (see Chapter 6). After that, *StepKinnection*, a Kinect-driven system mindfully designed to prevent falls in the elderly, was developed. This system combines appropriate age-related features, meaningful tasks aligned with the specific health outcomes, and an embedded clinical test for fall risk assessment. Chapter 7 presented the results of a usability study that determined whether the *StepKinnection* game was easy to use and suitable for the aged cohort. The results obtained during this study highlighted the importance of utilising user-centred design techniques and conducting usability assessments in order to identify the key design aspects to suit the needs, preferences and capabilities of the elderly. More importantly, the results suggested that the integration of age-related appropriate features showed a favourable reception by the participants not only as a tool to entertain but as an alternative way to exercise.

This chapter investigates the effects of playing with the *StepKinnection* Game for 12 weeks. This study aims to determine whether it is feasible to use the game as a home-based training tool, establish whether the game could potentially reduce the risk of falling by improving several physical and cognitive functions associated with falling, and determine whether the collection of clinical measures during gameplay can be used as a reliable indicator of improvement (see Chapter 3). The next sections present the methodology used for this intervention followed by the results of the three evaluations, then discussion and conclusions.

8.2 Participants

For this study, 10 participants aged 65 years and over were recruited, with eight residents from two retirement villages in Sydney and two independent-living older adults. Table 8.1 summarises the characteristics of the study participants. Eligibility was determined by the following inclusion criteria:

- lives independently in the community
- aged 65 years and over
- able to walk independently without assistance
- fluent in the English language
- has a flat screen TV (LCD, LED or Plasma) with HDMI Port
- internet connection (ideal)
- able to watch TV with their glasses from 3 m away
- has enough room for system use (1.2 m - 2.5 m)
- no major cognitive impairments.

Table 8.1: Characteristics of the 10 study participants

Characteristics	**Value**
Mean Age ± SD	76.8 ± 6.73
Age - Range	67 - 84
Women (%)	80%

Key exclusion criteria were:

- requires the assistance of a caregiver or lives in an aged care facility
- inability to understand instruction (non-English speaking background)
- unstable health conditions
- blind or colourblind
- no HDMI source on TV
- cognitive impairments
- unable to walk independently
- unable to step unassisted.

Written informed consent was obtained from all participants prior to their participation in this study. Also, this research was approved by the University of New South Wales Human Research Ethics Committee (UNSW HREC HC12316) and ratified by the University of Technology Sydney Human Research Ethics Committee (UTS HREC 2012-279R).

8.3 Study Design

The study is a long-term approach that investigates the effects of playing with the *StepKinnection* game as a means to exercise and reduce the risk of falling in older people. Due to limitations in the sample size, a longitudinal study approach was selected which involves repeated observations of the same variables over a long period of time, in this case 16 weeks. For this study, all participants played with the *StepKinnection* game for 12 weeks. Assessments were conducted at baseline and every four weeks, including a follow-up assessment in week 16. The last evaluation is to determine the effects of discontinuing the intervention (see Figure 8.1).

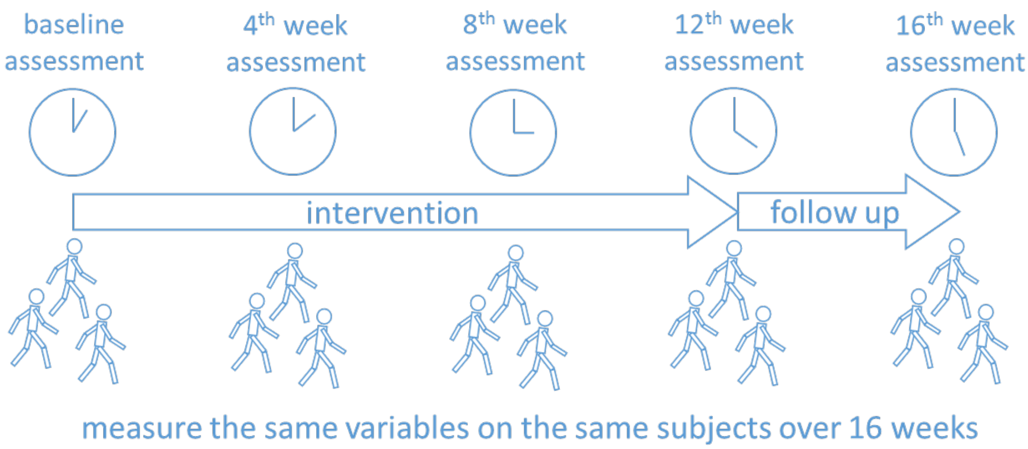

Figure 8.1: Design of the 12 week intervention study with 4 week follow-up

8.4 Intervention

Participants were provided with the developed Kinect-based step training system *StepKinnection* which consists of a small computer, a Kinect sensor and a wifi pocket modem (when required). The computer was attached to the participant's TV for the display of the game (see Figure 8.2). The Kinect was connected to the computer for skeletal tracking purposes. No controllers or wearable sensor are required to play the game. For three participants, a pocket wifi modem was attached to the computer for the purpose of uploading performance data on to a centralised server. The other seven participants had internet connection at their homes.

Figure 8.2: Technology components of the *StepKinnection* system

StepKinnection is an interactive video game for elderly users designed with the objective of reducing the risk of falling. The game consists of a traveller who needs to collect fruits around the world. In order to collect the fruits in each country, the player needs to reach the fruits by stepping on them. The player is guided by the game through a series of stepping exercises which increase in length and difficulty along with their health progress (see Chapter 7 for further details). For the stepping tasks in the game, the accuracy of the responses is automatically processed by the hybrid clinical test for fall risk assessment that is embedded in the game. Participants were encouraged to play as much as they wish. A minimum of three sessions of 20 minutes per week was the recommended dose. Participants exercised in their own homes with no supervision. Instructions were given upon installation and an instruction booklet was provided for further reading. To encourage ongoing use, participants were contacted either by phone or face-to-face on a monthly basis.

In week 8, 16 additional countries or levels were added to the original game in order to investigate the influence that new playable content may have on the subjects' adherence to the intervention. Finally, a phone number was provided to participants in case they had questions, inquiries or issues related to the use of the *StepKinnection* game.

The next section describes the methods for the assessment of changes in the physical and mental health.

8.5 Assessing Changes in Physical and Mental Health

8.5.1 Procedures

As explained in the previous section, clinical outcome measures were collected on a monthly basis in order to determine changes in the mental and physical health of the participants as a result of playing with the stepping game. For these assessments, participants were contacted prior to the assessment date and a two hour time slot was allocated to each person assessed. Assessments were performed in two different locations. For the village residents, these were performed in a quiet room within the retirement villages. For the independent-living participants, assessments were performed in a laboratory at the University of Technology Sydney. Participants were assessed under the same conditions at baseline, during the intervention, and at the end of the study in week 16. The assessment tasks are described below.

8.5.1.1 Mini Cog Test

The Mini Cog test was only used at baseline assessment in order to determine whether the participant had a mild cognitive impairment (Borson et al., 2003). In the literature it was found that this test has been widely used to discriminate between demented and non-demented older adults. The Mini Cog test consists of a three item recall task and clock drawing task (see Figure 8.3). One point is given for each word recalled without a cue and two points are given for successfully drawing the face of a clock. A minimum of three points is required to pass this test.

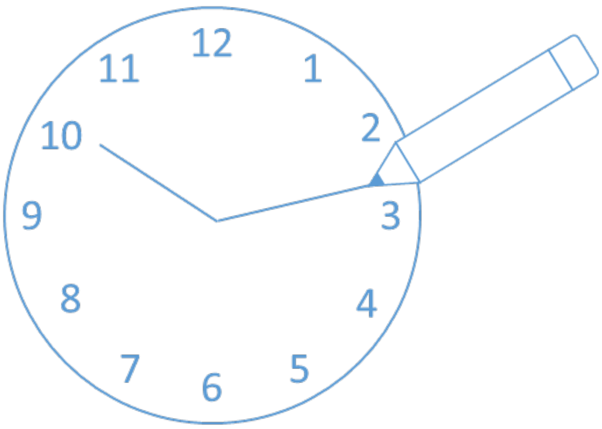

Figure 8.3: Baseline assessment: Mini cog clock drawing task

8.5.1.2 Gait Speed Test

In this test, participants are often instructed to walk a set distance of ten metres. However, due to space limitations the participants were asked to walk a set distance of eight metres, where two metres were given to allow participants to accelerate (and decelerate) to a comfortable walking speed (see Figure 8.4). The gait speed is then determined by dividing the covered distance over the time taken by the individual to walk that distance (Guralnik et al., 2000). The average time of three trials at normal speed is collected and compared to the average time of three trials at fast speed.

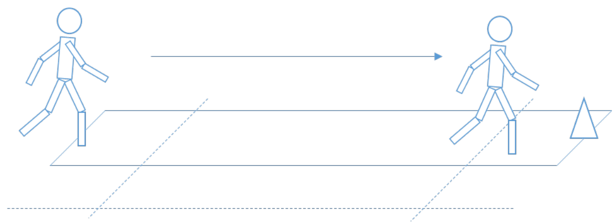

Figure 8.4: Assessment: Gait speed test

8.5.1.3 Timed Up and Go Test (TUG)

The Timed Up and Go test was used to assess mobility and dynamic balance of the participants (Shumway-Cook et al., 2000). Participants were asked to rise from a chair, walk a set distance of three metres indicated by a distinctive mark (in this case an orange cone), turn around, walk back to the chair and sit down (see Figure 8.5). The total time taken by the person to complete this task is measured. During the test, each person was expected to walk in the speed at which they would normally walk. The average time of two trials is used for the analysis.

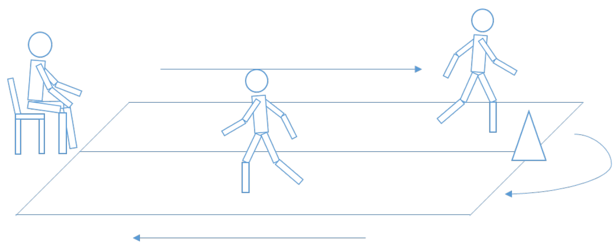

Figure 8.5: Assessment: Timed up and go (TUG) test

8.5.1.4 Choice Stepping Reaction Time (CSRT) Test

In the current version of the Choice Stepping Reaction Time (CSRT) test, the test is achieved through the use of a custom-made dance mat (or MAT) paired with a LCD monitor (Schoene et al., 2011). The person stands on the two central step panels of the mat while facing the LCD monitor (see Figure 8.6). Visual stimuli are presented on the LCD monitor and the user is expected to step accordingly on respective positions on the MAT. For this test, one of four surrounding panels illuminates on the LCD display and the person is required to step on this panel as quickly as possible and then return to the centre on the MAT. The sequence is presented randomly as well as the time between trials so that the user is unable to anticipate the time and location of the next stimulus. The mean reaction time of 36 trials is then measured and analysed.

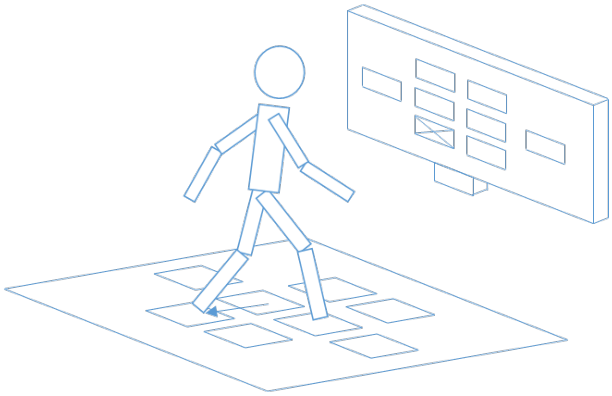

Figure 8.6: Assessment: MAT version of the Choice Stepping Reaction Time test

For the purpose of this study, the developed Kinect version of the CSRT test was also used. This was to assess the concurrent validity of this system with the MAT measure of the CSRT test in people over 65 years old. In the Kinect-driven system, the person stands in front of a computer screen or TV connected to a Kinect PC. The representation of the player in the system is a pair of shoes mirroring the person's feet movements. Six symmetrically distributed square-shaped virtual panels are drawn on the screen representing the step panels surrounding the person. The mechanics of the test are the same as the MAT version of the CSRT with the exception that the person steps in space (see Figure 8.7).

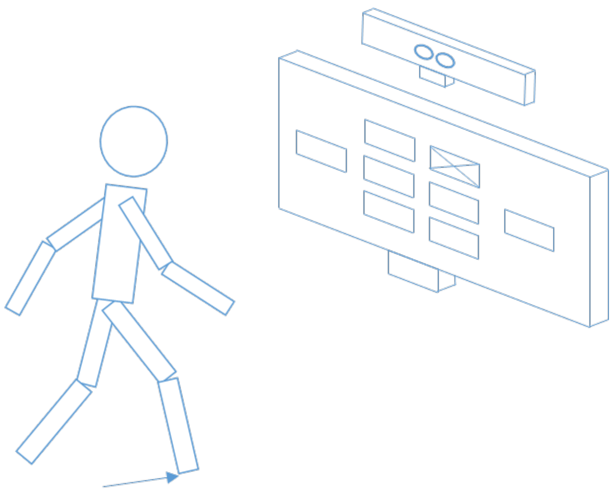

Figure 8.7: Assessment: Kinect version of the Choice Stepping Reaction Time Task

8.5.1.5 Inhibitory Choice Stepping Reaction Time Task (iCSRT)

Similarly to the CSRT test, this assessment involves the subject stepping onto a dance mat connected to a LCD display. Stimuli are presented on the LCD display and the subject is required to step accordingly onto the mat (see Figure 8.8). In addition to this, the Inhibitory CSRT test includes a response selection component which uses the "Go/No-Go" test paradigm (Schoene et al., 2013). During "Go" trials (indicated by the green colour) individuals are required to step as quickly as they can onto the mat. However, during "No-Go" trials (indicated by the purple colour) subjects are required to remain with both feet on the centre panels. The mean reaction time of 36 trials is also measured and compared to the measures obtained during the CSRT test in order to assess the interference of the increased cognitive demand.

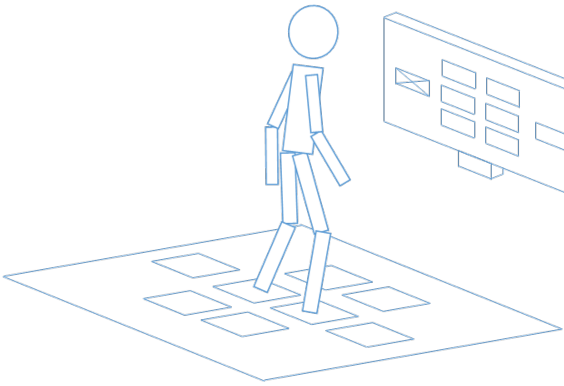

Figure 8.8: Assessment: Inhibitory Choice Stepping Reaction Time (iCSRT) task.

Note: During "No-Go" trials subjects are required to remain with both feet on the centre panels.

8.5.1.6 The Letter Digit Substitution Test

The letter digit test is a neuropsychological test sensitive to brain damage, dementia and depression (van der Elst et al., 2006). This tests consists of nine digit-letter pairs followed by a sequence of letters that randomly appear on the screen (see Figure 8.9). Upon the presentation of a letter, the subject is expected to name the corresponding number as fast as possible. The average response time of the correct trials is computed and used for the analysis.

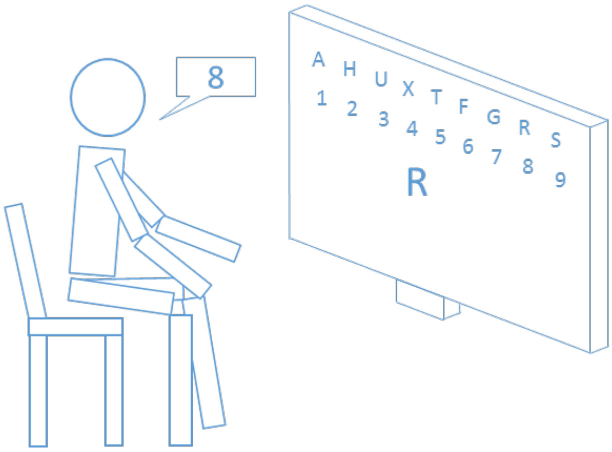

Figure 8.9: Assessment: Letter digit substitution test

8.5.1.7 Stroop Interference Test

The Stroop effect is a demonstration of interference in the reaction time of a task. This test involves the use of a LCD display paired with a computer running the Psychology Experiment Building Language (PEBL) software (Mueller and Piper, 2014) and a custom-made game pad that contains four coloured buttons: green, red, blue and yellow (see Figure 8.10).

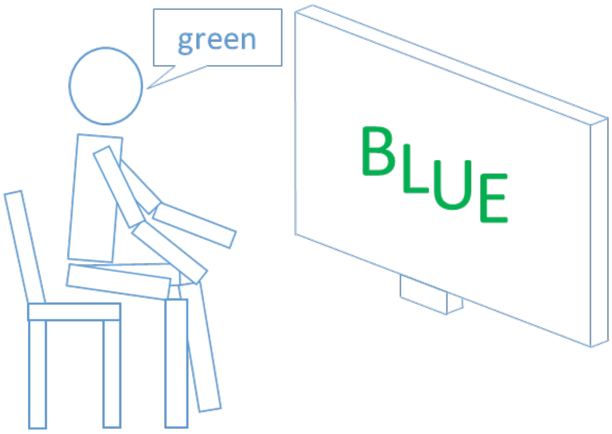

Figure 8.10: Assessment: Stroop interference test

In this test, the name of a colour is presented on the LCD display and the subject is expected to react accordingly by pressing the colour button on the game pad. The colour which the word is written in does not match the meaning of the word. Hence the subject must react to the colour which the word is written in and not read the word (Kane and Engle, 2003). For instance, if the subject reads the word “red”, but the word is printed in yellow ink, the subject is required to press the yellow button on the game pad. This means the player needs to consciously re-evaluate their instinctive response. For this test, the average reaction time of 24 trials is used.

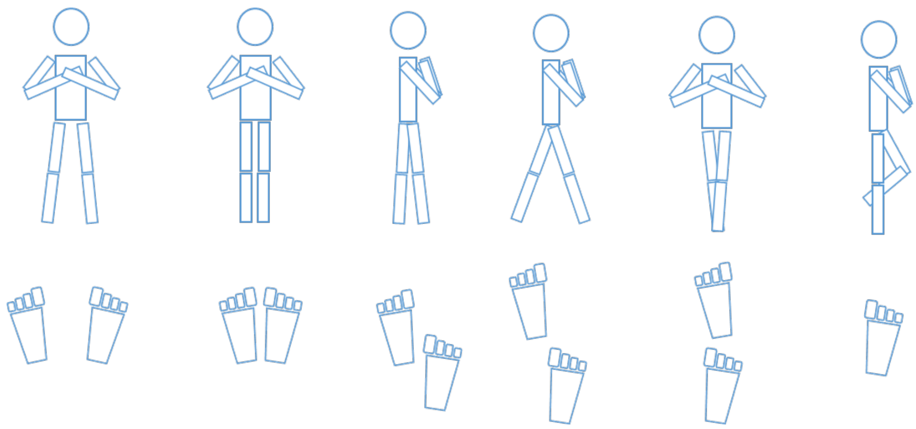

Figure 8.11: Assessment: Static balance test with six poses

8.5.1.8 Static Balance Test

This test is based on the premise that an individual needs a minimum of two senses to maintain a balanced position while standing. The three most important senses are: the ability to know the location of your body in space (also known as Proprioception), the ability to know the position of your head in space (also known as Vestibular Function), and the ability to monitor and adjust for changes in the position of your body (better known as Vision) (Khasnis and Gokula, 2003).

In this test individuals were asked to perform six different poses in which their base of support was reduced as they progressed through the test (see Figure 8.11). For each pose, the individual was required to maintain a balanced position for 10 seconds while holding their arms crossed. Although participants were encouraged to complete the six poses, they were also instructed to indicate whether a pose was considered uncomfortable or risky. If the individual failed to complete one of the poses, the test was suspended in order to avoid distress and potential falls. The total time that the individual was able to remain balanced is then used for diagnosis.

8.5.1.9 Five Repeats Sit to Stand Test

This test was used to assess functional lower extremity strength, transitional movements, balance, and fall risk (Lord et al., 2002). For this test, the subject is required to sit down with their back against the back of an armless chair (see Figure 8.12). Then, participants are asked to stand up and sit down five times as fast as they can while holding their arms crossed. To keep the individual oriented, each stand is counted aloud. The test finishes when the subject achieves the sitting position after completing the fifth repetition. The time taken by the participant is collected and used for subsequent analysis.

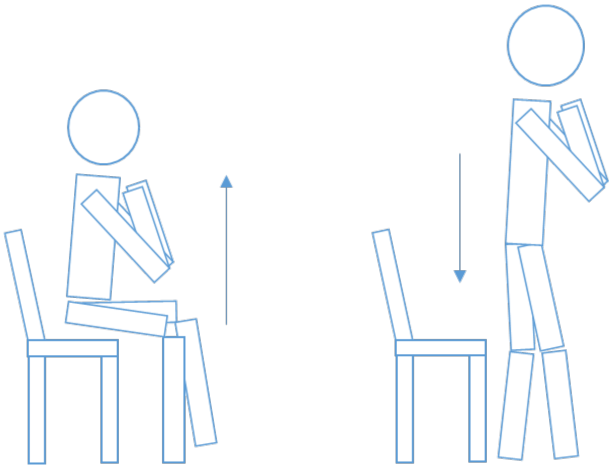

Figure 8.12: Assessment: Five repeats sit to stand test

8.5.2 Outcome Measures

In order to establish whether the game could potentially reduce the risk of falling, the following outcome measures were defined and collected throughout this experiment

- the Choice Stepping Reaction Time (CSRT) task was used to assess changes in physical performance (Lord and Fitzpatrick, 2001);
- the Time Up and Go test (Hassani et al., 2014), Sit to Stand test (Lord et al., 2002), Static Balance Test (Khasnis and Gokula, 2003) and Gait Speed test (Scott et al., 2014) were used to assess physiological functioning and risk of falling
- the Stroop Test (Kane and Engle, 2003) and the Letter Digit Test (van der Elst et al., 2006) were used to assess changes in cognitive performance

Samples of the collected measurements are in Appendix D.

8.5.3 Statistical Analysis

To investigate the effectiveness of the *StepKinnection* game, collected data was explored descriptively and graphically. Due to the small sample size of this study *(n = 10)*, non-parametric tests were applied for inferential statistics (Fraser, 1956). To determine changes over time Friedman's 2-way analysis of variance (ANOVA) by ranks was used (Demšar, 2006). Wilcoxon matched-pair signed-rank tests were then applied as post-hoc tests to determine which between group differences were significant (McCornack, 1965). Finally, the level of significance was set to 5%. Analyses were conducted using SPSS for Windows (Version 20).

8.5.4 Results

8.5.4.1 Gait Speed Test - Normal Walking

Statistical analysis shows a continuous increase in the gait speed measure across the subjects (see Figure 8.13). The Friedman ANOVAs model indicated that there was a significant difference between the four check points *(X^2 = 23.364, df = 3, p= 0.000, n=10)*. More importantly, a Wilcoxon signed-rank test showed that playing the *StepKinnection* game significantly changed the participants' ability to walk. The most noticeable improvements were observed between the baseline assessment and the first, second and third month of intervention *(Z = 2.803, p = 0.005)*. Also, there were significant differences between assessment 1 and 2 *(Z = 2.547, p = 0.011)*, and assessments 1 and 3 *(Z = 2.701, p = 0.007)*.

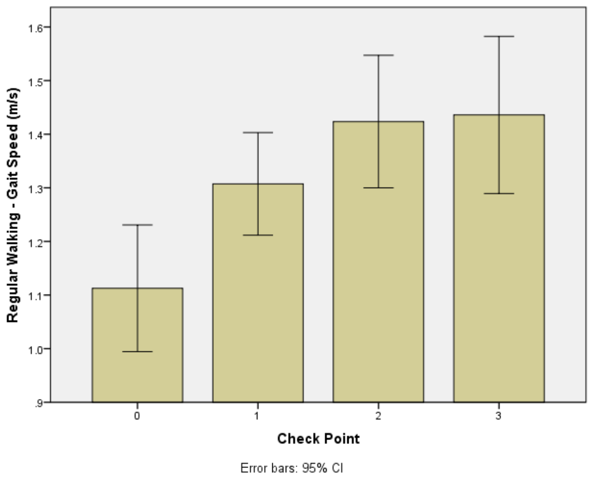

Figure 8.13: Results: Gait speed test - Normal walking

8.5.4.2 Gait Speed Test - Fast Walking

As showed in Figure 8.14, the results suggest a continuous improvement in the fast gait speed measured across the subjects throughout the intervention. Friedman ANOVAs showed significant differences between assessments *(X^2 = 14.455, df = 3, p = 0.002, n = 10)*. Post-hoc tests revealed significant differences between baseline and first month assessment *(Z = 2.09, p = 0.037)*, baseline and second month *(Z = 2.701, p = 0.017)*, baseline and third month *(Z = 2.395, p = 0.02)*, first month and second month *(Z = 2.192, p = 0.028)*, and first month and third month *(Z = 2.395, p = 0.017)*.

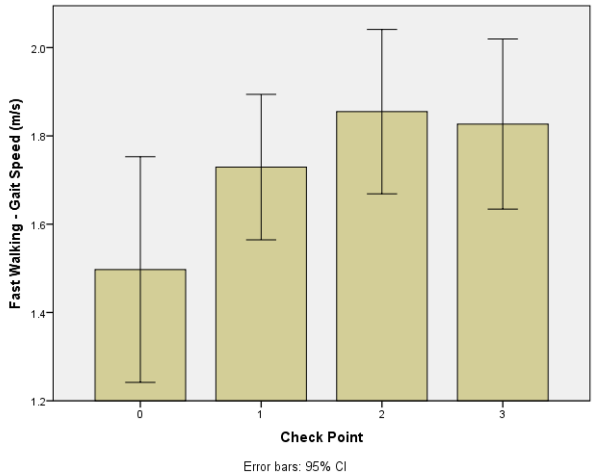

Figure 8.14: Results: Gait speed test - Fast walking

8.5.4.3 Timed Up and Go (TUG)

The Timed Up and Go test also showed significant improvements across the participants, where a continuous decrease in the time required by the subjects to cover the designated three metre distance was observed (see Figure 8.15). Friedman ANOVAs tests revealed that there were statistically significant changes throughout the intervention for all participants *(X^2 = 9.949, df = 3, p = 0.019)*. Although there were no differences between baseline and first month, the Wilcoxon signed-rank test revealed significant changes between baseline and second month *(Z = -2.599, p = 0.009)*, baseline and third month *(Z = - 2.652, p = 0.008)*, first month and second month *(Z = -2.192, p = 0.028)*, and first month and third month *(Z = -2.191, p = 0.028)*.

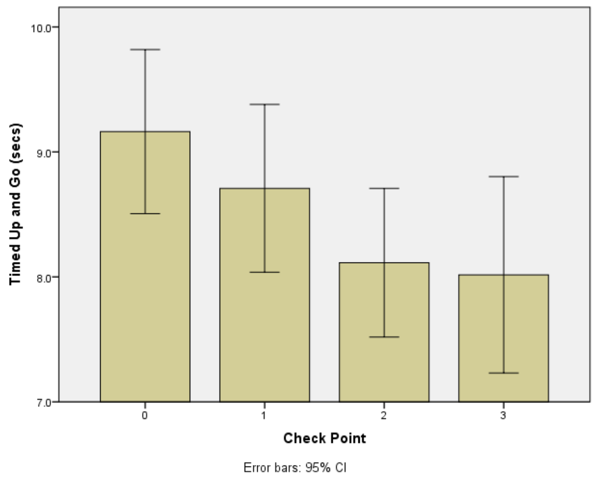

Figure 8.15: Results: Timed up and go (TUG) test

8.5.4.4 Choice Stepping Reaction Time Test (CSRT)

The CSRT test, being the most important outcome measure as the game builds on this test, showed significant improvements according to the Friedman ANOVAs test *(X^2 = 16.879, df = 3, p = 0.001)*. The most prominent improvement was observed after completing the first month of intervention where the Wilcoxon signed-rank test proved that there was a statistically significant change between the baseline and assessment 1 *(Z = -2.803, p = 0.005)*, baseline and assessment 2 *(Z = -2.803, p = 0.005)*, and baseline and assessment 3 *(Z = -2.701, p = 0.007)* (see Figure 8.16). For the subsequent assessments, this test reported a fairly stable behaviour across the participants.

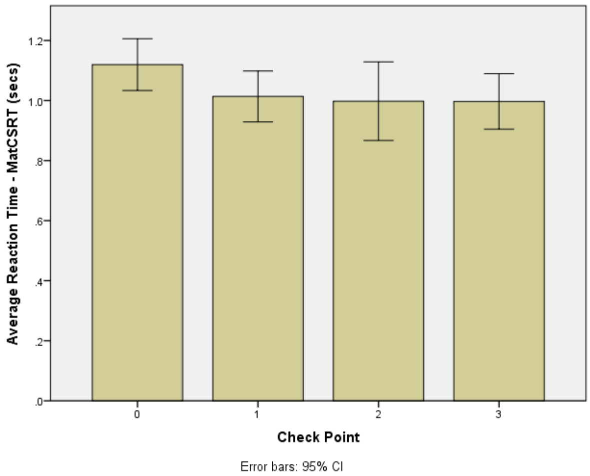

Figure 8.16: Results: MAT-based Choice Stepping Reaction Time

Similarly to the Kinect version of the CSRT test developed by the author, the MAT measure of the stepping test reported comparable results across the participants (see Figure 8.17). Despite the technological differences between these two platforms, the Friedman ANOVAs model indicated that there was a significant difference between the four assessments *(X^2 = 12.24, df = 3, p = 0.0.007, n = 10)*. A Wilcoxon signed-rank test showed noticeable improvement between the baseline assessment and the first month of intervention *(Z = -2.293, p = 0.022)*. Also, post-hoc assessments showed trends for improved stepping time performance between baseline and assessment 1 *(Z = -1.886, p = 0.059)*, and baseline and assessment 2 *(Z = -1.784, p = 0.074)*.

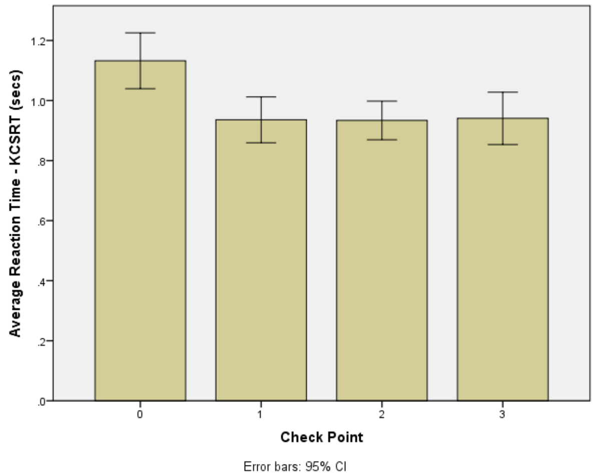

Figure 8.17: Results: Kinect-based Choice Stepping Reaction Time test

8.5.4.5 Inhibitory Choice Stepping Reaction Time Test (iCSRT)

For the Inhibitory CSRT test, graphical analysis shows trends for improved stepping performance with the inclusion of inhibitory stepping routines (see Figure 8.18). However, no significant differences were found across the subjects for all the assessments.

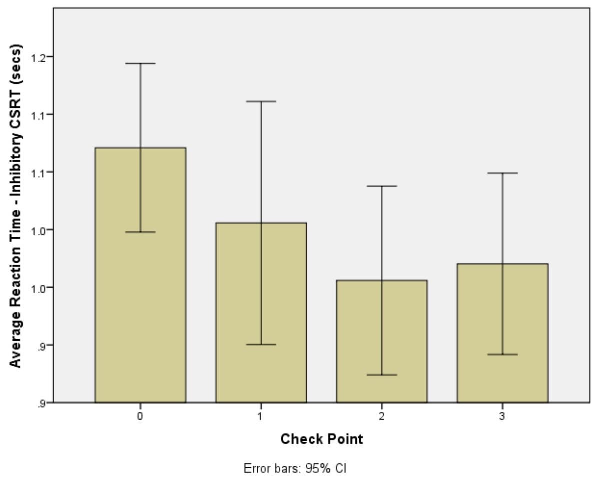

Figure 8.18: Results: Inhibitory Choice Stepping Reaction Time test

8.5.4.6 Letter Digit Test

Friedman ANOVAs test shows trends for quicker reaction times during the digit letter test for all subjects *(X^2 = 6.939, df = 3, p = 0.074, n = 10)* (see Figure 8.19). Post-hoc tests revealed statistically significant differences between baseline and first month assessment *(Z = -1.988 p = 0.047)* and trends for improvement between baseline and third month assessment *(Z = -1.886, p = 0.59)*. However, there were no substantial differences for the other assessments.

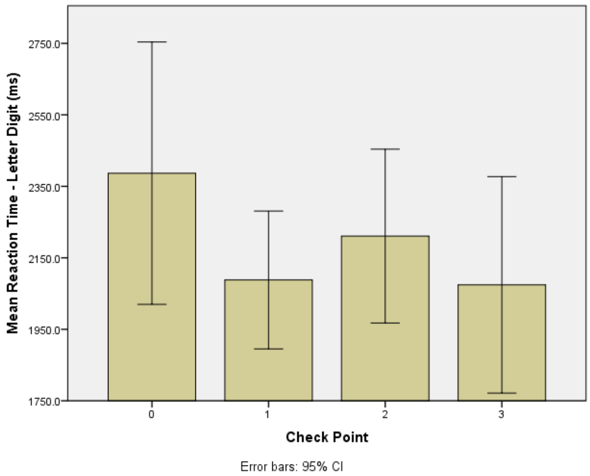

Figure 8.19: Results: Letter digit test

8.5.4.7 Stroop Interference Test

Similarly, the Stroop test results showed trends for quicker reaction times *(Friedman ANOVAs test X^2 = 6.236, df = 3, p = 0.101, n = 9)*. In addition to this, a Wilcoxon signed-rank test revealed that participants showed a significant difference in their reaction times between the first and second month *(Z = -2.429, p = 0.015)* (see Figure 8.20). Also, trends for improvement were observed between baseline and second month *(Z = -1.599, p = 0.110)*, and baseline and third month *(Z = -1.599, p = 0.110)*.

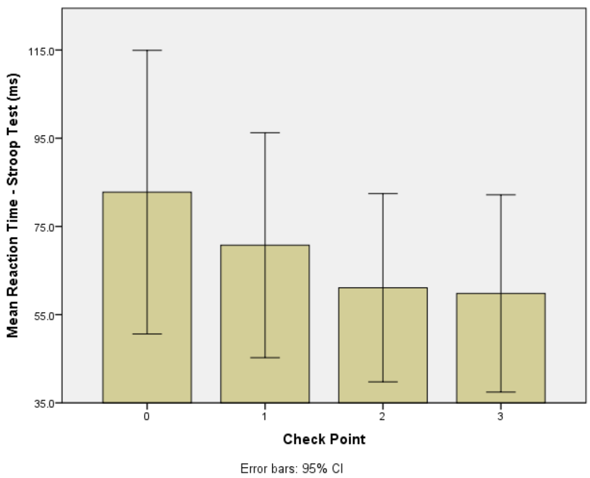

Figure 8.20: Results: Stroop interference test

8.5.4.8 Static Balance Test

As shown in Figure 8.21, a continuous improvement was observed across the participants throughout the intervention. Participants showed the ability to maintain a balanced position for longer periods of time during the experiments *(Friedman ANOVAs test, X^2 = 10.145, df = 3, p = 0.017)*. The most noticeable improvements were observed between baseline and second month and third month where the Wilcoxon signed-rank test showed statistically significant differences for these periods *(Z = 2.521, p = 0.012 and Z = 1.96, p = 0.05)*. Finally, trends for improvement were found between baseline and first month *(Z = -1.599, p = 0.110)*.

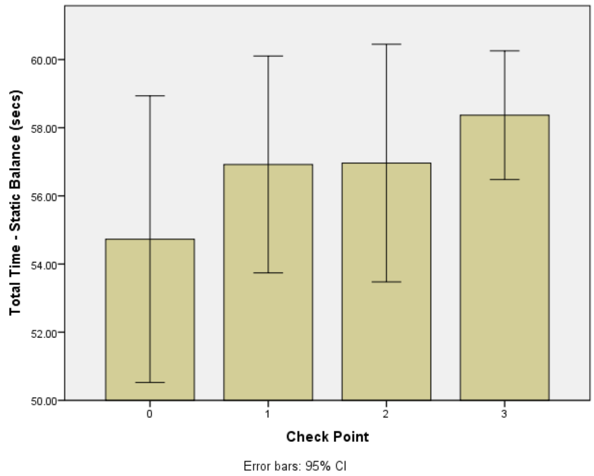

Figure 8.21: Results: Static balance test

8.5.4.9 Five Repeats Sit to Stand Test

The statistical analysis shows a continuous decrease in the time required by the participants to complete the five sit-to-stand test (see Figure 8.22). The Friedman ANOVAs model indicated that there was a significant difference between the four check points *(X^2 = 12.636, df = 3, p = 0.005, n = 10)*. Post-hoc tests revealed significant differences between baseline and first month assessment *(Z = -1.989, p = 0.047)*, baseline and second month *(Z = -2.395, p = 0.017)*, and baseline and third month *(Z = -2.701, p = 0.007)*.

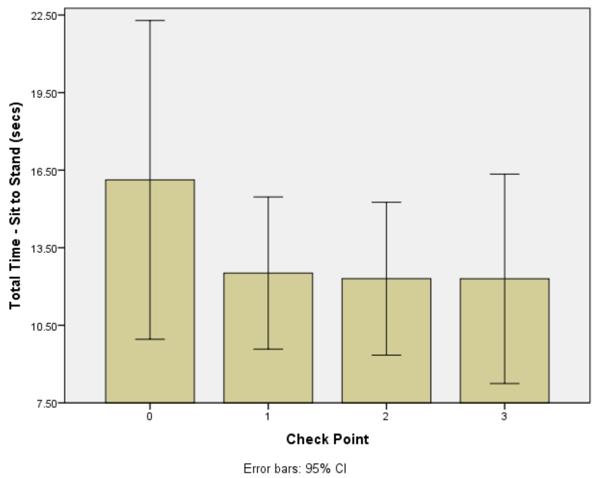

Figure 8.22: Results: Five repeat sit to stand test

8.5.5 Findings

Significant changes in the reaction times registered by both the Kinect and MAT version of the CSRT test were found, indicating improvements in the participants' central processing speed and movement velocity. While the MAT-driven test showed an overall improvement of 11%, the developed Kinect system registered an improvement of 17% (see Table 8.2). As explained in Chapter 6, the difference in the results is likely due to the technological differences of these platforms. While the MAT detects stepping actions based on pressure, the Kinect-driven system is based on the location of the lower limbs. Nevertheless, these values are in agreement with studies found in the literature where an eight week intervention with a modified version of the game Dance Dance Revolution showed a similar percentage of improvement in the CSRT test (Schoene et al., 2013). More importantly, the mean improvement of 192 ms (in the Kinect) and 123 ms (in the MAT), are clinically meaningful values as these are very similar to the 150 ms difference in CSRT times between recurrent fallers and non-fallers (Lord and Fitzpatrick, 2001).

The Timed Up and Go test results showed an overall improvement of 10% from baseline to the end of the intervention suggesting improved mobility, static balance and dynamic balance. This is a very important measure as it correlates very well with several tests for fall risk assessment such as the Gait Speed test, the Berg Balance Scale and the Barthel Index. Also, this mean improvement of 1.15 seconds is considered clinically meaningful as this agrees with the work done by (Lai et al., 2013), where a six week step training intervention on 30 older adults showed a similar improvement in the TUG task (1.0 second improvement, 10%).

The Gait Speed test also showed significant improvements across the subjects. This is a very relevant measure as the literature shows that slow gait speed is a good indicator and predictor of falls and fatality in high functioning older adults. Overall, participants increased their gait speed from *1.11 m/s (SD = 0.16)* to *1.44 m/s (SD = 0.19)* between baseline and the end of the intervention. This result suggests that playing the *StepKinnection* game can potentially improve muscle strength, sensation and coordination. This 29% improvement is considered clinically meaningful as it agrees with the work done by Agmon et al. (2011), where a 12 week intervention using a balance board to train strength and static balance showed a similar percentage of improvement in the Gait Speed test (*0.29 m/s* increment, 28%).

In the Five Repeat Sit to Stand test, there was a significant difference of 24% between baseline and week 12 of intervention, indicating that participants improved their flexibility, balance and muscle strength. The 3.8 second reduction in the time required by the participants to complete this task is considered clinically relevant as it is in agreement with a prior study found in the literature where a 10 week intervention on 55 older adults presented a similar level of improvement for this measure (3.72 second reduction, 21%) (Lee and Shin, 2013).

Also, there were significant differences in the Static Balance test suggesting improvements in several senses that are required to maintain balance while standing including proprioception (the ability to know one's body in space) and vestibular function (the ability to know one's head position in space). This test showed an overall improvement of 6.6% across the participants. Although this percentage of improvement was statistically significant, there was also observed a slight ceiling effect since participants were asked to perform the sixth pose for 10 seconds, not for as long as they could. Despite this, all subjects increased their ability to maintain a balanced position from 54.7 seconds *(SD = 5.58)* to 58.4 seconds *(SD = 2.51)* on average.

In relation to the cognitive measures, there were trends for improved processing speed and selective attention. The Digit Letter test showed a near significant improvement of 13% across the participants *(p = 0.074)*. This suggests that playing the *StepKinnection* game could potentially improve attention, response speed, visuomotor coordination, and incidental memory. Also, the Stroop test showed a 27% difference between baseline and week 12 of intervention. Although this improvement was not found statistically significant, participants showed a favourable reduction in the time required to complete this task improving from 82.78 seconds at baseline to 59.80 seconds at the end of the intervention. This mean improvement of 22.98 seconds may imply that conflict resolution tasks within the game may have been suitably challenging to produce such improvements. Finally, while the game included inhibitory stepping routines in the higher levels in order to train divided and selective attention as well as executive function, statistical analysis did not show significant changes for the

Inhibitory CSRT test among the participants. Although there was a mean reduction of 6% between baseline and week 12, the level of significance is not sufficient to determine that this change was a consequence of playing the stepping game *(p = 0.457)*. This null finding may be due to some technical difficulties with the MAT reaction time device, which in several occasions did not register stepping actions performed by the participants leading to reduced data entries for comparison.

Table 8.2: Summary of results from 10 outcome measures at baseline and 3 assessments

Outcome Measure	**Units**	**Baseline Assessment Mean ± SD**	**Week 4 1st Assessment Mean ± SD**	**Week 8 2nd Assessment Mean ± SD**	**Week 12 3rd Assessment Mean ± SD**	**% change from baseline**
Gait Speed	m/s	1.5 ± 0.3	1.73 ± 0.2	1.85 ± 0.2	1.83 ± 0.26	22% [a]
Fast Gait Speed	m/s	1.11 ± 0.2	1.31 ± 0.1	1.42 ± 0.2	1.44 ± 0.19	29% [a]
TUG	s	9.16 ± 0.9	8.71 ± 0.9	8.11 ± 0.8	8.02 ± 1.04	-13 [a]
Kinect CSRT	ms	1132.44 ± 123.5	935.91 ± 101.3	933.9 ± 85.3	940.74 ± 115.7	-17% [a]
Mat CSRT	ms	1119.73 ± 114.3	1013.68 ± 112.6	997.85 ± 173.6	996.99 ± 122.55	-11% [b]
Inhibitory CSRT	ms	1095.97 ± 96.9	1030.72 ± 139.7	980.87 ± 108.5	995.3 ± 104.29	-9% [a]
Letter Digit	ms	2386.76 ± 486.7	2088.02 ± 255.9	2210.67 ± 322.5	2074.43 ± 401.7	-13% [a]
Stroop	s	82.78 ± 39.4	70.75 ± 33.8	61.1 ± 28.3	59.8 ± 29.66	-28% [a]
Static Balance	s	54.73 ± 5.6	56.92 ± 4.2	56.96 ± 4.6	58.37 ± 2.51	7% [b]
Sit to Stand	s	16.13 ± 8.2	12.52 ± 3.9	12.3 ± 3.9	12.3 ± 5.37	-24 [a]
StepKinnection CSRT	ms	958.21 ± 106.3	846.86 ± 91.2	782.89 ± 68.5	794.67 ± 82.05	-17% [a]

[a] Statistically significant improvement at 5% level.
[b] Trends for improvement.

8.6 Assessing Ease of Use, Enjoyment and Adherence

8.6.1 Procedures

To determine whether it is feasible to use the game as a home-based training tool, a set of validated usability questionnaires were used after completing the first month of the intervention.

8.6.2 Outcome Measures

In order to assess enjoyment, adherence and the ease of use of the system, the following questionnaire-based scales were utilised:

- Attitude to physical activity was assessed through the Physical Activity Enjoyment Scale (PACES) (Kendzierski and DeCarlo, 1991).
- Gameplay and flow were assessed through the Play Experience Scale (PES) and the Flow State Scale (FSS) (Jackson and Marsh, 1996).
- The ease of use and friendliness of the game was assessed through the Systems Usability Scale (SUS) (Brooke, 1996).
- Feelings towards the game not covered in the other questionnaires, such as aspects that would make the game more enjoyable, difficulties experienced during the intervention and features that were not so good, were assessed through a semi-structured interview.
- Compliance and adherence to the exercise intervention were assessed throughout the intervention period with the system logs.

The participants' responses and statistical results are in Appendix D.

8.6.3 Statistical Analysis

To identify the participants' feelings and attitudes towards the *StepKinnection* game as a means to exercise at home, quantitative data obtained through the usability questionnaires were explored descriptively and graphically. For qualitative items obtained during the interviews, the answers were categorised and quantified to facilitate the presentation of the results.

8.6.4 Results

The usability questionnaires revealed that the game was perceived as easy to use, playful and enjoyable (see Figure 8.23). Results showed that seven of the 10 participants strongly agreed that they enjoyed playing the game, and instructions on how to use the game were clear, brief and precise.

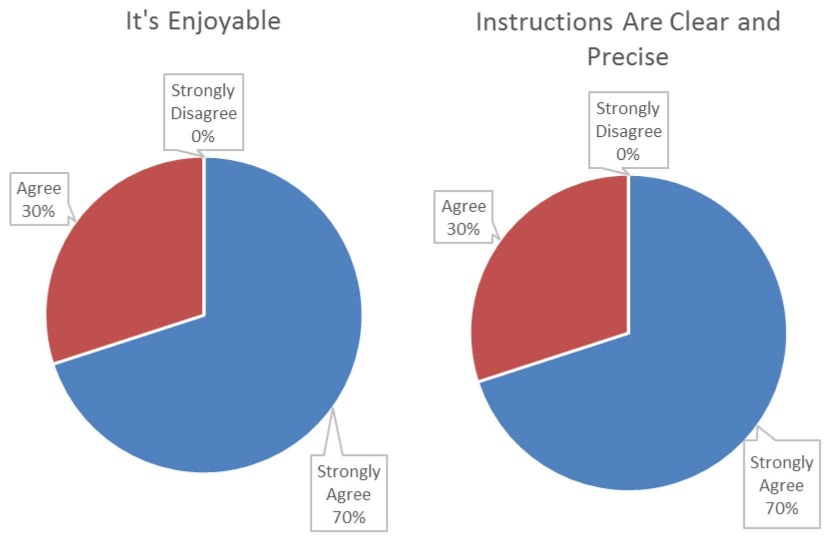

Figure 8.23: Participants' responses to questions on enjoyment and instructions

When asked if they felt that time seemed to alter while playing the game, nine out of 10 people responded favourably (see Figure 8.24). In fact, four participants said that time seemed to pass by quicker than usual and six participants indicated that they performed the exercises without even thinking about it.

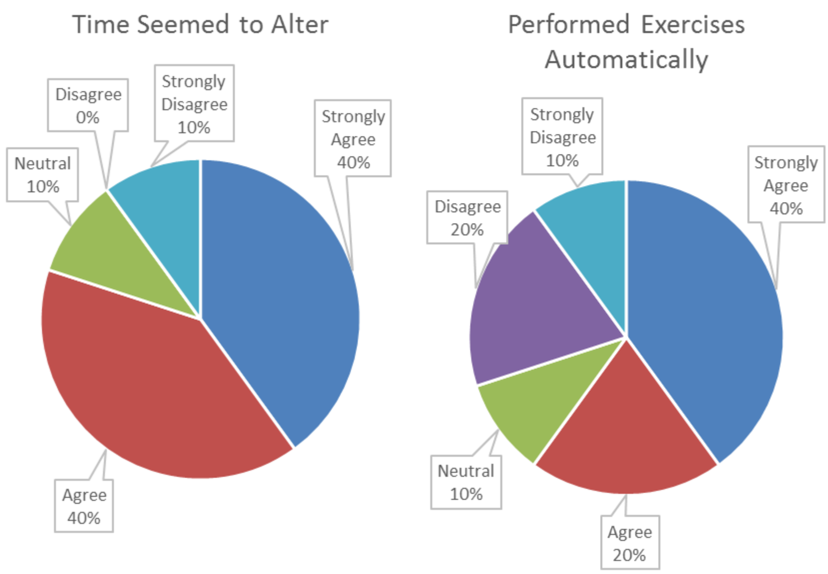

Figure 8.24: Participants' responses to questions on engagement and immersion

When participants were questioned about their attitudes and feelings towards the game, six agreed that the game was appealing, the game is playful, and they were able to use the game without help from anyone else (see Figure 8.25)

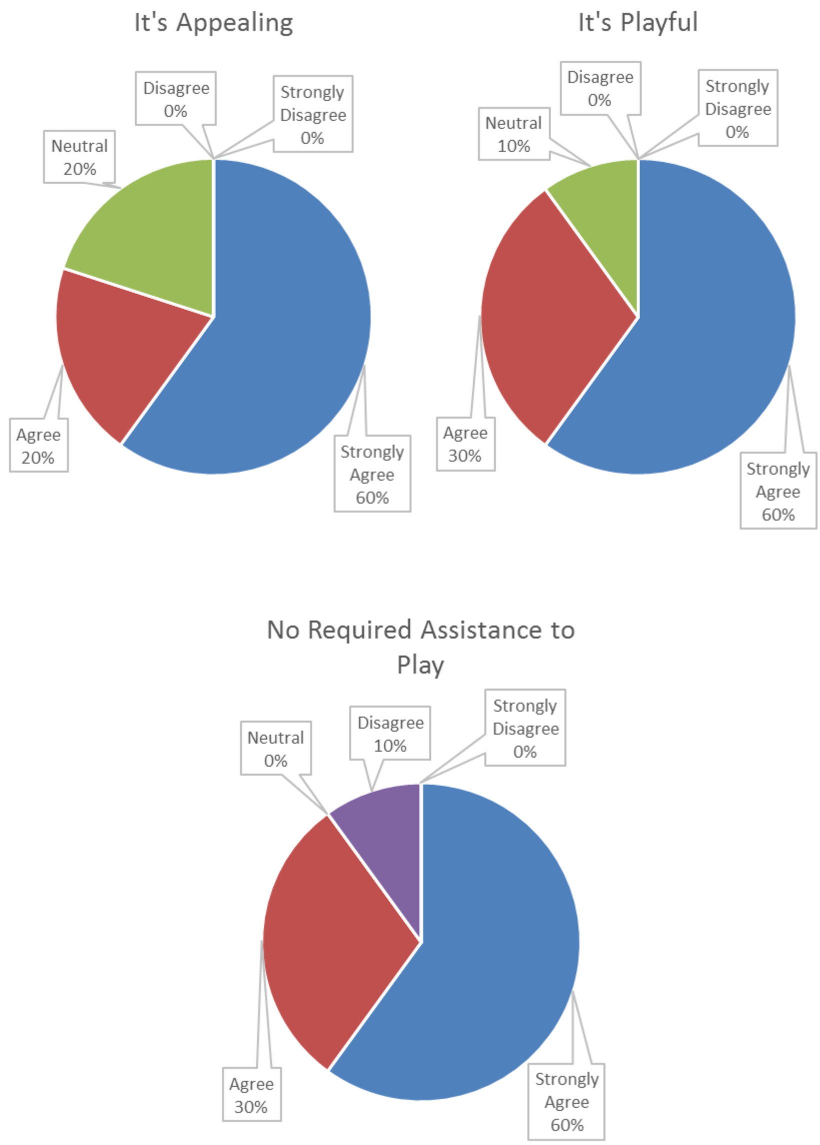

Figure 8.25: Participants' responses to questions on appealing, playability and requirement of assistance to play

Regarding the accuracy of the controllers and the ability to interact with the game, seven of the participants strongly agreed that the game reacted consistently to the movements they performed. Six out of 10 participants stated that they thought the avatar responded accurately and consistently to their movements (see Figure 8.26).

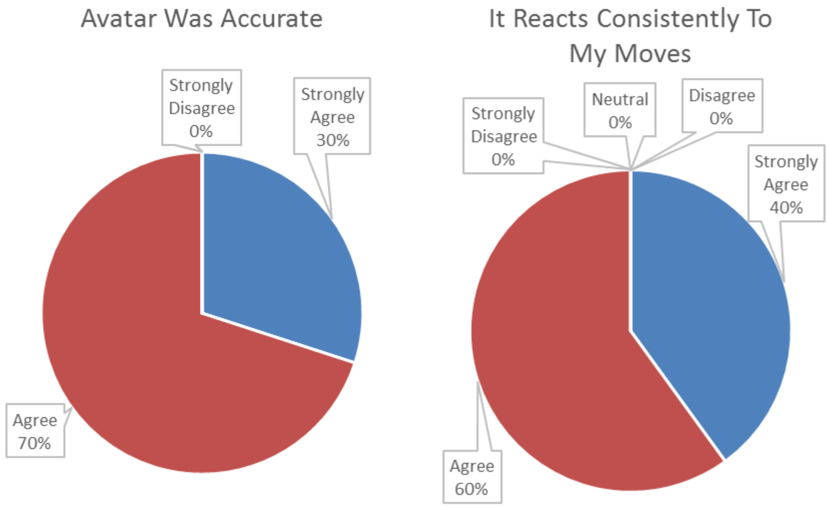

Figure 8.26: Participants' responses to questions on accuracy of the controllers

As shown in Figure 8.27, the majority also answered favourably to questions concerning challenge or level of exertion. While nine of the participants agreed that the game felt suitably challenging, there was one participant who did not agree at all.

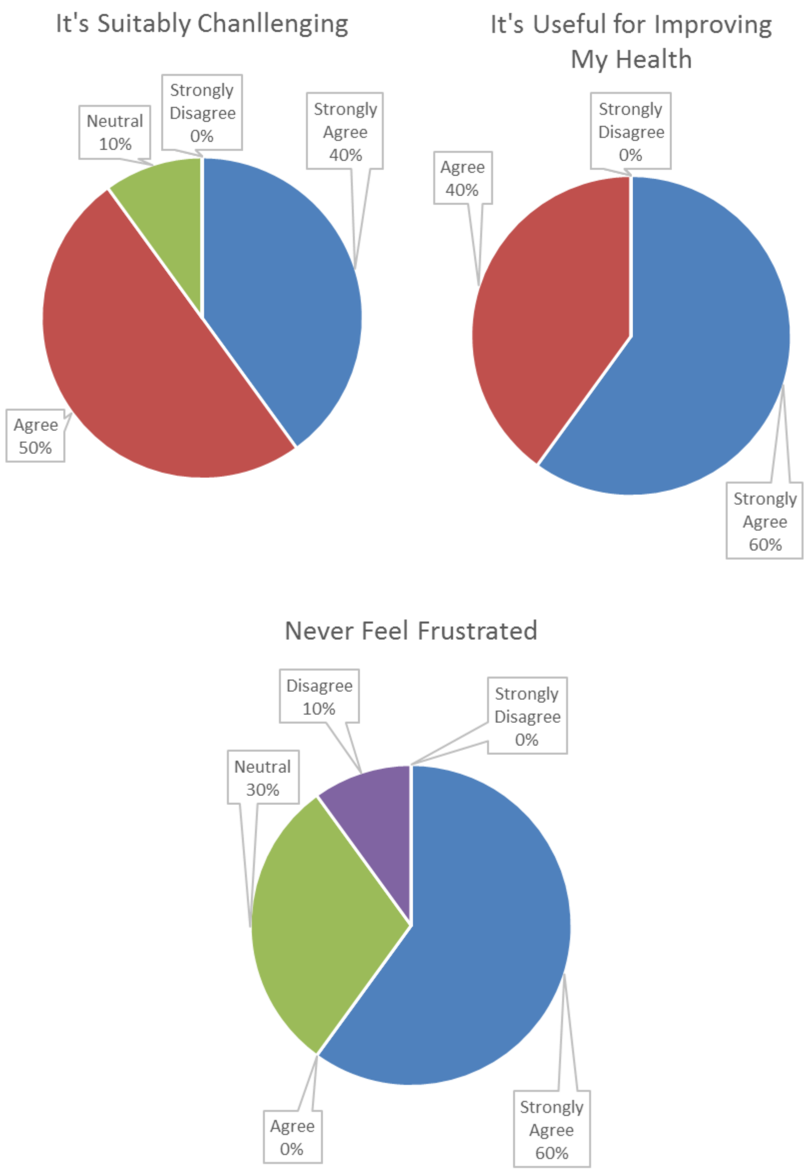

Figure 8.27: Participants' responses to questions on the level of difficulty, challenge and potential benefits for physical and mental health

On the potential benefits for mental and physical health, all participants expressed favourable opinions (see Figure 8.28). They felt that playing the game was useful for improving their overall health (six strongly agreed, four agreed). Six people even said they never felt frustrated while playing the game.

When asked if they would like to continue playing the game frequently, eight interviewees agreed with this statement, and the remaining two neither agreed nor disagreed.

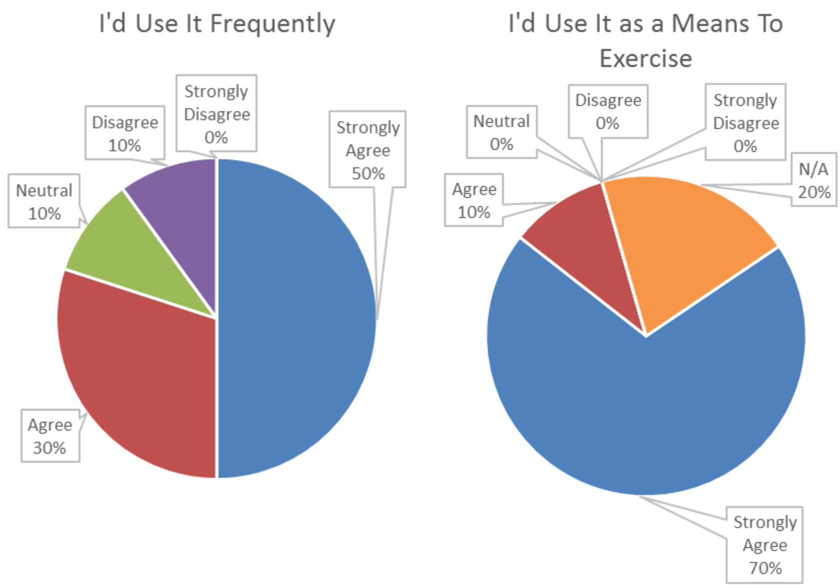

Figure 8.28: Participants' responses to questions on adherence

More importantly, when asked if they would consider using the system as a means to exercise, the majority responded positively: seven strongly agreed, one slightly agreed and two did not respond. Table 8.3 presents descriptive statistics regarding the most relevant aspects that were considered for this evaluation.

Table 8.3: Descriptive statistics for the perceived ease of use and suitability of the game

Scale	Item	Mean	SD
Usability of the System (SUS) *1-to-5 rating scale, where 5: Strongly Agree.*	I felt very confident using the system	4.6	0.66
	I think that I would like to use this system frequently	4.4	0.92
	I thought the system was easy to use	4.6	0.49
Physical Activity Enjoyment Scale (PACES) *1-to-10 rating scale, where 10: Strongly Agree.*	I felt as though there was nothing else I would rather be doing	7.33	3.27
	I am very absorbed in this activity	7.33	3.53
	I enjoyed using the game as a means to exercise	7.12	0.33
	I am not at all frustrated by it (the game)	8.38	2.34
	I feel good physically while doing it	8.25	2.95
Play Experience Scale (PES) *1-to-5 rating scale, where 5: Strongly Agree.*	I was able to make the game do what I wanted it to	3.1	1.3
	I am able to use the game without help from anyone else	4.4	0.92
Flow State Scale (FSS) *1-to-5 rating scale, where 5: Strongly Agree.*	I felt I was competent enough to meet the high demands of the situation	4.3	0.9
	It felt like time went by quickly	3.9	1.14
	I made the correct movements without thinking about trying to do so	4	1
	I really enjoyed the experience	4.56	0.68
	I loved the feeling of the performance and want to capture it again	4.1	0.7
	My goals were clearly defined	4.4	0.66
	I knew clearly what I wanted to do	4.2	0.87

The semi-structured interview revealed other aspects that the questionnaires did not show. When asked about their experience with the game, all participants responded favourably. Several stated that it was very enjoyable and a 70 year old female even said it was *great, well researched, good for concentration and co-coordination.*

When they were questioned about the characteristics they like about the game, four people stated that they liked *the challenges*. A male participant said he liked that the game was *simple and consistent*, and a 69 year old female stated that *it is a game to exercise your legs and brain attention with info from the countries you visit*.

Questions regarding aspects that participants dislike showed some opposite opinions. While a 79 year old male expressed *(he) had to be alert and ready to focus*, and a 69 year old man said *(the games) don't always hold (his) concentration*. Also, two people mentioned that in some cases *the gold coins (rewards) would disappear too quickly from the screen, so (their) step would not count*.

Regarding the existence of problems such as technical difficulties or game glitches, three participants indicated that they had trouble getting the avatar to move. Apparently, the Kinect sensor was not able to detect them. It is likely that the sensor was not recognised by the computer during the start sequence or perhaps inadequate lighting conditions or floppy clothes could have affected the skeletal recognition. However, participants indicated that the problem was quickly resolved by restarting their computers.

When asked about the challenge of the workouts, most of the participants stated that the game was suitable for their abilities, and one subject even said *a good challenge to concentrate and move quickly*. However, two female participants (aged 83 and 81 years) responded quite differently. While one thought the game was *quite challenging*, the other one said that she found it *fairly easy*.

Questions regarding changes that could potentially improve the game showed a favourable trend. Six of the participants stated that they would not modify the game. There were however two participants (a male aged 79 and a female aged 67) who suggested changes in the speed or quickness in which stimuli appear on the screen. The female participant said *I would make the first levels a little faster*. In addition to this, a 69 year old man suggested that the ability to play music of their preference would make the game more enjoyable. Also, an 83 year old female proposed the inclusion of more levels within the game in order to make it more interesting.

When asked if the game would motivate them to do their exercises, there were encouraging responses. Eight of the participants indicated that the game would motivate them more than usual exercises while the remaining two said that their motivation towards physical activity would be about the same as performing usual exercises.

Finally, when asked if they would like to use the game as a means to exercise, eight of the ten participants answered positively. One female even said *yes, it is quite different to the usual type of exercise we are given*. Another female stated that *(she) would like to keep using the game to ensure (she) keeps moving (her) body*. Also, there were some interesting perspectives and attitudes towards the game. While a 69 year old male expressed that he *preferred outdoor activities* rather than playing a game in his living room, a 83 year old female who *prefers to exercise in isolation* said she likes the game because it allows her to exercise in the confort of her home.

Regarding adherence and compliance to the program, system logs indicated that all the participants used the step training system throughout the 12 week intervention period. However, the frequency of use and amount of time spent on the system varied over time. In the first month there were high levels of adherence with an average of 2.5 sessions per week and a mean duration of 20 minutes per session. In the second month, there was a reduction in the frequency of use to 1.6 sessions per week and a decrease in the average session duration from 20 minutes to 16.9 minutes. Finally, in the third month there was an increase in the levels of motivation where the number of sessions played increased from 1.6 to 2.2 sessions per week and the amount of time spent per session increased from 16.9 minutes to 22.3 minutes (see Figure 8.29)

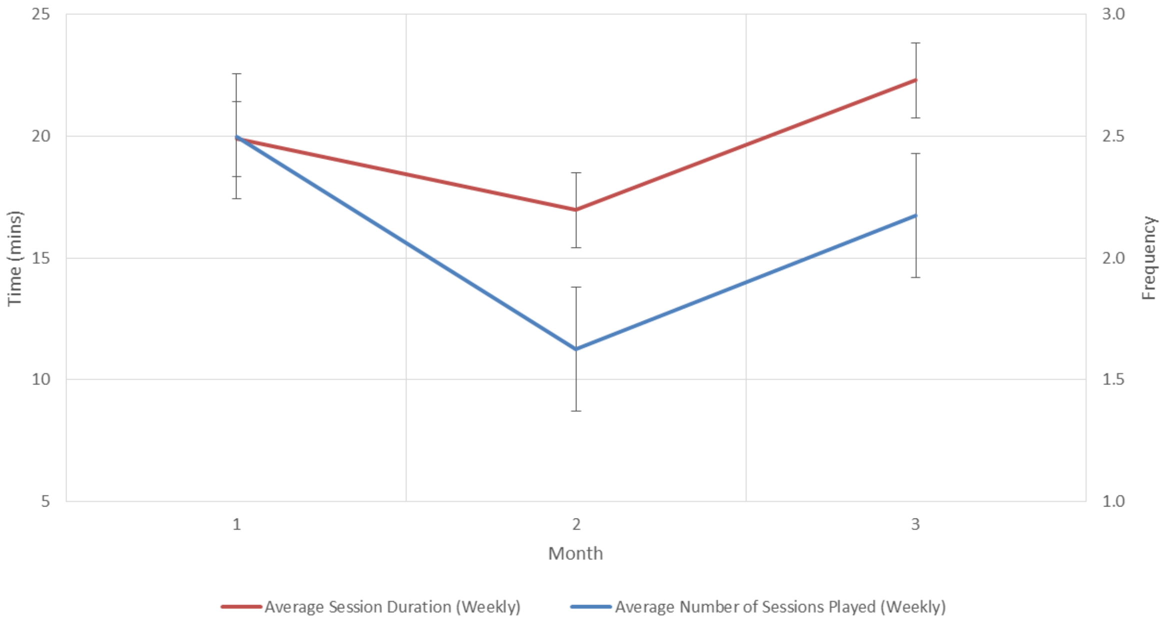

Figure 8.29: Participants' adherence throughout the 12 week intervention

At the end of the intervention in week 12, two participants had spent an average of 15.3 hours playing with the game, three had played an average of 10.5 hours, three had played between 5 hours and 6.4 hours, and the remaining two had played an average of 1.6 hours each. The participant who spent the most time on the game played a total of 15.5 hours in 25 sessions, and the participant who reported the highest frequency of use played 68 sessions in 15.2 hours (see Table 8.4).

Table 8.4: Descriptive Indicators of Adherence and Progression

ID	**Total Time Spent (Hours)**	**Total Number of Sessions Payed**	**Average Time Spent Weekly (mins)**	**Average Sessions Played per Week**	**Mean Session Duration (mins)**	**Number of Session At the End of Week 1**	**Max Level Reached in at the End of Week 1**	**Max Level Reached at the End of Week 12**
P1	9.9	35	37.1	2.2	17	5	7	31
P2	1.7	12	6.3	0.8	8.4	3	1	4
P3	15.2	68	57	4.3	13.4	7	9	31
P4	5	19	18.8	1.2	15.8	6	9	16
P5	6.4	17	24.1	1.1	22.7	5	9	31
P6	5.9	28	22	1.8	12.6	6	6	25
P7	1.5	6	5.7	0.4	15.1	1	0	8
P8	10	15	37.5	0.9	40	5	15	31
P9	15.5	25	58.2	1.6	37.2	7	15	31
P10	11.8	27	44.3	1.7	26.2	3	6	31
Average	8.3	25.2	31.1	1.6	20.8	4.8	7.7	23.9

Regarding progress within the game, results showed that at the end of the first week, two participants were playing at the easy levels (Level 0 and 1), six were at the medium difficulty levels (Levels 6-9) and two were at the highest level available (Level 15). In contrast, at the end of the intervention in week 12, seven of the participants reached the highest level (Level 31), one person was playing at the hard levels (Level 16) and the remaining two were still at the medium levels (Level 4 and 8).

8.6.5 Findings

Based on the results, the questionnaires showed that the participants had positive attitudes and feelings towards the *StepKinnection* game. Similarly to the usability assessments conducted prior to this intervention, the acceptance of the game was favourable. Overall, participants found the game pleasant, easy to use and enjoyable. More importantly, the game proved to be safe and effective as an unsupervised home-based training system for high functioning seniors. In regards to the cognitive tasks added to stimulate specific functions related to the risk of falling, participants found the lady bug and the coins interesting for the game story. Although there were two drop-outs before starting the intervention, the 10 participants who completed the 12 week program showed good levels of adherence and motivation throughout the study. According to the academic literature, the ability to train at home increases seniors' adherence to physical exercise in the long-term (Ashworth et al., 2005). Also, there is evidence that suggests that home-based exercises are effective in reducing the risk of falling in older people (Gillespie et al., 2009). Consequently, the high adherence rates and the health benefits found in this study suggest that the use of *StepKinnection* in the long-term may be effective as a tool to reduce the risk of falling in the elderly.

8.7 Evaluating the Validity of the Stepping Performance Data Collected During Gameplay

8.7.1 Procedures

To assess whether the collection of clinical data during gameplay can provide a reliable indication of health improvements, monthly collected measures were compared to the stepping performance data obtained by the *StepKinnection* game.

8.7.2 Outcome Measures

8.7.2.1 *StepKinnection* measurement of the CSRT

The stepping performance data collected by the game was analysed in order to determine whether this can be used as a reliable indicator of health improvements. During gameplay, the system automatically validates valid stepping responses and computes the average time taken by participants when reaction to stimuli are presented on the screen. Since the collection of this data is performed on an ongoing basis, the average reaction times were used for the comparison.

A copy of the collected data and statistical results is in Appendix D.

8.7.3 Statistical Analysis

Friedman's 2-way analysis of variance (ANOVA) by ranks was used to determine differences between assessments, with tests to determine which between group differences were significant. In order to determine the validity of the stepping performance data collected by the *StepKinnection* game, this was compared with the CSRT measurements collected throughout the assessments. Consistency and association were assessed through the Pearson Correlation Coefficient (Derrick et al., 1994) and the Intraclass Correlation Coefficient model 3,1 *(ICC3,1)* (Shrout and Fleiss, 1979). Finally, the level of significance was set to 5%. Analyses were conducted using SPSS for Windows (Version 20).

8.7.4 Results

Regarding the validity of the stepping performance data collected during gameplay, Pearson Correlation Coefficient showed fair association between the reaction time values collected by the game and the monthly performed CSRT test *(Pearson $r = 0.624$, $p = 0.000$)*. Like-wise, the ICC model 3,1 showed consistency and agreement between these values across the participants throughout the intervention *(ICC Single Measures = 0.597, Average Measures = 0.747, $p = 0.000$)* (see Figure 8.30)

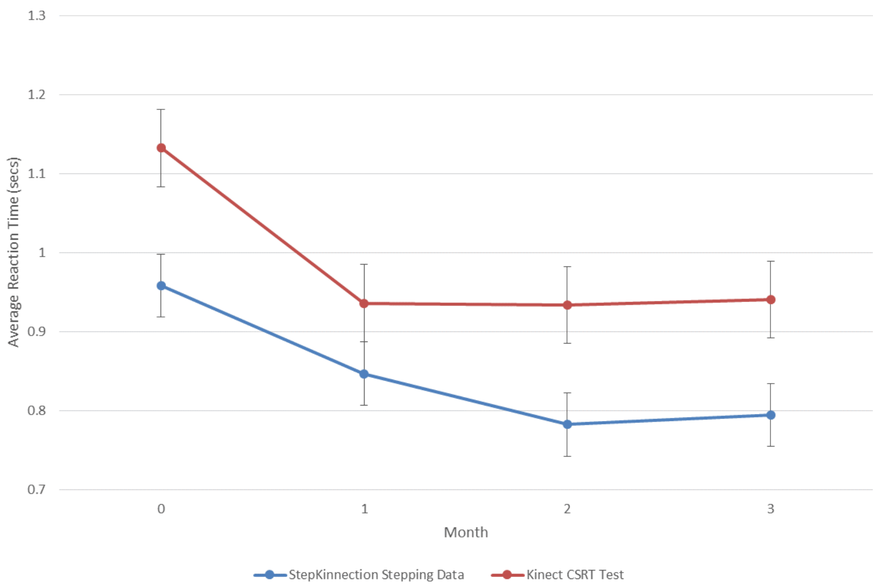

Figure 8.30: Results: Comparison between the validated CSRT test and the CSRT measure taken by the *StepKinnection* Game

Figure 8.31 shows a continuous decrease in the stepping reaction time calculated by the *StepKinnection* game across the participants throughout the intervention. Friedman ANOVAs showed significant differences between assessments (X^2 = *23.02, df = 3, p = 0.000, n = 10)*. Post-hoc tests revealed significant differences between baseline and first month assessment *(Z = -2.701, p = 0.007)*, baseline and second month *(Z = -2.803, p = 0.005)*, baseline and third month *(Z = -2.803, p = 0.005)*, first month and second month *(Z =-2.701, p = 0.007)*, and first month and third month *(Z = -2.599, p = 0.009)*.

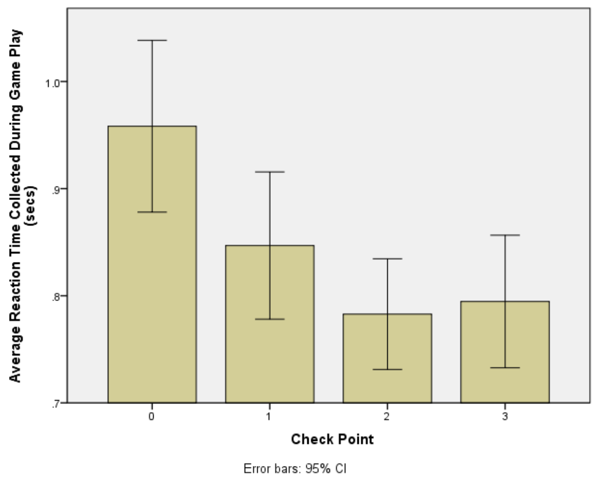

Figure 8.31: Results: StepKinection embedded CSRT test

8.7.5 Findings

One of the main limitations of commercial games is the inability to determine improvements in the mental and physical health of the players. Although high game scores might provide an indication of higher cognitive and physical abilities, these are not sufficient to reliably determine the improvement in health outcomes. For that reason, it is crucial to incorporate mechanisms that can measure clinically validated parameters during gameplay. This not only allows for the validation of the correct exercise movements, but also allows for the assessment of physical and mental functions in order to determine progress and health improvements on an ongoing basis. In this study the stepping performance data collected through the *StepKinnection* game was compared to the validated versions of the CSRT test for fall risk assessment. Statistical analysis proved that the stepping performance data collected by the *StepKinnection* system correlates and agrees with the Kinect measure of the CSRT, suggesting that this could be used as a reliable indicator for health improvements although a larger intervention is recommended to determine its validity.

Consequently, this measure was assessed to determine whether there were statistically significant changes among the participants. Results showed a significant improvement of 17% across the 10 participants with a high level of significance *($p = 0.000$)*, which is the same percentage of improvement reported by the Kinect CSRT test. Also, this value was found to be in agreement with a prior long-term study where use of a stepping mat device showed a similar rate of improvement in the stepping test. The results suggest that this measure is a reliable indicator to determine improvements in central processing speed and movement velocity. More importantly, the mean improvement of *164 ms* determined by the CSRT measure obtained during gameplay was found to be clinically meaningful as this exceeds the *150 ms* difference in CSRT times that discriminates between multiple fallers and multiple non-fallers (Schoene et al., 2011).

8.8 Discussions

Based on the obtained results, the 12 week intervention with the Kinect-based stepping game at home significantly improved several cognitive and physical functions that have been shown to be associated with high risk of falling in older people. The *StepKinnection* game was also demonstrated to be feasible to administer and easy to use. All the participants recruited for this study were able to play with the game, navigate through the menus, change levels of difficulty and perform the stepping routines. The 10 participants also indicated that they enjoyed the stepping training and found it useful to improve their health. More importantly, no adverse events related to the intervention were reported. This suggests that the *StepKinnection* game is a safe mode of exercise for higher functioning older adults and can be used without supervision in the comfort of the home.

One of the main limitations of this study is the small sample size that made it difficult to detect significant changes and improvements in some secondary outcome measures such as the Inhibitory CSRT test, the Letter Digit test and the Stroop Interference. Also, there was a 93 year old participant who withdrew from the study after one week of intervention. She stated that she was unable to progress within the game levels and found it difficult to remember how to use certain features of the game. This suggests that the system might not be suitable for people with mild cognitive impairments. Finally, due to complications during the intended recruitment of more participants for this study, it was not possible to set up and monitor a control group for comparisons pre and post intervention. Despite this, the findings are still considered relevant and clinically meaningful as the majority of the outcome measures presented similar levels of improvements to several studies found in the academic literature.

8.9 Conclusion

This chapter presents the results of a 12 week intervention to evaluate the effects of interacting with the *StepKinnection* game for fall prevention. Since the main interest of this project is to determine the effects that this game may have on the physical and mental health of the elderly, 10 independent-living older adults participated in this study. Firstly, the researcher explored several motor and cognitive functions that have been shown to be associated with falls in the elderly. These parameters were assessed on a regular basis every four weeks throughout the intervention in order to determine changes and improvements in the physical and mental health of the participants. Secondly, adherence, enjoyment and the ease of use of the game were investigated to determine whether it was feasible to use it as an unsupervised home-based training tool for the elderly. Finally, clinical outcome measures were utilised in order to assess if the collection of stepping performance during gameplay was a reliable indicator of improvement.

Results are summarised below.

- This pilot study found that long-term training over 12 weeks with the Kinect-based stepping game was safe and feasible to administer in the home in an unsupervised manner.
- Long-term exposure to the *StepKinnection* game led to the improvement of several physical parameters such as the Choice Stepping Reaction Time, Timed Up and Go, Gait Speed, Static Balance and Five Repeat Sit To Stand tests. Also, there were trends for improved cognitive parameters such as the Letter Digit test and the Stroop Interference test. All these are meaningful clinical indicators of risk of falling in the elderly.

- The collection of stepping performance parameters during gameplay was found to be a reliable indicator of health improvement. These parameters not only correlated well with a validated version of the CSRT test, but also showed significant improvements among the participants as a result of playing with the stepping game.

The results overcome the main limitation in commercial games that are only designed for the purpose of entertaining a younger audience. Incorporating mechanisms that can obtain clinically meaningful parameters during gameplay allows for assessment of physical and mental functions on an ongoing basis and the determination of progress in an unobtrusive manner.

More importantly, the 12 week intervention study tested two research hypotheses: firstly, that the collection of clinical data during gameplay can be used as a reliable indicator to determine health improvements (Hypothesis 2); and secondly, that a game mindfully designed for the elderly, with specific health alignments and an embedded health assessment tool can significantly reduce the risk of falling in the elderly (Hypothesis 3).

The continuation of this work includes studies with larger sample sizes in order to confirm these findings and show if secondary outcome measures that did not show significant changes among the participants can be improved.

The next chapter presents an analytical framework for game design for health purposes for the elderly, which builds on the results of this work. Conclusions and future research directions are presented.

Chapter 9

The Analytical Framework and Conclusions

9.1 Introduction

This concluding chapter discusses and maps the contribution of this research work in relation to the hypotheses set out in Chapter 1. The chapter then summarises the most significant findings and presents them in the form of an analytical framework that can be adapted for game design with health purposes for the elderly. This framework is expected to assist future researchers and the game industry to tackle the pervasive health problem of falling in the elderly community that affects many around the world. Finally, the strengths and weaknesses of this work are discussed.

As discussed in Chapter 1, the ultimate goal of this research project was to show that interactive video games can be used as an effective tool to improve the physical and mental health of the elderly. Additionally, this work also aimed to provide an analytical framework suitable for the development of serious games with the purpose of improving the overall health and quality of life of the elderly. The framework builds on the findings of several interventions that showed clinically meaningful results and help prove the research hypotheses set out in Chapter 1. Also it combines several disciplines, namely video game technologies, fall prevention and rehabilitation treatments for the elderly, clinical testing for the assessment of risk of falling, user-centred design and usability evaluation techniques.

This thesis is the result of the work done during the initial literature review (Chapters 2, 3 and 4); the functional aspects relevant to the planning, design, building and testing of both the *StepKinnection* hybrid test for fall risk assessment (Chapter 5 and 6) and the *StepKinnection* game for fall prevention (Chapter 7), and finally the logistics for the execution of interventions and experiments on older people living in the community (Chapter 7 and 8). The *StepKinnection* hybrid clinical test was developed primarily based on the academic literature by mapping the limitations and advantages of the technology selected (the Microsoft Kinect) with the requirements of several clinical tests for fall risk assessment. The *StepKinnection* game for fall prevention was built based on the continuous input of the elderly and several health experts. Although the first prototype was developed based on design guidelines found in the literature, the findings of an evaluation on the Nintendo Wii and the feedback of several focus groups led to the improvement of the system to be an effective home-based system with the potential of preventing falls.

The general framework visualised aided the foundations for the development of the *StepKinnection* hybrid clinical test for fall risk assessment and the *StepKinnection* game for fall prevention. In this chapter, *StepKinnection* project is used to refer to each and all of the different developed prototypes.

The next section presents a summary of the most relevant outcomes of this project followed by the details of the developed analytical framework. Recommendations and future areas of research are discussed at the end of the chapter.

9.2 Research Rationale and Outcomes

As explained in Chapter 1, this research aimed to answer three main questions:

- Could off-the-shelf game technology be utilised to reliably perform a clinical test for fall risk assessment?
- Could the collection of clinical data during gameplay be used as a reliable indicator to determine health improvements?
- Could an interactive video game mindfully designed for the elderly, with specific health alignments and a validated health assessment reduce the risk of falling?

To address these questions, the following studies were conducted that systematically built on each other.

- A comprehensive literature review in the area of games with health purposes for the elderly was conducted to identify the current status of the area and develop a clear understanding of the gaming tools used for this purpose. Since this is a relatively new area of research, literature from intersecting disciplines was reviewed in order to obtain more data. The most relevant work found throughout the literature was classified based on previous classifications and presented as a conference paper (Garcia et al., 2011a). The main purpose of this taxonomy was to extend previous work and contribute to the body of knowledge.

- A usability evaluation with six health and well-being specialists was conducted to assess the suitability of four Nintendo Wii balance games. This investigation highlighted the importance of a proper game design for the elderly in order to suit the functional limitations, motivations and preferences of the cohort. The findings of this evaluation were presented in conferences relevant to the area of investigation, namely eHealth Information systems and user-centric advanced applications (eTELEMED2011, ICONS2011, CENTRIC2011). (Garcia et al., 2011b; Lawrence et al., 2011; Felix Navarro et al., 2011).

- A proof-of-concept prototype was developed based on the academic literature in clinical assessment for fall risk in the elderly. First, tools for game development were explored looking for a game development tool compatible with the chosen state-of-the-art technology, the Kinect. Then a set of requirements for the development of a clinical test with the Kinect were identified. The selected test was the Choice Stepping Reaction Time (CSRT) task, a test that has been shown to prospectively predict older fallers. The development of this prototype was presented at the HIC2012 conference, the most relevant conference in health informatics within Australia where the paper was awarded the Branko Cesnik award for the best student scientific paper (Garcia et al., 2012)

- A hybrid clinical test for fall risk assessment was developed that incorporates mechanisms to assess several cognitive functions associated with high risk of falling in the elderly. This new Kinect-based system can not only measure and store indicators for the Choice Stepping Reaction Time (CSRT) but can also assess stepping performance under the Dual Task paradigm. The development and design considerations of this prototype were presented at ICEC2013 and CHI2014, two of the longest established and most prestigious conferences in the field of entertainment computing and human computer interaction (Garcia et al., 2014a; Pisan et al., 2013).

- A technical test on 10 high functioning adults was conducted in order to validate the accuracy of the measures obtained with the *StepKinnection* hybrid clinical test of fall risk. For this evaluation, the concurrent validity of the system was compared with a custom-made mat device that had been already validated and proved to reliably discriminate between fallers and non-fallers. The results showed high association between the reaction times obtained with both systems indicating that *StepKinnection* system is reliable and can be potentially used in the clinical setting. The findings of this evaluation were presented at the ICEC2014 conference on entertainment computing. (Garcia et al., 2014b)

- The *StepKinnection* game for fall prevention which builds on the Kinect-based test described above was developed to deliver stepping exercises, as stepping has been shown to be an effective strategy to prevent falls in the elderly. For the development of this system, user-centred design methodologies were applied in order to create a game story that was appealing to the elderly. Also, focus group sessions with independent-living older people were conducted in order to identify hidden usability issues and feelings and attitudes toward the game. More importantly, this game was built with an incorporated mechanism to clinically assess stepping performance during gameplay in order to determine health improvements in an unobtrusive manner. Two iterations were required to ensure that the game was suitable and the level of exertion was appropriate for the elderly. A conference paper describing the design considerations and building of this system was approved for publication at the HIC2015 conference, where the paper was shortlisted for the Branko Cesnik Student Scientific Award (Garcia and Felix Navarro, 2015).

- A 12 week longitudinal study on 10 older adults was conducted in conjunction with researchers at Neuroscience Research Australia (NeuRA) and the University of New South Wales. This study aimed to assess the validity and responsiveness of both the *StepKinnection* game for fall prevention and the *StepKinnection* hybrid clinical test of fall risk. Results of these trials suggested that the Kinect-based game showed high levels of adherence and enjoyment, significant improvement in seven out of 10 clinical outcome measures, and trends for improvement in two other cognitive tests. Also, the validity of the CSRT measure of the Kinect was in agreement with a validated stepping response time device. These findings indicate that the system is safe and feasible to administer in a home-based setting with no supervision. More importantly, it suggests that the game has the potential to prevent falls by the elderly.

The research studies outlined above have contributed to the development of the proposed game design framework that aims to assist the development of games with an alignment to particular health outcomes. This framework emphasises the importance of aligning the game goals to the expected health outcomes as well as the continuous assessment to monitor progress.

The details of the developed framework are presented and explained in the next section.

9.3 The Analytical Framework

Generic game design guidelines have showed favourable results regarding the usability of the system but showed little alignment to more specific health outcomes. Entertainment is important, but not the ultimate goal of these systems. Hence, training the specific cognitive and motor functions associated with the health condition that is being treated is essential. The framework in Figure 9.1 is developed as an aid for serious game design with specific health purposes for the elderly. This work aims to assist future researchers and the game industry by focusing on the inclusion of features that can bring therapeutic benefits for the elderly as well incorporation of mechanisms to clinically assess progress.

The details of this framework are presented below.

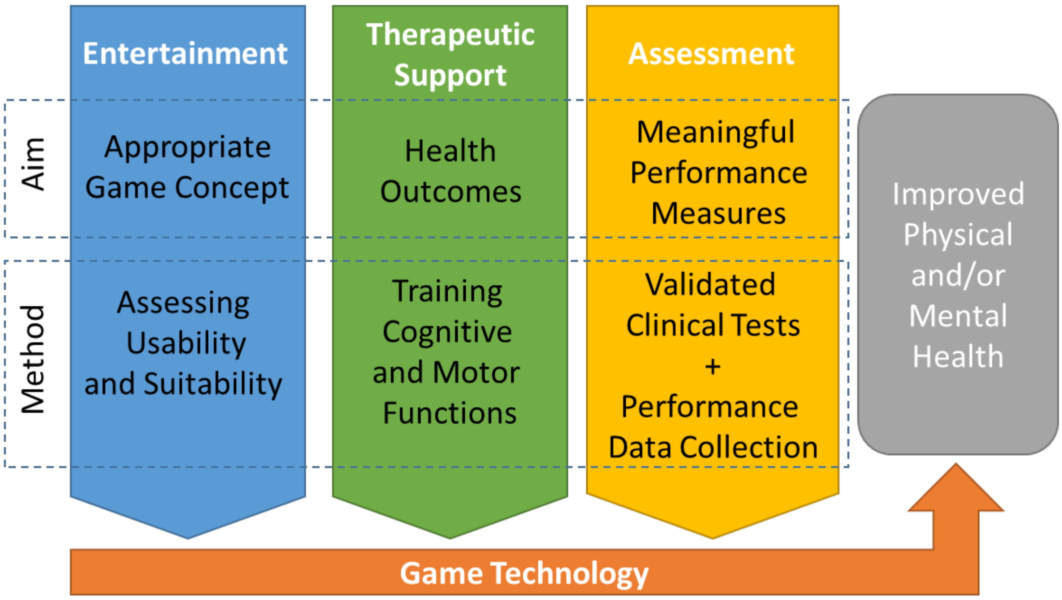

Figure 9.1: Analytical framework for designing interactive games with health purposes for the elderly

The details of this framework are presented as follows:

9.3.1 Entertainment

This dimension is related to the inclusion of playable content that is enjoyable and appropriate for the age-related changes of the elderly. The fun factor in video games is the key to keep people motivated and engaged with the desired activity. Simple tasks and clearly defined goals have been shown to be most effective when designing video games for this audience. However, feelings of frustration may rise when interfaces or game procedures are not simple enough. Older people with no computer literacy may develop feelings of confusion when interacting with interfaces that present too many options. Feelings of frustration and annoyance are the main cause of demotivation and dropouts. For that reason, it is highly recommended to apply user-centred design methodologies such as the heuristic evaluations of interfaces and the System Usability Scale. These inspection techniques have been shown to be very helpful to identify hidden usability issues of interfaces. These standardised methods identified a series of issues related to the use of the main menus in the *StepKinnection* game, which generated feelings of dissatisfaction among participants who were unable to make the game do what they wanted to.

9.3.2 Therapeutic Support

This dimension refers to the importance of aligning the game objectives and tasks to the specific health problem that is being addressed.

It is crucial to investigate the epidemiology and consequences of the health problem that the game is attempting to alleviate. Investigating risk factors can help to identify preventive strategies that can be incorporated into the game in order to train specific cognitive or physical functions associated with the health problem. For the *StepKinnection* project, it was identified that loss of muscle mass and power in the lower limbs was a risk factor of falling in the elderly. Subsequently, the game was designed to train the lower limbs by incorporating relatively difficult stepping tasks and inhibitory stepping routines. According to the literature, the ability to take a proactive or reactive step is considered the last resort to prevent a fall. In fact, several studies have proven that stepping is one of the most effective strategies to prevent falls in the elderly. More importantly, the levels of exertion should be customisable. The aged population is highly heterogeneous regarding their motor and cognitive functioning. Hence, the difficulty of the exercises should be adjustable to accommodate people's needs, limitations and capabilities. In the *StepKinnection* game, the ability to adjust the length of the stepping exercises based on the player's height made this task suitably challenging for tall and short participants.

9.3.3 Assessment

This refers to the ability to exploit the capabilities of the technology in use in order to collect clinical parameters that can reliably determine health improvements. Modern game technologies have a notable potential to deliver exercises and collect several parameters associated with the player's physical movements. This should not only be utilised to determine high scores of unlock achievements, but also to acquire clinical data that can assess the effectiveness of the intervention. There is a belief that high game scores reflect high health improvements, however, experimentation has shown that players are skilful and find ways to cheat within the game. Proper health-related measurements collected during gameplay can be used as an indicator to determine health improvements. For instance in the *StepKinnection* project, the collection of stepping performance data allowed the monitoring of the progress of the participants through the 12 week intervention described in Chapter 8.

9.4 Answers to the Research Hypotheses

The summary of the research outcomes presented at the beginning of this chapter allows the formulated hypotheses of this project to be evaluated. The three original hypotheses with their corresponding resulting outcomes are presented below.

9.4.1 Hypothesis 1 - Off-the-shelf Game Technology

Hypothesis 1 is "that off-the-shelf game technology can be used to reliably perform a clinical test for fall risk assessment".

Hypothesis 1 was demonstrated as **True**, as several studies showed that the selected game technology, the Kinect, was capable of measuring time-based parameters with high levels of accuracy. The results presented in Chapter 6 indicated that the Kinect measure of the Choice Stepping Reaction Time (CSRT) test had a significant correlation with an already validated response time device that has been shown to reliably predict falls in the elderly. In Chapter 8, statistical analysis demonstrated that the Kinect-based system was able to identify statistically significant changes across the participants of a 12 week intervention with the *StepKinnection* game (see Chapter 8). There were however some technological limitations regarding the Kinect's ability to detect fine movements such as the initiation of a step. While a pressure-based device can detect a fine movement based on the absence of pressure, the Kinect can only rely on the spatial data that is acquired by the built-in infrared sensor. Also, the scope of the technical evaluation and the small sample size made it difficult to determine the system's ability to differentiate between fallers and non-fallers. Nevertheless, the findings are still considered meaningful as the reaction times obtained are very similar to the CSRT times measured by a well-established response time device.

9.4.2 Hypothesis 2 - Embedded Clinical Test

Hypothesis 2 is "that the collection of clinical data (such as stepping performance and motor inhibition) during gameplay can be used as a reliable indicator to determine health improvements".

The outcomes presented and explained in this thesis demonstrate Hypothesis 2 is **True** as the clinical data collected during gameplay showed high levels of consistency and agreement with the stepping performance data measured throughout the 12 week intervention.

As indicated in Chapter 8, the embedded clinical test showed high correlation with both the Kinect version of the CSRT task and a well-established response time device that has been shown to reliably discriminate between groups of recurrent fallers and non-fallers. Similarly, statistical analysis proved that the embedded version of the CSRT test was able to determine statistically significant health improvements across 10 seniors who participated in the 12 week study, suggesting that this measure can be used as a reliable indicator of health improvement.

9.4.3 Hypothesis 3 - Mindful Design for the Elderly

Hypothesis 3 is "that a game mindfully designed for the elderly, with specific health alignments and an embedded health assessment tool can significantly reduce the risk of falling in the elderly".

The outcomes presented and explained in this thesis demonstrated Hypothesis 3 as **Conditionally True**, as limitations in the recruitment process for the 12 week intervention with the *StepKinnection* game led to a small sample size of 10 which made it difficult to detect statistically significant changes in the health outcomes, implying that findings cannot be generalised. Despite that, results indicated that the *StepKinnection* game proved safe and feasible to administer in the home, the 10 participants who had exposure to the game showed improvements in several physical parameters that are valid indicators of risk of falling in the elderly. These results are considered highly relevant and clinically meaningful as the majority of the outcome measures showed similar rates of improvements to larger clinical trials found in the academic literature (Van Diest et al., 2013).

More importantly, the reaction times measured by the embedded mechanism not only correlated well with the CSRT test, but also showed a significant mean improvement of 17% in the CSRT times across the participants.

9.5 Conclusions and Future Directions

The evolving systems developed as part of the *StepKinnection* project demonstrate that interactive game technologies can be used as an effective tool to reduce the risk of falling in the elderly. The results of this thesis suggest that the combination of appropriate age-related features, the inclusion of meaningful tasks aligned with specific health outcomes, and the use of embedded mechanisms to clinically assess the effectiveness of an intervention are important components to promote optimal health results.

The Kinect-driven system developed by the researcher showed that long-term training with interactive game technologies is safe and feasible, which is ideal for home-based training as no supervision is required. Also, it was found that long-term exposure to such games can potentially improve the physical and mental health of the elderly. More importantly, it was proven that mechanisms to clinically assess health outcomes can be used as reliable indicators of improvement, overcoming the main limitation in commercial games that are only designed for the purpose of entertaining users.

While the limitations in the sample size make it difficult to generalise the findings of this study, the obtained outcomes are still relevant and clinically meaningful as these were in agreement with the results of several studies with larger interventions found in the literature. The continuation of this work should focus on investigating the effectiveness of interventions with larger sample sizes over longer periods of time on low functioning older people to determine the generalisability of the study findings.

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Appendices

Appendix A

Heuristic Evaluation Data

A.1 Comments on the *Bubble* Game

Impact	Expert	Category	Problem
Comment	E1	D	They could pick up speed over time (Training period)
Comment	E3		Better than tightrope as a starting exercise
Negative	E1	E	Need to be much slower to get a chance of success
Negative	E1	H	Hitting the side the whole time could be frustrating, worrying
Negative	E3		Not useful for cardiac rehabilitation patients as it did not raise their heart rate sufficiently
Negative	E6	F	Unrealistic linking of human movements and display
Negative	E6	I	Potential dangerous for the elderly (learning unwanted movement patterns)
Positive	E1		Most impressed with this one
Positive	E2		This one was fun
Positive	E2		Easily to use in aged care facilities
Positive	E3		Gentle and safe
Positive	E4		Allows movement forwards and backwards and side to side, which is a good strategy
Positive	E5		Match in between user's movements and display
Positive	E6		good for stimulating body awarness of weight distribution on the feet
Positive	E6		Match in between user's movements and display
Suggestions	E2		It could be used by people holding onto a balance frame or rollator for support

A.2 Comments on the *SkateBoard* Game

Impact	Expert	Category	Problem
Comment	E1		Might appeal to males in better health (High Functioning)
Negative	E1	J	Patients would not relate to skateboarding as it's outside of their experience
Negative	E2	I	useful for younger and more able patients (Coordination and flexibility are needed)
Negative	E2	J	Enjoyable for younger and more able patients
Negative	E3	J	Perception that patients would not like it
Negative	E5	G	Difficult to read and do the actions at the same time
Negative	E5	I	Patients could have issues with putting the foot on and off
Negative	E6	I	Backward lean may be tricky for the elderly
Negative	E6	J	Patients would not relate to skateboarding
Positive	E3		Challenging
Positive	E3		Better workout, Expert likes it
Positive	E4		Good for counterbalance
Positive	E4		Good for locomotion practice
Positive	E4		Match in between user's movements and display
Positive	E6		Realistic linking of human movements and display
Suggestions	E1	J	Game with a scooter or Bicycle would have more appeal to the elderly

A.3 Comments on the *TableTilt* Game

Impact	Expert	Category	Problem
Negative	E5	I	Encouraged patients to tense up and lose balance instead of relaxing and loosening up
Positive	E1		Relevant fine balance movements
Positive	E1		Slow movements, with achievable goals
Positive	E1		Familiar game for the elderly
Positive	E2		Good for concentration
Positive	E2		Fun game
Positive	E3		Familiar game for the elderly
Positive	E4		Good exercise and suitable
Positive	E4		Good for counterbalance
Suggestions	E3		Wider walking frame around the foot pad for balance assistance

A.4 Comments on the *Tightrope* Game

Impact	Expert	Category	Problem
Comment	E3		Use of quads and bit of his core
Comment	E3		This game appeal more to men than women
Negative	E1	G	Instructions come up too quickly , health conequences
Negative	E2	G	Ability to read instructions (Users could not)
Negative	E4	F	Mismatch in between user's movements and display
Negative	E5	E	Challenging
Negative	E5	G	Difficult to read and do the actions at the same time
Negative	E5	H	Upsetting particulary if the avatar fail
Negative	E6	G	Reading structions confusing
Negative	E6	G	Reading structions less compatible with kinesthetic awarness than auditory feedback
Negative	E6	H	Anxiety producing stimulus makes people tighten their necks and shoulders and sabotages their balance reflex
Positive	E1		Not a problem for stroke patients if able to walk independently
Positive	E2		Low care patients would find it lots of fun
Positive	E3		Useful exercise for balance and shifting weight
Positive	E4		Good for balance and weight shifting
Suggestions	E2		They could use rollators to keep themselves steady
Suggestions	E5	G	Audio feedback
Suggestions	E6	G	Auditory feedback

A.5 Summary of Problems Found By Category

Game	Expert	Impact	D	E	F	G	H	I	J	Total
Bubble	E1	Comment	1							1
		Negative		1			1			2
	E6	Negative			1			1		2
SkateBoard	E1	Negative							1	1
		Suggestions							1	1
	E2	Negative						1	1	2
	E3	Negative							1	1
	E5	Negative				1		1		2
	E6	Negative						1	1	2
TableTilt	E5	Negative						1		1
Tightrope	E1	Negative				1				1
	E2	Negative				1				1
	E4	Negative			1					1
	E5	Negative		1		1	1			3
		Suggestions				1				1
	E6	Negative				2	1			3
		Suggestions				1				1
Total			1	2	2	8	3	5	5	26

Appendix B

Technical Validation Kinect vs MAT Data

B.1 Correlation of Time-Based Measurements

ID	Trial	Kinect		MAT		Pearson r
		N	Std. Deviation	N	Std. Deviation	
P1	1	80	15.56467067	80	15.56250757	0.9999911
	2	80	14.43157288	80	14.43126115	0.999987235
P2	1	80	18.91654102	80	18.90664084	0.999822323
	2	80	19.71492693	80	19.73572894	0.999940855
P3	1	80	17.73971789	80	17.72907329	0.999961649
	2	80	16.82095271	76	15.94496783	0.999704049
P4	1	80	18.02354825	76	18.48927966	0.999977464
	2	80	18.18808217	68	17.2919237	0.999950906
P5	1	80	18.48570545	80	18.64174088	0.999971618
	2	80	18.45842378	80	18.44799463	0.99997348
P6	1	80	21.85800911	74	21.64669451	0.999950308
	2	79	19.50015817	76	19.73465627	0.999746628
P7	1	80	19.53482242	80	19.51148194	0.999945062
	2	80	18.17107141	80	18.16846429	0.999970051
P8	1	80	17.61353115	74	17.88444223	0.999935631
	2	80	18.50616466	80	18.48954828	0.99996677
P9	1	80	17.46314264	78	17.29906984	0.999966276
	2	80	16.81403079	73	15.73762905	0.999970476
P10	1	80	15.93778758	66	16.67915396	0.999849066
	2	80	17.52502699	80	17.53113831	0.999966609
P11	1	80	18.8838098	78	18.98310121	0.99989703
	2	80	15.35932982	76	15.61333454	0.999981923
P12	1	80	16.8953369	80	17.00050836	0.99958524
	2	80	16.80901822	80	16.80507302	0.999765933
P13	1	80	18.53526089	70	19.48834297	0.999958811
	2	80	18.4733154	74	17.94939223	0.999956844

B.2 Kinect and MAT measurements of Reaction Time (RT), Decision Time (DT) and Movement Time (MT)

ID	Node	Kinect				MAT			
		Steps	DT	MT	RT	Steps	DT	MT	RT
P1	LF	5	0.664	0.016	0.680	5	0.559	0.183	0.742
	LL	5	0.588	0.016	0.604	5	0.483	0.173	0.657
	RF	5	0.716	0.004	0.720	5	0.655	0.171	0.827
	RR	5	0.648	0.020	0.668	5	0.510	0.164	0.673
P2	LF	5	0.772	0.000	0.772	5	0.737	0.278	1.016
	LL	5	0.720	0.004	0.724	5	0.655	0.234	0.889
	RF	5	0.700	0.032	0.732	2	0.704	0.203	0.906
	RR	5	0.732	0.016	0.748	5	0.682	0.266	0.948
P3	LF	5	0.632	0.008	0.640	5	0.653	0.147	0.800
	LL	5	0.616	0.028	0.644	4	0.541	0.126	0.667
	RF	5	0.560	0.008	0.568	5	0.595	0.133	0.727
	RR	5	0.604	0.008	0.612	4	0.521	0.110	0.631
P4	LF	5	0.700	0.008	0.708	3	0.669	0.167	0.836
	LL	5	0.688	0.032	0.720	4	0.581	0.204	0.785
	RF	5	0.716	0.020	0.736	4	0.728	0.155	0.883
	RR	5	0.668	0.000	0.668	5	0.619	0.165	0.784
P5	LF	5	0.536	0.000	0.536	4	0.491	0.117	0.608
	LL	5	0.584	0.008	0.592	5	0.496	0.080	0.576
	RF	5	0.584	0.000	0.584	4	0.513	0.088	0.601
	RR	5	0.608	0.012	0.620	5	0.451	0.077	0.528
P6	LF	5	0.692	0.000	0.692	4	0.511	0.134	0.645
	LL	5	0.640	0.000	0.640	5	0.497	0.147	0.644
	RF	5	0.748	0.004	0.752	3	0.679	0.114	0.792
	RR	5	0.616	0.004	0.620	5	0.546	0.112	0.658
P7	LF	5	0.668	0.008	0.676	5	0.468	0.234	0.702
	LL	5	0.636	0.000	0.636	5	0.483	0.161	0.644
	RF	5	0.844	0.004	0.848	1	0.688	0.164	0.852
	RR	5	0.716	0.016	0.732	5	0.570	0.149	0.719
P8	LF	5	0.692	0.008	0.700	4	0.567	0.221	0.788

ID	Node	Kinect				MAT			
		Steps	DT	MT	RT	Steps	DT	MT	RT
	LL	5	0.648	0.008	0.656	3	0.741	0.060	0.801
	RF	5	0.752	0.016	0.768	3	0.703	0.175	0.878
	RR	5	0.724	0.008	0.732	3	0.530	0.187	0.717
P9	LF	5	0.692	0.000	0.692	4	0.648	0.179	0.827
	LL	5	0.688	0.012	0.700	5	0.460	0.183	0.643
	RF	5	0.588	0.020	0.608	5	0.537	0.158	0.695
	RR	5	0.604	0.016	0.620	5	0.462	0.163	0.625
P10	LF	5	0.740	0.024	0.764	3	0.639	0.175	0.814
	LL	5	0.676	0.024	0.700	5	0.619	0.154	0.773
	RF	5	0.712	0.020	0.732	5	0.638	0.159	0.797
	RR	5	0.688	0.020	0.708	5	0.638	0.117	0.756

Appendix C

Usability Assessment Data

C.1 Responses to the System Usability Scale (SUS)

Item	P1	P2	P3	P4	P5	MEAN	SD	MODE
I think that I would like to use this system frequently		4	3	4	5	4	0.71	4
I found the system unnecessarily complex	1	3	1	1	1	1.4	0.80	1
I thought the system was easy to use	5	3	5	5	5	4.6	0.80	5
I think that I would need the support of a technical person to be able to use this system	3	3	1	4	1	2.4	1.20	3
I found the various functions in this system were well integrated	4	4	5	4	5	4.4	0.49	4
I thought there was too much inconsistency in this system	1	3	1	1	1	1.4	0.80	1
I would imagine that most people would learn to use this system very quickly	5	4	4	5	5	4.6	0.49	5
I found the system very cumbersome to use	1	2	1		1	1.25	0.43	1
I felt very confident using the system	5	3	4	5	5	4.4	0.80	5
I needed to learn a lot of things before I could get going with this system	1	4	1	1	1	1.6	1.20	1
I would rate the user-friendliness of this game as	6	4	5	6	6	5.4	0.80	6

C.2 Responses to the Flow State Scale (FSS)

Item	P1	P2	P3	P4	P5	MEAN	SD	MODE
I was challenged, but I believed my skills would allow me to meet the challenge	4	3	5	4	5	4.2	0.75	4
I made the correct movements without thinking about trying to do so	4	4	3	4	5	4	0.63	4
I knew clearly what I wanted to do	4	4	4	4	5	4.2	0.40	4
It was really clear to me how my performance was going	4	4	4	3	5	4	0.63	4
My attention was focused entirely on what I was doing	4	4	5	5	5	4.6	0.49	5
I had a sense of control over what I was doing	4	4	4	5	5	4.4	0.49	4
I was not concerned with what others may have been thinking of me	4	2	5	5	5	4.2	1.17	5
Time seemed to alter (either slowed down or speeded up)	4	2	4	2	5	3.4	1.20	4
I really enjoyed the experience	5	4	4	5	5	4.6	0.49	5
My abilities matched the high challenge of the situation	4	3	4	4	5	4	0.63	4
Things just seemed to be happening automatically	4	3	3	4	5	3.8	0.75	4
I had a strong sense of what I wanted to do	4	4	3	4	5	4	0.63	4
I was aware of how well I was performing	4	4	3	3	5	3.8	0.75	4
It was no effort to keep my mind on what was happening	4	4	4	5	5	4.4	0.49	4
I felt like I could control what I was doing	4	4	4	5	5	4.4	0.49	4

Item	P1	P2	P3	P4	P5	MEAN	SD	MODE
I was not concerned with how others may have been evaluating me	5	2	4	5	5	4.2	1.17	5
The way time passed seemed to be different from normal	5	3	4	5	5	4.4	0.80	5
I loved the feeling of the performance and want to capture it again	5	4	3	5	5	4.4	0.80	5
I felt I was competent enough to meet the high demands of the situation	5	3	4	3	5	4	0.89	5
I performed automatically, without thinking too much	4	3	4	4	5	4	0.63	4
I knew what I wanted to achieve	4	4	3	4	5	4	0.63	4
I had a good idea while I was performing about how well I was doing	4	4	4	3	5	4	0.63	4
I had total concentration	4	4	5	4	5	4.4	0.49	4
I had a feeling of total control	4		3	4	5	4	0.71	4
I was not concerned with how I was presenting myself	4	3	5	4	5	4.2	0.75	4
It felt like time went by quickly	4	3	4	5	5	4.2	0.75	4
The experience left me feeling great	5	3	4	5	5	4.4	0.80	5
The challenge and my skills were at an equally high level	4	3	4	4	5	4	0.63	4
I did things spontaneously and automatically without having to think	4	4	4	4	5	4.2	0.40	4
My goals were clearly defined	4	4	4	5	5	4.4	0.49	4
I could tell by the way I was performing how well I was doing	4	4	4	4	5	4.2	0.40	4
I was completely focused on the task at hand	4	4	5	4	5	4.4	0.49	4
I felt in total control of my body	4	4	4	4	5	4.2	0.40	4

Item	P1	P2	P3	P4	P5	MEAN	SD	MODE
I was not worried about what others may have been thinking of me	5	3	4	5	5	4.4	0.80	5
I lost my normal awareness of time	4	3	4	4	5	4	0.63	4
I found the experience extremely rewarding	5	3	3	5	5	4.2	0.98	5

C.3 Responses to the Play Experience Scale (PES)

Item	P1	P2	P3	P4	P5	MEAN	SD	MODE
I felt that I was free to use whatever strategy I wanted to while I was using the game	5	3	5	4	5	4.4	0.80	5
I was able to make the game do what I wanted it to	5	3	4	4	5	4.2	0.75	5
The game gave me the freedom to act how I wanted to	5	3	5	4	5	4.4	0.80	5
The game made it difficult to do what I wanted to do	1	3	1	1	1	1.4	0.80	1
I was not worried about someone judging how I performed in the game	5	4	5	5	5	4.8	0.40	5
Regardless of how I performed in the game, I knew there wouldn't be a real-world consequence	3	4	5	3	5	4	0.89	3
My performance in the game was not going to matter outside of the game	1	4	5	5	5	4	1.55	5
I felt like I had to do well, or the experimenter would judge me	1	2	1	5	1	2	1.55	1
When I was using the game, it felt like I was playing rather than working	5	4	4	5	5	4.6	0.49	5
I would characterize my experience with the game as 'playing'	5	4	4	5	5	4.6	0.49	5
I was playing a game rather than working	5	3	4	5	5	4.4	0.80	5
Using the game felt like work	1	2	1	1	1	1.2	0.40	1
When I was using the game, I didn't worry about anything in the real world	5	4	5	5	5	4.8	0.40	5

Item	P1	P2	P3	P4	P5	MEAN	SD	MODE
I was able to concentrate on the game without thinking about other things	5	4	5	5	5	4.8	0.40	5
When I was using the game, I was focused on the task at hand	5	4	5	5	5	4.8	0.40	5
I had a hard time concentrating on the game	1	2	1	1	1	1.2	0.40	1
I wanted to do well in the game, "just because"	5	4	4	NA	5	4.5	0.50	5
When I was using the game, I wanted to do as well as possible	5	4	4	4	5	4.4	0.49	4
I tried to succeed in the game because I felt like it	5	4	4	4	5	4.4	0.49	4
During the game, my performance didn't matter to me	5	1	4	5	5	4	1.55	5

C.4 Responses to the Physical Activity Enjoyment Scale (PACES)

Item	P1	P2	P3	P4	P5	MEAN	SD	MODE
I enjoy it vs. I hate it	1	1	2	1	1	1.2	0.40	1
I feel bored vs. I feel interested	10	10	7	10	10	9.4	1.20	10
I dislike it vs. I like it	10	10	7	10	10	9.4	1.20	10
I find it pleasurable vs. I find it unpleasurable	1	1	2	1	1	1.2	0.40	1
I am very absorbed in this activity vs. I am not at all absorbed in this activity	1	1	1	1	1	1	0.00	1
It's no fun at all vs. It's a lot of fun	10	7	7	10	10	8.8	1.47	10
I find it energizing vs. I find it tiring	3	4	2	5	1	3	1.41	
It makes me depressed vs. It makes me happy	10	7	7	10	10	8.8	1.47	10
It's very pleasant vs. It's very unpleasant	1	1	2	1	1	1.2	0.40	1
I feel good physically while doing it vs. I feel bad physically while doing it	1	1	5	1	1	1.8	1.60	1
It's very invigorating vs. It's not at all invigorating	2	3	7	1	1	2.8	2.23	1
I am very frustrated by it vs. I am not at all frustrated by it	10	10	9	10	10	9.8	0.40	10
It's very gratifying vs. It's not at all gratifying	2	4	8	1	1	3.2	2.64	1
It's very exhilarating vs. It's not at all exhilarating	5	5	7	1	1	3.8	2.40	5
It's not at all stimulating vs. It's very stimulating	10	6	9	10	10	9	1.55	10
It gives me a strong sense of accomplishment vs. It does not give me any sense of accomplishment	5	7	2	1	1	3.2	2.40	1

Item	P1	P2	P3	P4	P5	MEAN	SD	MODE
It's very refreshing vs. It's not at all refreshing	4	3	5	1	1	2.8	1.60	1
I felt as though I would rather be doing something else vs. I felt as though there was nothing else I would rather be doing	10	7	7	10	10	8.8	1.47	10
I enjoyed using the Kinect-based game as a means to exercise	4	4		4	4	4	0.00	4

Appendix D

12-Week Intervention Study Data

D.1 Outcome Measures - Baseline Assessment

Outcome Measure	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
FAST WALK	1.21	1.15	1.11	1.64	1.67	1.99	2.14	1.23	1.41	1.42
WALK	0.91	0.88	0.95	1.19	1.36	1.35	1.10	1.09	1.17	1.13
TUG	9.55	9.28	7.69	10.815	7.875	9.92	8.75	9.47	9.235	9.045
K RT	1.204	1.242	1.064	1.027	1.278	0.889	1.225	1.259	1.013	1.124
M RT	1.184	1.022	1.056	1.004	1.289	1.015	1.055	1.257	1.026	1.288
INHIBI	1.101	0.954	1.086	0.985	1.093	1.187	1.083	1.317	1.035	1.119
LETDIG	3561.8	2686.7	2242.43	1760.13	2563.13	1863	2619.9	2211.97	2244.47	2114.03
STROOP	136.25	122.14	50.99	124.13	42.93	42.51	42.98	122.58	60.54	
BALANCE	57.57	45.79	56.38	44	57.75	60	54.93	59.88	60	51
SITSTAND	15.06	17	8.13	39.12	11.22	17.09	12.75	11.72	12	17.16

D.2 Outcome Measures - First Month Assessment

Outcome Measure	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
FAST WALK	1.52	1.75	1.76	1.82	2.15	1.99	1.81	1.45	1.47	1.58
WALK	1.19	1.28	1.35	1.37	1.61	1.40	1.26	1.18	1.20	1.23
TUG	10	9.67	7.78	8.86	6.905	8.78	8.845	8.045	9.565	8.635
K RT	0.969	0.906	0.984	0.826	0.847	0.823	1.171	0.901	0.907	1.026
M RT	1.010	0.896	0.899	0.904	1.073	0.899	1.179	1.075	0.990	1.212
INHIBIT	1.140	0.969	0.874	0.908	0.982	0.888	1.317	1.170	0.941	1.119
LETDIG	2452.77	2243.6	2080.6	1925.23	2274.23	1667.8	1912.13	2490.53	1980.73	1852.57
STROOP	118.78	124.35	49.22	79.84	32.74	55.02	60.16	112.08	40.27	35.03
BALANCE	58.22	46.68	59.87	52.78	60	60	54.19	60	57.47	60
SITSTAND	15.18	19.38	8.03	18.88	10.53	10.6	8.19	9.32	11.9	13.19

D.3 Outcome Measures - Second Month Assessment

Outcome Measure	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
FAST WALK	2.00	1.75	1.88	1.81	2.19	2.21	2.02	1.39	1.57	1.72
WALK	1.37	1.28	1.52	1.53	1.74	1.63	1.26	1.29	1.25	1.36
TUG	8.31	9.67	7.39	9.16	6.7	8.075	7.795	8.05	7.94	8.045
K RT	1.137	0.906	0.905	0.902	0.855	0.813	0.918	0.936	0.946	1.022
M RT	1.433	0.896	0.934	0.920	0.762	0.921	0.998	1.030	0.931	1.153
INHIBIT	1.201	0.969	0.918	0.967	0.767	0.940	0.967	0.972	0.996	1.113
LETDIG	2950.13	2243.6	1834	2144.13	2045.43	1700.07	2247.67	2439.6	2228.33	2273.77
STROOP	75.3	124.35	45.14	55.86	28.21	52.43	59.92	95.73	38.35	35.7
BALANCE	60	46.68	60	50	60	60	55.1	60	60	57.84
SITSTAND	13.32	19.38	7.38	18.75	8.5	12.97	9.84	9.22	10.12	13.56

D.4 Outcome Measures - Third Month Assessment

Outcome Measure	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
FAST WALK	1.59	1.98	1.93	1.79	2.34	2.01	1.95	1.45	1.53	1.70
WALK	1.29	1.35	1.49	1.45	1.90	1.62	1.22	1.27	1.30	1.48
TUG	8.295	9.89	7.08	9.16	5.825	7.73	7.97	8.1	8.375	7.74
K RT	1.105	0.972	0.868	1.115	0.803	0.797	1.046	0.832	0.873	0.997
M RT	1.141	1.083	0.885	1.131	0.724	0.954	1.062	1.034	0.911	1.046
INHIBIT	1.107	0.967	0.914	1.119	0.788	0.943	1.140	0.960	0.955	1.059
LETDIG	2978.07	2405.07	1762.83	2189.3	1678.83	1589.57	1903.7	2385.1	2015.6	1836.2
STROOP	64.77	78.61	36.67	53.53	35.5	39.35	71.57	136.85	37.36	43.82
BALANCE	55.04	60	60	52.72	60	60	56.63	60	60	59.28
SITSTAND	13.22	15.88	6.91	26.28	7.37	10	9.16	9	12.41	12.75

D.5 Wilcoxon Matched Pair Signed Rank Tests Between Baseline and Assessment 1, 2 and 3

Outcome Measure	Overall				Month 0 vs 1		Month 0 vs 2		Month 0 vs 3	
	p	X^2	df	N	Z	p	Z	p	Z	p
FAST WALK	0.002	14.455	3	10	2.09	0.037	2.701	0.007	2.395	0.017
WALK	0	23.364	3	10	2.803	0.005	2.803	0.005	2.803	0.005
TUG	0.019	9.949	3	10	-1.172	0.241	-2.599	0.009	-2.652	0.008
K RT	0.001	16.879	3	10	-2.803	0.005	-2.803	0.005	-2.701	0.007
M RT	0.007	12.24	3	10	-2.293	0.022	-1.886	0.059	-1.784	0.074
INHIBIT	0.457	2.602	3	10						
LETDIG	0.074	6.939	3	10	-1.988	0.047	-1.58	0.114	-2.09	0.037
STROOP	0.101	6.236	3	9						
BALANCE	0.017	10.145	3	10	1.599	0.11	2.521	0.012	1.96	0.05
SITSTAND	0.005	12.636	3	10	-1.989	0.047	-2.395	0.017	-2.701	0.007
STP KNT RT	0	23.02	3	10	-2.701	0.007	-2.803	0.005	-2.803	0.005

D.6 Wilcoxon Matched Pair Signed Rank Tests Between Assessment 1-2, 1-3 and 2-3

Outcome Measure	Overall				Month 1 vs 2		Month 1 vs 3		Month 2 vs 3	
	p	X^2	df	N	Z	p	Z	p	Z	p
FAST WALK	0.002	14.455	3	10	2.192	0.028	2.395	0.017	-0.255	0.799
WALK	0	23.364	3	10	2.547	0.011	2.701	0.007	0.255	0.799
TUG	0.019	9.949	3	10	-2.192	0.028	-2.191	0.028	-0.652	0.515
K RT	0.001	16.879	3	10	0.296	0.767	-0.357	0.721	-0.255	0.799
M RT	0.007	12.24	3	10	-0.889	0.374	0.153	0.878	-0.051	0.959
INHIBIT	0.457	2.602	3	10						
LETDIG	0.074	6.939	3	10	1.362	0.173	-0.255	0.799	-1.886	0.59
STROOP	0.101	6.236	3	9						
BALANCE	0.017	10.145	3	10	0.105	0.917	0.676	0.499	0.944	0.345
SITSTAND	0.005	12.636	3	10	-0.652	0.515	-0.968	0.333	-1.07	0.285
STP KNT RT	0	23.02	3	10	-2.701	0.007	-2.599	0.009	1.12	0.263

D.7 Responses to the System Usability Scale (SUS)

Item	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
I think that I would like to use this system frequently	5	4	5	5	4	2	4	5	5	5
I found the system unnecessarily complex	1	3	1	1	1	1	3	1	1	2
I thought the system was easy to use	5	4	5	5	4	5	4	5	5	4
I think that I would need the support of a technical person to be able to use this system	1	4	1	1	1	1	1	1	1	2
I found the various functions in this system were well integrated	5	4	5	5	5	4	4	5	5	4
I thought there was too much inconsistency in this system	3	3	1	1	1	2	2	1	1	2
I would imagine that most people would learn to use this system very quickly	3	4	4	1	4	4	4	4	5	4
I found the system very cumbersome to use	1	2	1	5	1	1	2	1	1	2
I felt very confident using the system	5	3	5	5	5	5	4	5	5	4
I needed to learn a lot of things before I could get going with this system	5	2	1	1	1	1	2	1	1	2

D.8 Responses to the Flow State Scale (FSS)

Item	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
I was challenged, but I believed my skills would allow me to meet the challenge	4	4	5	5	4	3	4	5	5	4
I made the correct movements without thinking about trying to do so	3	4	5	5	2	5	4	4	5	3
I knew clearly what I wanted to do	3	3	5	5	3	5	4	5	5	4
It was really clear to me how my performance was going	4	3	4	5	4	4	4	5	5	4
My attention was focused entirely on what I was doing	5	4	5	5	5	2	4	5	5	5
I had a sense of control over what I was doing	3	3	5	4	5	4	4	5	5	5
I was not concerned with what others may have been thinking of me	5	4	5	5	5	5	4	5	5	4
Time seemed to alter (either slowed down or speeded up)	3	4	5	5	4	3	4	5	5	4
I really enjoyed the experience	5		5	5	5	3	4	5	5	4
My abilities matched the high challenge of the situation	4	3	5	5	4	4	4	5	5	4
Things just seemed to be happening automatically	4	2	5	5	2	4	4	5	5	4
I had a strong sense of what I wanted to do	5	3	5	5	3	5	4	5	5	4
I was aware of how well I was performing	5	4	5	5	4	4	4	5	5	4
It was no effort to keep my mind on what was happening	5	4	5	4	5	2	4	5	5	4
I felt like I could control what I was doing	4	4	5	4	4	4	4	5	5	4

Item	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
I was not concerned with how others may have been evaluating me	5	2	5	5	5	5	4	5	5	4
The way time passed seemed to be different from normal	4	4	5	1	4	3	4	5	5	4
I loved the feeling of the performance and want to capture it again	3	4	5	4	4	3	4	5	5	4
I felt I was competent enough to meet the high demands of the situation	4	2	5	5	4	5	4	5	5	4
I performed automatically, without thinking too much	3	2	5	5	2	4	4	4	5	4
I knew what I wanted to achieve	4	4	5	5	4	5	5	5	5	4
I had a good idea while I was performing about how well I was doing	4	3	5	5	4	4	4	5	5	4
I had total concentration	4	4	5	5	4	3	3	5	5	4
I had a feeling of total control	3	3	5	4	4	4	3	5	5	3
I was not concerned with how I was presenting myself	4	4	5	5	3	5	4	4	5	4
It felt like time went by quickly	4	4	5	1	4	3	4	5	5	4
The experience left me feeling great	4	2	5	5	5	3	4	5	5	4
The challenge and my skills were at an equally high level	3	2	5	4	4	4	4	5	5	3
I did things spontaneously and automatically without having to think	2	1	5	5	3	4	2	4	5	3
My goals were clearly defined	3	4	5	5	4	5	4	5	5	4
I could tell by the way I was performing how well I was doing	4	4	4	5	4	4	4	5	5	4
I was completely focused on the task at hand	5	4	5	5	5	3	3	5	5	4
I felt in total control of my body	3	3	5	2	4	4	4	5	5	3

Item	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
I was not worried about what others may have been thinking of me	5	4	5	5	1	5	4	5	5	4
I lost my normal awareness of time	4	4	5	1	4	3	2	5	5	4
I found the experience extremely rewarding	5	4	5	5	5	3	3	5	5	4

D.9 Responses to the Play Experience Scale (PES)

Item	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
I felt that I was free to use whatever strategy I wanted to while I was using the game	3	3	5	5	2	4	4	5	5	4
I was able to make the game do what I wanted it to	3	2	5	1	2	2	3	4	5	4
The game gave me the freedom to act how I wanted to	3	2	5	5	2	3	4	5	5	4
The game made it difficult to do what I wanted to do	2	2	1	1	2	3	3	1	1	2
I was not worried about someone judging how I performed in the game	5	4	5	5	5	5	4	5	5	4
Regardless of how I performed in the game, I knew there wouldn't be a real-world consequence	5	3	5	5	3	5	4	4	5	5
My performance in the game was not going to matter outside of the game	5	3	5	5	2	5	4	4	5	5
I felt like I had to do well, or the experimenter would judge me	1	2	1	1	1	1	2	5	1	3
When I was using the game, it felt like I was playing rather than working	5	3	5	5	2	3	3	5	5	4
I would characterize my experience with the game as 'playing'	5	2	1	5	3	4	4	5	5	4
I was playing a game rather than working	5	2	1	5	4	4	4	5	5	5
Using the game felt like work	1	3	1	1	2	2	2	1	1	1
When I was using the game, I didn't worry about anything in the real world	5	3	5	5	4	3	3	5	5	4

Item	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
I was able to concentrate on the game without thinking about other things	5	4	5	5	4	2	3	5	5	4
When I was using the game, I was focused on the task at hand	5	4	5	5	4	4	4	5	5	4
I had a hard time concentrating on the game	1	2	1	1	1	3	2	1	1	2
I wanted to do well in the game, "just because"	5	3	1	5	2	2	5	5	1	4
When I was using the game, I wanted to do as well as possible	5	4	5	5	5	5	5	5	5	4
I tried to succeed in the game because I felt like it	5	3	5	5	5	5	5	5	5	4
During the game, my performance didn't matter to me	1	1	1	1	1	2	2	1	5	2

D.10 Responses to the Physical Activity Enjoyment Scale (PACES)

Item	P1	P3	P4	P5	P6	P7	P8	P9	P10
I enjoy it vs. I hate it	1	1	1	1	3	2	1	1	2
I feel bored vs. I feel interested	10	10	10	10	4	8	10	10	9
I dislike it vs. I like it	10	10	10	10	7	9	10	10	9
I find it pleasurable vs. I find it unpleasurable	10	1	1	1	4	3	10	1	2
I am very absorbed in this activity vs. I am not at all absorbed in this activity	10	1	1	1	4	3	10	1	2
It's no fun at all vs. It's a lot of fun	10	10	10	10	7	8	1	10	9
I find it energizing vs. I find it tiring	1	1	5	1	3	2	10	1	2
It makes me depressed vs. It makes me happy	10	10	10	10	7	7	10	10	8
It's very pleasant vs. It's very unpleasant	1	1	1	1	5	3	10	1	2
I feel good physically while doing it vs. I feel bad physically while doing it	1	1	1	1	3	4	10	1	
It's very invigorating vs. It's not at all invigorating	1	1	3	1	4	3	10	1	2
I am very frustrated by it vs. I am not at all frustrated by it	10	10	10	10	8	5		10	4
It's very gratifying vs. It's not at all gratifying	1	1	1	1	5	4	10	1	2
It's very exhilarating vs. It's not at all exhilarating	1	1	1	1	8	4	10	1	4
It's not at all stimulating vs. It's very stimulating	10	10	10	10	8	8	1	10	2
It gives me a strong sense of accomplishment vs. It does not give me any sense of accomplishment	1	1	1	1	4	3	10	1	2

Item	P1	P3	P4	P5	P6	P7	P8	P9	P10
It's very refreshing vs. It's not at all refreshing	1	1	1	1	4	4	10	1	3
I felt as though I would rather be doing something else vs. I felt as though there was nothing else I would rather be doing	9	10	8	10	2	7	1	10	9

D.11 Participants' Adherence Throughout the Intervention

ID	Month	Time Played (hours)	Sessions Played	Max Level
P1	1	2.9	11	12
	2	2.1	6	16
	3	4.9	18	31
P2	1	0.5	5	2
	2	1.0	5	4
	3	0.2	2	4
P3	1	6.0	23	15
	2	3.2	20	15
	3	6.0	25	31
P4	1	4.4	16	15
	2	0.5	2	15
	3	0.1	1	16
P5	1	2.8	9	14
	2	0.3	1	15
	3	3.4	7	31
P6	1	2.4	10	14
	2	2.0	10	15
	3	1.4	8	25
P7	1	0.1	1	0
	2	1.2	4	6
	3	0.3	1	8
P8	1	3.7	5	15
	2	0.2	1	15
	3	6.1	9	31
P9	1	5.7	11	15
	2	4.9	9	16
	3	4.9	5	31
P10	1	5.0	9	15
	2	2.8	7	15
	3	4.0	11	31

D.12 Comparison of Game CSRT Times and Test CSRT Times

ID	Month	K RT	STP KNT RT
P1	1	1.08656507	1.012760152
	2	1.052779305	0.882905445
	3	1.120832827	0.785491353
P2	1	1.073889441	0.966801371
	2	0.906111842	1.016673114
	3	0.938889613	0.925028551
P3	1	1.023888102	0.793002697
	2	0.944446143	0.776559383
	3	0.886389847	0.750268492
P4	1	0.926390603	0.807171551
	2	0.863610798	0.759239369
	3	1.00854506	0.736178856
P5	1	1.062778063	0.832564143
	2	0.851111507	0.782600822
	3	0.829167049	0.782096554
P6	1	0.855675943	0.8250544
	2	0.81786028	0.771663867
	3	0.804804474	0.743636088
P7	1	1.198056767	1.036287543
	2	1.044698897	0.918947744
	3	0.981920843	0.899230521
P8	1	1.079746495	0.784692236
	2	0.918178226	0.731123121
	3	0.883936582	0.685586201
P9	1	0.959714676	0.870014682
	2	0.926369026	0.8085904
	3	0.909606865	0.785632277
P10	1	1.075056708	0.950785009
	2	1.023889617	0.909108217
	3	1.009119779	0.81737948