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Use, user experiences, and the relationship between game elements and movement characteristics.

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NORSK SAMMENDRAG

Exergaming for eldre

Bruk, brukervennlighet og forholdet mellom spill elementer og bevegelseskarakteristikker

Etter introduksjonen av det Playstation-baserte spillet Dance Dance Revolution (DDR) i 2004 og Nintendo Wii i 2006, har bruken av videospill som et middel for å fremme fysisk aktivitet økt kraftig i popularitet. Disse bevegelses-kontrollerte spillene, som blir kalt exergames eller trenings spill på norsk, ble raskt anerkjent som et mulig verktøy for å tilby artig og lett tilgjengelig trening i både generell treningssammenheng og spesifikk rehabilitering. Selv om disse spillene har vist seg å ha et stort potensiale, er det fortsatt begrenset kunnskap om bruken og brukervennligheten av disse spillene for eldre, og om de er egnet for å opprettholde fysisk aktivitet, eller til bruk ved opptrening etter sykdom eller skade.

Målet med denne avhandlingen er å evaluere bruken, brukervennligheten og forholdet mellom spill elementer og bevegelseskarakteristikker hos eldre, med spesielt fokus på spill som er designet for å ta steg for å få poeng. Resultatene viser at eldre synes at spill er en artig og spennende form for trening, men de påpekte en del mangler i forhold til tilbakemeldinger de fikk fra spillene, samt ønske om gradvis økning av vanskelighetsnivået. Eldre viser også forskjeller i bevegelsene de gjennomfører når de spiller ulike spill på ulike vanskelighetsnivå, noe som illustrerer viktigheten av å se på bevegelsene til spilleren, samt se på de ulike egenskapene som spillene innehar, før man tar i bruk spill i spesifikk trening og rehabilitering for eldre. Økt vanskelighetsgrad kan øke glede og gjøre spillet mer lystbetont, men kan samtidig redusere bevegelseskvalitet. Det er derfor viktig å velge spill ut i fra hva man ønsker at utfallet skal være.

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This thesis is a result of three interesting, educational, and eventful years of joy and frustrations on my part, but the completion would not have been possible without a number of people whom I have learned to admire on both scientific and personal level. I would like to take this opportunity to give a special thanks to…

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"In Africa, it is said that when an old man dies, a library disappears. This reminds us of the vital role older persons play as intermediaries between the past, the present and the future; of the veritable lifeline they provide in society. Without the knowledge and wisdom of the old, the young would never know where they come from or where they belong."

Former United Nations Secretary-General Kofi Annan

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List of publications

This thesis is based on the following papers and manuscripts. The papers are reprinted with permission obtained from the publishers (Elsevier, ACM and Karger).

Paper I *Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy*

Skjæret N, Nawaz A, Morat T, Schoene D, Helbostad J.L, Vereijken B. International Journal of Medical Informatics 2016; 85 (1): 1–16. Epub 2015 Oct 28.

Paper II *Assessing seniors' user experience (UX) of exergames for balance training.*

Nawaz A, Skjæret N, Ystmark K, Helbostad J. L, Vereijken B, Svanæs D. ACM, In Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational. 2014, October: 578-587.

Paper III *Designing for movement quality in exergames: lessons learned from observing senior citizens playing stepping games.*

Skjæret N, Nawaz A, Ystmark K, Dahl Y, Helbostad JL, Svanæs D, Vereijken B. Gerontology 2015; 61(2):186-94. Epub 2014 Nov 13.

Paper IV *Exergaming in older adults: Movement characteristics while playing stepping games*

Skjæret-Maroni N, Vonstad E.K, Ihlen E.A.F, Tan X, Helbostad J.L, Vereijken B. Frontiers in Psychology – Movement Science and Sport Psychology; manuscript in revision 06.05.2016.

Abbreviations and frequently used phrases

Physical activity	Any bodily movement produced by skeletal muscles that requires energy expenditure, generally the amount, type, frequency and duration of activity a person does during a day
Exercise	Subcategory of physical activity with targeted, planned, and structured activity
Rehabilitation	Specialized healthcare dedicated to improve, maintain, or restore physical function
Exergames	Movement-controlled games that entail the combination of exercise and videogames
Commercial game consoles	Available off-the-shelf systems, designed for consumers to use for playing video games, like The Nintendo Wii, PlayStation Eye Toy, and Xbox 360 and Xbox One with the Microsoft Kinect camera
DDR	Dance Dance Revolution, a motion-based video game played on several different game consoles
The Mole	A motion-based video game from the company SilverFit
LightRace	A motion-based video game found in YourShape: Fitness Evolved from Ubi Soft Divertissement played on Xbox 360
ICT	Information and Communication Technologies
SUS	System Usability Scale
UTAUT	Unified Theory of Acceptance and Use of Technology

Abstract

Older adults represent the single largest group of people requiring healthcare in modern-day society. As the number of healthcare personal is projected to decrease in the years to come, it is important that elderly stay healthy and independent as long as possible. Falls and fall-related injuries are a major cause for loss of independence, and physical activity aimed at improving balance that includes stepping movements with weight shifting tasks has been shown to decrease fall risk. After the promotion of the Playstation-based Dance Dance Revolution (DDR) videogames as a weight loss tool in 2004 and the introduction of Nintendo Wii in 2006 for general, active entertainment, the use of body movements to control video games gained momentum rapidly and almost overnight became the favoured mode for a player to interact with a game station. These movement-controlled games, referred to as exergames, were quickly recognized as a potential tool to provide enjoyable, easy access, low threshold exercise and before long, exergaming was implemented in both general exercise and specific rehabilitation settings. Soon after, the first scientific studies appeared in the literature about the usability of exergames for elderly and the potential effect of balance and stepping exercises on fall risk reduction and prevention. After a decade with increasing research activity, several studies have reported that exergames have a great potential and positive, if weak, effects on physical activity in older adults. However, there is still a lack of in-depth descriptions of different game technologies, physical functions targeted, and safety issues related to older adults playing exergames, as well as of knowledge about older adults' user experiences and preferences of exergame technologies to exercise balance and stepping abilities. Furthermore, little attention has been paid to the actual movements older adults display when playing step-based exergames, leading to uncertainty whether these exergames actually elicit the specific movements considered important for improving balance and stepping abilities in older adults.

The overall aim of this thesis is to evaluate the use of exergames among older adults, with special focus on exergames designed for stepping activities. Specifically, the thesis aims to provide an overview of the technologies, safety and efficacy of exergames, to explore whether this technology is a safe and effective exercise and rehabilitation tool for older adults, to provide insight into the potential usefulness of exergames by evaluating user experiences and preferences of exergame technologies, and to assess movement characteristics displayed by older adults and map these to game elements during game play of step-based exergames.

Results of the research reported in this thesis show that a variety of game technologies has been utilized to offer weight-bearing exercises to older adults, and that these exergames seem promising

as an intervention tool to improve balance and gait parameters in older adults, with only a few reported adverse events. However, large differences between studies in terms of intervention protocols, outcome measures, and methodological limitations makes it challenging to compare the different studies and to draw definite conclusions regarding the effect of the interventions. Regarding user experiences and preferences, older adults expressed that they want exergames to focus on challenging tasks, provide feedback on how to perform the correct movements in a game, and provide progression in the game by rewarding correct movements and gradually increasing difficulty. As both movements displayed and game elements varied across all three exergames, mapping movement characteristics to game elements, illustrated the value of including analyses of movement characteristics of the player during game play when developing guidelines for designing exergames for fall prevention. Three-dimensional motion analysis demonstrated that movement characteristics displayed during game play are affected by the specifics of the step-based exergames as well as by the difficulty level of each game. Although players appreciated the increased level of difficulty, it had an unexpected negative effect on almost all movement characteristics, such as shorter steps with less variation in length and velocity, and less weight shift within a smaller movement area.

This thesis provides new insight into the field of exergaming by providing a more thorough understanding of the use of exergames by older adults, particularly with respect to the preferences of older adults, movements displayed during game play, and the relationship between movements and game elements. The results of this thesis indicate that specific characteristics of the games influence how older adults move during game play. Gaining knowledge about game elements and movement characteristics is therefore important when designing and choosing exergames to exercise specific functions, such as balance and stepping abilities, in older adults. Exergames need to be selected and designed with care, taking into account the preferences of older adults, as well as the movement characteristics aimed for during game play by mapping the different elements in the game against the resulting movements of the players. Exergaming has great potential to become an important part of future personalized medical technology. However, to realize more fully the potential of exergames as an exercise and rehabilitation tool for older adults, there is a need for further understanding the movements displayed during game play, as well as establishing the safety of unsupervised exergaming, ensuring ease of use by older adults, achieving long-term adherence to the games, and gaining understanding about which technology to use for which exercise or rehabilitation purpose. The current thesis has provided several important steps towards gaining this understanding.

1. Introduction

Globally, insufficient physical activity in everyday life is one of the leading risk factors for mortality and, unfortunately, is on a further rise in many countries. One of the key factors to maintain independence in older age is the ability to maintain physically active. Given the projected trend in population aging over the next decades (1), older people's engagement with physical activity in daily life, as well as in rehabilitation settings, is a public health concern worldwide. Even though recommendations for physical activity are commonly known among the population, maintaining regular physical activity can be a challenging task for many older adults. Even though many older adults believe in the potential of physical activity to improve physical and mental well-being, various barriers often get in the way, such as lack of social support, the challenges of getting to exercise venues, competing priorities, and lack of motivation to be physically active (2).

Some of the barriers associated with traditional physical activities, exercise, and rehabilitation could possibly be overcome by using new motion sensor technology in videogames. Around the turn of the millennium, the incorporation of motion sensor technology in videogames allowed the latter to be played using whole body movements, and these games quickly became a popular pastime in children, adolescents, and young adults. These movement-controlled games, referred to as exergames (a combination of the words exercise and videogames) also became popular tools for promotion of physical activity and rehabilitation in older people when clinicians and researchers recognized the potential of exergames to provide enjoyable, easy access, low threshold training. Although the commercially designed gaming consoles most commonly used, such as the Nintendo Wii, Sony Playstation, and Microsoft Xbox, did not include games specifically designed for older people, research groups started to investigate the possible effect of exergames in both exercise and rehabilitation settings. Balance and step-based games such as the Dance Dance Revolution (DDR) drew considerable attention in the early stages of exergaming research in older adults, mainly due to the low cost and the potential effect on fall risk reduction and prevention. In general, early studies reported that exergames had a great potential and that they had but positive, if weak, effects on physical activity in older adults (3-5). The combination of great potential as an exercise and rehabilitation tool and the positive effects shown, led to a spiking interest in using exergames in both research and clinical practice. However, despite this quickly increasing attention, little focus has been placed on what older adults are actually doing when playing exergames, in other words, which movements they are displaying when playing exergames. Therefore, we lack knowledge about whether step-based games actually result in those movements considered important for improving balance and stepping abilities, such as shifting weight from one leg to the other and variation in step length, speed, and direction (6-9). This thesis aims towards getting a closer understanding of different aspects of the use of exergames for older adults, as well as gaining new knowledge regarding how older adults move when playing step-based exergames. More specifically, the thesis aims to provide an overview of the use of weight-bearing exergaming in older adults, explore whether this technology is a safe and effective exercise and rehabilitation tool for older adults, provide insight into the potential usefulness of exergames as an exercise tool by evaluating experiences and preferences of exergame technologies, and assess movement characteristics displayed by older adults during game play of step-based exergames.

1.1 The aging population

Even before the new millennium started, the aging of the global population attracted the world's attention as one of the most important global challenges in the next century (10). Life expectancy rose greatly during the 20th century, and is expected to continue to rise. Today, for the first time in history, most people can expect to live into their 60s and beyond (11). In Europe, life expectancy is projected to increase well into 80 years across OECD countries, which is an increase of ten years since 1970 (12). In Norway, life expectancy is predicted to increase by another 10 years from 83 and 79 years in women and men, respectively, over the next 80 years (13). The aging population is first and foremost a success story of preventive health care in childhood, as well as continued social and economic development. However, even though several people are living longer and healthier lives, several of the additional years gained are years with disabilities (14). The number of disabilities increases considerably with age, and above the age of 65 years most people have more than one chronic condition (15). Individuals with multiple chronic conditions have more complex health care needs and may have more rapid declines in health status, a greater likelihood of disability, and lower quality of life than those with a single chronic condition (16, 17). In total, lifestyle, disease, and biology put older people at increased risk of functional decline, often leading to augmented need for health care (18) and increased health care costs (19).

The increased life expectancy and increasing risk of disability together with a general decrease in average number of children per adult (1), creates a situation where the number of employees per person over 65 years is steadily decreasing, which in turn further increases the pressure on the health care system. To manage the concomitant challenge to provide adequate healthcare to a growing population of elderly, there is a need to maintain independency among older adults as long as possible by shifting focus from treatment towards prevention of age-related functional decline

(20). Generally, physical activity and exercise are believed to be the most effective interventions to improve quality of life and functionality in older adults, and physical activity and social engagement are important aspects to increase and maintain health in older adults (21). Physical activity generally describes the amount, type, frequency, and duration of activity a person does during a day, and is defined as "any bodily movement produced by skeletal muscles that requires energy expenditure" (22). The term exercise is often seen as a subcategory of physical activity where activity becomes more targeted, planned, and structured to improve or maintain one or more components of physical fitness (22). Adults that are physically active are more likely to live well into their 80s and have less risk of dying with disability compared to their sedentary counterparts (21). Although physical activity and exercise do not stop the aging process itself, it can limit development and progression of chronic disease and disabling conditions (23), as well as improve cognitive function (24). Exercise has also been found to reduce the rate of falls and risk of falling among older adults (8, 25). But despite the large international focus on the health benefits of physical activity among older adults, epidemiological studies consistently find decreasing levels of physical activity in older age (26). Today, inactivity is the 4th leading cause of death worldwide, and sedentary behavior is linked to a higher risk for several diseases such as osteoporosis, obesity, and depression, and to the increasing death rates from coronary heart disease, type 2 diabetes, and colon cancer (27, 28). In addition, an inactive lifestyle decreases the quality of life for older adults as functional ability and independence across the life span are not preserved (29).

The observed decline in physical activity is partly related to the aging process itself, with structural and functional changes in the cardiovascular, skeletal, and muscular systems that can impact the ability to be physically active (18). Among the physiological changes that occur during the aging process are the decline in aerobic capacity and the loss of muscle tissue resulting in reduced strength, which in turn affect quality of life, functional independence, and mortality (30). With regular exercise and physical activity, older adults have been found to increase their VO_{2max} and achieve a higher maximal cardiac output when compared to sedentary controls (31, 32). Physically active older adults have also been found to have less total and abdominal fat, and larger muscle mass in the limbs as well as higher bone mineral density (33). With age, muscle strength declines substantially (34), and the reduction in muscle strength and associated increased muscle weakness can lead to increased problems carrying out everyday activities. In addition, muscle weakness is associated with reduced walking speed (35), increased risk of disability (36), and falls (37) in older adults.

1.2 Physical (in)activity in older adults

Being regularly physically active is generally associated with a multitude of health benefits, and is recognized worldwide as one of the most important health behaviors in preventing the onset, or reducing the severity, of many chronic diseases (27, 38), as well as reducing fall rate and fall risk among older adults (25). In general, physical activity is recommended to consist of different kinds of exercises and activities, such as strength, balance, and endurance training, and can be used either as stand-alone interventions or as components of a multifaceted program. Typically, the types of physical activities most popular among older adults are of lower intensity, such as walking, gardening, golf, and other low-impact aerobic activities performed as part of their daily life activities in and around their homes (39). Guidelines and recommendations for physical activity are offered by different entities, such as The Norwegian Directorate of Health and the U.S. Department of Health and Human Services, as well as The World Health Organization (WHO). These typically focus on recommended intensity, frequency, and duration of physical activities, as well as different types of exercise such as aerobic activities and strengthening exercises (38, 40, 41). The Norwegian Directorate of Health recommends that young and older adults should have at least 150 minutes of moderate-intensity physical activity or at least 75 minutes of vigorous-intensity physical activity per week, or an equivalent combination of moderate- and vigorous-intensity physical activity. For additional health benefits, older adults should increase moderate intensity physical activity to 300 minutes per week. In addition, exercises that increase muscle strength should be performed two or more times a week. Older adults with poor mobility should perform additional physical activities to enhance balance and prevent falls, three or more days per week (42). Although the set of guidelines on physical activity is relatively straight forward, many elderly do not engage in enough physical activity, and the WHO World Health Survey suggests that around one third of 70–79-year-olds and half of people aged 80 years or older, fail to meet basic WHO guidelines for physical activity at older age (43).

Despite this worldwide focus on the need to remain physically active and the known positive benefits of exercising, evidence suggests that 50% of sedentary adults have no plans of starting an exercise program (44), and persuading elderly to become physically active is a notoriously difficult task. However, there is large heterogeneity in function levels at older age, and Norwegian elderly aged 67-79 years old have become more active the last years, with as much as 40 percent carrying out some kind of physical activity several times a week (45). While the importance of an active lifestyle is well known, also among the elderly, they often believe themselves to be too old or frail to exercise, and exercise is rarely viewed as a necessary prescription medicine for a longer, healthier life (46).

Without proper motivation, effort is not easily forthcoming. Thus, understanding the factors that are perceived as barriers and the factors that motivate older adults to be physically active is an important requirement for designing effective physical activity interventions (47). Common barriers for taking part in exercise activities for older adults are the feeling of not having good enough health, the lack of knowledge on how to exercise correctly, the time consuming part of traveling to the exercise site, and the accompanied discomfort, such as sweating, increased ratings of perceived effort, and the phenomenon of delayed onset muscle soreness (46, 47). Furthermore, lack of social support, previous sedentary habits, competing priorities, and lack of motivation can constrain older adults from taking part in physical activity even though they believe in the potential benefit to improve physical and mental well-being (2). Consequently, understanding different people's needs and expectations, and taking into account demographical differences such as race, gender, and ethnicity, are important factors when trying to motivate older adults to engage in different aspects of physical activity (46). The feeling of pleasure and satisfaction during and after activity are also important aspects to consider. Likewise, to promote adherence to physical activity, clear and manageable goals should be made, as well as raising awareness of the health benefits and minimize the perceived risks of physical activity (47). Moreover, older people's perspectives should remain central in future discussion regarding the design of effective health services (2).

1.3 The challenges of balance and falls in older adults

Balance is the ability to remain in a position without losing control or falling, by controlling the center of mass within the area called base of support (48, 49). Exercising balance helps maintaining stability during daily activities and other exercises, and can be either static by controlling the center of mass within a reduced base of support, or dynamic by adaptive increases and reductions in the base of support (21). Changing the base of support relative to our center of mass, or simply speaking, taking a step, provides the means by which we are able to counter potentially destabilizing events such as slips, trips, and missteps, and avoid obstacles. With increasing age, changes in the sensory, motor, and cognitive systems may affect balance control, leading to difficulties producing an adequate response to loss of balance (49). In response to an external perturbation of balance, older adults are more likely to take a step that is too short or step in the wrong direction, to collide one leg against the other during compensatory crossover steps (50), and to be too slow in initiating volitional step responses (51).

Studies undertaken over the past three decades have shown that balance exercises are the most important component of efficacious exercise programs for older adults in order to reduce falls (8, 25, 52). Falls are among the leading causes of injury and disability in older adults, and are the main reason for institutionalization and loss of independence (53, 54). In addition to the personal consequences, falls also represent a significant economic burden on society and health care, and fall-related costs range between 0.85% and 1.5% of the total health care expenditures within the USA, Australia, EU15, and the United Kingdom (55). Around 30% of community dwelling older adults and 50% of those living in long-term care facilities fall at least once each year (56, 57), and up to 20% of these lead to serious injuries such as head traumas and fractures (58, 59). Balance impairments are associated with increased fall risk in community-dwelling older adults (60), and falls most often occur in situations that affect postural stability such as turning and reaching, and during gait activities (61). Being able to adequately adjust posture to maintain balance in daily life situations is necessary to prevent a fall (18, 48). However, intrinsic bodily systems such as the sensory, motor, and cognitive systems that are essential for proper postural control, gradually deteriorate with age resulting in an increased risk of falling (49). In addition to the decline in postural control, gait characteristics also change with age. Compared to younger counterparts, older adults have a less stable gait pattern with slower gait speed, shorter step length, a wider base of support, longer double support, as well as increased variability in step time, step length, and step width (49, 54). To avoid falling in daily life situations where slips, trips, and different kinds of obstacles occur, fast and corrective stepping movements are necessary that involve changing the base of support relative to the center of mass in order to prevent or correct loss of balance. For older adults, however, the abilities to initiate such a fast voluntary step or to inhibit a preplanned step and find an alternative foot landing position to avoid instability, have been found to deteriorate, consequently leading to increased risk of ending up in a hazardous situation that can lead to a fall (51, 62, 63). One of the most important aspects to include in fall preventive exercise are tasks that challenge balance. Such tasks should include exercises that reduce base of support, move the center of gravity, and reduce the need for upper limb support (8). New technology-based exercise forms, such as exergames, create the possibility to provide easy access balance and stepping exercises without the need to travel to training centers or large devices, enabling older adults to easier engage in these exercises.

1.4 The age of technology

Technology has become an indispensable part of people’s everyday life. Different kinds of technologies meet a wide range of needs, from entertainment and socialization to safety, education, and health. With respect to the latter, an abundance of novel devices and technologies have appeared during the last decades with the promise to improve the quality and efficiency of health care. Furthermore, being able to employ enough people in the public sector to provide adequate health care to all is considered unrealistic in the years to come, and in order to secure the best possible care in the future the use of modern technology will play an increasingly important role.

Over the recent years, a number of Information and Communication Technologies (ICTs) have emerged that are aimed at promoting independence and well-being. The term assistive technology is used increasingly to cover a growing range of innovative equipment as well as more traditional items, such as wheelchairs and walking frames. Furthermore, the use of telehealth through internet and video technology that focuses specifically on home monitoring makes it possible for medical consultations to be conducted remotely. The overall aim of home monitoring and personalized models of health care is to avoid or delay hospitalization or admission to long-term care (64, 65). In Norway and the other Scandinavian countries, the term welfare technology has emerged as a collective term for the technology used to improve the services provided by the welfare society and to make them more efficient (66). The ultimate goal of welfare technology is to provide independence so that people can take care of themselves longer despite illness and reduced functional ability, by contributing to increased safety, social interaction, mobility, and physical and cultural activities (67). Different types of welfare technology exist that include alarm systems such as fall detectors and safety alarms, technical supports such as walking aids and robotic assistance, and interventions created or adapted to increase physical activity such as game technology and GPS-tracking (67). The different types of welfare technology are perceived to have great economical savings potential, and from a technical point of view they are already available for many needs. However, within the health care sector, the available technology is often seen as not well enough adapted to the problems and needs met in every day health care, that implementation of the technology entails restrictively large changes for the health personnel, and that it is too expensive. In addition, many people still have the perception that cold, hard technology does not fit into the warm, compassionate health care system (67), and a survey performed in the municipalities of Norway in 2011 showed that welfare technology, except for personal safety alarms, was barely utilized (68).

In addition to the above mentioned challenges with implementing technology into the health care sector, standardized technological solutions may not be sufficient for use in older adults. In order for ICT solutions to be applied as a tool in different aspects of the health care sector encompassing older adults, the different interests of various stakeholders should be taken into consideration. To mention but a few, one can distinguish between the interests of governments, care service providers, medical institutions, research facilities, and, not in the least, the older adults themselves and their families and next of kin. When it comes to the design and development of new devices and services for independent living, specific requirements of older adults have to be taken into account, such as restricted ability to hear, see, and control ICT equipment. The different stakeholders must ensure and guarantee that the accessibility and usability of the technology correspond to the needs and wishes older people have. However, one must bear in mind that elderly people are a heterogeneous group that differ by age, sex, degree of impairment, biography, income, education, religion, culture, interests, etc. Furthermore, the user's awareness, practical experiences, and expectations regarding technology should also be taken into account.

There is a lack of studies that investigate the acceptance of ICT-based solutions by older adults. It is usually thought that older people are less frequent users of technology and they are often considered "non-technological people". However, in the last few years, mobile phone usage by people over 60 years has been growing rapidly (69), and nearly a third of American adults older than 65 years play digital games (70). Previous research has shown that older adults are eager to learn more about technology and how it potentially can help them to maintain independence and a high quality of life, by retaining or even increasing both their physical and mental abilities (71). However, there may be several barriers for older adults to use technologies, including feelings of embarrassment and lack of knowledge, attitudes around control and safety, not understanding the feedback given by the system, and ease and comfort of use (71, 72). To understand which factors older adults consider most important when it comes to the use of different technology solutions, it is necessary to evaluate user experiences and preferences of the different technologies used in promoting e.g. physical activity.

1.5 Exergaming

Following up on the many positive health effects of an active life, many attempts have been made to encourage people to be more physically active. During the last decade, a new form of interactive gaming has emerged that requires physical body movements to play computer games, and researchers have begun to examine whether these games can be a means to engage in general or specific physical activity.

In the beginning of the 21th century, computer-based videogames were viewed as a sedentary living room activity, preferably used by children and adolescents, and considered one of the contributors to increased childhood obesity. However, looking back to the video arcades of the 1970s and 80s, playing video games meant standing up doing vigorous body movements (73). When players began sitting at home, much of the physical connection with the games disappeared, and handheld joysticks and paddle controllers became the new way of controlling the games. In 2004, GetUpMove.com promoted the Playstation-based Dance Dance Revolution (DDR) videogames as a weight loss tool. DDR is the pioneering series of the rhythm and dance genre in video games, where players stand on a "dance platform" or mat while stepping their feet on specific areas in correspondence with instructing arrows on the screen and to the beat of the music. Players are judged by how well they time their dance to the patterns presented to them and are allowed to choose more music to play to when they receive a passing score. The release of the DDR drew considerable media attention, and videogames started to be sold for the purpose of exercising. This newfound trend was labeled exergaming, reflecting the combination of exercise and videogames. After the introduction of Nintendo Wii in 2006, the use of body movements to control video games rapidly gained momentum and almost overnight became the new mode for a player to interact with a game system. Soon after, in 2009, Sony released the PlayStation Move, and in 2010 Microsoft released their Kinect for the Xbox 360.

With the Wii gaming console, Nintendo was the first to introduce affordable motion-sensing controller technology into the homes of people all over the world and quickly became the market leader, selling over 20 million units around the world (74). The Wii motion controller is a handheld device containing a 3-axis accelerometer, a high-resolution high-speed infrared camera, a speaker, a vibration motor, and wireless Bluetooth connectivity that allows the player to control the games by physically moving the remote controller within a range of 10 meters (75). In April 2007, Nintendo released the Wii balance board as a part of the Wii Fit package. The balance board contains four transducers that provide information relating to force distribution of the player during gaming and has a wireless connection to the game console (76).

Figure 1. Nintendo Wii gaming console with the Wii Fit balance board.

In 2009, PlayStation released their motion-sensing game controller platform for PlayStation 3, with the PlayStation Move motion controller and a PlayStation Eye camera. The Move is a wand controller using RGB (red, green, and blue color model) light-emitting diodes (LEDs) and containing a three-axis accelerometer, a three-axis gyro sensor, and a

Figure 2. The Playstation Move controller and Eye camera.

geomagnetic sensor, which allows the user to interact with the console through motion and position in front of the camera. The uniform shape and known size of the spherical light allows the system to determine the controller's distance from the camera through the light's image size, thus enabling the controller's position to be tracked in three dimensions with high precision and accuracy (77).

The Kinect sensor device was subsequently released in 2010 and comprises a depth camera, an RGB camera, an infrared laser speckle pattern projector, and a multi-array microphone, providing additional functionality to the motion-sensing game consoles by enabling depth detection of the players (77). This gave the Kinect the ability to recognize full-body motion in 3D, enabling the player to control the games without the need of an additional controller device. Instead the player’s body or speech controls the games, making it possible to automatically recognize and sign-in individual players (78).

Figure 3. The Microsoft Kinect camera.

With the continuous release of new technology, exergaming was quickly recognized as a potential way of getting people up and moving, and different establishments such as arcades, gyms, rehabilitations centers, and nursing homes started to install exergames. Soon after the release of Nintendo Wii on the market, the first scientific studies on exergaming appeared in the literature as well. This early research focused mainly on design requirements in order to foster physical activity among children and teenagers (79, 80). However, the potential of using digital games to increase physical activity was quickly recognized by researchers focusing on physical activity and rehabilitation in older adults. One of the main arguments for applying exergames was that while traditional exercise programs can be difficult to comply with, exergames are designed to be entertaining and motivational and may therefore increase time spent in physical activity. As IJsselsteijn et al. (2007) stated: ”Digital games hold a significant promise for enhancing the lives of seniors, potentially improving their mental and physical well-being, enhancing their social connectedness, and generally offering an enjoyable way of spending time” (81p.1). The commercially available games were mainly designed for entertainment and recreation for younger populations by creating sports-like experiences (82), which tend to have colorful and visually busy game interactions, fast music, and demanding navigation through the user interface. With advanced age, numerous underlying physiological changes, such as age-related losses in hearing, seeing, and moving (83-85), as well as cognitive decline (86), might pose several challenges for older adults as users of commercially developed game systems. For this reason, several studies have proposed guidelines for game design for older adults (87-89), and new exergame concepts and systems have been developed to meet the needs of older adults (90-92). Unfortunately, these game systems have mainly been developed for research only, and few are available on the market for the general user. Even though these custom-designed games, and exergames in general, show promise with respect to engaging older adults in physical activity, there is limited knowledge about safety and associated adverse events when using these games, whether adherence to exergames actually increases compared to other forms of exercise, and whether exergames provide a positive change in physical functions in older adults.

1.5.1 Usability of exergames

In order to make exergames suitable as an exercise and rehabilitation tool for older adults, games need to be developed based on the needs and preferences of the users. For exergames to be persuasive, the games should be designed so that seniors not only accept them, but are also willing to use them for a longer period of time. Thus, knowledge based on usability and assessment of user experiences is important in order to gain more insight into the needs and preferences of older adults regarding exergaming technology.

The term usability is often used in association with technology development, and refers to making digital systems understandable and intuitive to use for the end-users through user-friendly interfaces. Usability refers to the extent in which a system or product can be used in a curtain context by specific users to achieve specified goals with effectiveness, efficiency, and satisfaction (93). Effectiveness measures the degree to which systems cover all necessary functionality, and how easy they are to use and understand. Efficiency is about how well different tasks are performed, and how much time it takes to accomplish a task. Both effectiveness and efficiency can be measured objectively. The last element, satisfaction, focuses on the overall user experience and can be measured through e.g. interviews and questionnaires (93). In contrast to usability, user experience highlights non-utilitarian aspects of human-technology interactions, shifting the focus from user cognition and user performance to the person's perception and responses of such interactions in everyday life (93, 94).

There is no definitive solution on how to make a good and user friendly technology system. It is challenging and time consuming to understand the users' needs and wishes for a specific system. Furthermore, often the users struggle themselves with knowing clearly what they want. However, for a system design to experience success in interacting with the end users, designers have to pay attention to various aspects of the user. One way to ensure this is to involve users in the entire process of developing a system, from requirement definition and the design phase, to prototype and system testing, all the way to the end of the system's life cycle (95). Game-specific measures of usability for older adults have mainly focused on the relation between the game and the user in different contexts, as well as the design aspects of the games. One of the first considerations regarding game design for elderly players dates back to the 1980s, when Weisman (96) explored the accessibility of Apple II games (a groundbreaking computer system designed by Steve Wozniak with features such as color graphics and sound) among institutionalized older adults. Weisman suggested already back then that implementation of clear visual and generally adjustable games are important for the elderly audience. More than 25 years later, the same issues were addressed by Gamberini et al. (97), who focused on the impact game play has on cognitive decline, particularly addressing the design of graphical user interfaces. Likewise, IJsselsteijn et al. (81) analyzed age-related changes and presented a set of design recommendations including the creation of individually meaningful and visually adjustable games that provide multimodal feedback.

There is no general framework for assessing the user's preferences of technologies such as exergames, and many different models have been developed to describe barriers and intentions of users with respect to using technology. The Unified Theory of Acceptance and Use of Technology (UTAUT) model was developed by Venkantesh and colleagues (98) with the purpose of creating one unified model for technology acceptance. The UTAUT model integrates eight previously developed models into one comprehensive model, and has been used to assess the degree of technology acceptance by a target population through seven constructs. Three of these constructs are seen as having a significant role as direct determinants of behavioral intention. These are performance expectancy, effort expectancy, and social influence. In addition, facilitating conditions, the degree to which an individual believes that the organizational and technical infrastructures exist to support the use of the system, is a construct that has a direct effect on user behavior as well. Performance expectancy is defined as the degree to which a person believes that using a particular system will help to attain improvements in performance. Effort

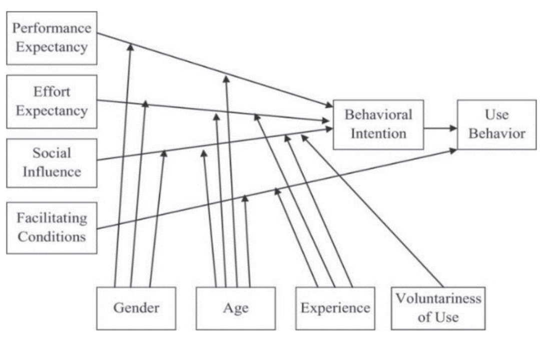

Figure 4. The unified theory of acceptance and use of technology (UTAUT) model (Source: Venkatesh et al., 2003).

expectancy measures the perceived ease of use of a system, while social influence is defined as the degree to which an individual senses that a person who is important to him or her thinks that (s)he should use the system in question (98). The UTAUT consists of four further moderators of key relationships factors that are not directly determinants of intention, gender, age, experience and voluntariness of use (see Figure 4) (98).

1.5.2 Advantages of exergaming

One of the main advantages of exergames is the added “fun” component to an exercise program which can be used to motivate and persuade older adults to exercise more (88). For instance, Nap et al. (99) found that senior gamers played digital games for fun and relaxation (i.e., enjoyment). The senior gamers also reported that an underlying intrinsic motivation was to escape from reality to have some private time, either from the sorrow of a deceased loved-one or from everyday life such as household chores (99). In addition to their entertainment value, digital games hold the potential to increase adherence to exercise by providing regular feedback and motivational messages to older adults (72). Adding a social factor could also be a perceived advantage of exergaming (100), and promoting social interaction is an area in which exergames can excel. Because games are popular with all age groups, they can be used to encourage different generations to play together. In addition, some games can be played online, allowing those who are unable to leave their homes because of disabilities or illness to have playful social interactions. However, there is some evidence that the senior population does not find co-playing quite as rewarding as the younger population (101), indicating the need to thoroughly evaluate the potential players before implementing an exergame into exercise and rehabilitation settings.

Another important advantage of exergames is the possibility to train both motor and cognitive skills while exercising (102). Previous research suggested that interventions aimed towards cognitive activity should include enriched environments that provide physical activities with decision-making opportunities (103), a requirement that exergames have the potential to meet. Other characteristics of exergames that seem to hold an advantage over traditional forms of exercising are the possibilities of training at home rather than in a center-based setting, the relatively low costs of exergaming systems, and the possibility to provide an exercise environment that can be adapted to the players’ ability and performance requirements. However, some of these possibilities are associated with several gaps in our knowledge, for instance whether exergames are safe for older adults to use at home without supervision. Specific lifetime experiences and knowledge about the world, as well as age-related changes in perception, cognition, and motor control have previously been shown to have the most influence on specific gaming preferences, motivations, and needs for older adults are (104). Hence, incorporating such aspects into a gaming system can additionally help increasing adherence to exercise.

1.5.3 Effectiveness of exergaming

Some of the first studies to evaluate the feasibility and effects of exergaming on physical functions in older adults were case reports where exergames were used as a rehabilitation tool in the context of balance and falls. These studies concluded that exergames could be an adjunct to traditional therapy and that exergame interventions could produce improvements in balance as well as a reduction in falls (105, 106). Following this, several case studies exploring the use of exergames among older adults showed a variety of positive effects on the well-being of older adults (107, 108) as well as being feasible and acceptable to older adults with depression (109). Also, the incorporation of exergames in physical therapy has been used to motivate older adults to engage in physical activity, as therapy related to interactive games are designed to be entertaining and motivational and therefore may increase the amount of time spent in physical activity (110). In addition, exergames were heralded as providing a number of advantages over conventional therapy. First of all, realistic movements and behaviors occur in a safe environment that can be shaped and graded in accordance to the needs and level of ability of the patient engaged in therapy. Secondly, exergames allow for consistency in how exercises are delivered and performed, giving the opportunity to accurately compare performance over time (111).

Following these initial studies, more and more attention was given to whether exergames could be effective when used to exercise specific physical functions, such as balance (112, 113), and as a rehabilitation tool in different patient groups, such as stroke survivors (114, 115). In general, these studies reported that the effects of exergames are equal to or better than conventional forms of therapy, and that exergames have the potential to be used in different exercise and rehabilitation settings. However, few, if any, studies have looked closer into the reasons why these games might have an equal or better effect compared to traditional exercise interventions. Usually, exergames have been implemented as an exercise intervention for a certain amount of time without further knowledge about the game other than it has been perceived as fun and easy to use. Further information about the movement patterns of the players during a gaming session has rarely been included, making it unclear whether the potential effect derives from generally increasing activity, or the specific movements made during gaming. In order to ensure that older adults achieve the benefits originally aimed for when deciding to use exergames, it is important to assess whether players perform true-to-life movements, or whether they adapt their movements to achieve success and gain a good game score when playing games like tennis or bowling. In addition, it is important to investigate and identify movement patterns displayed by the player in order to ensure good game design that reacts and rewards the correct movements made by the player (116). If exergames do not elicit the specific movements in the players originally aimed at, how can we expect them to be effective? For example, recommendations for fall preventive training include exercises aimed at transferring body weight from one leg to the other (52). If an exergame allows the player to stand with both feet positioned at the same spot on the ground, how can one expect to have a positive effect on a balance task that requires a stepping movement to move the center of mass? Not knowing what specific movements were made by players during exergaming makes it difficult to interpret the results of playing these exergames as part of intervention studies, to draw conclusions about the potential effectiveness of exergames to train specific movements and tasks, and gain knowledge on how to improve specific functions important for the elderly population.

1.6 Rationale for the thesis

An abundance of exergames has become available on the commercial market during the last decade, and several costume-designed exergames for specific research purposes have also emerged the last few years. Step-based exergames have the potential to stimulate complex and dynamic movements that contain variations in step length, direction, and speed, as well as inhibition of voluntary step initiations and avoidance of virtual obstacles. These are all skills that are necessary to successfully navigate through different situations in daily life. Although the use of exergaming seems promising as a means to promote not only general physical activity among older adults, but also specific functions such as balance and stepping, some important aspects should be highlighted for using this technology as an exercise and rehabilitation tool. First of all, if exergames are to be employed as a safe and effective exercise and rehabilitation tool for older adults, there is a need to obtain not only evidence of effectiveness, but also a broader understanding of the potential usefulness of exergames. Important aspects that we need better understanding about are safety measures and associated adverse events, adherence to exergames compared to other forms of exercise, and the qualities of the different gaming consoles and exergames that are used in research. Secondly, the exergames employed need to be evaluated in terms of user experiences and preference of the older adults actually using these exergames. By understanding which factors the older adults themselves consider important for exergaming, utilizing these games within a possible long-term setting is more feasible. Finally, we need more insight into the movements displayed by the players during a gaming session and how these are affected by game characteristics, in order to interpret results of intervention studies and draw conclusions about the efficacy of exergames to exercise and improve specific functions important for the elderly population. In addition, understanding how elements in the different games are related to movements displayed during game play can provide insight into aspects relevant for the design of exergames for older adults. Therefore, this thesis aims to assess different aspects of exergaming, from the overall use of technology and usability, to the movement characteristics displayed by older adults, with a special focus on exergames designed for stepping activities.

1.7 Aims of the thesis

The overall aim of this thesis is to evaluate the use of exergames among older adults, with a special focus on assessing exergames designed for stepping activities. More specifically, the thesis aims to provide an overview of technologies, safety and efficacy of exergames, to explore whether exergame technology is a safe and effective exercise and rehabilitation tool for older adults, to provide insight into the potential usefulness of exergames as an exercise tool by evaluating experiences and preferences of exergame technologies, and to assess movement characteristics displayed by older adults and their relationship with game elements during game play of step-based exergames. The work consists of four papers: an integrative review, a usability study evaluating user experiences and preferences, an observational laboratory study, and a motion capture study. The specific aims were as follows:

I. To provide a systematic overview, in-depth description, and discussion of the literature on exergames used for the elderly population, including the different game technologies, physical functions targeted, and safety issues related to older adults playing exergames.

II. To evaluate user experiences and preferences of exergame technologies to train balance and to identify different factors that affect seniors' intention to use exergames.

III. To compose guidelines for designing exergames for older adults by investigating the relation between game elements and relevant aspects of stepping behavior during gameplay of three stepping exergames.

IV. To describe movement characteristics displayed by older adults in terms of stepping movements and upper body movements elicited during game play of two different step-based exergames, and to ascertain to what extent different games, different difficulty levels, and repeated game play trials may influence these characteristics.

2. Methods

All studies in this thesis were carried out at the Norwegian University of Science and Technology (NTNU), Norway. Permission to carry out the project described in Papers II and III was given by the Norwegian Social Science Data Services, and the study reported in Paper IV was approved by the Regional Committee for Medical and Health Research Ethics. All studies were conducted in accordance with the Declaration of Helsinki.

2.1 Study designs

The four papers in this thesis focused on the use of weight-bearing exergames for older adults. An overview of designs and study populations for the different papers is presented in Table 1.

Table 1. Study design and population included in Papers I, II, II and IV

Paper	Design	Population	N included
I	Integrative review	Older adults (≥65 years), healthy or with a specific diagnosis, living independently or in-residential care facilities	60 studies (including a total of 1808 participants)
II	Usability study	Healthy older adults (≥65 years)	14
III	Observational laboratory study	Healthy older adults (≥65 years)	14
IV	Motion capture study	Healthy older adults (≥65 years)	20

2.2 Study sample characteristics

Three different study samples were used in the four papers. In Paper I, an integrative review, a total of 60 studies were included after a predefined literature search in PubMed and SCOPUS databases. The searches consisted of combinations of controlled terminology and free-text terms expressing the concepts game, exercise, and aged, and were adapted to each database. To be included the median or mean age of the study sample(s) had to be 65 years or above. In addition, the studies had to have an intervention design with pre- and post-measurements, utilize ICT-implemented games that included weight-bearing exercises, and have outcome measures that included physical activity variables and/or clinical tests of physical function. The combined study sample consisted of a total of 1808 participants with a mean age of 76.1 (SD ± 6.7) years (range 44 to 98 years) and included both genders. The study population in the included studies was categorized as healthy or non-healthy (i.e., with a medical diagnosis such as e.g. Parkinson's disease) living at home or in-care (e.g. in retirement homes).

A convenience sample of fourteen community-dwelling older adults (9 females, 5 males, mean age 73 years, SD ± 5.7 years, range 65 – 85 years) participated in the study reported in Papers II and III. For Paper IV, a convenience sample of 20 community-dwelling older adults participated (12 females, 8 males, mean age 75.7 years, SD ± 5.4 years, range 65-90 years). To be included in the latter studies, participants had to be over the age of 65 years, have no known physical or mental disabilities, and be able to walk safely without a walking aid. All subjects signed an informed consent form prior to participation and were informed that they could withdraw from the experiment at any time without having to provide an explanation.

2.3 Exergames

A variety of exergames were used in the studies reported in the different papers. In Paper I, studies had to utilize ICT-implemented games that used weight-bearing exercises. Details about the games and game technologies were extracted from all included studies. Gaming technology was divided into commercially available games, such as the Nintendo Wii game console and the X-box 360, or custom-designed games either from a company such as GestureTek's Interactive Rehabilitation and Exercise System (IREX®), or an interactive game-based virtual interface in a laboratory setting. The different games used in the included studies targeted different aspects of physical activity such as balance, either alone or in addition to other physical functions such as strength, endurance, and mobility, as well as walking/stepping, strength, and activities such as aerobics, dance, yoga, and different sports-related games.

In the study reported in Papers II and III, three step-based exergames were used, the open-source game DanceDanceRevolution (DDR) (www.stepmania.com), The Mole from SilverFit (SilverFit BV, Woerden, The Netherlands), and LightRace in YourShape: Fitness Evolved (Ubi Soft Divertissement Inc., Montréal, Canada) (see Figure 5). Based on the results reported in Papers II and III, two of the games were further used in the study reported in Paper IV, The Mole from SilverFit and LightRace in YourShape: Fitness Evolved.

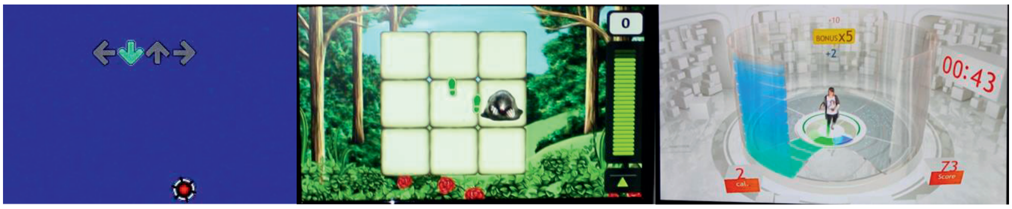

Figure 5: The interfaces of the modified DanceDanceRevolution (left panel), The Mole from SilverFit (middle panel), and LightRace in YourShape: Fitness Evolved (right panel).

2.3.1 Dance Dance Revolution

Dance Dance Revolution (DDR) is an interactive game produced by Konami Corporation (www.konami.com) that can be played on several game consoles, such as Sony PlayStation, Microsoft Xbox, and Nintendo Wii, as well as on a PC. The player stands in the center of a 3x3 pressure-sensitive panel (step pad), and controls the game by stepping left, right, forward, and backward. On a screen in front of the player, arrows drift from the bottom of the screen to the target arrows on the top of the screen and participants need to synchronize each of their steps to correspond with the drifting arrow passing over the target. The difficulty of the game is created by the sequence of the arrows and speed of the steps. After each step response, participants should return to the central panel. Feedback is given to the players based on their accuracy for each step in form of a word on the screen, Perfect, Good, or Miss. Points are given according to how well participants performed the stepping task. In the study reported in Papers II and III, a modified game version was used that was developed by Schoene et al. (117) to better suit senior players based on the open-source DDR game Stepmania (www.stepmania.com). In this version, an additional cognitive load is included in the form of a pictured bomb rather than an arrow, in which case the step response should be inhibited. If participants failed to inhibit a step response, the bomb exploded on the screen to indicate the error, and points were correspondingly deducted from their game score. There is a large selection of music to choose from and the game contains three levels of difficulty, Easy, Medium, and Hard, that can be selected by the player him/herself. In the study reported in Papers II and III, participants played the game at the easy level with accompanying music selected by the researchers.

2.3.2 The Mole from SilverFit

SilverFit is a virtual reality rehabilitation system (92) made by SilverFit BV in the Netherlands. The system consists of both hardware and software, with games being specifically designed for seniors in therapeutic sessions. A variety of different mini games are offered in the SilverFit software, which can be adjusted to the physical and cognitive level of the player. The SilverFit system uses a time-of-flight (ToF) 3D motion sensing camera to capture the player's movements. The player's movements are represented on a screen in front of the player as a simplified avatar, a graphical representation of the user on the screen, depending on the game chosen. In the game used for the current study, the players' movements were represented on the screen as feet. This happens in real-time, so the player can see where he/she is standing in relation to the gaming area at all times. The gaming area is 5x5 meters, and all gross body movements are traced in a 176x144 pixel array. For the studies reported in Papers II, III and IV, the mini game The Mole was selected. The Mole is categorized as a balance game, requiring players to take steps in different directions within a 3x3 grid covering most of the screen, designed to resemble a natural green environment. Two versions of the game were played, Basic and Precision Control. In Basic, a mole appears at different areas on the screen that the player should step on to make the mole disappear and receive points. In Precision Control, an additional cognitive element is added in the form of a mouse that moves between the areas and should be stepped on before disappearing, and a ladybug that should be avoided. Stepping on a mole or a mouse yields points, while stepping on a ladybug costs points. All animals appear randomly on the screen, making the player move in all directions. No music is accompanying the game, but feedback is given as an affirmative sound, and the area turns green when the player steps correctly on one of the targets.

2.3.3. LightRace in YourShape: Fitness Evolved

YourShape: Fitness Evolved (Ubi Soft Divertissement Inc., Montréal, Canada) is designed for physical activity in the general public and targets strength, balance, and cardiovascular training through a variety of boxing, Zen, and short gym exercises. The game is played on the X-box 360 (Microsoft Inc.) with the Kinect 3D motion sensing camera to detect the player's movements. The Kinect sensor device consists of an infrared depth-sensing camera, an RGB camera, and an infrared laser projector that estimates the 3D geometry of the acquired scene at 30 frames per second. The Kinect recognizes full-body motion in 3D, and the player controls the game through his/her virtual character on the screen. In Papers II, III and IV, the mini game LightRace was chosen. The game elements consist of a white space where the avatar of the player is situated in a transparent cylinder in the middle of the space. There is a fixed green circle on the floor which is the gaming area the player must remain in during game play in order for the camera to adequately detect the player's body. The game consists of stepping on the area that lights up around the avatar on the screen. There are five areas around the player, two in front, one on each side and one behind the player. The game has three difficulty levels, Easy, Medium, and Hard. In the study reported in Papers II and III, participants played the easy level, while they played at both the easy and the medium level in the study reported in Paper IV. At the easy level, lights appear in front or to the side of the player, while at the medium level lights appear behind the player as well. Stepping on the correct area turns it green, an affirmative sound is presented, and the score increases. When stepping on the wrong area, it turns red without further penalty. The game has accompanying background music and a personal trainer giving feedback, both positive and negative, on how you are performing.

2.4 Laboratory setup: equipment and data collection

Papers II and III are based on the same study that was conducted in the usability laboratory at the Norwegian Research Centre for Electronic Patient Records (NSEP) at the Norwegian University of Science and Technology (NTNU), Norway. The lab consists of two main rooms, one test-area and one observation room. The test-area was equipped with three ceiling-mounted cameras and a sound recording system, which were monitored and controlled from the observation room. Each session was recorded from the moment participants signed the written consent form until finalizing the experimental protocol. The main test area was set up with the gaming equipment and an interview table. The DDR and The Mole were run from a HP PC, and the LightRace was run on an X-box 360. Both the PC and the X-box were connected to a flat screen television to display the games to the participants. The Kinect camera connected to the X-box and the ToF-camera for the SilverFit system were placed on a table in front of the television. The DDR step pad was connected to the PC and placed on the floor in front of the television when participants played the game. All sound recordings from the interviews were transcribed manually in Norwegian and coded in ATLAS.ti based on the different constructs in the UTAUT model (98). Video recordings were manually edited using Movie Maker (Microsoft Inc.) to contain only the actual game sessions before further analysis of the videos.

The study for Paper IV was conducted at the movement laboratory at Dragvoll Idrettssenteret at the Norwegian University of Science and Technology (NTNU), Norway. An Oqus Motion Capture System (Qualisys AB, Gothenburg, Sweden) was used to track the movements of the participants while playing the two exergames. For the exergames, an Xbox with a Kinect camera (Microsoft Inc) and a HP PC with the Soft Kinect camera from SilverFit (SilverFit BV, Woerden, The Netherlands) was used. The Xbox and PC were connected to a 36” ASUS screen, placed 2.5 meters in front of participants’ starting position. The 3D game cameras were placed 3 meters in front of the start position and 1.80

meters from the floor at an angle of 45° from horizontal, in accordance with the setup manuals. Five passive reflective markers were attached with double-sided tape bilaterally to the participant's base of 1st toe, mid calcaneus, and approximately at the mid lumbar vertebras of the back (Figure 6). Seven infrared cameras were placed around the area where the exergames were played, and a digital video recorder was placed on the participants' right side. Two of the Oqus cameras were suspended from the roof, while the remaining five cameras were placed on tripods, approximately 1.80 meters above the ground. The Oqus cameras were calibrated to measure marker position to within 1.0 mm accuracy at a frequency of 100 Hz. Position data were recorded using Qualisys Track Manager (Qualisys) and processed in Matlab (Mathworks, MA, USA).

Figure 6. Placement of the reflective markers.

2.5 Experimental protocols

Testing in the usability laboratory (papers II and III) was carried out between April 17th and April 23rd 2013. All participants played DDR, The Mole, and LightRace. At the start of the test session, each participant filled out a consent form and a questionnaire with background information regarding age, experience with technology, and amount of weekly physical activity. Before playing the three exergames, a researcher demonstrated the games to the participants. The participants played the three exergames in a counter-balanced order. All participants played DDR for the length of one song ("That old black magic", lasting 3 min) at the easy level, The Mole from SilverFit for one minute at Basic and one minute at Precision Control, and LightRace in YourShape for one minute at the easy level. If needed, participants were provided with assistance during gameplay. A researcher always stood behind the participants to ensure safety while playing the exergames. After completing each game, participants filled out the Norwegian version of the Systems Usability Scale (SUS) questionnaire with 10 statements about the game system, and the participants marked to what extent they agreed or disagreed with each statement, ranging from 1 "Strongly disagree" to 5 "Strongly agree" (118). After finishing all three games, a semi-structured interview was conducted based on the constructs of the technology acceptance model to assess users' acceptance of the game technology. Finally, the participants were asked to rank the three exergames based on which game they liked the best using three different cards representing the exergames.

Testing in the movement laboratory (paper IV) was carried out between January 30th and March 24th 2014. Upon arrival the participants were given oral and written information about the project and signed a consent form. Before participants were introduced to the games the reflective markers were attached to the feet and lower back. All participants followed the same protocol for both games (Figure 7). All participants played the two exergames, The Mole and LightRace, on two difficulty levels, easy and medium, with five one-minute trials for each game and level, giving a total of 20 trials for each participant. The games were played in counter-balanced order across participants, and they always started with the easy level of the game. A researcher always stood near the participant to ensure safety while playing the exergames. After finalizing the five test trials for each game level, the participants marked the BORG Perceived Exertion Scale (score 6-20) (119) and answered a few short questions about enjoyment, possible usage, and fear of falling while playing the game. After completing both levels of each game, the participants filled out the Norwegian version of the SUS-questionnaire (score 1-100) (118) to evaluate the usability of each game system. After finalizing all 20 trials, participants filled out the Norwegian version of the 16-item Falls Efficacy Scale – International (FES-I) questionnaire that measures the level of concern for falling on a 4-point scale (score 16-64) (120, 121). In addition, they filled out a background questionnaire regarding age, gaming experience, medication, and weekly amount of physical activity. At the end of the protocol, height and weight of each participant were measured and two functional tests were performed: a six meter walk test (122) and a 30 seconds sit-to-stand test (123). For the six meter walk test, the start and end points were marked on the floor with tape at a total distance of 10 m. The first two meters (acceleration phase) and the two last meters (deceleration phase) were not included in the calculation of gait speed. Participants were instructed to walk straight ahead towards the end tape as fast and safely as they could, and time was measured with a stopwatch. For the 30 seconds sit-to-stand test, a straight-backed armless chair with a seat height of 47cm was used. The chair was stabilized by placing it against a wall. Participants were instructed to sit on the middle of the chair, feet flat on the floor with arms folded across the chest, and rise to a full standing position and then sit back again as many times as possible in a 30-

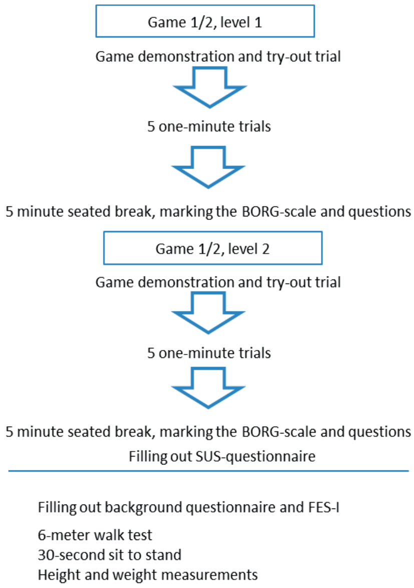

Figure 7. Schematic overview of the test protocol.

second time period. A completed stand was counted each time the participant reached a full standing position.

2.6 Data analyses and statistics

In Paper I, the integrative review, the included studies were classified as experimental studies with or without random allocation, or analytical observational studies such as case-control and cohort studies based on information from the papers. Game exercises were divided into the following categories based on which activity they targeted: balance, strength training, aerobic exercise, flexibility, dance, yoga, walking/stepping, and general sports. Because of the wide variety of outcome measures used in the 60 included studies, outcome measures were divided into six categories: balance, gait, center of pressure, physical function tests, patient-reported outcomes, and disease-specific outcomes. The 29 studies that compared exergaming against at least one other active control group were assessed regarding their methodological quality using the 10-point PEDro checklist (124). These studies were also assessed with respect to possible intervention effects.

Paper II reports on a usability study that combined both qualitative and quantitative methods of analysis. The general usability of three different exergaming systems was quantified based on the SUS-questionnaire. The SUS-questionnaire is designed as a ten-item Likert scale with a score of 0 to 100. The total score of the SUS- questionnaire was obtained by adding up the scores of each of the separate items, each contributing 0-4 points, and multiplying the sum by 2.5 to get the overall SUS score between 0-100 (118). If a system scores less than 70, it is considered to have usability issues that should be improved, while a system that gets a score above 80 is considered a good system (125). A one-way ANOVA on Game (3) was used to test for differences between the SUS-scores, with post hoc comparisons using Tukey's test. The preference of use was based on the card ranking, ranging from the least preferred game (score=1) to

Table 2. Constructs of the Unified Theory of Acceptance and Use of Technology (UTAUT) model.

Construct	Definition
Performance Expectancy	Degree that the user believes that using the system can improve performance
Effort Expectancy	The easiness that an individual thinks of when using the system
Social Influence	Degree that an individual senses that the person who is important to him thinks that he should use the system
Facilitating conditions	Degree of support that an individual feels from the organizational and technical relevant equipment towards system use

the most preferred game (score=3). To quantify which of the three exergames the seniors ranked the highest, a Friedman`s Test was conducted in PASW (Predictive Analytics SoftWare) Statistics version 21.0. To evaluate user experiences, the semi-structured interview was organized into four UTAUT constructs, namely performance expectancy, effort expectancy, social influence, and facilitating conditions. Definitions of the four constructs are presented in Table 2. In addition to the four UTAUT constructs, emerging constructs from the interviews were assessed, providing additional insight into why the participants preferred one game over another, and what motivational factors were important if they were to play these exergames on a regular basis. Positive experiences and issues were indicated with a (+), and negative experiences and issues were indicated with a (-) sign.

In the study reported in Paper III, seven game elements and five movement characteristics were chosen that were considered important characteristics during stepping exercises and evaluated based on video analysis. The game elements consisted of: 1) physical space, (2) sensing hardware, (3) game graphics and sound, (4) model of player, (5) avatar, (6) game mechanism, and (7) game narrative. To describe these elements, three experts within the field of human computer interaction and usability evaluation played and evaluated all three exergames, focusing on how the games differed. The five movement characteristics were: (1) weight shift, (2) temporal variation, (3) step length variation, (4) variation in movement direction, and (5) visual independency. Each of the five movement characteristics was scored on a five-point Likert scale with a range from 1 (bad) to 5 (very good) by three human movement scientists/physiotherapists. A protocol was made by the three raters on how to apply the scores to each characteristic on the Likert Scale and was piloted on several videos. When performing the ratings, videos were scored in the same order as the participants played the games. For each gameplay per participant, the raters watched that video section five consecutive times in order to score each of the five movement characteristics. After each viewing, the scores from all three raters on that particular movement characteristic were compared. Intraclass correlation coefficients across raters were ≥0.84 (range 0.84-1.0) for all characteristics across all three games. In case of disagreement, the raters explained why they arrived at that score, viewed the video section once more, and decided by agreement upon the final score for that movement characteristic before moving on to the next gameplay. For each of the five movement characteristics mean and standard deviation were calculated, as well as a total sum score of the five movement characteristics. All variables were within a normal distribution with no outliers, as indicated by histograms, Q-Q plots, and descriptive statistics. The homogeneity of variance assumption was tested for all six variables, and was considered satisfied with non-significant Levene's F tests and Box's M test (p's > .05). Therefore, a multivariate one-way ANOVA (MANOVA) was used to analyze the five movement characteristics and the total sum score, with Game as within-subject factor. Post-hoc tests were corrected for multiple comparisons using Bonferroni.

In Paper IV, a custom-made Matlab script (Mathworks, MA, US) was used to identify step characteristics and upper body movements made by the participants during gameplay of two step-based exergames, The Mole and LightRace. Steps taken by the left and right foot were registered as displacements of the toe markers in the horizontal x-y plane. Step initiation and termination was identified by velocity of the toe markers, with a cut-off at ±0.1 m/s. A step was set as a ≥.03 m displacement of the toe marker lasting for ≥ .05 seconds. All records were visually checked for identifications of spurious steps and these were eliminated (less than 2 % of all identified steps). Step length was calculated as the Euclidian distance between the point of step initiation and step termination. In addition, mean step velocity was computed as the mean of the Euclidian displacement divided by step time of the toe marker on the left and right foot individually. The mean and standard deviation of the step length and mean step velocity for each trial was assessed for the right and left leg combined. In addition, the total number of steps in each trial was assessed for the left and right leg combined. Upper body movements were registered by the marker placed at the lower back, and the mean and SD of upper body velocity were assessed in the medial-lateral (ML) and anterior-posterior (AP) directions individually. The area covered by feet movements and by movements of the upper body were calculated as the area of an ellipsoid with the length of the principle axis equal to 1.96*SD of the variation identified by singular value decomposition (126). In addition, a ratio of movement area was calculated as $\frac{area\ feet}{area\ upper\ body}$ where values close to 1.0 reflect more complete weight shifts displayed by the participants when taking steps. A linear mixed model for repeated measures over time was used to analyze characteristics of step and upper body movements displayed by the participants for both exergames and both difficulty levels with fixed effects of Game, Level, and Trial, and the interactions between them. The restricted maximum likelihood method (REML) was used for the estimation of the fixed and random effect parameters. All statistical analyses were performed with the IBM SPSS Statistics version 22. Statistical level of significance was set at $p< 0.05$.

3. Summary of results

A short description of the results from all four included papers in this thesis are presented in the following section, as well as some unpublished illustrations from the study reported in Paper IV.

3.1 Paper I: Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy

The purpose of this study was to provide a systematic overview of the literature on weight-bearing exergames used in the elderly population, including the different game technologies, progression within games and adherence to the games; safety issues and adverse events; physical functions targeted and outcome measures used; and the possible effect on physical function following exergame intervention. Two searches in PubMed and Scopus yielded a total of 1115 records of possible interest, and 60 studies were included in the final data analysis. Results showed a broad range in study aims and study designs, as well as in the interventions themselves with different exercise settings and interaction times with the games.

The majority of the included studies (43 of 60) used commercially available gaming technologies such as the Nintendo Wii game console, the Eye Toy developed for Sony PlayStation II, the motion-detecting camera system Kinect for X-Box360, and different versions of the DanceDanceRevolution (DDR). The remaining 17 studies used a variety of different custom-designed games. The games targeted physical functions such as balance, strength, and walking/stepping, as well as activities such as dance, aerobics, yoga, and different types of sports. Thirty-two studies reported that they applied some kind of exercise progression during the intervention, either within the game or by adding an additional load to the player, such as a weight vest. Six studies did not report number of participants completing the study, the remaining studies reported adherence to exercise in a variety of ways. Across the 54 studies that did include information about exercise completion, 88.8% of the participants completed the intervention on average, with a range of 56% to 100% of the participants. While 42 studies reported that a safety measure was applied during the intervention, only 21 of 60 studies reported whether adverse events occurred in the course of the intervention period.

A large variety of outcome measures has been utilized to assess potential effects of exergaming/VR exercise. Main outcome measures targeted balance such as the Berg Balance Scale, gait such as walking a set distance, center of pressure (CoP) measurements, or were derived from other physical function tests such as the Timed Up & Go test, patient-reported outcome measures using different questionnaires such as the FES-I, and disease-specific measures such as the Unified Parkinson's Disease Rating Scale. Measurements were typically performed at baseline and immediately after or shortly following the intervention. Only two studies involved a longer follow-up of the participants. Twenty-one studies included an exercise control intervention and were assessed with respect to the methodological quality according to the PEDro classification scale. The PEDro scores showed that most of the studies had several methodological weaknesses, with only four studies achieving more than 5 of the 10 criteria. Seven studies did not report on between-group effects, five studies had no observed differences between the exergaming and active control groups, and the remaining nine studies demonstrated improvements favoring the exergame group in one or more of the outcome measures evaluated. None of the studies reported a negative effect of exergaming.

3.2 Paper II: Assessing seniors' User Experience (UX) of exergames for balance training

The main objectives of this study were to assess seniors´ user experiences and preferences of exergame technologies regarding three different exergames aimed at balance training, and to identify different factors that affect older adults` intention to use these exergames. The Mole from SilverFit received the highest usability score as measured by the SUS-questionnaire (87±11.1, 95% CI 81.2-92.8) while DDR received the lowest score (69.6±18.9, 95% CI 59.7-79.5). LightRace received a score of 83.8±13.1 (95% CI 76.9-90.6). A one-way ANOVA indicated a significant difference between the SUS-scores ($F(2,39) = 5.68$, $p=.007$). The post hoc comparisons using Tukey's test showed that there was a significant difference in the SUS-score between DDR and The Mole and between DDR and LightRace (both p's <.05), but no difference between The Mole and LightRace. Overall, the participants ranked The Mole over the two other games using the card ranking, but there were no significant differences ($\chi^2(2) = 2.71$, $p=.26$). All participants stated that they saw the potential benefit of using exergames with respect to improving their balance and keeping in shape, and as a way to challenge cognitive aspects. Accompanying music was seen as positive, but as the music in the DDR was not synchronized with the steps to be made, the music made it more difficult to hit the targets at the correct time. Furthermore, all participants understood the concept of the exergames after a short demonstration, but they expressed a wish for more precise feedback from the exergame on the movements they made. None of the participants stated that they would feel uncomfortable telling others that they played exergames. However, several of the participants expressed concern about having enough space at home to play the games. The emerging constructs from the interview analysis revealed that the participants wanted to play together with others and that they were not concerned about falling while playing the games. The participants stated that they wanted progression in the exergames and that the exergames' menu and feedback should be in their native language. Furthermore, participants considered the exergame technologies to be quite advanced and were concerned whether they would be able to set up and start the exergames on their own without assistance.

3.3 Paper III: Designing for movement quality in exergames: Lessons learned from observing senior citizens playing stepping games

The purpose of this study was to related differences in game elements to differences in older players' movement characteristics during three different stepping exergames, in order to compose guidelines for exergame design for specific movement quality in the context of fall preventive exercise. In this study, movement quality was defined as the way different movements were executed with respect to the dimensions of time and space during gameplay. The three games differed with respect to all seven game elements (see Table 3 for details).

Table 3: Description of the three exergames with respect to game elements.

	Dance, Dance Revolution	**The Mole**	**Light Race**
Physical space	Static - step pad Small: 90x80cm	Static - detectable Large: 125x125cm	Dynamic - detectable Small: 100x100cm
Sensing hardware technology	Press-and-release step pad	Time-of-flight camera	Kinect camera
Game graphics and Sound	2D – simple Music Audio feedback Visual feedback	2D- simple cartoon No music Audio feedback Visual feedback	3D- Advanced animation Music Audio feedback Large visual feedback
Model of user	No sense of bodily element	Position of feet	Centre of player
Avatar/Mapping of movements	No avatar No mapping	Simplified avatar Mapping of feet	Avatar Mapping of player's body
Game mechanism	Constant time interval Hit target Avoid object	Player-dependent time interval Hit targets Avoid object	Player-dependent time interval Credit for speed Hit target
Game narrative	Target presented as arrow Object to be avoided presented as a bomb	Target presented as mole and mouse Object to be avoided presented as ladybug	Target indicated by light

The games also differed with respect to the five movement characteristics (weight shift, temporal variation, step length variation, variation in movement direction, and visual independency) displayed by the participants, and there was a significant difference between the games regarding both the sum score and each of the five movement characteristics (all p's <.05). The Mole received the best sum score as well as the best score on each of the five movement characteristics, and had a significantly higher score than DDR on all characteristics (all p`s < .05). LightRace had a significantly better score than DDR on weight shift, step length variation, variation in step direction, and visual independency (all p`s < .05), and a significant lower score than The Mole on weight shift, variation in direction, and the sum score (all p`s < .05).

3.4 Paper IV: Exergaming in older adults: Movement characteristics while playing stepping games

The main objective of this study was to investigate whether differences between two stepping exergames, different difficulty level, and short-term experience (5 trials per game and level) affected stepping and upper body movements of older players during game play. The results showed that the two games and the two difficulty levels within each game elicited different stepping and upper body movements in the older adults during game play.

For the number of steps taken per minute, there was a significant difference between the difficulty levels and between the games at each level (all p's< .001). There was also a Trial effect (p=.026), indicating that the number of steps taken increased from the first to the last trial in both games. On average, participants took longer steps when playing LightRace than when playing The Mole, and took longer steps at the Easy level compared to the Medium level for both games (both p's < .001). In addition, participants had more variation in step length when playing Easy compared to the Medium level of The Mole, while there were no such differences in LightRace. Step length variation was affected by Trial as well (p=.004), indicating that participants had less variation in their step length the more times they played the same level and game. For step velocity, there was a significant difference between the two games at the Medium level (p<.001) but not at the Easy level, while for variation in step velocity there was a significant difference between the two games at both levels (p≤.008). While LightRace had a significant difference between the two levels for both step velocity and step velocity variation (both p's < .001), for The Mole there was only a significant difference between the levels in step velocity (p=.005). For variation in step velocity, there was also an effect of Trial (p=.016), indicating that the variation in step velocity decreased from the first to the last trial.

The Mole induced higher velocity and more variation in upper body velocity for both AP- and ML-directions compared to LightRace (all p`s <.001). For both The Mole and LightRace, playing the Easy level gave higher velocity and more variation in upper body velocity in both AP- and ML-directions than at the Medium level (all p`s <.001). When playing The Mole, participants covered a larger area with both the upper body and the feet than when playing LightRace and for both games, participants moved within a larger area when playing the Easy levels than when playing the Medium levels (all p's <.001). For the area covered by the feet, there was also a significant Trial effect (p=.020), indicating that the participants decreased the area in which they moved their feet from the first to the last trial. Figure 8 is an unpublished illustration that shows the toe and upper body traces for a typical participant playing the Easy and Medium levels of The Mole and LightRace. LightRace had a higher ratio of movement area than The Mole at both Easy (5.3 vs. 1.6) and Medium levels (6.9 vs. 1.5), indicating that participants performed less weight shifting in LightRace than in The Mole. While there was no difference between Easy and Medium levels for The Mole, the movement area ratio was higher at the Medium level than at the Easy level for LightRace (p<.001).

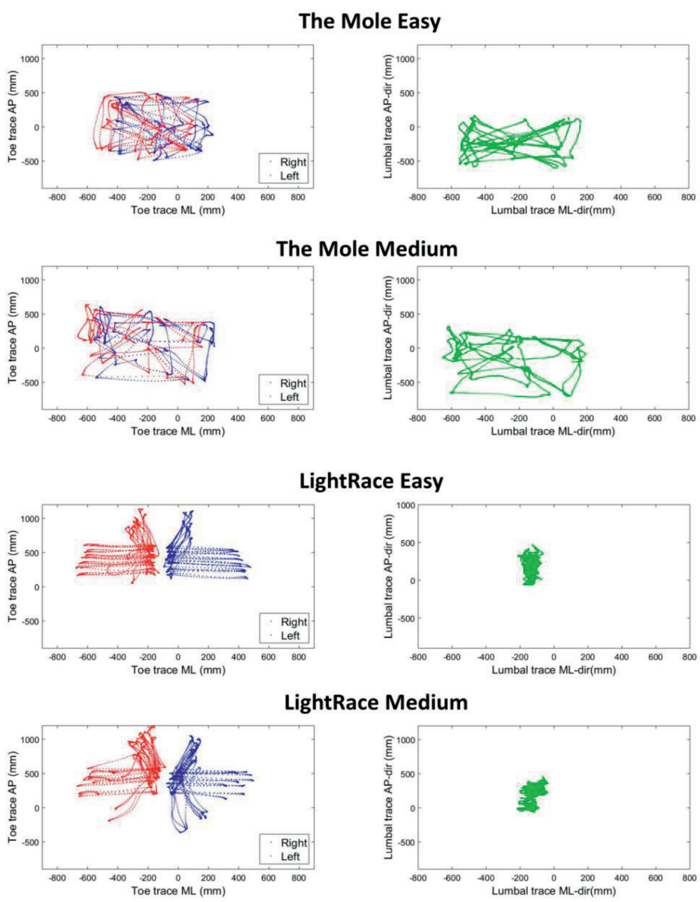

Figure 8. Unpublished illustration of a typical example of toe (blue=right, red=left) and upper body(green) traces for one participant in ML- and AP-direction playing The Mole and LightRace at Easy and Medium levels.

4. Discussion

The overall aim of this thesis is to evaluate the use of exergames among older adults, with a special focus on assessing exergames designed for stepping activities. In order to meet this overall aim, four papers were included in this thesis that ranged from a literature review focused on providing a broader understanding of the use of exergames among older adults, to a usability study investigating how older adults experience the use of this technology, to understanding basic movement characteristics displayed by the players during game play and how these are affected by game characteristics. Below, a summary of the results in each paper will be presented first, followed by a discussion of the different methods used. As detailed discussions of specific results are presented in papers I-IV, the subsequent discussion will focus on a broader perspective regarding the use of exergaming in older adults, potential implications of the current research for clinical practice, and directions for future research in order to establish exergaming as an appropriate exercise and rehabilitation tool for older adults.

Paper I provided a comprehensive overview, in-depth description, and discussion of the literature on exergames with weight-bearing exercises used for the elderly population. It was concluded that exergames utilizing weight-bearing exercises are promising as an intervention to improve physical function in older adults, with only a few adverse events reported across studies. With the rapid development in technology during the last decade, a large variety of game technologies and exergames has been used, including both commercially available and custom-designed consoles and games. Several of the studies that compared exergame-based exercise with other exercise programs found a positive effect on balance and gait parameters, and one study reported reduced incidence of falls. However, as there was large variability between studies in terms of intervention protocols and outcome measures, as well as several methodological limitations of most studies, it was challenging to compare the different studies and draw firm conclusions regarding the effect of the interventions. To realize the full potential of exergaming as an exercise and rehabilitation tool for older adults, there is a need to establish whether the games are safe, which technology to use for which purpose, how to ensure ease of use for the older adults, and how to achieve long-term adherence to the games.

Paper II evaluated user experiences and preferences regarding exergame technologies. The older adults participating in the study expressed that they saw the benefits of using exergames to improve balance and keep in shape. However, they also stated that they wanted exergames to focus on challenging tasks, to provide feedback on how to perform the correct movements in a game, and to offer progression in the game by rewarding correct movements and gradually increasing difficulty. The comments given from the older adults regarding the wish of getting feedback on correct movements made indicates that there is a need to focus more on the movements displayed during game play in both use and design of exergames for older adults.

In order to achieve better understanding about how older adults move when playing step-based exergames, two studies that looked into the movements performed by the older adults during game play were conducted. The study in Paper III investigated the relation between different game elements and movement characteristics during game play in three stepping exergames, while Paper IV further explored the movement characteristics displayed by older adults in terms of stepping- and upper body movements elicited during game play of two of these exergames, played at two difficulty levels with five repeated game play trials at each. The results presented in Paper III showed that the three chosen exergames (DDR, LightRace, and The Mole) had several differences in game elements that had differential effects on movement characteristics, providing several important lessons for the design of exergames for older adults. First of all, weight shifts should be elicited in the players by motivating them to move around a larger physical area and displace their center of mass. Secondly, temporal variation in movements should be provided by offering adaptive changes in the game speed. Thirdly, to promote step length variation, a variety in exergame tasks should be offered. Fourthly, the game should elicit variation in movement direction during game play. And lastly, the game should help the players to maintain visual independency and focus their attention on the exergame activity or task rather than on how to control the game. Building further on the capture and analysis of movement characteristics, the results in Paper IV showed that both game and game level affected stepping and upper body movement characteristics, indicating that the choice of exergame is not indifferent when aiming to exercise specific functions in older adults. Exergames for older adults need to be selected and designed with care, taking into account what movement characteristics one wants the player to perform, how to manipulate difficulty level in order to maintain motivation without sacrificing the quality of the movements, and how to use feedback and the scoring of points to ensure that the proper movements are executed.

4.1 Methodological considerations

The thesis employed several different research methods to address the overall goal of achieving better understanding of the use of exergames that utilizes weight-bearing exercises in older adults, their user experiences, and the movements they perform during step-based game play. Applying multiple methods towards an overall goal can produce more robust and compelling results, as it allows answering a research question from different perspectives. Each of the applied methods has its own specific strengths and limitations, both in general but also specifically with respect to how they were applied in the studies conducted for this thesis. These methodological strengths and limitations will be discussed further in the following paragraphs.

4.1.1 The integrative review approach

Literature studies generally aim to summarize and evaluate knowledge that exists on a particular topic from a larger body of publications. The integrative literature review conducted in Paper I deviates from a systematic review in a few ways. A systematic review requires a well-specified clinical question, uses systematic and explicit methods to identify, select, and critically appraise relevant research, and may use a meta-analysis to analyze and summarize the effects reported in the included studies. In contrast, an integrative review allows for the inclusion of diverse methodologies, aiming towards summarizing, evaluating, and presenting varied perspectives within a topic (127, 128). Furthermore, integrative reviews are often performed to address new, emerging topics, and are more likely to lead to an initial concept or idea of a topic (129). By performing an extensive integrative review, we were able to get a broader overview and understanding not only of the possible effects of exergaming, but also of the variety of games and technologies used, the different interventions employed, adherence to exergaming, safety issues related to game play, and which physical functions had been the main focus of the exergaming intervention.

The current review included 60 studies with several different research designs. However, the latter had to compare exergaming against at least one other active control group in order to be able to investigate potential intervention effects of exergaming compared to traditional forms of exercise. To assess the methodological quality of the 21 studies that included an exercise control intervention, the 10-point PEDro checklist (124, 130) was applied. By including assessment of the quality of the papers the validity of the results was strengthened, which was one of the strengths of the current review. Another strength of Paper I was that a methodical literature search was performed with a preplanned review protocol specifying inclusion and exclusion criteria, covering a broad range of search terms and databases in the fields of medicine, social sciences, health care, and technology. In general, a well-defined search for an integrative review is broad and diverse, combining at least two or three strategies such as searches in several electronic databases, manual searches in journals and the reference lists described in the selected publications, contact with researchers, and the use of unpublished material (127). In this respect, the current search was not complete in that we limited inclusion to original research with a pre-post intervention and English language publications only.

Combining data from studies with diverse designs in a meta-analysis is quite complex and challenging. On the other hand, performing integrative reviews with a pre-defined and thorough approach of the process allows for diverse research methods within the relevant field to be explored (127), resulting in comprehensive insight and understanding of accomplishments and problems relevant for exergaming in older adults. The review in Paper I not only shows the rapidly growing interest in this field of research, the results also illustrate the diversity of exergames as an exercise and rehabilitation tool for older adults. The 60 studies included in Paper I comprised a wide diversity both in game technology and in the participants, ranging from healthy community-dwelling older adults to in-hospital patients, as well as a broad range in duration of intervention, interaction time with each game, relevant safety issues, and outcome measures. Based on the findings, we provided further recommendations for both research and practice in order to successfully establish exergames as an appropriate and effective exercise and rehabilitation tool for older adults (see Paper I).

4.1.2 The challenges of measuring usability

Measuring the usability of a product is important in order to understand whether the intended users of a product are able to use it effectively, efficiently, and with satisfaction. The ultimate goal is to understand how usable a product is for the intended user-group and to this end, it is crucial to be aware of the complex interactions between the user, the intended outcome, the activities required to meet the outcome, and the product or equipment (93). The term usability is to a large extent determined by how we measure it, and often a usability test is conducted as a form of experiment where a sample of participants from the potential user group is set to complete specified tasks using the system being evaluated. Since usability cannot be measured directly, it can be difficult to find valid indicators of usability. One way to measure usability is by operationalizing the usability construct into aspects of usability that can be measured, such as effectiveness, efficiency, and satisfaction (131). It is therefore important to assess the validity of the results from a usability test such as conducted in Paper II.

One way to achieve a certain degree of validity is by building upon known measurement instruments, such as the System Usability Scale (SUS) and The unified theory of acceptance and use of technology (UTAUT) model. Even though the SUS scale may be a valid measure to compare two or more systems (132), it is designed for standard information systems, and may not reveal a complete overview of what the older adults preferred when testing the three exergames. Using the SUS to evaluate exergames provides an indication of game preference, but in the study performed in Paper II, the SUS results need to be interpreted in combination with the card-ranking test to give a broader understanding of preferences. Furthermore, the UTAUT does not consist of explicit constructs for measuring the participants' intrinsic motivation. Therefore, additional instruments that assessed the participants' subjective experiences could have been added to gain more insight about aspects of interest and enjoyment of the games. However, the interview that was conducted as well opened up for reflection and elaboration around the different constructs, providing more insight about the participants' motivation to use the games.

To ensure validity of the results, the exergames were introduced in a counter-balanced order across participants to reduce the possibility that the order in which the exergames were played would confound the results. However, the participants only played a pre-selected part of each game, meaning that the results can only provide an indication on the preference and ease-of-use regarding that game, and not as an evaluation of the entire game system. Furthermore, the usability tests focused on testing the actual games and systems in a lab rather than testing their use at home or in a clinical situation, and since the participants played all games for a short period only, the relation to real-life was limited. However, the equipment was used as it would be in a real-life context, providing the participants with the opportunity to test and understand the equipment as they would when using them at home. With respect to external validity, Hwang and Salvendy (133) reported that a sample size of 10±2 is sufficient for discovering 80% of all usability problems with a product or system. The convenience sample of the 14 older adults participating in the study in Paper II should therefore be sufficient to assess user experiences of older adults when playing exergames. However, as the participants were relatively fit for their age, generally physically active, and fairly familiar with digital technology, the results may not be representative for the entire intended senior user-group, and hence generalizations towards older adults as a whole should be made with caution.

Another aspect regarding Paper II was that the study was largely based on a semi-structured interview. Semi-structured interviews consist of several key questions that help to define the areas to be explored, but allow the interviewer or interviewee to diverge in order to pursue an idea or response in more detail. Semi-structured interviews are a flexible approach allowing for the discovery or elaboration of information that is important to participants but may not have been thought of as relevant before conducting the interviews (134). Even though the interviews in Paper II were based on the UTAUT constructs, it also opened up for emerging constructs that the older adults found important for the use of exergames, providing additional relevant information about the wishes and needs older adults have in order to use exergames as an exercise tool. When conducting an interview, researchers must possess skills and techniques that ensure that comprehensive and representative data are collected during the interview. One of the most important skills is the ability to listen attentively to what is being said without influencing the participant, so that the participants are able to recount their experiences as fully as possible, without unnecessary interruptions (134). One strength of the study performed in Paper II was that the same person conducted all the interviews. This could have ensured that all participants were treated equally by the interviewer. A general recommendation is that all interviews should be video recorded and transcribed afterwards to protect against bias and to obtain objectivity, as was done in the current study. By video recording it is also possible to analyze the interviews afterwards, which can help in making the interview process easier to engage in, not needing to absorb all information during the real-time interview only. Having video recording can also help in the further data analysis process, making the interview easier to code and analyze as one is able to revisit it as many times as necessary. Finally, analyzing the videos by using ATLAS.ti to code the constructs in the interview, as performed in the current study, also provided a helpful tool to visualize the often complex relations between the different constructs that one wishes to gain more information about.

4.1.3 Identifying relevant game elements

The seven exergame elements investigated in Paper III were identified partly by drawing on existing literature describing aspects of exergames that affect players' movements during gameplay, and partly by assessing the external environment of the games, the internal environment of the gameplay, and the functional and operational mechanism of the three games. Previous studies have indicated that while playing exergames, the player are affected by related hardware, software, and game experience itself such as game task, intensity, and representation of the player's movements in the virtual world of the game (135, 136). One important aspect highlighted in previous research is that mapping of the movements on the screen in the form of an avatar can play a part in eliciting specific movement characteristics during gameplay (136, 137). However, limited sensor accuracy can restrain mapping of the players' movements as it can be difficult to recognize small body movements (138). However, the popular low-cost markerless motion caption system, the Microsoft Kinect, has recently been found to have high accuracy in identifying movement patterns in whole body motion capture data (139). In the study performed in Paper III, seven measurable exergame elements were identified: (1) physical space, (2) sensing hardware, (3) game graphics and sound, (4) model of the player, (5) avatar, (6) game mechanism, and (7) game narrative.

The seven game elements in the three different exergames were qualitatively described by three experts within the field of human computer interaction and usability evaluation. They played all three exergames and described how the games differed with respect to the seven game elements. The scoring was based on a common discussion during and after game play, without a formal protocol on how to define the different elements. The descriptions of the elements were not scored on a predefined scale, but emerged during game play. However, the goal was not an in-depth analysis of the game elements in the three exergames, but to provide a first description of relevant game elements that could be related subsequently to the movements players elicit during game play. For future research, having a predefined and piloted protocol on how to score different game elements can provide further insight into how game elements affect how players move during game play. Furthermore, additional stakeholders such as game designers and older adults, can provide further perspective on relevant aspects in the games hardware and software.

4.1.4 Video analysis of movements

The choice of movement characteristics evaluated in Paper III was based on findings in previous research identifying relevant characteristics that should be part of exercise in order to be effective in balance training and fall prevention. First of all, impaired stepping responses in older adults have been associated with falls, and studies have shown that older adults are less able than young adults to recover balance by an appropriate stepping response, indicated by reductions in both step length and step speed (6, 7). Secondly, adequate mobility in real-life requires stepping and walking to possess richness in both the temporal and spatial domains, in other words, the ability to take steps of different sizes at different speeds in different directions (9). Furthermore, aging is accompanied by gradual deterioration in several adaptation mechanisms, resulting in older adults to be less capable of dealing with the same environmental changes and disturbances than younger persons. In addition, both healthy aging and disease have been associated with decreased flexibility (140, 141). For those reasons, weight shift and variations in step length, speed, and movement direction were chosen as the main characteristics to investigate. In addition, visual independence from the feet and/or support surface was included as well. The environment provides vital information for prospective control of movements, hence it is important to preserve the ability to take one's eyes off the feet or support surface without becoming disoriented or falling down (142).

Using video recordings to score movement characteristics provides a high degree of reproducibility compared to online observation and scoring, as video recordings can be replayed any number of times (143). In Paper III, three human movement scientists/physiotherapists scored each of the five movement characteristics on a five-point Likert scale, based on a pre-piloted protocol on how to score each movement characteristic. Intraclass correlation coefficients were calculated to check the reliability of the ratings across the three raters. The intraclass correlation coefficients across raters were ≥0.84 (range 0.84-1.0), indicating very good to perfect agreement between the raters. However, scoring of movement characteristics from video recordings has some limitations as well, limited accuracy of scoring movement details and inherently subjective evaluations, and is not suitable for analyzing high velocity changes in movement. To analyze movements objectively and in more detail, more advanced methods such as motion capture systems need to be utilized, as was done in the study reported in Paper IV.

4.1.5 Movement analysis using motion capture

Building further on the video-based movement scoring performed in Paper III, Paper IV used a motion capture system to track and analyze movement characteristics of the participants while playing two step-based exergames (LightRace and The Mole). Step length, step speed, and weight shifts, as well as the variability of the step characteristics were pursued further as relevant movement characteristics in Paper IV. In addition, older adults have been found to have impaired ability to control balance in the transversal plane of motion, which can lead to falls (144). Therefore, Paper IV also included analysis of upper body movement in both ML- and AP-directions.

Using motion capture systems can present several methodological issues. One of the main issues in the study in Paper IV was that the Oqus motion capture cameras interfered with the Kinect camera used for the games, so that the cameras of the two systems could not be placed directly in each other`s line of sight. Therefore, Oqus motion capture cameras could not be placed behind the participants, which resulted in the heel markers often being occluded from view and thus there were several gaps in the data. As the gap-filled data turned out to be too unreliable, the heel marker could not be used in the step detection algorithm. Step detection was therefore based on the toe markers only, with step initiation defined by a cut-off of ≥.03 m displacement of the toe marker lasting for ≥.05 seconds. Using only the toe marker to detect steps rather than both heel and toe markers may have misclassified toe movements such as a toe flick as steps. In addition, steps were identified using the X- and Y-planes only, not taking into account the Z-plane of the movement. If, for example, a participant inhibited a step by freezing the foot in the air, and then changed landing position, this could be detected as two separate steps. A possibly more reliable method to identify steps would be to identify toe-off and heel strike by calculating the vertical velocity of the foot center based on data from the toe and heel markers (145). Another aspect of the data collection was that the passive reflective markers were not placed on the skin directly over bony-landmarks but on the participants' shoes and clothes. As the Oqus cameras had a 1 mm resolution, small marker displacements could actually be movement artefacts, i.e., movement of the shoes and clothes relative to the bony-landmarks. To counter these potential problems, all recordings were visually checked in order to eliminate any such artifacts. Errors can also occur during the placement of the markers. However, the same researcher attached all markers on all participants, which were on the basis of 1st toe, mid calcaneus, and approximately at the 3rd lumbar vertebrae of the back. Furthermore, the markers were not taken off between the gaming sessions, limiting the source of error between the comparisons of the different exergames.

4.2 Using exergames in older adults

In the last few years, a rapidly growing number of studies have been published within the field of exergaming for older adults, which collectively provide good indication that exergames can be used as a rehabilitation and exercise tool for this population. Several reviews have been published recently as well, concluding that exergames hold interesting opportunities to be used as an exercise tool to maintain physical function and health in general, and have positive effects on balance and gait measurements in particular (146-148). In addition, previous reviews found exergames to be feasible as a rehabilitation tool for older adults with an acquired disease, such as stroke, Parkinson's disease, and multiple sclerosis (3, 5, 149, 150). These reviews are in accordance with the integrative review in Paper I, concluding that exergames show promise as an intervention to improve physical function in older adults. However, even though exergames in general seem feasible to use for older adults, there is still a lack of high-quality intervention studies that provide solid evidence about the effectiveness of these games (148, 150-152).

The lack of methodological quality restricts the capacity of studies to generate reliable evidence regarding the effectiveness of exergame interventions, and point out the need to further investigate several aspects of exergaming use for older adults. First of all, there are some initial questions that need to be answered before further pursuing the use of exergames for older adults. One of these aspects is to assess whether exergames are a safe exercise tool for older adults to use independently. One of the great advantages with exergames is that they can be used in a home-based setting as individual exercise. However, few studies have assessed the safety of administering exergaming in the homes of older adults, and those who have assessed safety often used extra safety measures such as supervision during game play or a chair positioned near the player. Chao and colleagues (153) concluded that exercising with the Nintendo Wii exergames was safe for older adults, as no serious adverse events or injuries had been reported in the 22 studies included in their review. However, they do refer to several reported Wii-related injuries for adult players such as falls and fractures (154). One of the disadvantages of using the Nintendo Wii with the balance board is that the participants have to stand on an elevated surface in order to play, which might pose a risk for tripping and falling particularly when attention is focused on the television screen. This aspect was also highlighted by Barry and colleagues (150) who concluded that more evidence was needed about the safety of using exergames for people with Parkinson's disease before exergames could be recommended for clinical and home-based use. One possible way to gain more knowledge about the safety of different games is by testing them in a real-life situation in a fully furnished lab setting where you can assess how the older adults interact with the games, as well as ask their feedback regarding the feeling of their own safety. In Paper II, none of the participants felt any risk of falling or acquiring an injury during game play of the three exergames assessed, DDR, LightRace, and The Mole. However, all participants were relatively healthy and physically active for their age. Different groups of older adults could react differently to the same games, pointing out the importance to assess the games using not only healthy older adults, but also older adults with an acquired disease such as stroke and Parkinson's disease if applying exergames to specific populations of older adults.

Another important aspect is adherence to exergaming. In accordance with findings in Paper II, several studies reported high levels of enjoyment and motivation among older adults when exercising using exergames (4, 147). However, as revealed in Paper I, adherence to exergaming interventions has rarely been examined quantitatively over longer time periods and compared with appropriate control groups. It is therefore needed to establish whether exergames indeed lead to higher adherence to exercising rather than continue to state that this is potentially one of the main advantages of using this technology in exercise and rehabilitation programs. One aspect that might challenge adherence to exergaming is whether the games are challenging enough to attract to the players' attention over a longer period of time. When using exergames as a means to improve a specific function, such as balance, the game needs to be used for an extended amount of time to ensure progress and positive benefits (52). It is therefore important to ensure that games are personalized, adaptive, and can meet each player's needs and abilities. Exergame technology holds the potential to provide an exercise environment in which game contexts can be changed and adapted, and includes challenging and variable exercises (155). However, the most utilized game consoles in research with older adults are commercial games such as the Nintendo Wii. The games made for these consoles are generally designed for a younger audience and might therefore be too complex and not entail the level of challenging and variable exercise required for older adults. Perhaps as a consequence of this, several research groups and smaller companies have started to develop games specifically designed for the older population. Several of these games seem feasible to use for older adults (156-158). However, even though several games have been developed with older adults' interest in mind few, if any, studies have taken into account the movements older adults display when playing these games, making it unclear to what extent older adults perform the movements required to improve specific physical functions.

4.2.1 Future usability aspects of exergaming

Exergaming holds great potential to be used in the future not only as an entertainment tool, but also as a specific exercise and rehabilitation tool for many age groups and disabilities. With continued advancements in technology, exergames are more and more likely to become a part of future health care for older adults. One interesting possibility is the potential for remotely monitoring the games when distributed to the homes of older people. For example, having the opportunity to play the games through an internet-based network can provide a virtual community of patients and clinicians that can help, educate, and motivate the player of the games to continue with the exercise. This can also ensure the social aspect that older adults have highlighted as one of the positive aspects of using exergames (see Paper II). In addition, remote monitoring allows for the possibility to guide the older adults through their exercise or rehabilitation schedules, as well as monitor the movements they perform and provide feedback about correct execution of the exercises (159). However, given that the remote monitoring to date has not been utilized to a large extent, few studies have addressed the different aspects of usability regarding this use of exergame technology. As one of the rare exceptions, Wuest and colleagues (156) evaluated usability of an online set of exergames for balance and gait in untrained healthy elderly. Based on feedback during the gaming sessions, adaptions to the games were made during the intervention, meeting firsthand the needs and preferences of the older adults. They found that the games were perceived as usable with high levels of acceptance among the players (156). Having a real-life usability project like this can provide more in-depth information from the users than for instance a normal lab setting would, and should be incorporated in future usability evaluations. However, doing continued adaptions to the game requires having a game designer available firsthand, a luxury that might be unrealistic for many researchers and especially for health professionals administrating the games. Alternatively, should future exergames include more possibilities for adaptions of the game already from the design process. Therefore, in future exergame research a comprehensive investigation of the usability, taking into account both the design and the use of a game, should be performed before implementing exergames in the home of older adults.

In addition, in order to achieve the specific use of exergames, the most important requirements of an exergame have to be established from several stakeholders. To make an exergame successful, differences in interests from various stakeholders such as the older adults, their family, health professionals, and game designers, need to be recognized and made explicit (160). To date, several researchers have provided guidelines for game design based on older adults' needs and preferences (81, 89, 99). However, by including focus groups with additional stakeholders, such as different health personnel and game designers, it can be possible to establish criteria that need to be fulfilled for an exergame to be successful in targeting specific movement functions. This information can then be included when designing games, or when searching for the best possible game, that targets the wanted function. Furthermore, including stakeholders throughout the entire process, from understanding preferences and needs, through testing prototypes, to finally testing the end product could make a valuable contribution to ensure the best possible outcomes for both the users and the health care professionals.

4.2.2 The interaction between game elements and players' behavior

Design of exergames for specific exercise and rehabilitation has generally been based on the users' requirements, preferences, and needs. However, the results in Paper III show that evaluation of different elements in the games as well as movements displayed by the players during game play should be incorporated as a part of the design process. The results in Paper III showed that the three step-based exergames differed in all evaluated movement characteristics as well as in the game elements. One of the most notable dissimilarities in the game elements were the differences in physical space and sensor technology between the three games. While the DDR used a press-and-release step pad, both The Mole and LightRace utilized a camera that detected the players' movements, without the need for standing on a specific physical surface placed on the ground. The cameras allow for more movement in all directions, giving the players more possibilities to display variations in size and speed of the movements, as well as removing the need to look down to ensure that one hits the right target. As pointed out earlier, the most utilized game console in research with older adults has been the Nintendo Wii with the Wii Fit balance board, particularly with respect to training balance and gait. The balance board can provide some of the same issues as the step-and-release pad used for the DDR as the movements are restricted to a limited space. However, the difference is that while most of the games played on the Wii balance board are static standing balance games, the DDR requires the player to step on different areas on the mat when playing the game. On the other hand, some of the Wii games, such as the soccer heading, can entice the player to move their body to the outer bounds of their base of support, and some will even make a little jump to reach the ball, posing a risk of actually stepping outside the borders of the balance board. For older adults, this can in the worst case lead to a fall, which ironically enough was the one thing to prevent when starting to use exergames.

Few studies have looked at the relation between game elements and movement characteristics of the players. In their study on children's movement characteristics during exergaming, Levac and colleagues (161) showed that quantity of movements, defined as the center of pressure path length displacement, differed between two Wii Fit sports games (soccer heading and ski slalom). They pointed out that the differences could be related to game-specific differences in movement requirements or responses. By analyzing the two games used in Levac and colleagues study with respect to the different game elements highlighted in Paper III, several of the game elements in Levac and colleagues study would be equal as the games are part of the category balance games in the Wii Fit package, and are played on the same game console with the same equipment. However, the narrative of the games together with the movements performed during gameplay might explain some of the differences that Levac and colleagues found between the two games. While the ski slalom game involves lateral and anterior-posterior weight shifting to navigate around the gates of a virtual downhill ski course, the soccer heading involves lateral weight shifting to head soccer balls that appear on the left, right, or center position of the player while also avoiding being hit by other objects. The ski slalom may not require moving to the outer bounds of the base of support to control the game and guide the avatar down the slope. However, when heading soccer balls the children would most likely stretch towards the outer limits of the base of support, creating larger displacement of their center of pressure. In the same manner, Paper III showed that differences in game narratives could describe why older adults had different weight shifting strategies in the three exergames. Likewise, Levac and colleagues (161) argued that game-specific differences could explain the differences in movements made by the children during game play.

Incorporating an evaluation of game elements in different exergames and their effects on gameplay before implementing them as an exercise or rehabilitation tool for older adults is both necessary and doable. As pointed out in Paper III, some important aspects in the game elements can reveal important differences between games that are relevant to consider when administrating games in a population of older adults. In addition to looking at the technology and evaluating the user friendliness of the console and the interface, evaluating the game itself is just as important to ensure ease of use and achieving the desired movement characteristics in the players. In future use of exergames, a check list of game elements and how they affect movement characteristics in the players could be made in order to gain a more comprehensive understanding of the games before administrating them to older adults. Such a check list could for instance include a few simple questions. A few examples relevant for step-based exergames aiming to improve balance and gait could be based on the recommendations made in Paper III: 1) Does the game elicit weight shift in players by motivating them to move around a larger physical area and displace their center of mass?; 2) Does the game offer variation in game task and adaptive changes in the game speed to ensure variations in step length, speed, and movement direction?; 3) Is the player's visual attention directed to where to place the feet on the support surface or on the screen and exergame activity or task itself? Addressing simple questions such as these in a clinical approach could ensure the use of games that elicit the specific movements aimed for when using exergames in exercise or rehabilitation. In addition, getting a more in-depth description of the games and their respective elements could provide a better understanding of the potential effectiveness of the different exergames.

4.2.3 Gaining knowledge about players' movements

Elvis Presley once said "my movements, ma'am, are all leg movements. I don't do nothing with my body". Regardless of whether we want older adults to perform the signature moves of Elvis, this quote points out an important aspect related to balance and fall prevention. As particularly dynamic balance also consist of the ability to anticipate and react to changes when moving around, balance exercises for older adults should include weight shifting such as occurring during stepping and walking (8), hence the need to do something with your body as well as your feet. When implementing step-based exergames as a balance or fall preventive exercise, one of the main aims is probably to entice the players to make weight shifts during game play. However, as shown in Papers III and IV, step-based exergames can vary largely in the amount of weight shifting during stepping necessary to play the game. Instead players might just partly move their upper body and tap their feet on the target rather than take a step onto the target. Together with the differences found in stepping movements and upper body movements in Paper IV, these observations underline the importance of having better knowledge about how the players move during game play in order to gain more knowledge about why exergames can be effective for older adults.

The importance of investigating movement characteristics in players is not confined to step-based games, it is just as important in static balance games or when using upper extremities to control a movement game. In exercise, and specifically in rehabilitation, the aim is often to perform a specific movement repeatedly to achieve better function. For example, with a shoulder injury, the goal can be to grasp a bottle on the table in front of you, aiming towards a full flexion motion of the shoulder in the sagittal plane. However, you can also grasp the bottle by freezing your shoulder movements, using your body to lean towards the table and only moving your elbow. In traditional therapy settings, you would likely have a therapist close by, instructing you on how to perform the most desired movement. However, during exergaming the virtual task is often performed without supervision, for example in a home environment. If the games allow for different kinds of movements to be performed, rewarding non-desired movements with the same game score as the intended movement with the fully flexed shoulder, the rehabilitation goals will probably not be met. Therefore, it is important to not only investigate the movements the players perform, but also to have technology that is sensitive enough to distinguish correct from incorrect movements and provide feedback on this during game play. Thus, the knowledge gained by investigating different movement characteristics displayed by the players when exergaming should be used in game design. One of the advantages of gaining more information about each player's movement characteristics is the possibility to personalize the game to that player's needs and challenges. New advancements in developing algorithms for quantification of balance ability may give valuable possibilities for adapting exergames to the balance capabilities of individual older adults (141). The ability to personalize the games by adapting the targets and the level of difficulty could also increase adherence to the games as players might feel that the games meet their own personal issues, thereby making them a more accessible and enjoyable activity. The recommendation to not only having predefined games but adapting games to individual differences and abilities has been highlighted in previous research as well, pointing out that game diversity and progression of difficulty are important factors to maintain the player's engagement (89, 162).

The studies performed in Papers III and IV were among the first studies to analyze movements displayed during game play in older adults, and point out the need to further pursue analysis of movements during game play. By analyzing movements during game play exergames have greater potential to be personalized to individuals and specific populations of older adults, such as people with Parkinson's disease. However, to be able to get to this point of use, more in depth analysis of several movement characteristics, as well as the relation between the game elements and the movement characteristics, is necessary to ensure that the most appropriate game is chosen to exercise specific physical functions.

4.3 Clinical implications

In recent years, exergames have started to be introduced in different clinical and rehabilitation settings as well. The interest of using exergames in these setting may partly stem from issues related to lacking adherence to standard rehabilitation programs. Even though there is ample evidence showing that physical activity and exercise have positive effects on diseases and conditions ranging from fall risk (8) to coronary heart disease (163) and dementia (164), uptake and adherence to these exercise programs are generally low for older adults (2, 165). Maintaining the patients' interest and motivation to perform repetitive training tasks over a given period of time is a critical issue with all rehabilitation programs. Exergames are often heralded as holding the potential to overcome some of those barriers imposed by traditional exercises, thereby increasing adherence to long-term exercise. The perceived enjoyment of playing exergames has been mentioned as one of the main reasons why exergames hold an advantage over traditional exercise when it comes to complying to an exercise or rehabilitation program (88, 99). However, as previously mentioned, adherence to exergaming has rarely been examined over longer periods of time and compared with appropriate control groups, leading to uncertainties about whether exergames really increase adherence to exercise in the manner they are often projected to do. It is therefore important to not assume that the introduction of an exergame into exercise or rehabilitation will automatically compel older adults to follow up the exercise. There is still a need to establish the potential long-term enjoyment and adherence to exergaming, and hence clinicians should continue to follow-up the patients as they would with traditional exercise programs.

Another issue important to settle before employing exergames on a large scale in different settings is related to safety. Even though several studies have found that exergames are safe to use (3, 153), others have pointed out the lack of evidence regarding safety for some patient groups (150) and that the evidence for using exergames at home is too insufficient to recommend as part of standard clinical practice (152). Even though few adverse events during gaming have been reported in the research, Paper I highlights that many studies do not report on this aspect, leaving the question of safety partly open. Hence, before applying specific exergames in an exercise or rehabilitation setting, it is important to test the games with the participants in a safe environment, ensuring the players safety and limiting the risk for injuries.

One of the most important clinical implications resulting from this thesis is that the choice of exergame in general and the specific game elements in particular affect how players move during game play. Hence, it is far from indifferent which exergame one use for specific exercise or rehabilitation in older adults. Both Papers III and IV highlight that even similar step-based exergames can lead to large differences in movement characteristics in older adults. By evaluating different game elements, Paper III gained insight into how movements are affected by different game aspects. For example, the game narrative, i.e., the representation of targets and the storyline of the game, plays a central role in which stepping movements are made by the players. If the game consists of a fixed game task with no variation in where targets appear, players will not be encouraged to take steps in different directions with different lengths and variations in speed. Therefore, in order to ensure that players perform the movements as required when used as an exercise or rehabilitation tool, it is important to evaluate the movements the older adults display during game play. Furthermore, movement characteristics are influenced not only by the game, but also by the difficulty level and prior experience with the game, pointing to the importance of evaluating these aspects of game play as well. Exergames need to be chosen and distributed to older adults based on the desired outcome of the exercise as well as knowledge of perceived enjoyment. Increasing difficulty level improves enjoyment of the exergame for many players, but can simultaneously affect the movement characteristics by limiting not only the amount of steps and upper body movements, but also negatively affect the variation in movements performed during gaming. It is also important to bear in mind that older adults may need technological support in order to be able to use the games in an unsupervised setting, potentially limiting current usefulness of exergames at home. Exergames can be promising with respect to home-based exercise and rehabilitation, but the game technology must be easy to use for the older adults, and it must provide relevant health personnel with pertinent information about the training sessions performed. In sum, for future use of exergames in the context of exercise or rehabilitation, it is important to select exergames with care (see Paper I), taking into account what older adults prefer (see Paper II), and which movement characteristics the player are required to perform (see Papers III and IV), as well as how to manipulate difficulty level to maintain motivation without sacrificing the quality of the movements. Furthermore, providing feedback and the scoring of points should be used to ensure that the proper movements are executed (see Papers III and IV).

4.4 Future research

The research reported in this thesis resulted in several recommendations for future research important to evolve the field further and to gain more insight into how to use exergames for older adults as an exercise and rehabilitation tool. With regard to the future design process of exergames, it is important to personalize the games to goals and performance level of the individual player, to address multiple physical functions and provide feedback regarding performance of the correct movements in the local language, as well as elicit the intended movement characteristics in the player, such as weight shifts, and variations in step length, direction, and speed when using games that aim to improve balance and mobility. Research also needs to ascertain which technology to use to achieve ease of use of the games, whether the games are safe to use in an unsupervised environment, and how to achieve long-term adherence to exergaming. In addition, more attention should be paid to understanding the actual movements displayed by older adults when playing exergames, both to ensure the proper exercise when aiming to improve specific functions and to be able to interpret results of intervention studies and to draw conclusions about the efficacy of exergames for the elderly population.

5. Conclusions

Even though exergames show promise as an intervention to improve physical function in older adults, there is large variability between studies in terms of intervention protocols and outcome measures, as well as several methodological limitations. To successfully establish exergames as an exercise and rehabilitation tool for older adults, this thesis provided several recommendations for clinical practice and further research on exergames in general and step-based games in particular, as well as for the design of exergames to be used as fall preventive exercise. These recommendations consist of including adherence and long-term follow-up in study methods, ensuring safety of the players during exergaming, personalizing exergames to goals and performance levels, and designing step-based exergames so that they ensure weight-shift, variations in step length, speed, and movement direction, and maintain visual independency. In addition to these recommendations, investigating how different game elements contribute to eliciting specific movement characteristics should be pursued in order to gain more insight into how different games affect the players. This insight is necessary in order to design effective exergaming interventions for specific exercise goals in specific populations. The current thesis illustrated that movement characteristics during game play are affected by the game, level of difficulty, and (even short-term) experience with the games. Therefore, when using exergames in exercise and rehabilitation settings, it is important to both select and design the games with care, taking into account the specific movements that need to be trained, how these are affected by the different exergame elements, and the user preferences of older adults. To realize more fully the potential of this technology, we need to better understand how game elements affect the movements displayed during game play, establish the safety of unsupervised exergaming, ensure ease of use by older adults, achieve long-term adherence to the games, and have broader understanding about which technology to use for which exercise or rehabilitation purpose.

6. References

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Review article

Exercise and rehabilitation delivered through exergames in older adults: An integrative review of technologies, safety and efficacy

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ABSTRACT

Background: There has been a rapid increase in research on the use of virtual reality (VR) and gaming technology as a complementary tool in exercise and rehabilitation in the elderly population. Although a few recent studies have evaluated their efficacy, there is currently no in-depth description and discussion of different game technologies, physical functions targeted, and safety issues related to older adults playing exergames.
Objectives: This integrative review provides an overview of the technologies and games used, progression, safety measurements and associated adverse events, adherence to exergaming, outcome measures used, and their effect on physical function. Methods: We undertook systematic searches of SCOPUS and PubMed databases. Key search terms included "game", "exercise", and "aged", and were adapted to each database. To be included, studies had to involve older adults aged 65 years or above, have a pre-post training or intervention design, include ICT-implemented games with weight-bearing exercises, and have outcome measures that included physical activity variables and/or clinical tests of physical function.
Results: Sixty studies fulfilled the inclusion criteria. The studies had a broad range of aims and intervention designs and mostly focused on community-dwelling healthy older adults. The majority of the studies used commercially available gaming technologies that targeted a number of different physical functions. Most studies reported that they had used some form of safety measure during intervention. None of the studies reported serious adverse events. However, only 21 studies (35%) reported on whether adverse events occurred. Twenty-four studies reported on adherence, but only seven studies (12%) compared adherence to exergaming with other forms of exercise. Clinical measures of balance were the most frequently used outcome measures. PEDro scores indicated that most studies had several methodological problems, with only 4 studies fulfilling 6 or more criteria out of 10. Several studies found positive effects of exergaming on balance and gait, while none reported negative effects.
Conclusion: Exergames show promise as an intervention to improve physical function in older adults, with few reported adverse events. As there is large variability between studies in terms of intervention protocols and outcome measures, as well as several methodological limitations, recommendations for both practice and further research are provided in order to successfully establish exergames as an exercise and rehabilitation tool for older adults.

Contents

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1. Introduction

During the last decade, there has been a rapid increase in research on the use of virtual reality (VR) and gaming technology in the elderly population [1,2]. Exercise through video games, so-called exergames, is used progressively more to increase physical activity and improve health and physical function in older adults [1,3–5], and there is growing interest in using exergames as a potential rehabilitation tool to facilitate specific exercises in different clinical groups [6–8]. Studies suggest that exergaming promotes improvements in mobility [9,10], muscular strength of the lower limbs [11], balance control [2,12,13], and cognition [14] in older adults.

In line with this increased research interest, several reviews on exergaming have recently appeared. A Cochrane review from Laver et al. [8] evaluated the effects of VR and interactive video gaming in stroke rehabilitation. The authors concluded that exergaming is a promising rehabilitation approach for stroke recovery. Furthermore, few adverse events were reported across studies, and those that were reported (transient dizziness, headache, pain) were mild, indicating that the interventions were relatively safe for this patient population. However, interventions varied greatly with regards to which technology and games were used, leading to uncertainty about which characteristics of the interventions, such as technology, game consoles and game activity, may have been most important.

Similarly, Barry et al. [15] evaluated the evidence for the safety, feasibility, and effectiveness of exergaming as a rehabilitation tool in people with Parkinson's disease. They commented that commercial exergames that required fast decision making and rapid movements to avoid virtual obstacles, might be too difficult to use for many patient populations. Furthermore, only two of the included studies addressed patient safety, and neither objective (such as falls or near falls) nor subjective (participant perceptions) measures of safety were reported in any of the studies [15].

Likewise, Verheijden Klompstra et al. [16] conducted a scoping review that focused on the feasibility and influence of exergames on physical activity in different groups of older adults, to assess whether exergames increased physical activity in patients with heart failure. Even though they concluded that exergames could be feasible to increase physical activity in patients with heart failure, they also highlighted that it would be challenging to find the most suitable exergame for any specific patient group as both the demands of games and the ability of the patients vary considerably [16].

In sum, these reviews indicate that exergames seem to be a feasible exercise tool for older adults with an acquired disease. Exergaming is also increasingly offered to elderly in general as a means of maintaining physical function, health, and, as a result, independence. Several reviews indicate that engaging older adults living in the community in an exergaming program is safe and feasible, and may enhance the participants' balance capabilities [5,17–20]. Laufer and colleagues [17] concluded that exergame programs may be an alternative to more conventional forms of exercise aimed at improving balance control. However, research on exergaming varies greatly in methodological quality as well as in intervention protocols and outcome measures used [17,19]. These factors make the evidence to support the effectiveness of using exergames for improving physical functioning in older adults inconclusive [19].

Exergames may have fundamental advantages compared to traditional exercise, as they easily allow for task-specific exercises to be delivered across a range of difficulty levels. This allows each user to begin at an appropriately challenging level that is attainable and comfortable, and then proceed with a gradual progression of difficulty that can be based on the individual's performance in real time [21]. However, commercial games that are readily available on the market are primarily designed for entertainment and recreation for younger populations, and tend to have colorful and visually busy game interactions, unsuitable music, and demanding navigation through the user interface. No easy one-touch interface is yet available, making the exergaming technology less feasible for many older people [21–23]. Furthermore, commercially available games are mostly designed for enjoyment and not based on basic exercise principles. In order for the games to be effective, they need to elicit specific movement characteristics in the players that are considered relevant for the function being trained. As falls and fall-related injuries are the leading cause for institutionalization and loss of independence amongst senior citizens [24,25], key components in exercise for older adults should focus on elements shown to reduce fall risk, i.e., weight-bearing exercise with elements that challenge balance and improve strength [26–28].

As technology continues to become more accessible and affordable, exergames may become more widely used in rehabilitation settings, in-patient hospital care, retirement homes, and home settings. It is therefore, important to evaluate not only the effectiveness of these games on physical performance and health outcomes, but also which type of technology and games to use in order to ensure high adherence and safety for older adults in different settings.

Existing reviews concerning exergames and VR have revealed that there is a large variety of study designs, technologies and exergames, and there is a notable lack of high quality studies with regard to methodology. However, previous reviews have mainly been systematic, focusing on the effect of exergaming, often in specific patient groups, and typically with few included studies. Also missing is an extensive overview of the technologies and games used in interventions with older adults, safety measurements and associated adverse events, adherence to exergames compared to other forms of exercise, and how game features may influence effectiveness. If exergames are to be employed safely and effectively as an exercise and rehabilitation tool for senior citizens there is a need to obtain not only evidence about efficacy and effectiveness, but also a broader understanding of the potential usefulness as a training tool, as well as the qualities of the commercial games and gaming consoles that are being used.

The aim of the current paper is to fill these gaps by providing a systematic overview, in-depth description, and discussion of the literature on exergames used for the elderly population, including the different game technologies, physical functions targeted, and safety issues related to older adults playing exergames. Specifically, the following research questions will be addressed using an integrative review approach: [1] which game technologies and exergames have been used in studies with older adults, which games provided exercise progression, and how was the adherence to the exergaming exercise? [2] What safety measures were used and have adverse events been reported? [3] Which physical functions have been targeted, and which outcome measures have been used? [4] Was there a change in physical function following exergame intervention?

2. Methods

2.1. Search strategy and selection criteria

A systematic literature search was performed with a preplanned review protocol specifying inclusion and exclusion criteria for the revealed studies and subsequent data analysis. Only original research, peer-reviewed, English-language studies were considered, excluding review articles and short conference abstracts. Inclusion criteria were as follows: (1) median or mean age of the study sample(s) had to be 65 years or above; (2) the study had to have an intervention design with pre- and post-measurements; (3) ICT-implemented games had to include weight-bearing exercises; and (4) outcome measures had to include physical activity variables and/or clinical tests of physical function. Papers were excluded when exercises were limited to the upper extremities, wheelchair activities, or cognitive function only.

Electronic searches were performed on July 10th 2013 in PubMed and SCOPUS. The searches consisted of combinations of controlled terminology and free-text terms expressing the concepts game, exercise, and aged, and were adapted to each database. Detailed search criteria are presented as supplementary material. The search was updated on February 22nd 2015.

2.2. Selection process

Prior to the extraction of data, two reviewers assessed a random sample of 50 studies to ensure that the selection criteria were unambiguous. All identified records were screened for duplicates and non-English papers by the first author. The abstracts of the remaining records were each screened independently by two reviewers and in case of uncertainty or disagreement, the paper was screened in full-text. Subsequently, included studies were each independently assessed in full-text by two reviewers. Disagreement about eligibility of a study was resolved by a third reviewer's assessment of the study.

2.3. Data extraction

Data from included studies were extracted using a custom-made, pre-piloted electronic form using Microsoft Excel 2010. Data on study design, participants, interventions, games and game technologies, outcome variables, and study findings were extracted. Details relating to the interventions included: intervention setting; length, frequency, and duration of intervention; and time of testing. Details relating to the games and game technologies included: game system; exercises and exercise order; game progression during intervention; safety measures to prevent falls; and adverse events.

2.4. Data analysis

For the purpose of this review, *physical function* refers to any physical performance or patient-reported outcome (e.g. balance, gait, quality-of-life) that is self-reported, observed, and/or objectively tested. Furthermore, game exercises were divided into categories based on which activity they targeted. Sport games such as bowling and golf were classified as a separate subgroup in accordance with the definitions in Nintendo Wii Fit games [29]. In sum, the categories included: balance, strength training, aerobic exercise, flexibility, dance, yoga, walking/stepping, and general sports. Study design is reported based on information from the papers and classified as experimental studies with or without random allocation, or analytical observational studies such as case-control and cohort studies. Regarding classification of outcome variables, physical tests refer to all clinical and objective tests of e.g. mobility, strength, and flexibility. Regarding intervention effect, we selected the studies that compared exergaming against at least one other active control group for analysis. Two reviewers independently assessed the methodological quality of these studies using the 10-point PEDro checklist [30,31]. Incongruities between the two reviewers were discussed and resolved by consensus.

3. Results

The results are presented in the subsequent sections: study selection, characteristics of the included studies and participants, gaming intervention, adherence, safety measures, outcome measures, and exergaming effects.

3.1. Study selection

Fig. 1 illustrates the flow of papers through the review process. The database search identified 706 records of possible interest. After removing duplicates, titles and abstracts of the remaining papers were screened against the selection criteria. Eighty papers were assessed in full-text review, yielding 47 studies for final data analysis. The most common reasons for exclusion were (1) median or mean age below 65 years; (2) focus on the upper extremities; (3)

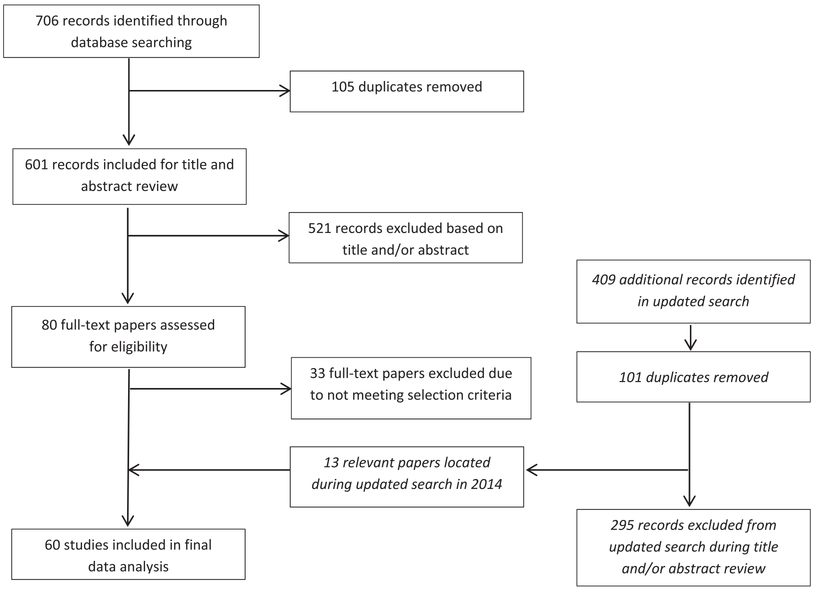

Fig. 1. Flow chart over study selection through the different phases.

Table 1
Study design of included studies.

Study design	Number of studies	References
Experimental with random allocation	27	[10–13,32,33,38,41–43,46–49,53,55,57,61,62,64–66,69,72,78,80,81]
Experimental with non-randomized allocation	6	[9,44,50,56,73,74]
Single group intervention	14	[35–37,39,40,51,52,54,68,70,76,77,79,85]
Case-control	2	[60,67]
Single group repeated measures	1	[63]
Feasibility study with single group	1	[75]
Prospective cohort study	1	[58]
Mixed methods	3	[59,71,82]
Case reports	5	[34,45,83,84,86]

Table 2
Exercise design in included studies.

Exercise design	Number of studies	References
Group exercise	11	[40,51,55,58,65,66,69,71,72,75,82]
Exercising in pairs	5	[10,11,50,74,77]
Individual exercise	24	[9,12,13,32–35,38,39,43,45,49,54,56,57,59,60,63,67,68,73,80,81,86]
Individual exercise at home	7	[52,62,70,78,79,83,84]
Exercise individually or in pairs	1	[76]
Not mentioned	12	[36,37,41,42,44,46–48,53,61,64,85]

Table 3
Study population in included studies.

Study population	Number of studies	References
Community-dwelling healthy older adults	22	[9–11,13,32,36–38,41,42,44,47,48,51,54,59,61,62,67,69,78,79]
Healthy older adults living in-care[a]	14	[12,35,39,40,55–57,65,66,71,72,74,76,77]
Non-healthy[b] older adults living at home	10	[33,45,49,58,60,68,70,75,83,84]
Non-healthy[b] older adults living in-care[b]	3	[34,52,85]
In-hospital patients	4	[64,80,81,86]
Both healthy and non-healthy[b] living at home or in-care	2	[46,82]
Both healthy and non-healthy[b] older adults without specification of residency	5	[43,50,53,63,73]

[a] Older adults living in retirement homes, nursing homes, or senior living centers.
[b] Older adults with Parkinson's disease, diabetes, heart failure, balance disorders, chronic obstructive pulmonary disease, or chronic stroke.

cognitive training only; and (4) method development studies without pre-post exercise design. An updated search in February 2015 identified 409 additional records. After excluding papers based on the selection criteria, 13 additional studies were included. Thus, a total of 60 studies were included in the final data analysis.

3.2. Study characteristics

Of the 60 included studies, the majority (53, >85%) were published between 2011 and February 2015, while the oldest published study was from 2007, reflecting that research on exergaming is a young field of science with rapidly increasing activity. The primary aim of the reviewed studies was to evaluate the potential effect of gaming/VR exercise on balance, either alone [9,12,32–46], in combination with other physical abilities such as strength or mobility [11,13,47–51], or in combination with falls or fear of falling, cognition, quality of life, or user experience [52–62]. Seven studies investigated the effect of gaming/VR exercise on gait parameters [63–69], and six studies examined the effectiveness with regard to different physical functions and associated fall risk [10,70–74]. The remaining 12 studies investigated the feasibility of using gaming/VR exercise to increase physical activity in healthy older adults [75–79], in hospitalized older adults [80,81], or in a patient population [82–86].

This broad range in study aims was reflected in the study designs as well. As can be seen in Table 1, 33 studies used an experimental design with either random or non-random allocation. The remaining studies were single group intervention studies, case-control studies, single group repeated measures studies, single group feasibility studies, prospective cohort studies, or mixed methods studies. The last five studies were case reports (see Table 1 for references).

The gaming interventions were carried out either in a clinical setting, in a laboratory setting, or at home. How participants performed the exercises differed between studies and could consist of group exercises, exercising in pairs, or individual exercises (see Table 2 for details). In one study, participants could choose whether to exercise individually or in pairs. Twelve studies did not mention how exercises were performed (see Table 2 for references).

The interaction time with each game within the intervention period was extremely variable. Across the included studies, the length of the VR intervention ranged from 1 to 24 weeks, with a median of 8 (mean: 8.2 ± 4.7) weeks. The frequency of the intervention ranged from 1 to 7 times per week, with a median of 3 (mean: 2.8 ± 1.3), and a median duration of each session of 32.5 (mean: 40.9 ± 20.0) minutes with a range of 15–120 min. Two studies reported that length of intervention was determined by either the individual participant's physical therapy treatment [49], or phase of dopaminergic medication [85]. Three studies did not report on intervention frequency [49,51,62], and three studies did not report on intervention duration [44,62,79]. Finally, one study had optional duration [60], and one study had self-regulated duration and frequency of each exercise session [71].

3.3. Participant characteristics

Mean participant age across the 60 studies was 76.1 (± 6.7) years, with a range of 44–98 years. Except for one study that included only female participants [75], all studies included both genders, with a higher average number of female participants (66.2%). Excluding the case-reports, the sample size varied between 6 and 104 participants, with a median of 25 participants.

As can be seen in Table 3, the majority of participants in the included studies were older adults who were community-dwelling or living in retirement homes, nursing homes, or senior living centers. The remaining studies included different patient groups living at home, in nursing or retirement homes, or in-hospital patients, either as the only study sample or in combination with healthy older adults (Table 3).

3.4. Gaming technology and game exercises

The majority of the included studies (43 of 60) used commercially available gaming technologies. The Nintendo Wii game console (Nintendo; Redmond, WA, USA) was the most commonly used technology (35 studies). Six studies used some or all the games in the Wii sport package with the handheld remotes [34,55,71,72,75,83], 22 studies used the balance, fitness, and strength games in the Wii Fit package with the accompanying Wii balance board [11–13,32,35,37,40,42–45,47,49,52,56–58,60,73,74,77,86], and the remaining seven studies used both the handheld remotes and the balance board [10,53,69,70,80–82]. Other gaming systems utilized were the gesture recognition system Eye Toy developed for Sony PlayStation II (Sony Computer Entertainment, Foster City, CA, US) [50,84], the motion-detecting camera system Kinect for X-Box360 (Microsoft Corporation, One Microsoft Way, Redmond, WA, US) [48,85], and DanceDanceRevolution (DDR), either as the Dancetown™ (Cobalt Flux Inc., Salt Lake City, Utah, US) [76], or an open-source DDR game (www.stepmania.com) [65,66,78]. The last 17 studies used custom-designed games. Of these, nine games were designed to target balance and consisted of GestureTek's Interactive Rehabilitation and Exercise System (IREX®) (GestureTek Health, Toronto, Ontario, Canada) [9], the SensBalance Fitness Board Sensamove (SensBalance Fitness Board; Sensamove®, the Netherlands) [36,39,54], the Balance Rehabilitation Unit (BRU™, Medicaa™, Montevideo, Uruguay) [38], virtual environments created using Virtools 4.0 (Dassault Systems) software with Wii Balance board [46], an interactive game-based virtual interface designed in MatLab® 2007a and Psych toolbox V2.54 with 5 wearable inertial sensors (LegSys™, BioSensics LLC, MA, USA) [61], and different pressure mats or force platforms [33,59]. Five of the custom-designed games targeted walking and stepping movements and used either a treadmill with a VR simulation [63,64,68], the Xavix Measured Step System (The Xavix Measured Step System, SPECTRUM9000MB-500system, UIS Co., Japan) [41], or developed inertial motion sensors to facilitate interaction with the exergames on a laptop computer (Toshiba Satellite L855; Intel Core i5 processor; 4 GB RAM; AMD Radeon dedicated graphics card) [62]. Two studies targeted several physical functions and utilized either modular interactive tiles (Entertainment Robotics, Odense, Denmark) [51] or the OGRE 3D graphics library together with a Kinect camera [79]. Finally, one study targeted strength with fast sit-to-stand movements using a set of uni-axial force plates, so called lower limb power rehabilitation [67]. The distribution of game technologies used across publication years is displayed in Fig. 2.

As with the game technology used, there was a wide variety in exercise games. For the 35 studies using Nintendo Wii, two studies used only the Wii Sports bowling game [34,55], while the remaining 33 studies used two or more games during the intervention. Furthermore, 11 of the Nintendo Wii studies used games that targeted balance only [11,35,37,42–44,47,57,58,73,82], while 16 used a combination of games that targeted different physical functions in addition to balance, such as strength, endurance, and mobility [10,13,32,40,45,49,52,56,60,69,70,74,77,80,81,86]. For those studies that did not utilize Nintendo Wii, only three studies [51,79,84] aimed to have an effect on more than one physical function. As can be seen in Table 4, the studies utilizing commercially available exergames targeted a wide variety of physical functions and activities, with balance being the main target of improvement (see

Table 4
Physical functions targeted using commercially available game consoles.

	Nintendo Wii balance board	Nintendo Wii handheld controller	Wii both	PlayStation EyeToy	Xbox Kinect	DDR
Balance	[11,13,32,35,37,40,42–45,47,49,52,56–58,60,73,74,77,86]		[10,69,70,80–82]	[50,84]	[85]	
Strength	[12,45,52,74,77,86]		[80,81]	[84]		
Aerobics	[40,56,60,74,77]		[70,80]	[84]		
Dance						[65,66,76,78]
Yoga	[13,32,49,56,60,74,77]		[80]		[48]	
Sports	[45]	[34,55,71,72,75,83]	[10,53,69]			
Walking				[84]		

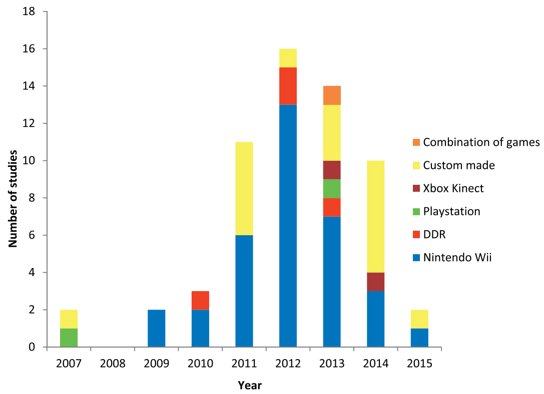

Fig. 2. Distribution of game consoles in exergame studies until February 2015.

Table 4 for references). For the custom-designed games three functions were mainly targeted; balance [9,33,36,38,39,46,54,59,61], walking/stepping [41,51,62–64,68], and strength [67,79].

3.5. Exercise progression

Thirty-two studies reported that they applied some kind of exercise progression during the intervention. The progression varied from increasing exercise duration [45,77], proceeding to the next level of the same game or to other games [10,13,32,38,39,43,46,49,50,52,54,57,61,65,66,73,74,78,85], adding more load in e.g. weight vests worn by the participants [53,69,72], and/or manipulating speed, orientation, size, frequency or shape of obstacles on the screen [33,45,59,60,63–68,76,78]. Two studies reported not having any form of progression during the intervention [56,86], while the remaining twenty-six studies did not report whether progression mechanisms were implemented during the intervention.

3.6. Adherence

Six of the included studies did not report the number of participants that completed the study [36,38,51,53,54,69]. Across the 54 studies that did include information about exercise completion, 88.8% of the participants completed the intervention on average, with a range of 56 to 100% of the participants. However, 24 of the studies did not report on the number of completed training sessions during the intervention [9,12,13,33,35,37,39,41,42,44–46,49,51,53,54,67,69,73–75,79,82, 85]. For the studies that reported on number of completed training sessions the methods varied between reporting adherence as a percentage of the maximum number of training sessions, compliance as the degree of accuracy with the prescribed intervention, or as the number of exercise sessions completed. Seven studies reported on adherence for both the intervention and the control group(s). Four of these showed no difference in adherence between the control exercise group and the group having an exergame intervention [57,72,80,81] while Pichierri et al. [65], Portela et al. [55], and Uzor and Baillie [62] showed better adherence in the exergaming group than in the control group(s).

3.7. Safety measures and adverse events

Forty-two studies reported that a safety measure was applied during the intervention. Of these, three interventions were conducted in a home environment

[52,83,84], while the others were performed in a laboratory setting or at a rehabilitation or community center [10-12,32,34,35,38–40,43–47,49,50,53–56,58–61,63–68,72–74,76,77, 80–82,86]. Of the 42 studies that reported on safety measures, 17 interventions were supervised by a physical therapist, researcher, trainer, or nursing staff [10,11,34,38–40,43,44,47,54,55,59,64,72,73,76, 84]. Eleven studies placed a chair, walker, or walking frame near the participants, or used a gait belt or harness to ensure safety among the participants during game play [32,46,49,52,53,56,60,63,65,66,68]. Twelve studies had both a safety aid and supervised exercise [12,35,45,58,61,67,74,77,80–82,86]. The remaining two studies reported that they provided the participants with safety guidelines or a consultation with an exercise trainer before conducting the exercises [50,83].

Regarding adverse events, only 21 of the 60 included studies (<35%) reported whether adverse events occurred in the course of the intervention period. None of the studies reported any serious adverse events during the intervention, but four studies informed about adverse events occurring outside the intervention. In these four studies participants either withdrew with complaints about pain or discomfort after playing [76,81,83], or had a fall between the initial screening session and the first group exercise session [58].

3.8. Outcome measures

As can be seen in Table 5, a plethora of different outcome measures have been utilized to assess potential effects of gaming/VR exercise. Main outcomes were measures targeting balance, gait, center of pressure (CoP), other physical function tests, patient-reported outcome measures using different questionnaires, and disease-specific measures. The most commonly used tests employed were clinical measures of balance, such as the Berg Balance Scale (BBS) and the Functional Reach test (FR), measures of gait such as walking a set distance, and measures of physical functions such as the Timed Up & Go test (TUG), and Sit-to-Stand test. Alternatively, some studies employed more complex assessments of balance ability such as computerized stepping tests and CoP-measurements on force platforms. A wide range of different patient-reported outcome measures such as fear of falling, quality of life (QoL), and motivational questionnaires have been utilized as well. In addition to a wide variety of outcomes, there were also variations within measures based on differences in study protocols across the included studies.

With respect to assessment schedule, outcome measurements were typically performed at baseline and immediately after or shortly following the intervention. Four studies had a time interval until post-test follow-up of less than 6 weeks [41,56,63,80]. Only two studies involved longer follow-up, one at six months post intervention [84] and one at nine months post-initial assessments [38].

3.9. Methodological quality

Of the 29 studies that used a RCT or pre-posttest design, 21 studies included an exercise control intervention [9,13,32,33,38,43,44,47,49,53,55,57,60,64,65,67,69,72,73,80,81]. The methodological quality of these 21 studies according to the PEDro classification scale is presented in Table 6. The PEDro scores show that most of the studies had several methodological weaknesses, with only four studies achieving more than 5 of the 10 criteria [33,38,64,81]. Most studies fulfilled the criteria "random allocation" and "point estimates and variability". In approximately half of the studies, "baseline comparability", "key outcomes", and "between group comparisons" were fulfilled. In contrast, only six studies used blinded assessors [33,38,64,73,80,81]. Furthermore, "concealed allocation" was fulfilled in six studies only [13,33,38,64,65,81], and "intention to treat analysis" in three studies only [32,49,81]. None of the 21 studies could achieve a perfect score of 10 as the nature of the intervention (exercise) precludes blinding of the participants and the therapists.

3.10. Changes in physical function

None of the studies that compared an exergaming group with an active control group reported any negative effect of exergaming (see Table 6). In seven studies, no between-group effects were reported [32,44,55,60,67,72,80], and five studies had no observed differences between the exergaming and active control groups [9,13,49,57,73]. The remaining studies demonstrated improvements favoring the exergame group in one or more of the outcome measures evaluated [33,38,43,47,53,64,65,69,81].

For the Timed Up & Go test, four studies indicated improvements in favor of the exergame group [43,53,64,81], while the other four studies did not observe this [13,33,47,73]. With regard to the Berg Balance Scale, four studies obtained significant improvement after exergaming in comparison with an exercise control group [33,43,64,81], while Franco et al. [57] did not find any between-group effects. Szturm et al. [33] found positive between-group effects of the Clinical Test of Sensory Interaction and Balance. Furthermore, positive effects on postural sway measures were noted in two studies [38,53].

With respect to spatiotemporal gait parameters, there were no consistent findings across the five studies that used these outcome measures. Pichierri et al. [65] found that a few of the gait parameters, mainly single support time in different conditions, improved more in the exergaming group than in the exercise control group. On the other hand, Lee et al. [69] found positive effects with regard to double support time and swing time, while Cho and Lee [64] observed an advantage for the exergaming group with regard to gait velocity and cadence. Two studies [33,38] did not find any significant improvements in spatiotemporal gait parameters from exergaming compared to other exercise control groups.

Finally, patient-reported outcome measures indicated less fear of falling in one study only [38], and improved scores on the Activity-specific Balance Confidence scale in another [33]. The study by Duque et al. [38] was the only one reporting on fall incidence, which was significantly lower in the exergaming group than in the exercise control group nine months after initial assessments.

4. Discussion

The current integrative review aimed to provide an overview of the use of exergaming/VR games, and to explore whether this technology is a safe and effective exercise and rehabilitation tool for older adults. The review included 60 studies that used ICT-implemented weight-bearing games in an elderly population above the age of 65 years. Most of the studies included healthy older adults with a wide range of number of participants, duration of intervention, game technologies, and interaction time with each game. The majority of included studies were published in 2011 or later, reflecting that exergaming as a method of exercise and rehabilitation for older adults is still in its infancy. In addition, the studies used a variety of outcome measures and study designs, making it challenging to compare them and draw conclusions regarding the effect of interventions. However, several studies found an effect of improved balance and gait parameters, and one study reported improvement in incidence of falls.

Table 5
Outcome measures.

	Outcome measures	n	References
Balance	FRT, Tinetti POMA, BBS, One-leg stance, 4-square step test, computerized stepping testes, CTSIB, SOT, alternate step test, figure-8-test, tandem, FAB, Romberg, balance board, game task, bubble test in Wii	40	[13,32–37,39–41,43–46,50,52–61,63,64,66,67,71,73,74,77–82,85,86]
Gait	Tinetti POMA, 4 meter timed walk test, Spatiotemporal gait variables, single/dual task, 6-min walk test, DGI, 2 min walk test, 10 meter walk test, Endurance Shuttle Walk test	29	[10,13,33,34,38,47,49–53,57–59,62–65,68–70,73,74,76,77,82–85]
Center of pressure	Sway, Area, mean (SD) ML+AP, velocity, excursion, Dynamic Motion Analysis score, Tetrax stability score, optokinetic stimuli, GRF on stepping task, Wii Fit CoP test	16	[9,11,13,32,37,38,42,43,45,48,54,58,59,61,78,86]
Physical function tests	TUG, SPPB, PPA, Sit-to-stand, Grip strength, Heartrate, arm lifts, arm curls, back scratch, ramp walk power test, obstacle course, Gallon-jug shelf transfer test, medicine ball chest press throw test, knee extension and flexion strength test, muscle strength, MVC, rate of force development, LEFS, SFT, Timed IADL, FIM, Barthel index, tri-axial (RT3) accelerometers, MET, Wii Fit Age, ROM, Kinect posture estimation	41	[10–13,33–35,38,41,43,45,47–51,53,55,56,59–62,64,67,68,70–82,84,86]
Patient-reported outcomes (QoL, Falls, physical activity, balance, motivation, cognition)	FES-I, fall risk for older people in community setting, SAFFE, ABC-scale, SF-36, upper extremity functional index, CHAMPS, LLFDI, Health-related quality of life EQ-5D, numeric pain rating scale, WHO quality of life, PACES, AFRIS, self-regulation questionnaire for exercising, SFQ, RAPA, activity log, SEE, OEE, level of enjoyment on Likert scale, GDS, Beck depression inventory, Montreal Cognitive Assessment, Trail Making Test, digit symbol substitution test, MMSE, Self-efficacy for Exercise scale, VAS	33	[9,11–13,33–36,38,41,45,46,49,50,52,55,57,58,60–63,65,67,71,72,74,76–78,81,83,84]
Disease specific	UPDRS, PDQ-39, Chronic respiratory questionnaire, Fugl-Meyer scale, modified Ashworth scale, The community balance and mobility scale	5	[9,63,70,84,85]

n: number of studies looking at one or more of the mentioned outcomes.
FRT: Functional Reach test; Tinneti POMA: Tinetti Performance Oriented Mobility Assessment; BBS: Bergs Balance Scale; CTSIB: Clinical Test of Sensory Interaction and Balance; SOT: Sensory Organization Test; FAB: Fullerton Advanced Balance Scale; DGI: Dynamic Gait Index; TUG: Timed Up & Go; SPPB: Short Physical Performance Battery; PPA: Physiological Profile Assessment score; MVC: maximal voluntary contraction; LEFS: Lower Extremity Functional Scale; SFT: Senior Fitness Test; IADL: instrumented activities of daily living; FIM: Functional Independent Measure; MET: Melbourne Edge Test; ROM: Range of motion; FES-I: Falls Efficacy Scale International; SAFFE: Survey of Activities and Fear of Falling in the Elderly; ABC: Activity-specific Balance Confidence scale; SF-36: The Short Form [36] Health Survey; CHAMPS: Community Healthy Activities Model Program for Seniors; LLFDI: Late Life Function and Disability Index; PACES: Physical Activity Enjoyment Scale; AFRIS: Attitude to Falls-Related Interventions Scale; SFQ: Short Feedback Questionnaire; RAPA: Rapid Assessment of Physical Activity; SEE: Self-Efficacy for Exercise scale; OEE: Outcome Expectations for Exercise scale; GDS: Geriatric Depression Scale; MMSE: Mini Mental Status Evaluation; VAS: Visual Analogue Scale; UPDRS: Unified Parkinson's Disease Rating Scale; PDQ-39: The Parkinson's Disease Quality of life questionnaire.

Table 6
Study characteristics, PEDro score, and effect on physical function of 21 intervention trials comparing exergaming with other forms of exercise.

Study; design; sample size; intervention dose	PEDro score	Sample characteristics	Exergaming group(s) (E)	Other exercise group(s) (O)	Progression	Between group change in physical function
Laver et al., [81]; RCT-pilot; $N = 42$; stay at rehab unit, 5×/week, 25 min	8	Hospitalized; age 84.9 (±4.5)	E: Nintendo Wii	O: Conventional PT focused on functional mobility	NR	**POS** TUG $p = .048$; modified BBS $p = .042$ **NO** SPPB, Timed IADL, ABC, HQoL EQ5D
Cho & Lee [64]; RCT; $N = 14$; 6weeks, 3×/week, 30 min	7	Chronic stroke (rehab); E:64.6 (±4.4), O:65.1 (±4.7)	E: Virtual walking training program using a real-world video recording, and therapeutic exercise, occupational therapy, functional electrical stimulation	O: Therapeutic exercise, occupational therapy, functional electrical stimulation, treadmill gait training	E: Speed was increased by 5% if the subject could maintain the training speed while feeling safe for 20secs O: NR	**POS** BBS $p = .011$; TUG $p = .013$; gait velocity $p = .013$; cadence $p = .035$ **NO** Step length, stride length, single limb support%
Duque et al., [38]; RCT; $N = 68$; 6weeks, 2×/week, 30 min	6	Community-dwelling with balance impairment (home); E:79.3 (±10), O:75 (±8)	E: Balance Rehabilitation Unit	O: Invitation to join an exercise program (Otago protocol), medication review, home visit by occupational therapist (if more than 60% of the falls occurred at home), hearing and visual assessment, nutritional supplements, vitamin D supplementation, education materials on falls prevention	E: Increasing levels of complexity (maximum 15 levels) O: NR	**POS** (after 9 months) limits of stability cm^2 $p < .01$; optokinetic stimuli $p < .01$; vertical VVC $p < .01$; horizontal VVC $p < .01$; SAFFE $p < .01$; falls $p < .01$ **NO** (after 9 months) sway (eyes open on floor), sway (eyes closed on floor and foam), gait velocity, cadence, stride length, double support time, Grip strength, GDS
Szturm et al., [33]; RCT; $N = 27$; 8weeks, 2×/week, 45 min	6	Independently living; E:80.5, O:81	E: Built COP-game with pressure mat	O: Rehab program with strength and balance exercises in sitting and standing	E: Increasing sensitivity of COP movements, speed, precision and duration O: NR	**POS** BBS $p < .001$; ABC scale $p < .02$; CTSIB $p < .007$ **NO** TUG, avg. gait speed, spatiotemporal gait variables
Pichierri et al., [65]; RCT; $N = 22$; 12 weeks, 2×/week, 40 min	5	Community dwelling (hostels for older adults); 86.2 (±4.6)	E: Modified version of DDR (Stepmania) + progressive resistance and postural balance training	O: Progressive resistance and postural balance training	E: Through the beats per minute and the difficulty level O: number of repetitions and load were progressively increased with weight vests	**POS** foot placement accuracy (condition 2) $p = .03$; velocity (fast with cognitive task) $p = .041$; single support time (fast with cognitive task) $p = .029$; single support time (normal dual task) $p = .05$; single support time (fast dual task) $p = .04$ **NO** foot placement accuracy (distance errors, walking velocity condition3, quality evaluation); temporal-spatial parameters (normal, fast and normal with cognitive task: velocity, cadence, step time, cycle time, stance time, single support time, double support time, step length); temporal-spatial parameters (fast with cognitive task: cadence, step time, cycle time, stance time, double support time, step length); relative dual task costs (normal and fast: velocity, cadence, step time, cycle time, stance time, double support time, step length); FES-I
Cho et al., [43]; RCT; $N = 22$; 6weeks, 3×/week, 30 min	5	Chronic stroke at outpatient department of rehabilitation hospital; 64.2 (±7.6)	E: Nintendo Wii + standard rehabilitation program	O: Standard rehabilitation program with physical therapy, occupational therapy and speech-language therapy	E: Encouraged to increase level O: NR	**POS** BBS $p < .001$; TUG $p < .01$ **NO** Postural Sway Velocity AP and ML with eyes open and closed

Table 6 (*Continued*)

Study; design; sample size; intervention dose	PEDro score	Sample characteristics	Exergaming group(s) (E)	Other exercise group(s) (O)	Progression	Between group change in physical function
Lee et al. [69]; RCT; $N = 82$; 10weeks, 3×/week, 45 min	5	Community-dwelling (senior center); 75.2(±6.6)	E: Nintendo Wii	O: Traditional group fitness with walking, strength and stretching	E: Weight vest with 2 pounds and adding 2 additional pounds every 2 weeks O: Modifications (e.g. deeper lunges and stiffer bands)	**POS** double support time% $p = .013$; swing time% $p = .010$ **NO** gait velocity, stride length, cadence, CV stride length, CV swing time, balance efficacy scale
Pluchino et al., [13]; RCT; $N = 27$; 8weeks, 2×/week, 60 min	5	Independently living; 72.5 (±8.4)	E: Nintendo Wii	O1: Standard balance exercise program O2:Tai Chi	E: 3 levels within each game, progress as soon as max score was attained O1: E.g. closing eyes, reducing base of support O2:NR	**NO** TUG, one-leg-stance, FR, POMA, FROP-Com, FES, sway, dynamic posturography
Fung et al., [49]; RCT; $N = 50$; length of stay in physical therapy service, 15 min	5	Outpatients following total knee replacement; 68 (±11)	E: Nintendo Wii	O: Lower extremity exercises that addressed balance, posture, weight shifting and strengthening	E: Other games once demonstrating a plateau in scoring O: Progressed to next level when similar exercises was performed successfully	**NO** active knee flexion, active knee extension, 2minute walk test, numeric pain rating scale, ABC-scale, LEFS
Reed-Jones et al., [47]; RCT; $N = 45$; 12 weeks, 2/week, 90 min	4	Community dwelling (retirement home); 67.5 (±5.9)	E: Nintendo Wii	O1: ACSM exercise recommendations for elderly O2: Agility drills	NR	**POS** obstacle course (hits) $p < .001$ (.212) **NO** grip strength, STS, arm curl, 6-min walk test, FR, TUG, ramp walk power test (long), ramp walk power test (short), Gallon-Jug shelf-transfer test, medicine ball chest press throw test, obstacle course (time), obstacle course (time + hits)
Franco et al., [57]; RCT; $N = 32$; 3 weeks, 2×/week, 10–15 min	4	Community dwelling (independent living senior housing); 78.3 (±6)	E: Nintendo Wii + supplemental home exercises	O1: Completed exercises from the MOB Program O2: No intervention	E: Introduced to different games O1: Regular MOB protocol O2: -	**NO** Tinetti, BBS, SF-36
Toulotte et al., [32]; RCT; $N = 36$; 20weeks, 1×/week, 60 min	4	Independently living; 75.1 (±10.3)	E1: Nintendo Wii E2: Nintendo Wii + Adapted physical activities	O: Adapted physical activities	E1: Based on different levels in each video game E2: Levels of game + increased numbers of repetitions and difficulty O: Increased numbers of repetitions and difficulty	**NR**
Crotty et al., [80]; RCT-pilot; $N = 44$; stay at rehab unit, 5×/week, 25 min	4	Acute care hospital inpatients; E:85.2 (±4.7), O:84.6 (±4.4)	E: Nintendo Wii	O: Conventional therapy designed to improve balance, strength and aerobic capacity	E: NR O: NR	**NR**
Ray et al. [53]; RCT; $N = 87$; 15weeks, 3×/week, 45 min	3	Community dwelling; 75	E: Nintendo Wii	O1: Group fitness with strength exercises sitting and standing O2: Control group	E: Weighted vest of 2 pounds, 2-pound increase every 2nd week until 10 pounds O1: Progressively increasing intensity routine	**POS** SOT $p = .007$; 8-foot TUG $p = .017$ (main effect) **NO** SOT strategy, 6-min walk, arm curls, chair stands, shoulder stretch

Singh et al. [73]; pre-post controlled; N = 28; 6weeks, 2×/week, 120 min	3	Community stroke rehabilitation centers; E:65.4 (±9.8), O:67.0 (±8.4)	E: Nintendo Wii and Xbox Kinect	O: Standard group therapy conducted by PT, stretch, strengthening, balance, coordination, endurance	E: Increasing difficulty level based on performance O: NR	**NO** TUG, 30 sec STS, 10 min walk test, 6 min walk test, Static balance, Barthel index
Daniel [72]; RCT pilot; N = 21; 15 weeks, 3×/week, 45 min	3	Community dwelling (residential living centers); 77 (±5.3)	E: Nintendo Wii	O1: Traditional senior fitness program, and rigorous seated aerobics program O2: Control asked to continue usual exercise	E: 2% of body weight added to weight vest every 2 weeks O1: increasing intensity O2: NR	**NR**
Bisson et al., [9]; pre-post intervention; N = 24; 10weeks, 28/week, 30 min	2	Independently living; E:74.4 (±3.7), O:74.4 (±4.9)	E: IREX	O: Dynamic balance training with visual biofeedback	E: NR O: NR	**NO** AP displacement, ML displacements reaction time, community balance and mobility
Portela et al., [55]; RCT; N=58; length NR, 20sessions, 50min	2	Community dwelling (nursing home); 79	E1: Nintendo Wii with supervision E2: Nintendo Wii unattended	O: Geriatric gymnastics	E1: NR E2: NR O: NR	**NR**
Bateni [44]; quasi-experimental; N = 17; 4weeks, 3×/week, no information on duration	2	Independently living; 73 (±13)	E1: Nintendo Wii E2: Nintendo Wii+ physical therapy	O: PT training to increase strength, and improve posture and balance.	E1: NR E2: NR O: NR	**NR**
Chen et al., [67]; case-control; N = 40; 6 weeks, 2×/week, 30 min	2	Independently living; E:76.4 (±7.4), O:75.4 (±8.5)	E: LLPR (video-game-based rehabilitation device)	O: Home exercise with sit-to-stand movements, knee extension, one leg stance	E: Increased target power threshold O: NR	**NR**
Williams et al. [60]; case-control; N = 17; 12 weeks, 2×/week, optional duration	1	Community-dwelling fallers (home); E:76.8 (±5.2), O:76.5 (±4.8)	E: Nintendo Wii	O: Exercise/education program supervised by PT	E: Modified at weeks 4 and 8 O: NR	**NR**

N = number of participants completed; intervention dose = length, frequency, duration; NR = not reported; E = exergaming group; O = control group; PT = physiotherapy; POS = significant positive group effect in favor of exergame; NO = no significant group effect. Effects are presented as: outcome variable (condition) p-value (effect size, if reported). Note: No studies reported a significant negative group effect of exergaming.

4.1. Game technologies and exergames

The review revealed a variety of game technologies and exergames being used. The Nintendo Wii console was the most frequently used, with variations depending on the package and accessories used. However, other commercial game consoles such as the Xbox 360 with Kinect and PlayStation II with EyeToy have been brought into play in recent years. Even though most studies have used games that are available on commercial consoles, several custom-designed consoles and games have also been utilized. However, these latter exergames tend to be characterized by fairly simple designs and exercises. Some of the custom-designed systems, such as the balance rehabilitation unit, require specific training before implementation, have a high cost compared to commercial systems, and depend on access to sufficient playing space and safety accessories. In addition, custom-designed games are usually employed by a single research group only. Although exergaming technology developed within the context of research addresses several of the problems that commercial exergames represent for an older age group, it remains to be seen to what extent these custom-designed systems can be widely disseminated.

Although several of the exergames were found to have a positive effect on balance and gait parameters among older adults, we know from previous research [22,87] that some games are rather demanding in terms of game interfaces that can be colorful, visually busy, and accompanied by unsuitable music, noises, and running commentary. To ensure that exergames reach the same acceptance as other exercise tools and methods, the games need to offer accessible and enjoyable activities for older adults in the same manner as more traditional forms of exercise. This might be important to consider when implementing or testing certain exergames in the elderly population. However, it will still be a challenge to find the most suitable exergame for older adults as they are a heterogeneous group, and physical and mental health status should be taken into consideration before implementing exergames as an exercise or rehabilitation tool.

About half of the included studies in this review reported having some kind of progression in exercise during the intervention. However, how progression was attained differed between studies, ranging from increasing the difficulty of the game to adding additional cognitive challenges or increasing the weight of a vest worn by the participants while playing. Studies also differed in how progression was achieved, often requiring a manual action by the researcher or participant. If exergames are to be used widely as an individual exercise tool, progression should be implemented within the game design itself, automatically adapting the level of challenge for each individual player based on their current performance [23]. The use of implemented standardized tests that have to be performed in regular intervals may also provide individual adjustments in loading and difficulty level. The games should set clear goals and both record and display progression so that the users feel that they are achieving their goals and managing to improve their physical function.

As exergames are typically reported to be fun and motivating, it has been claimed that they may increase adherence and compliance to exercise. Nonetheless, this has rarely been examined quantitatively and compared with appropriate control groups. Studies included in the current review generally revealed high attendance to exergaming. However, as most of the studies were conducted in a laboratory or clinical setting with supervision, there is little evidence to conclude that exergaming in general provides better adherence than standard exercise. Even though Miller et al. [88] reported strong retention and adherence rates in their systematic review concerning effectiveness and feasibility of VR/exergaming systems in a home setting, little is known about long-term participation in this form of activity. User characteristics and personality are likely to influence the types of exergames that seniors like to play and a "one-size fits-all" approach may result in low or even non-adherence. Likewise, exergaming has the potential to include a social context where older adults can chat with each other while exercising, play together with other people, or against each other in a competition. In addition, through use of new technologies people have the possibility to play together remotely through the internet without both players needing to be at the same location. However, the social aspects of exergaming and how these might influence adherence have not been studied thoroughly. Furthermore, even though the multi-player option is generally perceived as social and fun, we lack empirical data about whether playing together remotely is an equally enjoyable possibility as actually being in the same room.

4.2. Safety measures and adverse events

There is only limited evidence available to assess whether exergaming is safe for older adults as only one third of the studies included in this review presented information regarding the occurrence of adverse events during the interventions. The few adverse events that were reported ranged from mild discomfort to musculoskeletal pain and none of the studies reported any serious adverse events during exergaming, suggesting that exergaming interventions might be safe for older adults. However, most studies were conducted in a laboratory, rehabilitation, or community center setting and applied extra safety measures such as supervision, walking frames, or gait belts. One of the potential benefits of exergaming interventions is that they can be administered at home as individual exercise. Home-based exercise has been shown to be effective in reducing mortality, injuries, and falls, as well as being more cost-effective than other interventions [27,89]. However, few studies have assessed the safety of administering exergaming in the homes of older adults. In the current review, the five studies with a home-based intervention reported that there were no adverse events during the exergaming intervention [52,70,78,84,90]. However, as some of the latter studies applied extra safety measures and generally had few participants, it is premature to conclude that exergaming is equally safe as other, more conventional forms of home-based exercise.

Importantly, half of the 60 studies we reviewed used the Nintendo Wii and Wii fit balance board, and an additional six studies used pressure mats or force platforms. Both the Wii fit balance board and the step mat for DDR are elevated platforms that the player has to stand on in order to perform the exercises. They may therefore present a risk of tripping and falling, particularly when attention is focused on the television screen. Newer commercial exergaming systems such as the Microsoft Kinect do not require the player to stand on an elevated surface, and may therefore provide a safer alternative of exergaming for older adults. However, at the moment few studies have been published on these newer commercial systems, so the improved safety aspect of these games remains to be established.

4.3. Measures of physical function

Studies on exergaming for older adults have focused on a wide range of physical functions, but the most common focus has been to establish whether exergaming has an effect on balance.

The general recommendations to stay active and healthy for adults above 65 years are to carry out moderate-intensity aerobic physical activity, in addition to balance and strength training [28]. However, only a few studies using commercially available exergames, and none of the custom-designed games, have used games that target more than one physical function. Future studies should include games that target multiple physical functions in order to establish the extent to which exergaming can contribute to keeping older adults active and healthy.

Finally, the plethora of different assessment tests and outcome measures makes it difficult to do a comprehensive meta-analysis on the effectiveness of exergaming. This will be further discussed below.

4.4. Changes in physical function

The studies that compared exergame-based training with other exercise programs found that exergames showed comparable or slightly better changes in physical function in several outcome measures. Interestingly, none of the studies included in this review showed a negative effect of exergaming when compared to other exercise interventions. This might indicate that exergaming is an effective alternative to conventional exercise or rehabilitation for older adults. Nevertheless, a generalized conclusion must be regarded with caution as only two of the included studies had a long-term follow-up of at least six months. However, the results of both these studies are encouraging. Duque et al. [38] reported a significant improvement in limits of stability as well as in the incidence of falls and in levels of fear of falling nine months after initial assessment. In addition, Flynn et al. [84] found a sustained or improved function for all outcome measures in their case report at six-month follow-up.

Another point to be taken into consideration is that positive effects were often limited to specific functions trained during exergaming, without generalizing to other functions not specifically trained. In addition, it should be noted that in some studies reporting improvements in favor of the exergame group, participants took part in additional balance and strength exercises [43,64,65]. Finally, these results are mostly obtained from fairly healthy, community-dwelling older adults as most samples were based on convenience sampling rather than strictly population samples. Hence, generalizability of results to community-dwelling older people in general and at-risk groups in particular may be problematic and requires further investigation.

Results regarding the methodological quality indicated a general lack of concealed allocation and use of intention-to-treat analysis in most of the included studies. Only four of 21 studies attained a score of 6 or above (of 10) on the PEDro scale. As a consequence, this restricts the capacity of these studies to generate reliable evidence regarding the effectiveness of exergame interventions. Previously published reviews on exergaming/VR-interventions report similar problems [5,16,19,88].

4.5. Strengths and limitations

The main strength of this review lies in its extensive search strategy, covering a broad range of search terms and databases in the fields of medicine, social sciences, health care, and technology. This systematic and multidisciplinary approach is also reflected in the inclusion of all types of pre-post intervention studies, regardless of research design. Another strength is the use of the PEDro scale to evaluate the methodological quality of studies that compared exergaming against at least one other active control group in order to investigate the potential effect of exergaming.

Nevertheless, there are some limitations to our review. First of all, although we conducted an extensive search, it was not complete in the sense that we limited our search to original research with a pre-post intervention and English language publications only. Furthermore, aspects such as social potential and user perspectives were not included in this review as they fell outside the main objective. However, these aspects have relevance for long-term engagement in exergaming (cf. [91]) and should be included in future research.

5. Recommendations and conclusion

In general, exergames show good potential as an exercise or rehabilitation tool for older adults. It is encouraging to note that only a few studies reported on, relatively mild, adverse events and that all studies reported exergaming to be as effective as or more effective than conventional forms of exercise. Based on the findings in the current review, we provide the following recommendations for both research and practice to successfully establish exergames as an exercise and rehabilitation tool for older adults.

1) Exergames need to be personalized to goals and performance level

A “one-size fits all” approach is not the best solution to engage older adults in exergaming. Before implementing an exergame in a home, community center, or rehabilitation center, the needs, wishes, and motivation of the intended user should be assessed, for example by use of focus interviews, workshops or user-centered design methods, and further taken into account to increase engagement in the exergame. Progression should be ensured by automatically adapting the level of challenge (difficulty and load) to the current performance level, making games more challenging when the user achieves consistently good performance and less challenging when performance drops.

2) Exergames should address multiple physical functions when used as an exercise tool

Future studies should include games that can target multiple physical functions to establish the extent to which exergaming can contribute to keeping older adults active and healthy. New technologies such as the Microsoft Kinect have the potential to incorporate complex and continually adaptive exercises requiring specific movements and track the extent to which these movements are indeed performed by the players. By way of example, exergames that only require an individual to repeatedly reach for an object do not exploit this potential and therefore, do not utilize the full potential of exergaming as an exercise and rehabilitation tool.

3) Exergames need to be safe for players without the need for additional safety measures

If exergames are to be used by healthy older adults at home, in frail older adults, or in older adults with an acquired disease, the safety of playing needs to be established more firmly. Ideally, no extra equipment such as harnesses and frames should be required in order to play. However, for frail older adults a walking aid can be useful in the initial phase of playing exergames. To establish safety, objective and subjective measures of this should be reported, as well as the participants' ability to play the games.

4) Adherence to exergaming should be included in study methods

Even though exergaming is largely purported to be fun and motivating, there is little evidence of whether exergames achieve higher adherence than conventional forms of exercise. Future studies should include outcomes on adherence for both exergaming interventions and exercising control groups. Here as well, new technology provides great opportunities as one can save and store large amount of information from an exergaming session. Information about which games have been played, how much they have been played, and how the players moved during the gaming session can be obtained from the technology. This information can give insight into exercising routines that traditional exercise logs

Summary points

What was known before this study?

- Exergames are used progressively more to increase physical activity and improve health and physical function in older adults.
- Previous reviews have mainly focused on the effect of exergaming in specific populations.

What did this study add to our body of knowledge?

- The current review contributes with an extensive overview of game technologies and exergames, physical functions targeted, outcome measures, and safety measures used in intervention studies.
- Results of the review indicate similar or better effects of exergaming compared to traditional forms of exercise, with few and relatively minor adverse events.
- The review points out several areas that are in need of more research, including adherence to the exergaming and tailored progression of exercises.
- Based on the results, the review provides recommendations for both practice and further research in order to successfully establish exergames as an exercise and rehabilitation tool for older adults.

typically do not. Exploiting the information given by the technology can provide insight not only into adherence, but also enable personalized feedback on how movements should be performed and adjusting and adapting the games to each player. Although social aspects of exergaming were not part of the objectives in this review, exergaming and exergaming technology have an important but under-exploited potential that should be explored further. Having the possibility to play together with, or against, one or several people might be a way to keep older adults involved and engaged in exercise. Furthermore, including one or more social components into the gaming sessions such as a chat function or a multiplayer function might contribute to keeping older adults more socially active and less isolated.

5) Studies with longer follow-up should be conducted to establish long-term effects

To establish the long-term exercise effect of exergaming, we recommend that randomized controlled trials should be conducted with a longer follow-up, including larger group sizes, follow-up assessments, and more standardized protocols and outcome measures.

Exergaming has great potential to become a crucial part of future personalized medical technology and a significant tool for health professionals such as physiotherapists and occupational therapists. This requires the use of appropriate games that are tailored specifically to older adults, provide personalized exercises based on each individual's needs, and ensure long term follow-up. Furthermore, as many elderly increasingly become tied to their homes with age and disease, they are at risk of decreasing levels of social and physical activity, as well as increased isolation. In these situations, exergames have the potential not only to be a fun and motivating way to exercise, but also to engage older adults in social activities. In order to realize the full potential of exergaming as an exercise and rehabilitation tool for older adults, research is needed to establish whether the games are safe, which technology to use for which purpose, how to ensure ease of use for the older adults, and how to achieve long-term adherence to the games.

Author's contributions

Nina Skjæret and Beatrix Vereijken managed the review process with input from Ather Nawaz, Tobias Morat, Daniel Schoene, and Jorunn L. Helbostad. Nina Skjæret and Beatrix Vereijken reviewed the full papers. Beatrix Vereijken and Tobias Morat assessed the methodological quality of the included studies. All authors critically revised the paper for publication.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijmedinf.2015.10.008.

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Paper II

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Paper III

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Paper IV

Exergaming in older adults: Movement characteristics while playing stepping games

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Keywords: Aged, Stepping, Exergames, Movement characteristics, Movement analysis, Motion capture

Abstract

Despite frequent use of exergames in intervention studies to improve physical function in older adults, we lack knowledge about the movements performed during exergaming. This causes difficulties for interpreting results of intervention studies and drawing conclusions about the efficacy of exergames to exercise specific functions important for the elderly population. The aim of the current study was to investigate whether game and game level affect older adults' stepping and upper body movements while playing stepping exergames. A 3D-motion capture experiment was performed with 20 healthy elderly (12 women and 8 men; age range 65-90 yrs, mean age 75.7±5.48 yrs), playing two exergames, The Mole from SilverFit and LightRace in YourShape:Fitness Evolved, on 2 difficulty levels, with 5 one-minute trials for each game and level. Reflective markers were placed on bases of 1st toe, heels, and lower back. Stepping parameters (number of steps per minute, mean and SD of step length and step velocity), upper body movements (mean and SD of upper body velocity in medio-lateral (ML) and anterior-posterior (AP) directions), and weight shifting (movement area covered by the upper body in relation to the feet) were analyzed with a linear mixed model. Results indicated that both game and game level affected movement characteristics. Participants took shorter steps and had lower step velocity when playing The Mole compared to LightRace, while The Mole prompted more variation in step length and step velocity. Compared to LightRace, The Mole elicited larger upper body movements in both ML- and AP-directions and participants' feet and upper body covered a larger area. Increasing difficulty level from Easy to Medium resulted in overall decrease of movement, except for number of steps and step speed when playing LightRace. Weight shifting was affected by the game as well, with The Mole inducing more weight shift than LightRace. Even with only 2 games, 2 levels, and 5 trials at each, this study indicates that the choice of exergame is not indifferent when aiming to exercise specific functions in older adults and that exergames need to be chosen and designed carefully based on the goals of the intervention.

1 Introduction

The European population is rapidly ageing and we have a longer life expectancy than ever before. With advancing age comes increased risk for disease and functional decline, which again may increase the risk of cognitive impairment, frailty, and falls, with concomitant negative consequences for quality of life (Horak et al., 1989;Bolandzadeh et al., 2015;Bridenbaugh and Kressig, 2015). Falls in particular can have dramatic consequences in terms of fractures and fear of future falls, and are the leading cause for loss of independence among older adults (Hausdorff et al., 2001;Kannus et al., 2005). In order to keep the additional years added to life expectancy mostly healthy years, maintaining regular physical activity is heralded as one of the most important lifestyle factors (Chodzko-Zajko et al., 2009).

Studies have shown that physical activity is one of the most important pathways to improve and maintain health in older adults (Chodzko-Zajko et al., 2009;Montero-Fernandez and Serra-Rexach, 2013). For example, exercise interventions among older adults living in the community can reduce falls by 17–30% (Sherrington et al., 2011;Gillespie et al., 2012). A considerable proportion of falls can be attributed to incorrect weight-shifting activities, such as during walking (Topper et al., 1993;van

Dieen and Pijnappels, 2008;Robinovitch et al., 2013) or in situations that require performance of several tasks simultaneously (Melzer et al., 2010). In situations like these, older adults are more likely than younger counterparts to make steps that are too slow, in the wrong direction or too short, or to collide one leg against the other during compensatory crossover steps (Maki and McIlroy, 2006;Hsiao-Wecksler and Robinovitch, 2007).

One of the most important components in exercise interventions aimed at reducing falls among older adults is balance training (Sherrington et al., 2008). In many intervention studies, balance training consists of controlling the center of mass over a reduced base of support (Sherrington et al., 2008). However, daily life situations such as a slip, trip, or trying to avoid an obstacle during walking, require fast and corrective stepping movements that involve changing the base of support relative to the center of mass in order to correct or prevent loss of balance. The abilities to initiate a fast voluntary step or to inhibit a preplanned step and find an alternative foot landing position to avoid instability, have been found to deteriorate with age (Lord and Fitzpatrick, 2001;Potocanac et al., 2014;Potocanac et al., 2015). Additional changes in gait with increased age include lower gait speed, shorter step length, a wider base of support, longer double support, as well as increased variability in step time, step length and step-width (Himann et al., 1988;Winter et al., 1990;Hausdorff et al., 2001).

Exercise interventions with focus on performing appropriate, rapid, timed, and well-directed steps have a valuable role in interventions and rehabilitation for older adults, and it has been found that both reactive and volitional stepping interventions reduce falls among older adults by approximately 50% (Okubo et al., 2016). Thus, exercise interventions for older adults should not focus on standing balance tasks alone, but should also include activities that focus on improving stepping, with varying speeds, multi-directional weight-shifts, dual tasking, and gaze shifting (Patla et al., 1992;Lundin-Olsson et al., 1997;Gillespie et al., 2012;Hackney and McKee, 2014;Balasubramanian, 2015).

New technology-based exercise methods, such as exergames that open up for full-body interaction with computer games, appear promising as a means to promote and maintain physical activity. Step-based games such as the Dance Dance Revolution (DDR) drew considerable attention in the early stages of exergaming research in older adults, much due to the low cost and the interaction between the sensory, information-processing, and neuromuscular systems during controlled body weight transfers (de Bruin et al., 2010). With increasingly advanced technology, exergames now have the potential to stimulate more complex and dynamic movements that contain variations in step length, direction, and speed, as well as inhibition of voluntary step initiations and avoidance of virtual obstacles. These are all skills that are necessary to successfully navigate through different situations in daily life.

A rapidly growing number of studies comparing exergame-based exercise interventions with other interventions have found that exergames show either comparable or slightly better changes in physical functions (e.g. Laver et al., 2012;Cho and Lee, 2013;Duque et al., 2013). However, we lack knowledge about the specific movements that players perform during exergaming, making it difficult to interpret results of intervention studies and to draw conclusions about the efficacy of exergames to exercise and improve specific functions important for the elderly population. The limited research that has been conducted on movement quality and movement patterns in commercial exergaming, have been on younger gamers (Pasch et al., 2009), healthy children (Levac et al., 2010), and children with cerebral palsy (Berry et al., 2012). These studies suggest that movements performed during gaming are highly variable between players and that it might be necessary to explore more games in order to ensure that the intended movement characteristics are practiced during game play (Pasch et al., 2009;Berry et al., 2012). Furthermore, it is unclear to what extent players can do meager renditions of the intended movements that yield scoring of points despite these renditions not being the specific movement characteristics that are required to achieve the intended exercise (Pasch et al., 2009;Levac et al., 2010). In addition, increasing game level is a natural part, and often a goal, in gaming. However, it is unknown how increasing difficulty level, for example by adding a cognitive element, having additional movements in the game, or increasing game speed, affects the movement characteristics older adults display during gaming.

There are promising indications that stepping exergames may be applicable to improve physical and cognitive functions that are necessary to successfully navigate through different situations in daily life. However, to date, no studies have been published that focused on the stepping characteristics people display when playing stepping exergames. We lack knowledge about whether stepping games actually result in players shifting their weight from one leg to another, whether they take large or small steps, and whether they vary their steps during a game session. The current study is the first to address these gaps in our knowledge by objectively investigating the movement characteristics that older adults display when playing step-based exergames. In order to study the stepping movements older adults perform during gaming, two different stepping exergames were chosen, based on a previous observational study investigating the relationship between relevant aspects of stepping behavior during game play and game elements, where The Mole and LightRace elicited better overall movement quality compared to DDR (Skjaeret et al., 2015). The main aim of the current study is to investigate whether differences in game, difficulty level, and short-term experience affect movement characteristics of the players during game play, by describing step and upper body characteristics displayed by older adults.

2 Methods

2.1 Participants

A convenience sample of 20 community-dwelling older adults (12 female, 8 male) participated in the study. To be included, participants had to be over the age of 65 years, have no known physical or mental disabilities, and be able to walk safely without a walking aid. The participants were recruited from recreational exercise groups in the municipality of Trondheim, Norway. All subjects provided informed, written consent. The study was approved by the Regional Ethical Committee for Medical and Health Research Ethics, and conducted in accordance with the Declaration of Helsinki.

2.2 Exergames

Based on a previous observational study on older adults' movement characteristics during stepping exergames (Skjaeret et al., 2015), two step-based exergames were chosen for the current study, The Mole from SilverFit (SilverFit BV, Woerden, The Netherlands), and LightRace in YourShape: Fitness Evolved (Ubi Soft Divertissement Inc., Montréal, Canada) (see Figure 1). Both games require the players to take steps in different directions and hit a target in order to play the game and score points.

Figure 1: The interfaces of The Mole from SilverFit (left panel) and LightRace in YourShape: Fitness Evolved (right panel).

SilverFit is a virtual reality rehabilitation system with several mini games specifically designed for older adults in exercise and rehabilitation settings (Rademaker et al., 2009). The system uses a 3D motion-sensing camera to detect the player's movements, and shows the displacement of the player's feet on the screen. In the current study, the mini game The Mole was played at two levels of difficulty, "Basic" and "Precision Control". The game is played by stepping on stationary moles and moving mice to chase them from a garden (Basic) while avoiding stepping on lady bugs (Precision Control). All animals appear randomly on the screen, prompting the player to move in all directions.

LightRace in YourShape: Fitness Evolved is one of a variety of mini games designed for the general public on Xbox One (Microsoft Inc.), using a Kinect motion-sensing camera to detect the player's movements and visualize these on the screen in the form of a full-body avatar. The player stands in front of the screen and has to step on the area that lights up around the avatar on the screen. At the Easy level, lights appear in front or to the side of the player, while at the Medium level lights appear behind the player in addition.

2.3 Experimental setup

An Oqus Motion Capture System (Qualisys AB, Gothenburg, Sweden) was used to track the movements of the participant's feet and upper body. Five passive reflective markers were attached with double-sided tape bilaterally to the participant's base of 1st toe, mid calcaneus, and approximately at the 3rd lumbar vertebrae of the back. Seven infrared cameras were placed around the area where the exergames were played, and a digital video recorder was placed on the participants' right side. As both Oqus and Kinect cameras use infrared light, they could not be placed in each other`s line of sight, as this would cause interference between the cameras. Therefore, the Oqus cameras could not be placed directly behind the participants. The Oqus cameras were calibrated to measure marker position to within 1.0 mm accuracy at a frequency of 100 Hz.

2.4 Procedure

All participants played each exergame on two difficulty levels, Easy and Medium, with five one-minute trials for each game and level, giving a total of 20 trials for each participant. Each exergame was demonstrated to the participant and each participant received one try-out trial for each game and level before playing the five recorded trials. There was a one-minute break after each trial, and a 5-minute seated break between levels and games. The games were played in counter-balanced order across participants, and they always started with the easy level of the game. One researcher stood near the participant to ensure safety while playing the exergame. After each game level, the participants marked the BORG Perceived Exertion Scale (score 6-20) (Borg, 1998) and answered a few short questions about enjoyment, possible usage, and fear of falling while playing. After completing both levels of each game, the participants filled out the Norwegian version of the Systems Usability Scale (SUS) questionnaire (score 1-100) (Brooke, 1996) to evaluate the usability of each system.

After finalizing both games, participants filled out the Norwegian version of the 16-item Falls Efficacy Scale – International (FES-I) questionnaire that measures the level of concern for falling on a 4-point scale (score 16-64) (Yardley et al., 2005;Helbostad et al., 2010). In addition, they filled out a background questionnaire regarding age, gaming experience, medication, and weekly amount of physical activity. Finally, two functional tests were performed: a six meter walk test (Guralnik et al., 1994) and a 30 seconds sit-to-stand test (Rikli and Jones, 1999).

The start and end points for the walk test were marked on the floor with tape at a total distance of 10 m. The two first and last meters, i.e., the acceleration and deceleration phases, respectively, were not included in the calculation of gait speed. Participants were instructed to walk as fast and safely as they could, and gait speed was measured with a stopwatch.

For the 30 seconds sit-to-stand test a straight-backed armless chair with a seat height of 47cm was used. The chair was stabilized by placing it against a wall. Participants were instructed to sit in the middle of the chair, feet flat on the floor with arms folded across the chest and rise to a full standing position and then sit back again as many times as possible in a 30-seconds time period.

2.5 Data processing and analyzing

A custom-made Matlab script (Mathworks, MA, US) was used to identify step characteristics and upper body movements. Step initiation and termination was identified by velocity of the toe markers, with a cut-off at ±0.1 m/s, as the heel markers were missing in several data sets. A step was set as a ≥.03 m displacement of the toe marker lasting for ≥.05 seconds. Spurious steps were eliminated after visual check of all records (less than 2 %). The following parameters were calculated from the identified steps: number of steps per minute and mean and SD of step length and step velocity for both feet combined. Upper body movements were registered by the marker placed at the lower back, and parameters were calculated separately for medio-lateral (ML) and anterior-posterior (AP) directions. The following parameters were calculated for upper body movements: mean and SD of upper body velocity in medio-lateral (ML) and anterior-posterior (AP) directions. Area covered by the feet and the upper body markers was calculated as the area of an ellipsoid with the length of the principle axis set equal to 1.96*SD of the variation identified by singular value decomposition (Oliveira et al., 1996). In addition, a movement area ratio was calculated as $\frac{area\ feet}{area\ upper\ body}$, where values close to 1.0 reflect more weight shifting by the participants when taking steps.

2.6 Statistics

A linear mixed model for repeated measures was used to analyze characteristics of step and upper body movements displayed by the participants for both exergames and levels with fixed effects of Game, Level, and Trial and interactions between them. We also checked Trial as a covariate given that this is considered as a trend over time; this did not affect the results. The restricted maximum likelihood method (REML) was used for the estimation of the fixed and random effect parameters. Spearman's correlations were calculated to test for redundancy of the movement characteristics. All statistical analyses were performed with the IBM SPSS Statistics version 22. Statistical level of significance was set at $p < 0.05$.

3 Results

3.1 Participants and background information

Participant characteristics are shown in Table 1. All participants were retired, independently living elderly in good health for their age. Three of the participants had some previous experience with game consoles designed for entertainment, but none of them had used exergames on a regular basis. During game play, all participants expressed high levels of enjoyment when playing both exergames, and participants preferred the Medium level to the Easy level due to the increased cognitive and physical challenge.

Table 1. Participant characteristics

	Mean (SD)	Range
Age (years)	75.7 (5.4)	65 - 90
Height (cm)	167.6 (10.5)	152 - 185
Weight (kg)	74.6 (9.8)	54 - 91.5
Daily prescription medication (n)	2.0 (1.7) (median 1.5)	0-7
FES-I (score)	19.5 (2.8)	16-27
Experienced a fall within the last year (n, %)	6 (30%)	
Walking speed (m/s)	1.4 (0.3)	0.5-1.8
30 sec Sit-to-stand (n)	14.6 (2.9)	8-19
Physical activity (min pr. day)	61.0 (27.7)	26.8-150

The BORG-scores ranged from 6-15 for both games and levels, indicating low to medium perceived exertion. Both exergames were given above average scores (>70 on a scale from 1-100) on the System Usability Scale (SUS), with The Mole having a slightly higher average SUS-score (80.7 ± 15.2) than LightRace (75.8 ± 19.2).

3.2 Game score

In both exergames a game score was calculated and displayed for the participants while playing. The participants scored more points at the Easy levels than at the Medium levels in both The Mole (30.5

vs 23.1) and LightRace (114.3 vs. 84.8), giving a relative difference in score between the levels of 24.3 % and 25.8 %, respectively. There was a significant interaction between Game and Trial (F(1,374.02)=4.59, p=.033), indicating that the game score increased across trials when playing LightRace, while there were no such increase in the score for The Mole. While there was no significant difference between the levels in The Mole, participants achieved a significantly higher game score at the Medium level compared to the Easy level when playing LightRace (29.48, CI 95% 15.43 - 43.53, p<.001).

3.3 Movement characteristics

In general, the two exergames and the two difficulty levels within each game elicited different step and upper body movements in the participants during gameplay. Table 2 shows the mean and standard deviation for all 11 movement characteristics and the calculated movement area ratio for each game and level across all participants and all trials. Also indicated are the significant differences between the games and levels from the linear mixed model. More detailed description of the results and statistical tests from each characteristic are provided in the following sections. Furthermore, correlations between the 11 movement characteristics varied from 0.014 to 0.883. All characteristics related to upper body movement were significantly correlated, and varied from 0.638 to 0.856 (all p's < .01).

Table 2: Group means (SD) for all movement characteristics and the calculated movement area ratio for The Mole and LightRace at Easy and Medium levels.

	The Mole Easy	The Mole Medium	LightRace Easy	LightRace Medium
Number of steps per minute [a,b,c,d]	97.85 (3.86)	86.25(3.68)	86.51 (4.42)	104.14(5.04)
Step length (cm) [a,b,c,d]	34.45 (.96)	30.57 (.98)	42.52 (1.67)	39.4 (1.2)
SD step length (cm) [a,c]	18.06 (.84)	16.2 (.61)	16.34 (.69)	16.31 (.62)
Step velocity (m/sec) [a,b,d]	11.32 (.27)	10.83 (.35)	11.58 (.38)	12.28 (.33)
SD step velocity (m/sec) [b,c,d]	4.03 (.19)	3.92 (.16)	3.4 (.16)	3.71 (.18)
Upper body velocity AP-direction (m/sec) [a,b,c d]	2.36 (.09)	1.8 (.09)	1.24 (.09)	1.05 (.08)
Variation in upper body velocity AP-direction (m/sec) [a,b,c,d]	2.05 (.08)	1.73 (.08)	1.32 (.08)	1.1 (.08)
Upper body velocity ML-direction (m/sec) [a,b,c,d]	1.99(.04)	1.7 (.06)	1.5 (.1)	1.31 (.09)
Variation in upper body velocity ML-direction (m/sec) [a,b,c,d]	2.02 (.07)	1.81 (.07)	1.42 (.11)	1.23 (.1)
Area upper body (m^2) [a,b,c, d]	0.54 (.06)	0.5 (.05)	0.15 (.04)	0.09 (.02)
Area Feet (m^2) [a,b,c,d]	0.73 (.05)	0.66 (.05)	0.42 (.03)	0.38 (.02)
Movement area ratio [b,c,d]	1.57 (.14)	1.51 (.13)	5.24 (.74)	6.85 (.9)

a=significant difference between The Mole Easy and The Mole Medium; b= significant difference between LightRace Easy and LightRace Medium; c= significant difference between The Mole Easy and LightRace Easy; d= significant difference between The Mole Medium and LightRace Medium

3.3.1 Step characteristics

As can be seen in Table 2, both Game and Level had an effect on number of steps per minute. Whereas participants took fewer steps per minute at the Medium compared to the Easy level when playing the Mole, the opposite was found for LightRace with participants taking more steps per minute at the Medium compared to the Easy level. For both games the difference between levels was significant (both p's <.001), and there was a significant difference between the two exergames in both Easy (11.3, CI 95% 7.8-14.9, p<.001) and Medium (17.9, CI 95% 14.3-21.5, p<.001) levels. There was also an effect of Trial (p=.026), indicating that the number of steps taken increased from the first to the last trial in both games (see Fig.2A). In addition, there was an interaction between Game and Level (F(1,376)=129.9, p<.001), indicating that the number of steps taken per minute increased from Easy to Medium level in LightRace, while it decreased from Easy to Medium when playing the Mole.

Game and Level also affected step length. Participants took longer steps on average when playing LightRace than when playing The Mole, and for both games, participants took longer steps at the Easy level than at the Medium level (both p's <.001) (see Table 2). Furthermore, participants had more variation in step length at the Easy level than at the Medium level when playing The Mole (-1.9, CI 95% -2.4- -1.0, p<.001), while there was no significant difference between the levels in LightRace (p=.935). For step length variation, there was an effect of Trial (p=.004), indicating that participants varied step length less the more times they played the same level and game (see Fig.2B). Furthermore, there was a significant interaction between Game and Level in step length variation (F(1,376)=14.2, p<.001), indicating that participants had less variation in step length when playing the Medium level of the games, especially for The Mole.

Step velocity and variation in step velocity was affected by Game and Level as well. LightRace yielded higher step velocity, but less variation in step velocity in both Easy and Medium levels compared to The Mole (see Table 2). For The Mole, there was a significant difference between the two difficulty levels in step velocity (p=.005), but no significant difference in step velocity variation (p=.158), while LightRace displayed a significant difference between the levels in both step characteristics (both p`s <.001). Furthermore, there was a significant difference in step velocity between the two games at the Medium level (-1.5, CI 95% -1.8 - -1.1, p<.001), but no significant difference at the Easy level (p=.141). For variation in step velocity there was a significant difference between the games at both the Easy level (-0.6, CI 95% -0.8 - -0.5, p<.001) and at the Medium level (-0.2, CI 95% -0.4- -0.1, p=.008). For variation in step velocity there was also an effect of Trial (p=.016), indicating that the variation in step velocity decreased overall from the first to the last trial (see Fig.2C). While participants increased their step velocity and variation in step velocity from Easy to Medium level when playing LightRace, both characteristics decreased in The Mole, yielding a significant interaction between Game and Level for both step velocity and step velocity variation (F(1,376)=23.02, p<.001 and F(1,376)=14.2, p<.001, respectively).

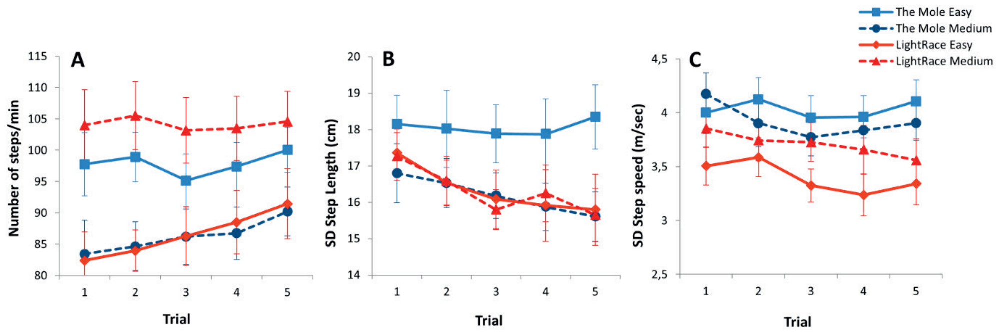

Figure 2. Mean number of steps per minute (±SE) (A), SD Step Length (±SE) (B), and SD Step velocity (±SE) (C) for The Mole and LightRace in Easy and Medium level across five trials.

3.3.2 Upper body movements

Characteristics of upper body movements in AP- and ML-directions were also affected by Game and Level. As shown in Table 2, The Mole induced higher velocity and more variation in upper body velocity for both AP- and ML-directions compared to LightRace (all p`s <.001). For both games and both movement directions, playing the Easy level gave higher velocity and more variation in upper body velocity than at the Medium level (all p`s <.001). There were no Trial effects for any of the upper body movement characteristics. For upper body velocity in AP-direction, there was a significant interaction between Game and Level (F(1,376)=29.9, p<.001), indicating that The Mole elicited higher velocity when taking forward and backward steps at the Easy level than at the Medium level, while there were no such difference in LightRace.

3.3.3 Movement area and movement area ratio

Game and Level also affected the movement area covered by the feet and upper body, and their ratio. While playing the two games, the participants covered a larger area with both the upper body and the feet when playing The Mole compared to LightRace (see Table 2). In both The Mole and LightRace participants covered a larger area with both their feet and upper body when playing the Easy levels of the two games than the Medium levels (all p`s <.001) (see Fig.3A and B). For area covered by the feet, there was a significant Trial effect (F(1,377)=5.4, p=.020), indicating that the participants decreased the area in which they moved their feet from the first to the last trial (see Fig.2B). There were no significant interactions for movement area in the upper body or the feet.

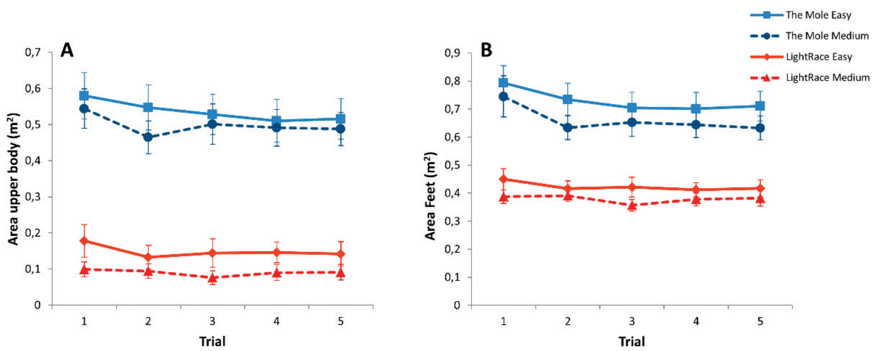

Figure 3. Mean area (± SE) covered by the upper body (A) and mean area (± SE) covered by the feet (B) for The Mole and LightRace in Easy and Medium levels over five trials.

With respect to the movement area ratio, LightRace had a higher ratio than The Mole at both Easy (5.3 vs. 1.6) and Medium levels (6.9 vs. 1.5), indicating that participants had more weight shifting in The Mole than in LightRace. For The Mole, there was no difference between Easy and Medium levels (p=.867), while LightRace had a higher movement area ratio at Medium level than at the Easy level (1.5, CI 95% 0.8 - 2.2, p<.001). There was a significant interaction between Game and Level (F(1,376)=10.37, p=.001), indicating that LightRace had an increase in the ratio from Easy to Medium level, while there was no such change in The Mole. There was no effect of Trial on movement area ratio.

4 Discussion

The last decades have shown a rapidly growing interest to use exergames to increase physical activity and improve health and physical function in older adults (Laver et al., 2011;Verheijden Klompstra et al., 2014;Skjaeret et al., 2016). However, we lack in knowledge about how older adults actually move when playing these exergames, making it difficult to deduce whether the exergames prompt the exercise and functions intended, and interpret inconsistent findings from intervention studies. The current study is the first to study movement characteristics in detail while older adults played different stepping exergames, in order to investigate whether movement characteristics are influenced by the choice of game, difficulty level, and repeated trials.

We chose two stepping exergames for this study that came out positive in an earlier study (Skjaeret et al., 2015) and that share many similarities in terms of the technology used and the movements the players have to perform in order to play the game and score points. Nevertheless, our results indicate that stepping and upper body movements performed by older adults while playing the two exergames demonstrated important differences that can affect the intended exercise these games provide when used as an intervention.

Being able to vary stepping movements in terms of e.g. step length and step direction is important in order for stepping and walking to be adaptive in daily life and to successfully achieve a task (Latash and Anson, 2006;Moe-Nilssen et al., 2010). The two exergames used in this study yielded different stepping characteristics with LightRace prompting the participants to take longer steps at a higher step velocity than when playing The Mole, but with less variation in both movement characteristics. This illustrates that when an intervention aims at improving variation in movement characteristics, the context of the games needs to be thoroughly examined prior to their use to ensure that players achieve this desired variation in step and upper body movements. With regards to step velocity, both games provided new targets as soon as the current target was hit, but in LightRace the players can get a bonus multiplier if they hit multiple targets in a row without any missteps. This bonus multiplier might have triggered the players to take faster steps in order to beat their own game score, hence increasing their step velocity. Thus, if velocity of stepping movement is in focus, having a trigger in the game that prompts the player to take new steps fast might be a solution.

Results in this study also showed that the characteristics of the game influence how large a movement area participants covered during playing. They had more upper body movements in both AP- and ML-directions as well as covering a larger movement area with both the feet and upper body when playing The Mole compared to LightRace. If the goal of an intervention is to induce stepping in a larger area and in different directions, evaluating game characteristics and game design might give an indication of how to make a choice. While game play in LightRace consists of stepping from a fixed circle in the middle of the game area, The Mole consists of a 3x3 grid where the targets appear randomly in the different areas, making the participants take steps in several different directions within a larger area. In addition, LightRace requires the player to step back into the middle of the circle before taking a new step, while for The Mole the player can take new steps in a different direction immediately after hitting the object on the screen. The game characteristics thus allow – and may even prompt - the player to take steps in several directions during game play.

Older adults have been found to be more unstable when shifting weight from double to single leg support compared to younger adults (Ihlen et al., 2012). This period of transfer or shifting of body weight has also been identified as the moment where most falls among older adults occur (Robinovitch et al., 2013). In the current study, weight shifting was assessed by calculating the ratio between upper body and feet movements. This movement ratio turned out to be one of the largest differences between the two games used in this study. While players displayed almost complete weight shifts when playing The Mole, as the upper body followed the movements of the feet during each step, in LightRace the upper body moved only a fifth or sixth of the step itself, indicating more tapping movements with the feet than weight shifts. These differences point to two separate but important aspects of balance exercises, depending on what the goals of the exercise are. Based on the results of the current study, if the focus of an exercise is on performing complete stepping movements that require transferring the body weight from one leg to the other, playing The Mole is the more appropriate choice. However, if the goal is to perform balance exercises by reducing the base of support, playing LightRace where participants stood on one foot while tapping the other on a target in front, behind or to the side, would be a preferred exercise. Both these abilities are important parts of exercises aiming to challenge balance in older adults (Sherrington et al., 2011) and should be taken into consideration when using exergames as exercise interventions for older adults.

Interestingly, this study not only showed a difference in the elicited movement characteristics between the two exergames, but also between the two difficulty levels within each game. By increasing the level of difficulty, almost all movement characteristics decreased, with the players in general taking shorter steps with less variation in length and velocity, with less weight shifting movements within a smaller movement area. However, there were some important differences between the two exergames.

When playing The Mole, participants had an overall decrease in movement from the Easy to the Medium level. This is likely linked to the additional cognitive challenge at the medium level of The Mole, which consists of a ladybug that one should avoid stepping on, as this would cost points. To avoid getting a reduction in points, some participants tried stepping over the ladybug, like one might naturally do outdoors. However, the game system was not sensitive to vertical motions and consequently, stepping over the ladybug was considered the same as stepping on it, costing the player points. This led some participants to decrease the size of their steps and make small, shuffling steps around the ladybug, while others stopped entirely, waiting for the ladybug to disappear so they could move straight towards the mole. Adding an additional cognitive element to an exergame is often perceived as fun and challenging by the players, as also shown in the present study, but might thus have unintended effects on the movements performed to play the exergame. This again illustrates the importance of knowing how games and choices within the games affect players' movements if exergames are to be used to exercise specific functions. If the goal is to make the player perform and improve specific movement characteristics, the games and difficulty levels used to accomplish this needs to be chosen with care. In addition, the technology of the game system needs to be sensitive enough to ensure that the intended manner of playing the game is rewarded, for example by adding points to a game score, and that performing incorrect movements does not yield points. The competitive side of beating one's previous score was in itself seen as a motivation to play the games by the participants. Therefore, it is important to ensure that participants perform the movement characteristics intended by the game when rewarding points.

In LightRace, an additional stepping direction was added at the Medium difficulty level, requiring the players to take steps backwards as well as forwards and sideways. One could expect that this would increase overall movements made by the participants . However, as the avatar on the screen was mirrored, several of the participants became confused and stepped in the wrong direction, especially for the backward/forward steps, leading to a reduction in stepping and upper body movements. Perhaps partly because of these initial errors, the total number of steps per minute and step velocity increased when playing the Medium difficulty level.

As this study illustrates, changing the game or the difficulty level changes players' movement characteristics. Thus, if the goal of the exercise or intervention is to be able to carry out specific physical functions or specific aspects of balance, in other words, to perform specific movement characteristics, one cannot pick a game or difficulty level at random. It is important to select games with care based on the movement characteristics they elicit in the players while keeping the intended exercise in mind, and not only based the choice of game on aspects like convenience, promoted enjoyment of the game, the game technology and ease of use for the players. The same goes for designing and developing games for older adults. In recent years researchers have come up with several important aspects that should be taken into consideration when designing games for older adults (IJsselsteijn et al., 2007;Gerling et al., 2012). However, little attention has been given to the movement characteristics of the players in the design process.

Another aspect that the current study illustrates is that repeated trials of the same game and same game level also can have an effect on the movement characteristics performed by the players. In other words, there might have been a potential learning effect occurring due to familiarization to the games. While the number of steps per minute increased from the first to the fifth trial, both step length variation, variation in step velocity, and area covered by the feet during game play decreased from the first to the last trial, illustrating that the participants were able to adapt their movements to the game requirements after playing an exergames a few times only. At the same time, the game score increased or remained the same, indicating that a reduction in movement characteristics did not affect the game score. If an exergame is to be used over a longer period of time, e.g. at home as a rehabilitation tool, being able to adapt movements during five attempts only might not ensure the intended exercise movements aimed for. Exergames have in the last decade been used in exercise and rehabilitation settings much due to their perceived enjoyment. However, little attention has been directed towards the potential learning effect that might affect movements negatively in the long run and make the games less fun to perform, resulting in low adherence to exercising. New technology provides great opportunities to save and store large amount of information from an exergaming session, which in turn can enable personalized feedback on how movements should be performed, as well as adjusting and adapting the games to each player.

Although this study found a few significant trial effects, five repetitions at each level in each game was not enough to perform an in-depth investigation of the relationship between trials and the development of movement characteristics and game score. Future studies should include more game trials over a longer period in order to correlate the relation between the game score and the movements made by the participants to ensure that the exergames maintains the movements intended.

The results of the current study illustrate that stepping and upper body movements performed by older adults when playing stepping exergames are influenced by the choice of game, how the difficulty level, and whether players play multiple trials, and it is therefore not indifferent which games are chosen to achieve specific aims. If the goal is to increase general physical activity, both exergames used in this study show promise as all participants took several steps with variation in step length, speed, and direction. However, if a rehabilitation goal is to train a specific function, one needs to evaluate different opportunities to find the best suited game that affect the movement characteristics in mind. In addition to finding the best suited game, game elements that appear or even disappear with increasing difficulty level should be taken into consideration. How will an additional cognitive load such as a ladybug in The Mole, or an additional movement direction such as in LightRace, affect the movement characteristics that are aimed for? In early stages of acquiring new movement skills, people often reduce their movements by freezing degrees of freedom, while later in the learning process releasing these degrees of freedom to allow for more flexible movements (Vereijken et al., 1992). In conventional forms of exercise as well, movements might decrease when adding an additional load or changing from one exercise to a new exercise. However, the change should not be so large that people are not able to achieve the desired movement characteristics at all.

There are some limitations to the current study that should be pointed out. Firstly, the present study compared only two different step-based exergames but nevertheless found important differences in what movements were performed while playing them. In order to ensure that an appropriate game is chosen to exercise specific physical functions, in-depth analysis of movements performed during exergames is necessary, and this study is the first step in that direction. The current results illustrate that movement analysis during gaming is necessary in order to understand the effect (or lack thereof) of exergaming. Another limitation is that the steps were identified by velocity of the toe markers only, whereas most step detection algorithms make use of both toe and heel information. As the Oqus motion capture cameras could not be placed behind the participants because of interference with the gaming cameras, the heel markers were often occluded from view, making them unreliable to use in the step detection algorithms. For the purpose of the current study, this was less relevant as we compared across games, levels, and trials, but when accurate details of individual steps need to be detected, algorithms should be based on both heel and toe markers to ensure the most accurate identification of step characteristics.

5 Conclusion

The current study provides several important insights regarding the use of exergames by analyzing the movements performed by older adults when playing step-based exergames. Although exergames in general seem effective in increasing general physical activity among older adults, there has been no focus on whether stepping exergames train specific movement characteristics important for maintaining balance and gait in real life, such as weight shifting and variation in step length, speed, and direction. The results from the current study illustrate that it is not irrelevant which games are chosen to exercise these functions and show that movement characteristics are affected by the game, level of difficulty, and (even short-term) experience with the games. For future use of exergames in the context of exercise or rehabilitation at home, it is important to select exergames with care, taking into account what movement characteristics one wants the player to perform, how to manipulate difficulty level to maintain motivation without sacrificing the quality of the movements, and how to use the scoring of points to ensure that the proper movements are executed.

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