MOTION-BASED VIDEO GAMES FOR
OLDER ADULTS IN LONG-TERM CARE

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Department of Computer Science
University of Saskatchewan
Saskatoon, Saskatchewan, Canada

by

KATHRIN MARIA GERLING

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ABSTRACT

Older adults in residential care often lead sedentary lifestyles despite physical and cognitive activities being crucial for their well-being. Care facilities face the challenge of encouraging their residents to participate in leisure activities, but as the impact of age-related changes grows, few activities remain accessible. Video games in general – and motion-based games in particular – hold the promise of providing mental, physical and social stimulation for older adults. However, the accessibility of commercially available games for older adults is not considered during the development process. Therefore, many older adults are unable to obtain any of the benefits.

In my dissertation, this issue is addressed through the development of motion-based game controls that specifically address the needs of older adults. The first part of this thesis lays the foundation by providing an overview of motion-based game interaction for older adults. The second part demonstrates the general feasibility of motion-based game controls for older adults, develops full-body motion-based and wheelchair-based game controls, and provides guidelines for accessible motion-based game interaction for institutionalized older adults. The third part of this thesis builds on these results and presents two case studies. Motion-based controls are applied and further evaluated in game design projects addressing the special needs of older adults in long-term care, with the first case study focusing on long-term player engagement and the role of volunteers in care homes, and the second case study focusing on connecting older adults and caregivers through play.

The results of this dissertation show that motion-based game controls can be designed to be accessible to institutionalized older adults. My work also shows that older adults enjoy engaging with motion-based games, and that such games have the potential of positively influencing them by providing a physically and mentally stimulating leisure activity. Furthermore, results from the case studies reveal the benefits and limitations of computer games in long-term care.

Fostering inclusive efforts in game design and ensuring that motion-based video games are accessible to broad audiences is an important step toward allowing all players to obtain the full benefits of games, thereby contributing to the quality of life of diverse audiences.

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INTRODUCTION

The group of older adults in Western societies is growing [162], and an increasing number of persons live in residential care. Older adults in residential care often lead sedentary lifestyles despite physical and cognitive activity being crucial for well-being in old age. Decreased activity adversely affects an individual's life expectancy, frequently leading to *sedentary death syndrome* [163]. Care facilities face the challenge of encouraging their residents to participate in leisure activities. Despite various efforts, few activities remain accessible, and it is difficult to motivate older adults to remain cognitively and physically active as the impact of age-related changes grows (e.g., cognitive impairments or mobility disabilities [39]). Video games in general – and motion-based games in particular – hold the promise of engaging older adults, and games have been applied in a variety of settings, e.g., to entertain nursing home residents [84] or to motivate older adults to participate in physical therapy and rehabilitation [1]. Additionally, research studies specifically investigating the effects of older adults playing games show that motion-based video games have a positive impact on their cognitive [8], physical [184] and emotional [84] well-being.

1.1   Problem Statement

Most studies suggesting benefits of video game play for older adults apply commercially available games that were designed for younger audiences, and only marginally address concerns regarding the usability and accessibility of motion-based game interaction for older adults – particularly persons living in long-term care. In addition, studies generally provide few insights into the long-term engagement of institutionalized older adults with video games and how to best integrate video games into the daily lives of older adults who reside in in long-term care. Due to the impact of age-related changes and impairments on the engagement with games in late life [69], additional considerations are necessary to ensure that motion-based games are safe, accessible, and enjoyable for this audience. Only if motion-based video games can accommodate the special needs of institutionalized older adults, will they enable this group to obtain the full benefits associated with motion-based play.

This results in a twofold problem that I address in this thesis: first, game designers and developers have little guidance on how to ensure that motion-based games are accessible to older adults; thus, it is important to explore the accessibility of motion-based interaction for older

adults in long-term care. Second, researchers and designers cannot be certain that their game-based interventions are effective outside of a research context; thus, it is necessary to examine the development of game mechanics and game concepts that are suitable to keep older adults in long-term care engaged in play over a longer period of time.

1.2   Steps to Solution

This dissertation addresses the issue of creating suitable motion-based video games for institutionalized older adults by examining motion-based game controls from the perspective of Human-Computer Interaction. The first part of this dissertation provides an overview of motion-based game interaction for older adults (Motivating Motion-Based Game Interaction for Older Adults: Chapters 1 to 3). This work lays the foundation for the further examination of motion-based video games for older adults with a focus on their accessibility and usability for older adults in long-term care (Exploring Motion-Based Game Interaction for Older Adults: Chapters 4 to 7). The third part of this dissertation looks at potential applications of these technologies with a focus on the challenges specific to game design for older adults in long-term care (Applying Motion-Based Games for Older Adults in Long-Term Care: Chapters 8 and 9). The final part (Discussing Motion-Based Games for Older Adults: Chapters 10 and 11) discusses the most important findings and outlines areas for future work.

As our population ages, and digital entertainment systems become more pervasive, we can expect interest in video games among older adults to increase. This dissertation exposes the needs of older adults, and aims to prepare practitioners to design motion-based video games for a broader audience with a range of physical and cognitive abilities. In this context, fostering inclusive efforts in game design and ensuring that motion-based video games are accessible to broad audiences is an important step toward allowing players with different skills and abilities to engage in play and obtain the full benefits of games, thereby contributing to the quality of life of audiences beyond older adults.

1.3   Contributions

This dissertation examines the design of motion-based video games for older adults in long-term care. In this context, it makes the following three main contributions:

1. It demonstrates that motion-based game interaction is generally accessible for older adults, and that motion-based game controls can be designed in a way that they are

safe and enjoyable for institutionalized older adults, regardless of age-related changes and impairments.

2. It provides gesture sets for motion-based video games for institutionalized older adults, and it provides an overview of design recommendations that make the findings actionable for game developers and researchers wishing to design motion-based games for older adults.

3. It shows that it is possible to deploy motion-based games in residential care settings. In this context, it outlines core challenges that need to be addressed for the successful long-term integration of motion-based video games in the lives of older adults.

Apart from these main contributions, this dissertation makes additional contributions in the following areas:

1. It provides the first systematic review of custom-designed motion-based games for older adults from the perspective of human-computer interaction, and identifies gaps in existing work that need to be addressed by future research.

2. It shows that motion-based game controls have positive effects on older adults, leading to an increase in positive affect resulting in improved mood, and that motion-based games can have a positive effect on the relationship between older adults and caregivers by improving relatedness within caregiving dyads.

3. It shows that wheelchair-based game controls are a means of changing the perspectives of older adults with mobility disabilities on assistive devices device,with the potential of encouraging the elderly to become more familiar with their wheelchairs, thereby supporting their independence and increasing their quality of life.

4. It is the first work to demonstrate that commercially available motion-based game controls can be made wheelchair-accessible, and provides a toolkit as well as design considerations for wheelchair-based game interaction that can be applied for audiences beyond older adults.

1.4   Overview of Dissertation

This dissertation discusses motion-based video games for older adults in four parts. The first part discusses the foundations of motion-based video games for older adults, the second part examines the design of accessible motion-based game controls for older adults, the third part applies findings of part two in motion-based game design for older adults in long-term care, and

the fourth part presents a general discussion of the results of this dissertation in the context of motion-based games for older adults.

Part 1: Motivating Motion-Based Games for Older Adults

Chapter 2: Related Work - This chapter provides background information on formal definitions of older adults, gives an overview of common age-related changes and impairments that are relevant when designing interactive systems for older adults, and summarizes existing work in the field of motion-based game design with a focus on motion-based games for older adults.

Chapter 3: Core Challenges in Motion-Based Game Design for Older Adults – Based on the preceding analysis of related work, this part of the dissertation identifies three core challenges in motion-based game design for older adults: (1) making commercially available game input devices accessible for active older adults and older adults in residential care, (2) creating accessible game mechanics and adapting game concepts to the needs and preferences of institutionalized older adults, and (3) designing for the caregiving context to allow older adults in residential care to benefit from motion-based video game play. These challenges are addressed in the remainder of the thesis.

Part 2: Exploring Motion-Based Game Interaction for Older Adults

Chapter 4: Sedentary versus Motion-Based Game Controls – To establish the general suitability of motion-based game controls, this chapter investigates the use of motion-based and sedentary input devices among older adults in the context of a baseline user study with active older adults and younger adults. Findings show that motion-based game controls are generally suitable for older adults, but additional considerations are necessary if the impact of age-related changes and impairments grows.

Chapter 5: Full-Body Motion-Based Game Interaction for Older Adults – This chapter investigates the accessibility of full-body motion-based game controls for institutionalized older adults. It provides a gesture set for game input that was developed together with a physical therapist and evaluated in a user study. It demonstrates the feasibility of the gestures in the context of a second user study that evaluates the accessibility and player experience of a gesture-based gardening game for institutionalized older adults.

Chapter 6: Wheelchair-Based Game Design for Older Adults – Building on the previous study, this chapter discusses the design and evaluation of wheelchair-based game controls for institutionalized older adults. It presents details on the design and evaluation of Cupcake Heaven, a wheelchair-based game for older adults, and shows that wheelchair-based game controls are generally suitable for institutionalized older adults.

Chapter 7: Design Guidelines for Motion-Based Game Interaction for Older Adults in Long-Term Care – This chapter summarizes findings from the previous chapters and synthesizes them into design guidelines that provide actionable advice for researchers and designers wishing to create motion-based video games for older adults. It focuses on both full-body motion-based game input as well as considerations for wheelchair-based game design.

Part 3: Applying Motion-Based Games for Older Adults in Long-Term Care

Chapter 8: Long-Term Player Motivation in Motion-Based Games – This chapter presents results of a long-term study that investigated the use of custom-designed and commercially available motion-based games among older adults living at a senior residence and older adults living at a nursing home. It shows that motion-based games generally appeal to older adults over a longer period of time, but suggests that the context of play as well as the degree of age-related changes and impairments needs to be considered when designing and deploying games. Based on these findings, this chapter provides considerations for the integration of motion-based games into the lives of older adults in long-term care.

Chapter 9: Motion-Based Games to Connect Older Adults and Caregivers – This chapter presents two motion-based games that were designed to connect older adults and family caregivers with the goal of improving their relationship. Results of a user study show that older adults and caregivers enjoy playing motion-based games together, and that games have the potential of increasing relatedness within caregiving dyads. Building on the results of the user study, this chapter discusses the deployment of motion-based games in the caregiving context.

Part 4: Discussing Motion-Based Games for Older Adults

Chapter 10: Discussion – In this chapter, the core findings of this dissertation are summarized and critically reviewed with a focus on whether the core challenges identified in Chapter 3 were addressed appropriately. Additionally, this chapter discusses how findings

presented in the previous chapters generalize beyond motion-based games and can be extended to audiences other than older adults.

Chapter 11: Future Work and Conclusion – This chapter outlines challenges for future work with a focus on motion-based games for older adults with a purpose beyond entertainment, the player experience of older adults, and the development of video games to be applied in the caregiving context.

PART I: MOTIVATING MOTION-BASED GAMES FOR OLDER ADULTS

The first part of this dissertation provides an introduction to the topic of motion-based game interaction for older adults. It offers an overview of relevant background literature and concludes with an outline of the core challenges in motion-based game design for older adults that this thesis aims to address.

CHAPTER 2
RELATED WORK

Related publication: Gerling, K. and Mandryk, R. 2014. Custom-Designed Motion-Based Games for Older Adults: A Review of Literature in Human-Computer Interaction. Gerontechnology 12, 2 (2014),68-80.

To investigate the design of motion-based video games for institutionalized older adults, it is important to understand special characteristics of this target audience so that we can adequately address their needs in the design process. This section provides a working definition of older adults and institutionalized adults to outline design challenges specific to older adults living in a caregiving context. Additionally, it gives an overview of common age-related changes and impairments that are likely to have an impact on older adults' interactions with video games. Furthermore, this chapter provides an overview of design efforts in the field of motion-based video games for older adults with a focus of the suitability of such games for institutionalized older adults.

2.1 Working definition: Older Adults and Institutionalized Older Adults

There are a number of approaches toward defining the term *older adult*; different scientific disciplines look at a range of factors to determine whether a person can be considered part of this group of the population. A generally accepted definition in Western societies is provided by the World Health Organization, concluding that reaching the age of 65 marks belonging to the group of older adults [180]. Contrasting this general definition, research in Biology, Psychology and the Social Sciences suggests that it is important to consider individual factors that may contribute to a person being considered an *older adult* [43, 59]. In this context, transitions in one's social life, e.g., retiring from a job, may have a profound impact on daily routines [147]. Apart from that, biological changes such as reduced sensory acuity or problems related to one's motor skills may further contribute to a person being considered an older adult [39].

In this dissertation, we adopt the definition of the World Health Organization – stating that persons of the age of 65 and older – to identify a basic target audience for the work

presented in this thesis. We assume that after reaching the age of 65, most individuals are likely to experience some degree of age-related changes. In this context, we recognize the heterogeneity of this target audience and the fact that age-related changes and impairments do not affect all older adults in the same way by further differentiating between *older adults* and *institutionalized older adults*: older adults who experience a high degree of age-related changes in cognition and physical ability, and depend on assistance in their daily lives (e.g., older adults living in residential care or being cared for by a family member) are considered *institutionalized older adults*. To further support the distinction, a set of frailty criteria suggested by VanBeveren [163] is taken into account, including symptoms such as muscle weakness, a decrease of walking speed, and a generally low level of activity, which are typical for older adults living in residential care.

This distinction is particularly important in the context of motion-based game interaction for older adults as extreme differences in cognitive and physical abilities are likely to have an impact on the way these persons can access motion-based games. The following section provides an overview of common age-related changes and impairments to outline characteristics of older adults that may affect their ability of engaging with interactive technologies.

2.2   Age-Related Changes, Impairments, and the Impact of Age-Related Diseases

As outlined in the previous section, aging is a complex process that affects individuals on different levels, leading to large individual differences and creating a heterogeneous group of older adults. To better understand the processes that go along with aging, this section gives an overview of age-related changes and impairments that are common among older adults, and that influence their daily lives – including their interaction with information technology – on different levels. In this context, it has to be stressed that the appearance of these changes is highly individual and in various degrees of magnitude.

2.2.1   Changes in Vision and Hearing

Decrements in vision and hearing are common age-related changes. Regarding visual perception, older adults are faced with declining eyesight, and therefore experience difficulties perceiving and understanding information that is transmitted visually [39]. Research suggests that older adults require more time to adjust to dark surroundings, that visual acuity is reduced, and that peripheral eyesight and motion perception decline [59]. Additionally, aspects that are

relevant when interacting with information technology are changes in color perception and reduced sensitivity to contrast [59]. Likewise, aging has an impact on hearing abilities, which are essential in social interaction [56], but also an important aspect when using information technology as many applications provide auditory feedback. Many older adults experience an overall decline of their hearing abilities, leading to a lack of sensitivity, which is usually addressed through the use of hearing aids [59]. Other than that, aging processes can cause a wide range of problems associated with the auditory system, e.g., impaired speech perception, reduced ability to determine the location of sounds, and auditory problems when communicating in noisy environments [39, 56].

2.2.2 Effects of Age on Cognition

Aging affects cognition on different levels; this section discusses the impact of age-related changes on older adults' memory as well as processes that guide attention. Regarding changes in memory, research shows that age-related processes mainly affect short-term and procedural memory, and that older adults experience higher latencies when trying to access information that is stored in their semantic memory [14]. Changes in short-term and working memory lead to older adults experiencing problems that require memorizing and processing information, for instance, keeping track of a sequence of actions, which is important to consider when designing user interfaces and game mechanics – i.e., the rules and procedures that govern the game [58] – for older adult players. Along these lines, older adults also experience an increased level of retrieval failures, e.g., being unable to remember a certain piece of information, which is also crucial when designing technology for older adults. However, despite these age-related changes in memory performance that are likely to have an impact on the way older adults can apply interactive technologies, there are other aspects of the human memory that are generally not affected by age-related changes [14], most importantly, the procedural memory which plays an important role when learning new skills, e.g., how to control a motion-based game. This suggests that regardless of age-related changes, older adults would have the basic ability of gaining access to interactive technologies. In addition to age-related changes in memory, many older adults experience changes in their ability to direct and hold attention [59, 138], particularly when faced with complex tasks that incorporate vigilance, for instance, waiting for a certain event and reacting to it, an aspect that is frequently incorporated into video games, e.g., waiting for an item to appear on screen and then making user input. Additionally, automatic

processes may be affected by age-related changes as sensory decrements may play a role [59]. On a general level, research suggests that cognitive problems experienced by older adults are amplified when they are faced with content they are not familiar with or skills they have previously not exercised [48], which is an aspect that needs to be kept in mind when designing motion-based games that are likely to be an entirely new experience for many older adults.

2.2.3   Reduced Motor Control

Effects of aging on cognition and physical changes of the muscular system result in reduced motor control among many older adults [87]. This significantly reduces control that older adults have over their movements, leads to higher execution times of movements and a lack of coordination [39], and affects their posture and gait [87]. A common consequence of these changes is an increased risk of falls, particularly among frail older adults [163], with falls being a major cause of age-related disability, potentially limiting an individual's independence [107]. An aspect that is interesting in the context of motion-based game design for older adults is that some research results report age-related decrements in motor learning [87], suggesting that older adults are more likely to experience difficulties when acquiring new motor skills – e.g., learning how to play motion-based video games – not only because of a lack of prior gaming experience, but also because of age-related changes that affect their fundamental ability of interacting with new technologies that build on motor skills of their users.

2.2.4   The Impact of Age-Related Diseases

In addition to age-related changes, age-related diseases are another aspect that can contribute to the frailty of older adults, often affecting their physical independence and cognitive abilities [163]. Common age-related diseases that affect a significant number of older adults are *cardiovascular diseases*, which are frequent causes for heart attack, stroke, or diabetes, and which have a profound impact on an individual's physical abilities [141, 185]. Apart from that, neurodegenerative disorders such as Alzheimer's disease severely affect the individual's cognitive and physical abilities [62].

This overview of the effects of aging shows that aging processes influence cognitive and physical abilities of older adults, that age-related diseases may lead to physical impairments in late life, all of which influence the independence of older adults and have a profound impact on their quality of life. In this context, it is important to consider that age-related changes have a

negative impact on the accessibility of many activities, and should be accounted for in the design of information technology addressing this audience. The following section provides a brief overview of the most important considerations regarding general design recommendations addressing older adults in the context of human-computer interaction.

2.3   Motion-Based Games for Older Adults

In this section, we provide a literature review focused on motion-based interactive technologies for older adults to summarize the current state of the field. We examine case studies from the research area of human-computer interaction (HCI) that focus on the design of motion-based applications for older adults to provide an overview of the current state of the field, and to highlight opportunities for future research efforts. Papers were selected from conference proceedings and journals that are relevant to the HCI community and within the scope of this dissertation. Criteria for inclusion in this review were the application of custom-designed video games (as compared to the application of commercially available products) and a design process that specifically focused on older adults. In our review, we particularly focus on the scope of existing projects, the context in which they were evaluated, and the implications this may have regarding the deployment of such games 'in the wild' – especially in senior residences, care homes and therapy. Our findings suggest that despite various case studies addressing different aspects of motion-based game design for older adults (e.g., interface design, difficulty adjustments, or the development of senior-friendly game mechanics), current results do not add up to provide a comprehensive overview of motion-based game development that could help inform the work of game designers who wish to create motion-based video games that can be played by older adults without extensive support, and that remain engaging over repeated and extended play.

Addressing these issues is a crucial step in motion-based game design for older adults. In order to obtain the suggested benefits of playing motion-based games, users have to be able to set up and engage with interactive systems without extensive support of instructors or nursing staff, and applications have to be engaging enough to keep the interest of older adults over a longer period of time outside the context of research.

During the past few years, the wide availability of motion-based input devices has led to an increase in the popularity of applications that are designed to motivate physical activity among their users. Many of these applications – which are often marketed as video games – hold

the promise of fostering physical activity among their players, thereby addressing the issue of video game play being related to unhealthy, sedentary lifestyles [166]. Preliminary results of research on motion-based game play suggest a variety of positive effects of engaging with physically challenging games. Potential benefits range from an increased level of overall physical activity [175] to acute cognitive benefits [61], and from an increase in social interaction [88] to emotional well-being [84]. Additionally, exergames can be applied to help address the problem of childhood obesity in Western societies [40], which is suspected to be partially caused by increasingly sedentary lifestyles among children and teenagers. Likewise, research results suggest that games that motivate physical activity may be beneficial for older adults [68].

2.3.1 *Definition and Theoretical Frameworks*

Exergames are a relatively young research area, and a variety of definitions as well as theoretical approaches towards the design and analysis of such games is available. In order to provide a basis for the further discussion of exergames, this section provides an overview of the most important definitions and theoretical frameworks of exergames, and suggests a working definition of applications that motivate physical activity, which distinguishes between video games that feature different degrees of activity.

One of the earliest definitions of exergames is provided by Parker [130], who uses the term *kinetic video game*, defining it as a game that "has as a critical aspect of its interface the input of information concerning the overall physical activity of the player". Furthermore, he states that such games include the "movement of body parts that are interpreted by the computer to have specified meanings", highlighting the importance of player activity, particularly body movements. Sinclair et al. [152] define exergaming as "the use of video games in exercise activity", not only highlighting the physicality of the interaction process, but also pointing out the necessity of exertion. Likewise, Adams et al. [3] define exergames as "video games that use exertion-based interfaces to promote physical activity, fitness, and gross motor skill development". In contrast to Sinclair et al. [152], this definition does not only look at physical activity and energy expenditure, but assumes that such games should support players in the development of their gross motor skills, thereby adding another dimension to the concept of exergames. A broader understanding of exertive technologies is propagated by Vossen [172], who states that "physical activity must actually influence the game outcome" for a game to be an exergame. In a similar manner, Mueller et al. define exertion interfaces as interfaces that

"deliberately require intense physical effort" [116]. Bogost [28] defines exergames as "games that combine play and exercise", and "that use physical input devices". Likewise, Lieberman et al. [101] define active-play video games, a term they suggest be used as a synonym for exergames, as games that "have an interface that requires physical exertion to play the game". Building on this understanding of exertion interfaces, Mueller et al. define exergames as games "in which the outcome is predominantly determined by physical effort" [119] and that "demand intense physical effort from players" [118]. Hence, they do acknowledge the necessity of physical activity for a digital game to be an exergame, but do not define any degree of energy expenditure other than the activity being "intense", and define no further goals of exergaming in terms of skill development or improving one's fitness. This issue is addressed by Silva and El Saddik [150], who introduced the idea of *meaningful exercise*. Their goal is to distinguish between games that include physical activity either to create a fun experience, or to provide a meaningful workout. According to their definition, *exergames* are such games that require some physical activity, but are primarily designed to create a positive player experience, whereas *game-based exercising* aims to provide a physically challenging experience that results in meaningful energy expenditure and allows players to improve their level of fitness. On a general level, all definitions seem to agree that some degree of physical activity is necessary for a digital game to be regarded as an exergame; hence requiring physical activity of players can be regarded as the distinct feature of such games.
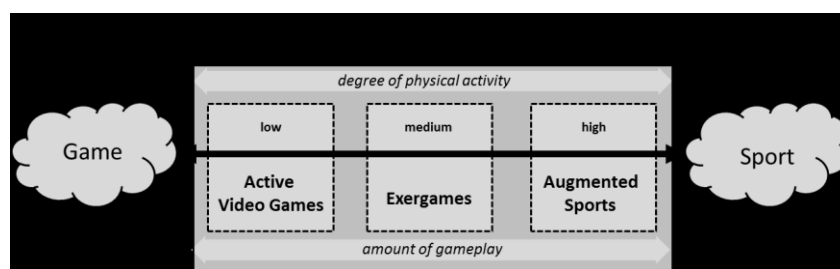
Figure 1. Distinction between applications that motivate physical activity based on the integration of exertion and gameplay.

To further distinguish between and to assist with the analysis of different types of exergames, several approaches towards creating theoretical frameworks have been made, ranging from frameworks that address social implications and educational aspects to considerations regarding physical implications of exergaming. Mueller et al. [119] address the design of exergames from the perspective of sports. Their conceptual framework was designed to support the creation of engaging exergames and focuses on the human body: The authors distinguish include the three dimensions of rules, play, and context; for each of them, they analyze how body movements, sensory experiences, and the response of the body ties into the experience: Rules refer to the uncertainty and awareness of exertion, play is connected with the expression and rhythm of exertion, whereas context refers to the risk and understanding of exertion. Thereby, they support the further analysis of exergames in that they provide a vocabulary for designers and researchers that is strongly associated with the experience of the player. Another approach towards the analysis of exergames by Mueller et al. [117] accounts for social aspects. In their work, the authors frame exergames using a triangle consisting of sociality (i.e., the support of social interaction through the game), engagement (which leads to user involvement with the game), and exertion (i.e., the physical activity of the user). If all three aspects are met by a game, the authors assume that meaning evolves, which gives value to the overall experience.

In contrast to these analytical approaches, Mueller et al. [120] also provide a high-level framework for the classification of exergames. After a primary distinction between non-exertion games and exergames, the authors differentiate between non-competitive and competitive exergames, which allow players to engage in competition with each other and compare their performances. They then further distinguish between non-parallel and parallel competitive exergames depending on the interaction patterns that are provided, i.e., whether people compete at the same time, or take turns. Another classification approach is suggested by Yim and Graham [183]. They describe three different categories of exercise games based on the degrees of freedom the user interface offers to the player. Free motion interfaces allow for various player movements and can be compared to games such as soccer. Equipment-based physical interfaces are interfaces that are closely related to regular sports equipment, e.g., stationary bikes. Finally, they identify traditional electronic interfaces as another category of exergames, where they are often applied in a supporting role.

Additionally, Yim and Graham [183] consider the environment in which the game takes place and distinguish between virtual worlds, augmented reality, and reality, resulting in a total of nine exercise game categories. However, their classification approach does not account for different levels of player activity and energy expenditure that is necessary to engage with exergames, therefore neglecting differences in exergames regarding the balance between exertion and gameplay, as identified by Silva and El Saddik [150].

In a review of exergame definitions, Oh and Yang [129] comment on common problems when trying to define exergames. They highlight the lack of clear terminology as a main issue, which results in a variety of concepts referred to as exergames, and they discuss the importance of an energy expenditure threshold at which an activity can be considered exercise. They suggest a new definition of exergames that states that exergames are games that foster "players' physical movements that is generally more than sedentary and includes strength, balance, and flexibility activities". Furthermore, they define exergaming as "an experiential activity where playing exergames […] is used to promote physical activity that is more than sedentary activities", highlighting the importance of energy expenditure among players but not addressing differences in workout intensities triggered by different types of movement-based games.

In order to provide a classification of exergames in this dissertation, for the purpose of discussing case studies of exergaming with older adults, we extend the concept of *exergames* and *game-based exercising* introduced by Silva and El Saddik [150] and the ideas promoted by Oh and Yang [129]: On one hand, we consider the amount of physical activity necessary to engage with the game, and on the other hand we consider the emphasis on and degree of gameplay. The idea of differentiating between different kinds exergames to provide a more precise definition was present in work by Gao and Mandryk [60], who use the terms *exergames* and *active video games* to distinguish between commercially available games that require physical activity (*active video games*) and research projects (*exergames*).

In the context of this dissertation, we will use the terms *exergames* and *active video games* in a slightly different manner as we do not focus on the development background of games, but are rather interested in the degree of exertion and gameplay that they provide. Mueller et al. [115] present the idea of *augmented sport*, where "sports actions are augmented with pervasive computing technologies and borrow from computer game principles to help users improve their skills", thereby suggesting another category of game-related exercise activities

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with a higher amount of physical activity and a stronger focus on creating a sports-like experience.

We combine these approaches and distinguish between three types of applications that motivate physical activity: *Active video games*, *exergames* and *augmented sports*. The distinction is made based on the emphasis on either sports-related aspects (physical activity) or game components (gameplay mechanics) within these applications; namely whether physical activity is implemented as an add-on to the user interface or whether it is a core game element and allows the player to experience medium to vigorous physical exertion (**Figure 1**).

Active video games are applications that motivate physical activity that require a low degree of physical activity, but feature rich gameplay and a variety of game mechanics. Usually, physical activity will be an add-on to improve the player's overall interaction experience, whereas burning calories and improving one's physical fitness is not the primary goal. Thus, engaging with the game might not lead to a significant increase in energy expenditure. In contrast, we define *augmented sports* as applications that primarily build on physical activity, and are designed to foster moderate to vigorous levels of workout with the goal of increasing the user's energy expenditure. While the activity itself and the related actions and rules represent the core of the application, game elements are introduced to improve the user's overall experience, thereby increasing the motivation to exercise. This approach is closely related to the idea of gamification, which refers to the inclusion of game elements in a non-gaming context in order to achieve an improved user experience [42]. In the context of this dissertation, we understand *exergames* as applications that motivate physical activity by combining features of active video games and augmented sports to create a balance between exertive elements and gameplay.

Generally, creating a fun and rewarding gaming experience is as important as fostering significant physical activity for yielding potential benefits to the player. Game elements and physical activity are often closely tied together instead of either being treated as a mere add-on to the application.

2.3.2 Exercise Games: Case Studies

Academic research has addressed the design of exergame case studies from different perspectives, and a variety of projects aim to address issues of obesity among younger audiences. However, recent design efforts have also been directed towards the creation of games that motivate physical activity specifically addressing older adults. This section provides an overview

of exergames particularly accounting for the needs of senior citizens; it applies the previously suggested classification of applications that motivate physical activity in order to identify current trends in the design of such applications for older adults.

Active Video Games

As defined in the previous section, *active video games* are games that feature a low degree of physical activity and implement physical user actions to augment the player's experience, rather than to primarily result in high energy expenditure.

Research has addressed the implementation of games for older adults from different perspectives. Age Invaders [91], a mixed-reality version of the traditional Space Invaders game in which aliens are invading Earth and have to be shot, tries to engage multiple generations (children, parents and grandparents) in play and requires some degree of physical activity as players are expected to move around on the playfield. The case study SilverPromenade by Gerling et al. [73] builds on insights gained through the implementation and evaluation [71] of the research tool SilverBalance, which was designed to explore the use of foot-based user input in exergames for senior citizens. Results of the evaluation that compares SilverBalance to Wii Fit balance games show that while Wii Fit is accessible to healthy older adults, SilverBalance also allows institutionalized older adults to participate in play. SilverPromenade addresses institutionalized older adults and implements Nintendo's Wii Remote and Balance Board controllers as input devices. The game allows users to set out on virtual walks, such as moving through the local forest. It features three different player roles that are associated with different challenges: The shaker has to shake the Wii Remote whenever certain game elements appear on screen, the pointer has to track different objects on the screen, while the walker has to imitate walking behaviour on the Balance Board to progress through the game. By offering competitive and collaborate multiplayer challenges, the game tries to foster social interaction between the players. Evaluation in a single session with 18 people showed that the game was appealing and allowed older adults in nursing homes to work together to achieve in-game goals, but also that senior-friendly interaction paradigms need improvement to make games accessible regardless of the impact of age-related changes and impairments. Walk2Win by Mubin et al. [114] is a card game for older adults that is played on mobile platforms. Based on the idea of fostering both mental and physical activities, information regarding the user's location is used within the game:

Players have to search the room and find hotspots in order to be able complete a simplistic card-based game. The goal was to engage senior citizens in social interaction while requiring mild levels of activity. A single-session evaluation with eight participants showed that seniors enjoyed engaging with the games, and appreciated the slower pacing of the game, but wanted to include children and grandchildren in play, following the approach of intergenerational gaming.

Active video games for older adults have largely focused on integrating activity to supplement other goals within the game without requiring intense levels of player activity. However, the positive perception of games that encourage physical actions among older adults shows that games can be used to foster activity among this population – especially institutionalized older adults living in nursing homes who are at risk of leading sedentary lifestyles – and that such games may be applied as a first step towards engaging these audiences in more challenging physical activities.

Exergames

In contrast to active video games, *exergames* aim to balance physical activity and gameplay to provide the user with a fun and engaging gaming experience while ensuring that physical player activity leads to significant levels of energy expenditure. This requires a workout at an appropriate intensity level, so activity has to be considered as more than just a way to improve player experience. Different exergaming systems have been designed to engage older adults in play. Many games try to account for the needs of senior citizens to allow them to engage in play even if they experience age-related changes or do not have prior gaming knowledge.

Rice et al. [137] explore the feasibility of gesture-based games for healthy older adults. They introduce three mini games for large screen displays that feature different interaction paradigms, and which can be played by up to two persons at the same time. Virtual Soccer requires players to use their upper and lower body limbs to keep a ball in the air. Because the game recognizes body shapes to determine whether the ball touched the ground, users are free to choose movements they are most comfortable with. In Human Tetris, players have to adjust their body according to shapes displayed on the screen in order to win the game. Mosquito Invasion asks players to use a custom-built swatter to kill mosquitoes that are trying to attack a baby that is displayed at the bottom of the screen. The authors evaluated their mini games in a single

session with 36 senior citizens. The results show that the games were perceived as entertaining and physically beneficial, with Mosquito Invasion being the most challenging game. Additionally, participants reported that the gesture-based interface allowed them to easily engage in play. Albaina et al. [7] present the exergame Flowie, which aims to increase the number of daily steps taken by the players in a way that is similar to game concept Fish'n'Steps by Lin et al. [103]. In Flowie, a virtual flower is displayed on a digital photo frame and is affected by user activity measured through a wireless pedometer: Depending on user activity (which is evaluated based on predefined goals), the flower shows positive or negative emotions. Participants of a preliminary user study reported that Flowie presents a good way of reminding them of the importance of daily exercise, and participants stated that the theme of the game was generally appealing. Regarding the design of more complex mixed-reality applications encouraging physical activity, Keyani et al. developed the augmented dancing environment DanceAlong [88]. The system offers a set of dancing scenes from well-known movies that may be selected by users to be danced along with. Footsteps are projected on the floor while the movie scene is presented on large screens. The authors hoped to foster dancing activities and social engagement among elderly users through the design of the system. An evaluation at a community centre for the elderly showed that senior citizens generally enjoyed dancing along with video clips and reported that they would like to use the system for physical exertion in the future.

Exergames aim to create a balance between gameplay and physical interaction in order to provide users with an enjoyable player experience and foster physical activity. With the release of the latest generation of game input devices, exergaming has become more affordable and thus accessible to broader audiences because games no longer require specialized hardware setups such as elaborate camera-based tracking systems or sports equipment. Relatively little work has focused on the creation of exergames for older adults, particularly those experiencing age-related changes and impairments that are likely to interfere with the use of commercially available games. This is supported by research results, which suggest that special considerations are necessary when designing for senior citizens, and first efforts in the field of full-body motion-based gaming show that individual adjustments improve the accessibility of exergames for older adults.

Augmented Sports and Activity

Augmented sports are activities that primarily focus on providing users with exertion or foster motor learning and rely on information technology to supplement this goal. Design efforts in the field of augmented sports for older adults shift the focus from providing intensive workouts and significant levels of energy expenditure to rehabilitation and physical therapy, thus setting motor learning as the main goal of physical activity. Due to this difference, we refer to these activities as *Augmented Activity* rather than *Augmented Sports*. Different case studies in academia have focused on this issue, and there have also been attempts at the integration of commercially available games in physical therapy for older adults.

Physical Therapy

The commercially available rehabilitation system SilverFit [151] was particularly designed for motor rehabilitation and physical therapy among older adults. It implements a custom-designed camera-based setup in combination with mini games, aiming to increase exercise motivation among elderly and to support medical staff. The system supports different types of rehabilitation measures, ranging from upper limb rehabilitation to balance exercises to wheelchair training. In some cases, the commercially available exergame Wii Fit has been applied as an instrument in clinical settings to support balance training among older adults [157]. Research results suggest that the system is feasible for physical therapy if applied under the supervision of medical staff, but that additions to the general setup are necessary, for instance adding hand bars to help older adults hold their balance. Apart from that, the exergame Dance Dance Revolution [96] has been applied in physical therapy for older adults, likewise leading to the conclusion that adapting the pacing of the game is necessary to provide a safe experience for older persons [155]. To address this issue, different custom software applications using foot-based gaming hardware as the input device have been designed. Young et al. [184] created an application for the Nintendo Wii Balance Board that allows for the calculation of the user's centre of pressure in order to determine further therapy measures. Kerwin et al. [86] created a mobile dancing game that uses accelerometer information as player input. The game combines music with a coach who is displayed on a TV screen, trying to encourage older adults to be more active. Accelerometer information on older adult posture before and during falls is used to support the application. A single-session usability test with twelve showed that older adults

generally liked the game, but the authors do not provide evaluation results regarding the actual reduction of the risk of falls among players. Gerling et al. [71] introduced the research tool SilverBalance, which features different balance tasks and was designed to evaluate the players' abilities of using the board as input device. Billis et al. [23, 24] use the board as controller for different game-like tasks such as steering a ball through a golf course. Thereby, the authors hoped to improve the players' balance and support physical therapy. They integrate their approach into a web-based platform [16], which allows for the direct assessment of player progress and was designed to support the application of motion-based game interfaces in physical therapy. Smith et al. [155] developed a basic version of Dance Dance Revolution (DDR) and evaluated the tool in one session with ten older adult participants aged 70 and older. Their results show that stepping interfaces are suitable in balance training and falls prevention; however, because they removed all game elements including music from their version of DDR, it is unclear whether the application would be motivating and enjoyable over a longer period of time. Building on these rather promising examples, Assad et al. [10, 11] developed WuppDi!, a selection of mini games aiming to foster physical therapy among older adults with Parkinson's disease. Blurring the boundaries between exergames and augmented activity, this approach integrates richer gameplay and therapeutic goals by combining therapy-appropriate movements with interaction paradigms and game mechanics.

Rehabilitation

Apart from these systems focusing on general balance training for older adults, different applications have been designed to support stroke rehabilitation among the elderly. Alankus et al. [5] created a rehabilitation system combining different input devices to determine user actions in mini tasks such as catching a baseball. The authors attached a Wii Remote to the user's arm in order to detect movements and added a webcam and glove to track hand movements. A user study with a single participant that was conducted in cooperation with a physical therapist over a period of six weeks showed that patient motivation increased when examining the short-term effects of augmented stroke therapy. Balaam et al. [12] present different approaches towards using information technology to support stroke rehabilitation, such as Rehab Reader, an e-book reader that moves through text as users interact with a squeeze ball (to increase muscle strength and motor skills). The results of various user studies suggest that it is important to individually

adapt rehabilitation measures to user preferences for therapy to be successful. Overall, the authors concluded that the augmentation of stroke rehabilitation with information technology represents a valuable design opportunity.

Exertion: Augmented Sports and Activity

In contrast, Carmichael et al. [32] developed a TV-based application to encourage physical activity among older adults, focusing on providing an exertive experience instead of motor learning and therapy. However, an evaluation of the system revealed that the exercise levels are not high enough to result in significant health benefits, and that further considerations regarding the design of digital exercise systems for older adults are necessary. Along these lines, Doyle et al. [45] present another TV-based application to foster the participation of older adults in exercise programs. A single-session usability evaluation with 19 participants showed that the system is generally accessible to older adults and that they enjoy engaging with it; however, results regarding potential benefits have not been provided. A similar approach is followed by De Morais et al. [113], who present a game designed to encourage older adults to practice Tai Chi. The game features a virtual instructor who shows poses that should be imitated by the player, and the system applies wearable sensors to determine and evaluate user input; the authors do not provide any information on the evaluation of the system. Fan et al. [49] present Spark, a pedometer-based system similar to Flowie [7]; however, instead of combining pedometer input with a game, they provide visualizations of user activity. A three-week evaluation showed that participants enjoyed using the system and that it provided them with useful feedback on their daily activity.

In contrast to exergames and active video games, augmented sports focus on providing a workout that goes along with significant levels of energy expenditure or a training experience that leads to motor learning of the user. This goal can either be achieved by augmenting indoor and outdoor activities through the inclusion of information technology, or by allowing users to combine their activity with non-gaming applications that were designed to foster exercise motivation. In terms of augmented sports for older adults, a variety of applications focusing on physical therapy and rehabilitation has been designed that provide augmented activity. The goal of such applications is to support the recovery, preservation and development of motor skills among older adults. A first approach towards designing augmented sports systems aiming at

exertion among elderly has been made, but more work is necessary to design applications that foster significant levels of energy expenditure to yield long-term health benefits.

2.4 Conclusion

This chapter presents an overview of the field of motion-based games for older adults. We provide a working definition of active and institutionalized older adults within the context of this thesis. Additionally, considerations regarding the impact of age-related changes and impairments are discussed. This is followed by an analysis of theoretical approaches towards games that motivate physical activity in order to provide a working definition of exergames.

The summary shows that only few case studies addressing motion-based games for older adults are available. First attempts aiming to address the impact of age-related changes and impairments on the use of games that motivate physical activity have focused on the implementation of safe, accessible and usable game interfaces. In terms of the development of accessible exergame interfaces for older adults, future work needs to explore the creation of senior-friendly game mechanics to further engage this audience, and to allow older adults to benefit from positive effects of playing exergames regardless of age-related changes and impairments. In the following chapter, we build on these results to outline core challenges in the field of motion-based game design for older adults in residential care, and to outline the design space of this thesis.

CHAPTER 3
CORE CHALLENGES IN MOTION-BASED GAMES FOR OLDER ADULTS

Based on the summary of age-related changes and impairments as well as an analysis of existing motion-based game design projects for older adults in the previous chapter, this chapter identifies core challenges in motion-based game interaction for older adults, and outlines the design space addressed in this thesis.

3.1   Adapting Games to the Needs of Institutionalized Older Adults

The analysis of age-related changes and impairments provided in the first part of Chapter 2 shows that processes related to aging potentially influence older adults' abilities of engaging with video games on different levels, e.g., increasing the effort required to learn how to play games, limiting their abilities of participating in physically challenging play, and increasing the overall level of difficulty of in-game challenges. When addressing motion-based game design for older adults, it is important to understand how these changes and impairments create barriers for older adults wishing to play video games, particularly when trying to engage with commercially available games. Playing video games can be a positive experience for older adults, foster long-term engagement among players, and allow institutionalized older adults to truly benefit from play only if the video games can be adapted to meet the needs of older adults.

In this context, it is important to understand that commercially available video games are generally designed for younger audiences with prior gaming experience, building on the assumption that players have no cognitive or physical impairments that might limit their participation in play, and aiming to challenge players by pushing their personal boundaries. When comparing this approach with the abilities of institutionalized older adults, it is likely that such games will be overwhelming: **Figure 2** illustrates the physical and cognitive demand required to play commercially available video games, and contrasts it with the physical and cognitive abilities of institutionalized older adults. Even when accounting for the fact that not all institutionalized older adults are severely affected by age-related changes and impairments, Chapter 2 suggests that institutionalized older adults are a user group with a range of special needs and diverse physical and cognitive abilities. Currently, this aspect is not addressed by commercially available motion-based video games; however, the research community has begun

to explore this issue. In this context, the overview of motion-based research applications presented in the previous chapter shows that a growing number of projects have the goal of addressing or exploring the needs of older adults.
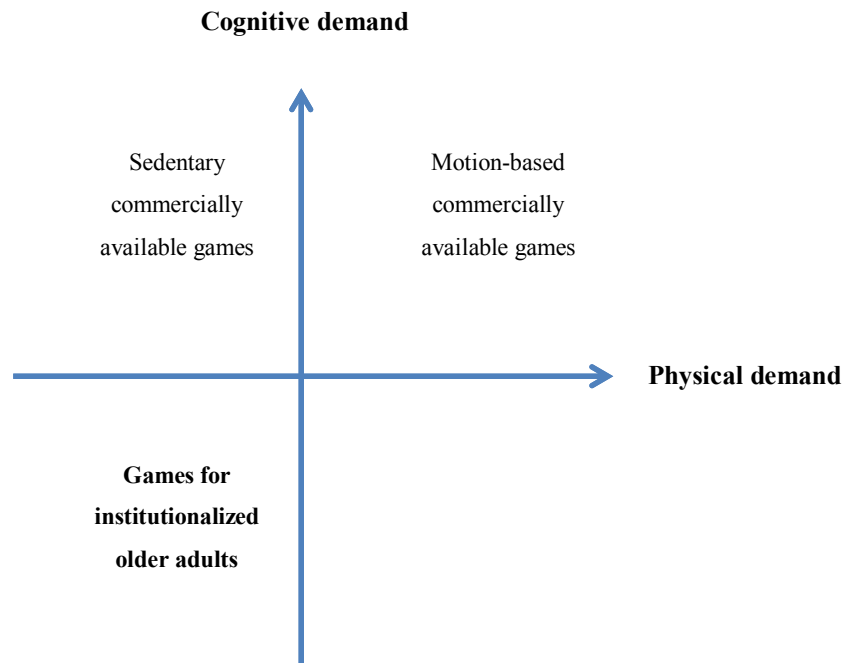
Figure 2. Contrasting the cognitive and physical demand of commercially available games with video games for institutionalized older adults.

It also gives insights into which design areas have been most popular in the past: the categorization of applications into *active video games*, *exergames* and *augmented sports* shows that the large majority of design efforts has focused on the creation of applications in the field of augmented sports and activity, particularly focusing on therapy and rehabilitation, but that little is known about games designed to entertain older adults in residential care. In terms of technologies and user interfaces, many of the games presented in this paper implement custom-designed camera-based systems or rely on accelerometer information. Regarding evaluation, it has been demonstrated that most systems are accessible and usable for older adults. However, our overview shows that most systems are evaluated in only a single session with few users; there has been little focus on user engagement in either the short or long term. In this chapter, we discuss the limitations of existing research on motion-based input for interactive technologies for older adults to outline the gaps that this thesis aims to address. Based on the overview of motion-

based applications for older adults in the previous chapter, along with considerations regarding the impact of age-related changes and impairments, we highlight open research questions with a focus on input technologies and application contexts, and outline areas for future work that will be addressed in the remainder of this dissertation.

3.1.1 Closing the gap: Has existing work covered all relevant aspects of motion-based games for older adults?

The case studies presented in Chapter 2 cover a variety of aspects of motion-based game design for older adults; the overviews of their main characteristics (**Table 1**) and evaluation approaches (**Table 2**) show the broad range of problems that they address. In the following section, we discuss the generalizability of these results, with a focus on interaction design and evaluation. We show that currently available case studies and evaluation results provide insights into detailed aspects of motion-based game design for older adults and can help inform the work of interaction and game designers in specific cases, but fail to provide a comprehensive overview of the field to help inform the work of designers or to assist the target audience in the deployment of such games. In this context, we outline challenges that need to be addressed in order to facilitate the deployment of motion-based video games in the daily lives of older adults.

3.1.2 Input devices for motion-based interactive technologies for older adults

Many of the case studies presented in Chapter 2 focus on the implementation of motion-based interaction paradigms that are suitable for older adults. An analysis of commonly-used input technologies showed that a lot of projects implement custom-designed input solutions to track user movements, e.g., camera-based systems or accelerometer-based approaches (see **Table 1**). An advantage of custom input is that it gives researchers the possibility of fine-tuning input devices according to the needs of the target audience. However, it also limits the extent to which research results can be applied to projects that aim to deploy motion-based applications for older adults on a bigger scale: sometimes, applications cannot be used without specialized hardware that would be too expensive in a non-research context, and interaction paradigms cannot always be mapped onto cheaper input devices that would be available to a broader audience. In this context, it would be valuable to put design efforts towards the development of applications using commercially available input devices, such as Nintendo's motion-based controllers or the

Table 1. Overview of applications to foster physical activity among older adults.

	Authors	Year	Title / Description	Input Device	Audience
Active Video Games	Gerling et al.	2011	*SilverPromenade*: players can participate in virtual walks and play mini games.	Nintendo Wii Remote, Balance Board	Institutionalized older adults
	Mubin et al.	2008	*Walk2Win*: tabletop game with active part in which players search the room.	Mobile phone	Older adults
Exergames	Albaina et al.	2009	*Flowie*: daily steps are measured and represented in game environment.	Pedometer	Older adults
	Keyani et al.	2005	*DanceAlong*: application in which users dance along with famous movie scenes.	Custom-designed camera system	Older adults
	Rice et al.	2012	Gesture-based mini games; players perform full-body gestures.	Custom-designed camera system	Older adults, family members
Augmented Sports / Activity Therapy	Assad et al.	2011	*WuppDi!*: Mini games using upper body gestures to support physical therapy.	Custom-designed camera system	Persons with Parkinson's disease
	Billis et al.	2010	Mini games for balance training using foot-based input.	Nintendo Wii Balance Board	Older adults with increased fall risk
	Gerling et al.	2010	*SilverBalance*: Research tool designed to help examine user balance in foot-based interaction.	Nintendo Wii Balance Board	Older adults, researchers
	Kerwin et al.	2012	Mobile dancing game in which players dance along with music.	Accelerometer	Older adults with increased fall risk
	SilverFit B.V.	2009	*SilverFit*: commercially available system, mini games to support physical therapy.	Custom-designed camera system	Older adults
	Smith et al.	2011	Simplified version of the commercial stepping game *Dance Dance Revolution*.	Dance mat	Older adults with increased fall risk
	Young et al.	2010	Research tool designed to determine user balance using foot-based input.	Nintendo Wii Balance Board	Older adults, researchers

Rehabilitation	Alankus et al.	2010	Gesture-based mini games, e.g., catching a baseball.	Custom-designed camera system, Nintendo Wiimote	Older adults in stroke rehabilitation
	Balaam et al.	2011	Applications for stroke therapy, e.g., e-book reader combining hand-based input.	Custom-designed haptic input	Adults in stroke rehabilitation
Exertion	Carmichael et al.	2010	TV-based exercise application that encourages full-body input.	Custom-designed camera system	Older adults
	DeMorais et al.	2011	Tai Chi simulation that full-body input through the imitation of poses.	Accelerometer	Older adults
	Doyle et al.	2010	TV-based exercise application building on *Otago Exercise Programme*, application encourages full-body input.	Custom-designed camera system	Older adults with increased fall risk
	Fan et al.	2012	*Spark*: different visualisations of daily steps.	Pedometer	Older adults

Microsoft Kinect sensor. Furthermore, many of the case studies show a strong focus on foot-based input (e.g., using the Nintendo Wii Balance Board or pedometer input) due to many case studies investigating applications of interactive technologies in physical therapy and rehabilitation, frequently focusing on interventions to reduce the risk of falls among senior citizens, which is primarily achieved through balance training (**Table 1**). In this context, it is important to further explore the application of full-body motion-based input using commercially available input devices to explore additional opportunities for designers.

What do the evaluation results really tell us?

The overview of evaluation results shows that a majority of studies looks at results of single sessions, short intervention times, and small sample sizes (**Table 2**); which is an acceptable approach when evaluating initial user experience, accessibility and usability of interactive technologies for older adults. Further examination of existing work showed that particularly active video games and exergames do not provide information on long-term effects and focus on immediate issues of interface design, whereas some projects with a focus on therapy and rehabilitation include long-term studies with small sample sizes. Additionally, a review of these studies showed that evaluation sessions are generally facilitated by instructors

and accompanied by researchers; only three out of the nineteen studies analyzed in this thesis were in-home studies in which participants were encouraged to use the system on their own. When drawing conclusions regarding the general feasibility of motion-based applications for older adults, and their value for persons living in senior residences and care facilities, this is a serious limitation: the generalizability of results is limited in the sense that many studies cannot make statements regarding the feasibility of interactive technologies for the independent use of older adults, and the scope of research is too small to investigate the long-term appeal of such games, which is a crucial factor if games shall be applied to encourage activity and positively influence a player's health.

In this context, existing work often points towards clinical studies examining potential benefits of commercially available video games on older adults. Such studies usually feature larger sample sizes and hold multiple interventions over a longer period of time, e.g., research by Anderson-Hanley and colleagues [8] featuring a three-month study with 79 participants showing positive effects of cybercycling on older adult cognition, or research by Aarhus et al. [1] exploring the value of the commercially available system Wii Fit in physical therapy in a long-term study with 13 institutionalized older adults. However, a caveat of tightly controlled clinical research studies is they do not hold any implications regarding the deployment of video games for older adults 'in the wild' for the following three reasons: (1) investigators encourage participation in intervention sessions and represent an additional incentive that may not be present in unsupervised play; (2) investigators and instructors can provide technical support to lower entry barriers to the use of interactive technologies; and (3) being part of a research study adds to the importance of participating in intervention sessions and might interfere with participant motivation. While an investigation of potential benefits of interactive technologies on older adults is valuable to show that video games are beneficial for older adults and also achieves the purpose of motivating further research, it is also important to follow up on these results with longer-term field studies designed to investigate the feasibility of video games and other interactive technologies for older adults in unsupervised scenarios or situations with minimal support. That way, it would be possible to investigate whether older adults are sufficiently technology literate and motivated over the longer term to engage with interactive technologies outside the research context.

Deployment 'in the wild': Independent setup and long-term player motivation

An important question that needs to be answered by future work is how motion-based applications can be designed for deployment 'in the wild'; that is whether interactive technologies appeal to older adults enough to keep them engaged over a longer period of time, and whether applications can be designed in a way that they can be played by older adults without assistance by instructors or – in the case of institutionalized older adults – without extensive help of nursing staff. If such applications are to be deployed to foster in-home therapy and rehabilitation, users have to be empowered to set up and engage with systems on their own. Likewise, an important step to help institutionalized older adults adopt game-based activities is to design games that are accessible without the continuous presence of nursing staff. In that context, it is important to create accessible games in terms of menu structures and interaction paradigms. Prior work has addressed these issues through the compilation of design recommendations; the next step will be implementing these recommendations into game concepts that can be deployed 'in the wild'. Likewise, recommendations have identified themes that are expected to be relevant to older adults (e.g., IJsselsteijn et al. [79]), which need to be examined through the design of applications addressing older adults. Generally, there is a growing body of theoretical considerations regarding the design of interactive technologies for older adults, but little work has been put into practice. The next step should be the implementation of existing considerations into applications that are suitable for deployment among the target audience to validate and further refine existing design recommendations. In that context, it might be valuable to explore how older adults in residential care approach video games, and whether video games can successfully be integrated into the caregiving context.

3.2   Core Challenges in the Design Space of Motion-Based Games for Older Adults

In order to design motion-based video games that are safe, accessible and enjoyable for older adults, it is important to understand factors related to aging, characteristics of today's older adults, and how they influence the interaction with and perception of video games among older adults. Based on the considerations presented in the previous section, we identify three core challenges that need to be addressed in order to allow institutionalized older adults to engage with motion-based games, and that will be examined in the context of this dissertation.

Table 2. Overview of evaluation routines (AVG = Active Video Games; EG = Exergames; AS = Augmented Sports, T = Therapy, R = Rehabilitation, E = Exertion).

	Authors	Year	Evaluation details	Duration / Sessions	N	Age	Venue
AVG	Gerling et al.	2011	15 minute intervention, standardized questionnaires, observations, metrics	Single session	18	M: 80.5	Care home
	Mubin et al.	2008	2 hour session, group discussion, observations	Single session	8	M: 71	Community centre
EG	Albaina et al.	2009	Round-the-clock intervention, metrics, stand. questionnaires	11 days / 5 sessions	2	65 & 73	Participant home
	Gerling et al.	2012	10-15 minute intervention, metrics, observations, standardized questionnaires	Single session	12	M: 76.7	Care home
	Keyani et al.	2005	1 hour intervention, interview	Single session	12	56-83	Community centre
	Rice et al.	2012	2 hour session with 6 participants, custom questionnaires and observations	Single session	36	55-70	Community centre
AS	Assad et al.	2011	Metrics, standard. questionnaires, interviews	Single session	13	M: 70	NA
	Billis et al.	2010	One hour intervention, standardized scales and questionnaires	8 weeks / 40 sessions	14	M: 69.2	Hospital
T	Gerling et al.	2010	10 minute intervention, standard questionnaires, metrics, observations	Single session	8	M: 82	Lab
	Kerwin et al.	2012	Usability testing; interviews, observations	Single session	10	68-89	NA
	SilverFit	2009		*- No published evaluation -*			
	Smith et al.	2011	Metrics	Three single sessions	20, 21, 26	M: 78.9	NA
	Young et al.	2010	20 minute sessions, standardized scales and questionnaires	4 weeks / 10 sessions	6	M: 84.1	NA
R	Alankus et al.	2010	Weekly meeting with therapist; interview, metrics	6 weeks / 30 sessions	1	62	Participant home
	Balaam et al.	2011	Interview, metrics	6 weeks – 7 months, multiple sessions	2	70s	Participant home
E	Carmichael et al.	2010	60-90 minute sessions, standardized scales and questionnaires, interview	Single session	19	M: 62.5	Lab
	DeMorais et al.	2011		*- No published evaluation -*			
	Doyle et al.	2010	Usability testing; observations, think-aloud	Single session	12	NA	Hospital
	Fan et al.	2012	Round-the-clock intervention, interviews	3 weeks	3	58-71	Participant home

3.2.1 Challenge one: Making commercially available game input devices accessible for active older adults and older adults in residential care

The first challenge that needs to be addressed to allow older adults to benefit from motion-based games is to make commercially available motion-based game input devices accessible for older adults in order to facilitate the broader deployment of such games. To reach this goal, the following steps have to be taken: first, commercially available game controls have to be examined with a focus on their general suitability for older adults, comparing how older adults interact with motion-based game controls compared to sedentary input devices (e.g., mouse input that they are more likely to be familiar with, or sedentary game controllers like the gamepad that require no intense physical effort). Second, suitable motion-based game controllers identified in the previous step have to be implemented into game concepts to assess the levels of accessibility, usability, and player experience they provide for older adults. In this context, special consideration has to be given to the impact of age-related changes and impairments that were described in Chapter 2 and that may interfere with the use of motion-based game controls, e.g., if older adults experience difficulties in learning how to use motion-based game controls, or if persons with age-related mobility disabilities (e.g., after stroke) cannot apply interaction paradigms commonly integrated in motion-based games.

These challenges are addressed in Part 2 (Exploring Motion-Based Game Interaction for Older Adults) of this dissertation. First, we explore the general suitability of motion-based game controls for older adults. Second, we look at the accessibility of full-body motion-based game controls for institutionalized older adults, and we examine how such games can be made accessible for older adults with mobility disabilities. Finally, this part of the dissertation aims to provide actionable design recommendations for researchers and game developers wishing to further explore motion-based game design for older adults.

3.2.2 Challenge two: Creating accessible game mechanics and adapting game concepts to the needs and preferences of institutionalized older adults

The second challenge is extending considerations regarding the accessibility of motion-based video games for older adults beyond game controls as age-related changes as well as low levels of computer literacy among older adults are likely to affect their interaction with video games on different levels (e.g., not being familiar with commonly used game mechanics, or being unable to follow fast-paced games that were initially designed for younger audiences).

Thereby, it is possible to investigate which game mechanics and game concepts are suitable for older adults, particularly persons experiencing different age-related changes and impairments. In this context, it is important to investigate how game mechanics and game designs have to be adapted to meet the needs of this audience, and to examine which game topics appeal to different groups of older adults in residential care.

These issues are addressed in the context of Part 2 (Exploring Motion-Based Game Interaction for Older Adults) and Part 3 (Applying Motion-Based Games for Older Adults in Long-Term Care) of this dissertation: Along with looking at accessible motion-based game controls, Part 2 provides insights into game mechanics that are suitable for institutionalized older adults. Building on these results, Part 3 presents different game concepts that are designed with a focus on older adults experiencing a wide range of age-related changes and impairments, and that are evaluated with different groups of older adults living in home care, senior residences, and nursing homes, to provide further insights into the player experience of older adults.

3.2.3 Challenge three: Designing for the caregiving context to allow older adults in residential care to benefit from motion-based video game play

The final challenge that needs to be addressed to allow older adults to benefit from motion-based video games is their integration into the care context. Existing work outlined in Chapter 2 strongly focuses on either making games accessible for older adults, or exploring their benefits beyond entertainment, however, little research has examined challenges that need to be addressed to facilitate the deployment of video games in residential care beyond research studies. Questions that need to be answered in this context are how much support institutionalized older adults need to be able to play games, whether it is possible to design games that allow them to independently engage in play, and how games can be designed to match the daily routines at residential care facilities. Furthermore, it is important to explore how older adults in residential care engage with games over a longer period of time (e.g., if games hold their interest), and whether games can contribute to the caregiving process. Addressing these challenges is a crucial step in the deployment of motion-based video games in residential care; only if we can answer open questions regarding the suitability and appeal of motion-based games for institutionalized older adults it will be possible to assess their true potential for this target audience.

Part 3 (Applying Motion-Based Games for Older Adults in Long-Term Care) of this dissertation aims to address these challenges by deploying motion-based games in the caregiving

context, focusing on how video games can be integrated into caregiving relationships in a family caregiving context, and how they can be designed in a way that they can benefit older adults living in senior residences and nursing homes. Thereby, this dissertation aims to provide insights into the development of motion-based video games for older adults in residential care that extend beyond considerations solely focused on the design of accessible and usable game control and game mechanics, to help contribute to the integration of motion-based games into the daily lives of institutionalized older adults.

This dissertation explores the design of motion-based video games for older adults in long-term care who experience a broad range of age-related changes; it focuses on the accessibility of motion-based video games for individuals who experience age-related changes in cognition and physical abilities. The next part of this thesis addresses motion-based game interaction for older adults. Based on the results, the remainder discusses motion-based game design in the context of the lives of older adults in residential care.

PART II: EXPLORING MOTION-BASED GAME INTERACTION FOR OLDER ADULTS

This part of the thesis investigates motion-based game interaction for older adults. The first study compares sedentary and motion-based game controls with a focus on user performance and preferences to establish the overall suitability of motion-based game input devices for older adults. Based on results showing that older adults do enjoy engaging with motion-based game controls, the second study examines the design of full-body motion-based game controls for older adults in long-term care. It suggests that older adults in long-term care can engage with motion-based game controls, but that additional considerations are necessary in the design process to ensure the accessibility of motion-based interaction. Finally, the third project addresses the integration of wheelchairs in the interaction process, which is an important step towards increasing the accessibility of motion-based video games for institutionalized older adults who frequently use mobility aids.

CHAPTER 4

SEDENTARY VS. MOTION-BASED GAME CONTROLS

Related publication: Gerling, K., Dergousoff, K., and Mandryk, R. 2013. Is Movement Better? Comparing Sedentary and Motion-Based Game Controls for Older Adults. Proceedings of Graphics Interface 2013, Regina, SK, Canada.

While research has shown that motion-based games have positive effects on the well-being of older adults, these studies have only marginally addressed concerns regarding the usability and accessibility of such games. Thus, there are still unanswered questions regarding the suitability of motion-based game controls for older adults, e.g., whether the increased physical effort of motion-based play has a negative effect on player experience. Without answers, designers of games for seniors do not have guidance on whether motion-based games are as accessible for older adults as games that implement sedentary control schemes. Answering these questions is particularly important, as age-related changes in sensorimotor skills are known to affect the interaction process. Different research results make it difficult to make recommendations regarding the choice of input device: HCI research has shown that older adults perform worse than younger audiences when using sedentary input devices such as the mouse [179], and research on motion-based controls for older adults suggests that full-body interaction creates additional difficulties for older adults who experience age-related changes in gross motor skills [68].

In this chapter, we provide answers to these questions about the effects of motion-based game control on the game experience of older adults. We compare motion-based and sedentary game controls for older adults by exploring user performance, device comfort and overall experience using two motion-based input devices (Microsoft Kinect, hands-free camera-based input; Sony PlayStation Move, controller and camera-based input) and two sedentary input devices (Microsoft Xbox 360 GamePad, traditional game input; Mouse, traditional input) in a game implementing pointing, steering and tracking tasks. We present a study with 17 older adults (average age 72) and 16 young adults (average age 24) playing our game. Young adults with little to no gaming experience were included as a comparator group to obtain additional

insights on the effects of age on the use of game controllers. Our results show that the in-game performance of older adults is generally worse than that of young adults regardless of input device. However, results do not show any age-related differences in device comfort and overall enjoyment, suggesting that older adults do not perceive motion-based game controls as more tiring than younger adults. Rankings of controller preference show that older adults have no preference for sedentary input devices over motion-based game controls, rating the Move equally well with their most familiar device, the mouse.

This chapter makes three contributions: 1) we provide the first structured comparison of sedentary and motion-based game input devices for older adults; 2) we show that motion-based game controls are comfortable for older adults, and that they can be applied in an enjoyable way; and 3) based on our results, we provide design implications for motion-based games for older adults, and we discuss how our findings generalize beyond game interaction.

4.1   Related Work

The following sections provide an overview of research on input devices for older adults, as well as efforts in games research addressing the issue of game interface design.

4.1.1   HCI Research on Input Devices for Older Adults

Research on input devices for all audiences has a long history in HCI, focused primarily on dependencies between input devices, tasks and user performance. MacKenzie et al. [108] explored performance of pointing and dragging tasks using a mouse, trackball and stylus/tablet, and showed that while the stylus is best suited for pointing tasks, the mouse performs well on dragging, and stylus and mouse generally outperform the trackball. This suggests that input devices have different advantages, and there may not be an optimal solution across tasks. Likewise, Cao et al. [33] compare finger, whole-hand and hybrid 2D pointing and find that hybrid devices improve performance. In a study designed to explore performance differences in fingers, wrist and forearm using a point-and-click task, Balakrishnan and MacKenzie [15] find that fingers do not generally perform best.

Research has also acknowledged the impact of age-related changes on the interaction process and begun to focus on input devices and interaction paradigms for older adults. Czaja and Lee [39] provide an overview of the field, indicating that the use of mouse and keyboard setups may be problematic, and highlighting a high variability in task performance among older

adults as a core challenge. Fisk et al. [51] analyse the suitability of traditional input devices for older adults, suggesting that joysticks are well suited for tracking tasks while keyboard input is problematic for users with dexterity impairments. Chaparro et al. [34] compare the performance of younger and older adults in point-and-click and click-and-drag tasks using mouse and trackball input. While age did not influence user performance across devices, mouse input required a bigger range of motion, and older adults reported a higher degree of perceived exertion after using the mouse. Another comparative study by Wood et al. [179] reinforces these findings. The authors compare user performance in selecting and dragging tasks using a touchscreen, touch pad, a mouse, and an enlarged mouse, and find that mouse input is most cognitively and physically demanding, yet touch input creates problems when older adults must sustain pressure in dragging tasks. Bobeth et al. [26] examine motion-based TV input and conclude that older adults prefer direct mappings (i.e., using the hand to point).

4.1.2 Game Controls, Performance, and Experience

In contrast to the focus on interaction efficiency in traditional HCI research, game interaction design faces the challenge of providing an efficient interaction process that also produces an enjoyable player experience (PX).

Game Input Devices and General Audiences

Research on game input for general audiences address player performance, but also consider the effect on PX. Kavakli et al. [85] compare user performance and controller preferences in racing games. They find that participants prefer joystick input for games that provide higher precision, while keyboard input is more enjoyable in fast-paced games. Most notably, these differences in controller preference and user performance prevail despite both games featuring steering tasks. In addition, research has shown that contextual factors such as view or level layout also affect player performance in steering tasks [17]. Klochek and MacKenzie [89] explore player performance in 3D tracking tasks using an Xbox GamePad and a mouse. Results suggest that both input devices allow players to track targets, but the mouse outperformed the GamePad when users had to make quick corrections. Isokoski and Martin [81] report that mouse controls yield better pointing performance results than an Xbox 360 controller in target acquisition. In their ISO 9241-9 evaluation of game input devices, Natapov et al. [124] conclude that while the mouse still performs best, the Nintendo Wii Remote is preferred among

participants and provides higher throughput than a GamePad. In another study, Natapov et al. [125] show that mouse and keyboard outperform both GamePad and a custom-built trackball GamePad in accuracy and task completion time in pointing in the first-person shooter (FPS) Call of Duty 4: Modern Warfare.

Regarding the effect of input device on PX, Gerling et al. [66] show that although players felt more challenged when forced to use an unfamiliar device, the control scheme had no impact on their overall PX in the FPS Battlefield: Bad Company 2. Likewise, Limperos et al. [102] compare user enjoyment playing Madden Football 2008 using the Sony PlayStation2 controller or Nintendo's Wii Remote, and found that participants prefer a traditional control scheme over gesture-based input. Using a different approach, Lindley et al. [104] compare player experience using sedentary and motion-based controls and find significantly higher levels of social interaction among persons playing motion-based games. Prior work has generally evaluated game input device performance based on single tasks (e.g., pointing, tracking or steering) or using off-the-shelf games. Both approaches are problematic: single tasks do not account for interaction complexity in games and the range of interaction across genres, whereas commercially available video games cause difficulties due to task complexity and limitations on controlling in-game variability, an issue raised by [125].

Game Input Devices and Older Adults

Research on game input devices for older adults has largely been carried out in the form of case studies with a focus on game accessibility. Shim et al. [149] developed an online poker game for older adults using mouse and keyboard input, with results suggesting that players who experience tremor had problems completing dragging tasks using the mouse, and that offering alternative button input increased accessibility. Work involving motion-based input devices such as the Nintendo Wii Remote and Balance Board [1] as well as the Microsoft Kinect [68] has shown that the devices are generally accessible if interaction paradigms are designed particularly addressing the needs of older adults. Pham and Theng [135] present a preliminary comparative study on how game controllers affect PX and device preference. Older adults played commercially available bowling and sports games using the Wii Remote, the Xbox 360 GamePad, and the Microsoft Kinect. Results suggest that participants prefer gesture-based controls despite performance deficits. While the results hold interesting implications for game design for older adults, the exploratory nature of the study calls for further research using

standardized tasks across all controller conditions to be able to draw conclusions on performance and experience and dependencies between controllers and in-game tasks.

Given the growing popularity of video games among older adults, more research on game input devices for this audience is necessary, as the impact of age-related changes influences the interaction process and may also have an effect on controller preference and performance. Furthermore, evaluations that feature different interaction tasks while maintaining characteristic game elements represent a promising approach for the evaluation of game input devices in terms of PX and performance.
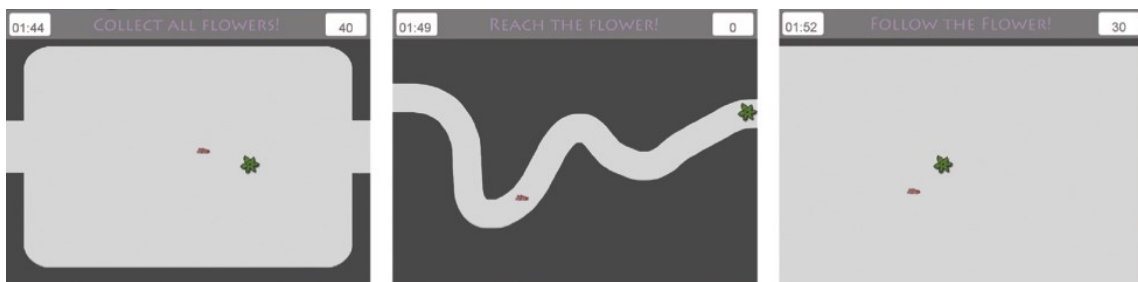
Figure 3. (1) Pointing, (2) steering, and (3) tracking tasks involving the collection of flowers.

4.2 Game Interaction For Older Adults

In this section, we summarize age-related changes that specifically affect the interaction process when using different input devices, and present a game created to evaluate performance and experience among older adults when completing pointing, tracking and steering tasks with four game controllers.

4.2.1 Age-related Changes and Impairments

Age-related changes often affect older adults' ability of interacting with computers and video games [39]. In the context of interaction design and the use of input devices, the following aspects should be considered: Generally, age leads to a reduction of muscle mass, which causes decrements in strength and stamina [87], resulting in a lack of movement control and higher reaction and movement times [39]. Additionally, older adults may experience a decline of force control. Furthermore, research suggests that age affects motor learning [87], an important aspect to be considered when creating gesture-based interaction. Additionally, some older adults are affected by age-related diseases (e.g., arthritis or orthopaedic impairments [39]), which in turn

their physical abilities and their capacity to use standard interfaces. Studies investigating the effects of age-related changes in motor skills report higher variability in arm movements, slower movement initiation and a general decline of rapid arm movement control [182]. Research with a focus on HCI found that the range of motion of the wrist decreases with age, which affects the use of pointing devices [35], and that there are difficulties among older adults in carrying out complex point-and-click tasks [156].

When designing interfaces for older adults, it is important to understand that different age-related changes differentially influence the interaction process and may lead to a range of needs among the target audience. Thus, it is important to ensure the general accessibility of interfaces by accommodating a variety of abilities by accounting for common age-related changes that influence interaction, and to compare particular groups of input devices (i.e., sedentary and motion-based controls) to determine how the age-related changes differentially affect their use.

4.2.2   Game: System Design

To evaluate player experience and performance depending on game input device, we created a test bed game that supports different game controllers. In the game, the player is invited to control a caterpillar that needs to consume flowers in order to turn into a butterfly. To reach this goal, different in-game challenges have to be completed.

Game Input Devices

The test bed game supports four different devices that are commonly used for game input: Traditional mouse input, the Microsoft Xbox 360 GamePad, the Sony PlayStation Move controller, and the Microsoft Kinect sensor. The mouse was included because it is a device that both younger and older adults are likely to be familiar with, and thus could provide baseline data for comparison with the game-specific devices. Likewise, we included the Xbox 360 GamePad as it represents traditional game controllers, which are widely used. Because we are interested in how traditional, sedentary game input devices compare against gesture-based controllers, the game supports Sony PlayStation Move as an example of a position-based controller. Additionally, Microsoft Kinect was included as it supports hands-free gestural input, and our study aims to explore whether age-related changes and impairments affect performance depending on whether or not players are provided with a tangible input device. Despite the large

popularity of the Nintendo Wii Remote, we decided to instead include the Move controller to represent positional input, as its RGB camera-based tracking process is more precise and provides users with more interaction freedom than Nintendo's infrared system. Users are not required to accurately point at the camera, which could be difficult if they are affected by age-related changes in motor abilities. We decided not to include hardware that supports foot-based input (e.g., Nintendo Balance Board) as this type of interaction comes with a different set of challenges; we are primarily interested in hand-held controllers.

In-Game Tasks

The test bed game features three different in-game tasks that were integrated to evaluate controller performance. Our in-game tasks include *pointing* (the speed at which a person can move a pointer to a target), *steering* (the speed at which a person can move a pointer along a path without colliding with the path's borders), and *pursuit tracking* (the ability to move a pointer so as to accurately match the location of a moving target). These tasks are common interaction tasks in HCI and are those considered in the evaluation of input device performance [34]. In addition, pointing, steering, and pursuit tracking represent three common in-game tasks: pointing is used in any click-based game (e.g., Farmville); steering is important in driving games and other path-following games (e.g., line grapefruit); pursuit tracking is used in FPS games with moving targets (e.g., Quake Live). In order to ground our three tasks in the premise of a game, all tasks include flowers as the target, which have to be consumed by the avatar (caterpillar). Our game tasks include the following:

Collect flowers. In this pointing task, players are asked to collect flowers that are sequentially displayed in an open area on the screen. Levels of difficulty are introduced by reducing target size and increasing distance between targets [108]. Performance is evaluated based on completion time.

Navigate through maze. This task requires players to complete a steering challenge, in which the avatar has to be navigated through an increasingly difficult maze to reach a flower, which is located at its end. To increase the level of difficulty, tunnel width is decreased [2]. Player performance is determined based on collision frequency with tunnel borders and completion time.

Follow the flower. In this pursuit tracking task, the avatar has to follow a moving flower. Task difficulty is adjusted by changing the velocity of the target (constant, constant increase,

random increase) [2]. Performance is determined based on the average distance between avatar and target.

To provide players with feedback on their in-game performance, information on elapsed time as well as a score as reward for consumed flowers is displayed.

Implementation and Controller Mappings

The game was implemented in C#, using XNA 4.0. It required only that the participant could target an object by manipulating the x- and y-position of the avatar. For the Mouse condition, standard x- and y-mappings between controller and cursor were used to position the avatar. For the GamePad, avatar position was controlled through the right analog stick. For the Move, the avatar was positioned using the x- and y-position of the controller, and for the Kinect, avatar positioning used the x- and y-joint coordinates of the participant's right hand; control-display gain was kept constant between the two motion-based controllers.

4.3   Study

Using our test bed game, we explored the suitability of different motion-based and sedentary game input devices for older adults, and how the performance and experience of older adults compare to that of younger persons.

4.3.1   Participants and Procedure

Thirty-three persons participated in our study – 16 younger adults (9 female; mean age 23.9, SD=2.5, range 18 to 27), and 17 older adults (11 female; mean age 71.5, SD=7.3, range 62 to 86). All participants were right-handed, and none reported motor problems that would have influenced participation in this study. Most younger adults reported spending five to ten hours per week using the computer, older adults reported two to five hours a week. Participants in both groups did not play video games for more than two hours a week, with younger adults being slightly more experienced in the use of game controllers (among older adults, two had used the Wii Remote, two a GamePad, and none had experience using the Kinect or Move; among younger adults, five had used the Wii Remote, three a GamePad, three the Move, and one had used the Kinect).

After completing an informed consent, participants were asked to fill out a demographic questionnaire to assess possible medical conditions interfering with the use of game input devices as well as computer and prior gaming experience. Then participants played the game

using each of the controllers (Kinect, Move, Mouse or GamePad) while sitting in a chair. Order of presentation of the controllers was randomized with a Latin Square. Within each game, participants completed all three tasks in a single order (pointing, steering, tracking). They were given six minutes to complete the three tasks before the system moved onto the final feedback screen. Within a task, players began at the lowest level of difficulty and progressed in increasing difficulty until completing all difficulty levels within a task or until two minutes had passed. After each round (all three tasks with one controller), device comfort, physical fatigue, and task load were assessed using the ISO 9241-9 [44] and NASA-TLX [169] questionnaires. Finally, participants were asked to rate fun on a 5-point Likert scale. This procedure was repeated for each controller. At the end of the experiment, participants ranked controllers based on personal preference, and gave an overall rating of the game.

4.3.2 Setting and Apparatus

The system ran on a Windows 7 PC with a 22-inch monitor with a resolution of 1280 by 960. The game software logged performance measures. Participants sat in a chair for all conditions, and completed all questionnaires on paper.

4.3.3 Data Analyses

We performed RM-ANOVAs on performance, comfort, fatigue, and task load with group as a between-subjects factor (younger adults, older adults), and controller as a within-subjects factor (Kinect, Move, Mouse, GamePad). Pairwise comparisons used the Bonferroni correction and all tests were conducted with $\alpha=.05$. Enjoyment was analysed using a Mann-Whitney U test for the between-groups analysis and Friedman's Analysis of Variance of Ranks for controller ratings. Overall controller rankings were analyzed with Friedman's test, with pairwise comparisons made with Wilcoxon Signed Rank tests.

4.3.4 Results

In this section, we summarize the results of our study with a focus on player performance, device comfort and effort, as well as controller preferences and player enjoyment.

Performance

Performance was assessed for each input device based on three different in-game tasks (pointing, steering, tracking). Performance was measured by completion time in seconds for the

pointing task, by completion time in seconds and total number of collisions for the steering task, and by average distance (in pixels) between the avatar and target for the tracking task. See Table 3 for descriptive results. For the pointing task, there was a main effect of group ($F_{1,20}$=26.4, p<.001, η^2=.468) on completion time, showing that older adults perform worse than young adults regardless of input device (Table 3). Additionally, we found a main effect of controller ($F_{3,60}$=119, p<.001, η^2=.798) that showed that the Mouse was the fastest device, followed by the Move, the Kinect, then the GamePad; all pairwise comparisons were significant (all p<.003) These main effects need to be interpreted in the light of the significant interaction between group and controller ($F_{3,60}$=3.6, p=.016, η^2=.107). Pairwise comparisons showed that although all of the input device differences were significant for older adults (all p<.008), for young adults, the GamePad was not significantly faster than the Kinect (p=.711). All other device comparisons were significant (all p<.002). For the steering task, there was no main effect of group on completion time ($F_{1,20}$=2.1, p=.163, η^2=.917) or number of collisions ($F_{1,20}$=.1, p=.716, η^2=.693). However, there was a main effect of controller on both completion time ($F_{3,60}$=20.6, p<.001, η^2=.507) and collisions ($F_{3,60}$=10.5, p<.001, η^2=.343). Pairwise comparisons for completion time showed that the using the Mouse was faster than Kinect (p=.003) and GamePad (p=.035). Move was faster than Kinect (p=.008).

		Pointing	Steering		Tracking
		Time (s)	*Collisions*	*Time (s)*	*Distance (px)*
Kinect	*Young*	14.7(2.8)	77.6(71.5)	13.4(9.6)	70.3(33.8)
	Old	19.9(5.9)	75.1(64.3)	13.5(4.5)	95.5(45.8)
Move	*Young*	9.0(1.4)	24.5(24.8)	5.8(1.9)	36.3(21.0)
	Old	12.8(2.7)	29.7(45.8)	7.6(2.2)	46.9(23.3)
Mouse	*Young*	5.9(0.7)	25.1(26.0)	3.6(1.1)	23.3(15.5)
	Old	10.3(4.4)	25.4(30.1)	5.7(2.3)	36.5(26.5)
GamePad	*Young*	17.2(2.6)	36.3(25.0)	7.1(2.2)	49.8(16.8)
	Old	25.8(6.9)	52.3(10.8)	9.7(3.7)	93.1(32.9)

Table 3. Mean results for younger adults (Young) and older (Old) adults for the Kinect, Move, Mouse, and GamePad.

All other comparisons were not significant (all p>.191). Pairwise comparisons for collisions showed that the most collisions occurred using the Kinect, followed by GamePad, Move, and then Mouse. All device comparisons were significant (all p<.022), except for that

between Move and GamePad, which was marginally significant (p=.063). There was no interaction between group and controller on completion time ($F_{3,60}$=0.3, p=.821, η^2=.015) or collisions ($F_{3,60}$=0.4, p=.725, η^2=.022). For the tracking task, we found a main effect of group ($F_{1,20}$=8.7, p=.007, η^2=.243) on completion time, with older adults performing worse than young adults regardless of input device (Table 3). Additionally, we found a main effect of controller ($F_{3,60}$=39.0, p<.001, η^2=.591) showing that using the Kinect and GamePad was slowest, followed by Move, and then Mouse. All device comparisons were significant (all p<.001), except between Kinect and GamePad (p=.922). These main effects need to be interpreted in the light of the significant interaction between group and controller (F_3=3.5, p=.018, η^2=.116). Pairwise comparisons revealed that the trends of the main effect of controller (Kinect not different than GamePad (p_{older}=1.0, p_{young}=.359) held (the comparison between Move and Mouse was only marginally significant at p=.055 for older adults); however, for younger adults, the difference between Move and GamePad was not significant (p=.139). Other comparisons were significant for both groups at p<.004.

Comfort and Effort

Device comfort, physical fatigue, and task load were assessed using the ISO 9241-9 Questionnaire on Device Comfort and the NASA Task Load Index. Items in the NASA-TLX were aggregated into a composite score using raw format [74]. Descriptive results are presented in Table 4 and Table 5. Regarding physical effort (finger, wrist, arm, shoulder, and neck fatigue assessed using the ISO 9241-9 items 7, 8, 9, 10, and 11), we found only a marginal effect of group on fatigue ($F_{1,29}$=4.2, p=.051, η^2=.125). We did find a main effect of controller on fatigue ($F_{3,87}$=28.9, p<.001, η^2=.499). Pairwise comparisons revealed that players found the Kinect to be most tiring, followed by the Move, GamePad, and then Mouse.

All inter-device differences were significant (all p<.006), except for GamePad-Mouse difference (p=1.0). For device comfort (ISO 9241-9 item 12), there was no main effect of group ($F_{1,29}$=.06, p=.814, η^2=.002). There was a main effect of controller ($F_{3,87}$=12.5, p<.001, η^2=.301). Pairwise comparisons showed that within the motion-based controllers, the Move was perceived as more comfortable than the Kinect (p<.001). The Mouse was rated as more comfortable than any other device (all p<.016), and all other comparisons were not significant (all p>.130). There was no interaction of group and controller on comfort ($F_{3,87}$=0.74, p=.531, η^2=.025). Overall

results of the NASA-TLX (Table 5) showed no main effect of group ($F_{1,29}=0.8$, $p=.368$, $\eta^2=.028$), but did show a main effect of controller ($F_{3,87}=33.0$, $p<.001$, $\eta^2=.532$).

		Fatigue	Comfort	Ease of Use
Kinect	*Young*	2.84(0.88)	2.56(1.15)	2.19(0.98)
	Old	2.24(0.81)	3.00(1.25)	3.20(1.37)
Move	*Young*	2.31(0.97)	3.44(0.89)	3.50(1.10)
	Old	1.73(0.87)	3.53(1.36)	3.87(1.19)
Mouse	*Young*	1.51(0.71)	4.31(1.08)	4.50(1.03)
	Old	1.28(0.54)	4.0(1.39)	4.47(0.74)
GamePad	*Young*	1.70(0.68)	3.38(1.26)	3.25(1.39)
	Old	1.33(0.53)	3.40(1.24)	3.20(1.01)

Table 4. Results of the ISO 9241-9 Questionnaire for Fatigue (1 = none, 5 = very high), Comfort (1 = very uncomfortable, 5 = very comfortable) and Ease of Use (1 = very difficult, 5 = very easy).

		Mental	Physical	Overall
Kinect	*Young*	7.29(4.25)	14.59(4.99)	10.91(3.11)
	Old	10.79(6.44)	11.50(6.33)	10.25(4.80)
Move	*Young*	5.29(3.80)	9.24(5.57)	7.16(3.09)
	Old	7.07(4.92)	7.36(5.44)	7.19(4.13)
Mouse	*Young*	3.12(2.32)	3.65(3.14)	3.55(2.20)
	Old	5.50(4.38)	5.14(3.53)	5.99(3.16)
GamePad	*Young*	6.53(4.39)	6.00(4.70)	7.72(3.33)
	Old	9.07(5.99)	6.93(4.55)	9.60(3.76)

Table 5. Results of the NASA-TLX Questionnaire for Mental and Physical Demand (1 = very low, 20 = very high), and Overall Comfort (1 = very comfortable, 20 = very uncomfortable).

Participants rated the Kinect as worst overall, followed by GamePad, Move, and then Mouse. All differences were significant (all $p<.035$), except for the one between GamePad and Move ($p=.186$). This effect has to be interpreted considering a significant interaction between controller and group ($F_{3,87}=3.0$, $p=.036$, $\eta^2=.093$). Pairwise comparisons showed that the trends of the main effect were true for young adults (all differences significant (all $p<.006$) except for GamePad-Move ($p=1.0$); however, for older adults the GamePad-Move difference was not significant ($p=.114$) along with the Move-Mouse difference ($p=.697$) and the Kinect-GamePad difference ($p=1.0$). All other differences were significant (all $p<.009$).

Participant comments support these results, underlining that motion-based controls are more tiring than sedentary input: "*My arms are too exhausted during the game*", "*Kinect required a lot of energy to keep the arm up*", "*The move is too heavy*". However, comments particularly made by older adults also indicated that they "*enjoyed the exercise and found it interesting and challenging*", with the Move being more comfortable than the Kinect: "*Move is easier to use because of the bulb, because you can see where you are.*", "*It was easier because I had something to hold on to.*" In contrast, comments made by young persons suggest a slightly different view on physical effort in games: "*I don't like the move at all in this game. Felt tired after all.*"

Enjoyment

Participants rated fun playing with each of the controllers using a 5-point Likert scale. We also asked them to rank the controllers based on overall preference (1=best, 4=worst). There was no effect of controller on fun among young adults (χ^2_3=1.85, *p*=.603) or older adults (χ^2_3=5.13, *p*= 162). There were significant differences in controller rankings among young adults (χ^2_3=31.04, *p*<.001) and older adults (χ^2_3=27.49, *p*<.001). Pairwise comparisons using the Wilcoxon Signed Rank test revealed that young adults rank the Mouse significantly higher than Kinect (*z*=-3.60, *p*<.001), Move (*z*=-3.60, *p*<.001) and GamePad (*z*=-3.40, *p*=.001). When looking at movement-based controls only, they ranked the Move significantly higher than Kinect (*z*=-2.13, *p*=.033). Pairwise comparisons among the results of older adults revealed that they rank the Mouse significantly higher than GamePad (*z*=-3.70, *p*<.001) and Kinect (*z*=-3.49, *p*<.001), but not higher than the Move (*z*=-1.20, *p*=.230). Regarding motion-based devices only, they ranked the Move controller higher than Kinect (*z*=-3.46, *p*=.001).

	Fun		Ranking	
	Young	*Old*	*Young*	*Old*
Kinect	3.35(1.41)	3.36(1.08)	4.00	4.00
Move	3.71(1.16)	3.86(0.86)	2.00	2.00
Mouse	3.35(1.00)	4.00(1.04)	1.00	1.00
GamePad	3.59(1.06)	3.79(0.89)	3.00	3.00

Table 6. Average ratings for Fun (SD) and controller rankings (Med) per group (Young = Younger Adults, Old = Older Adults).

Participant comments underline that the game was perceived as fun: "*The game was fun, and generally easy to play*". Regarding their controller rankings, younger adults pointed out that they enjoy using the mouse: "*The mouse was most fun and easiest to use.*", and are highly familiar with it: "*I use mouse every day, and it is probably why I think it is the best controller as opposed to others*". One participant compared the Move controller to the Nintendo Wii Remote, again highlighting device familiarity in the context of enjoyment: "*The Move was similar to a Wii Controller which made it easier for me*". Comments on device familiarity were also made by older adults, with many participants pointing out that they were most familiar with the mouse: "*I am a mouse-user!*", "*Like mouse because I'm used to it*", "*I know the mouse best, the others are new to me*". While some older adult participants pointed out that they would not consider adopting any of the new devices: "*I'll stick with my mouse.*" Others expressed interest in learning about new input devices: "*I liked the challenge of trying new devices to see if I could use them properly.*", particularly pointing out the Move controller: "*Move is something I could enjoy*", "*I would [...] like to use the Move device*", "*I liked the move controller. Could be used for exercising.*"

4.3.5 Findings

The results show that both age and controller affect user performance, suggesting that the consideration of age-related changes and choice of input device is crucial when designing for older adults. Across both groups and all tasks, we show that the Mouse is the most efficient input device, outperforming the GamePad and Kinect controllers for pointing, steering and tracking, and performing better than the Move controller in pointing and tracking. Despite similar interaction paradigms for the motion-based controllers, the Move controller performed better than Kinect across both groups and all tasks. While young adults outperformed older adults in pointing and tracking tasks, we could not find any significant differences between young and older adults for the steering task, suggesting that the impact of age on user performance also depends on the specific requirements associated with a task. In general, our results suggest that older adults were able to complete all tasks within a reasonable time and with acceptable accuracy, and that older adults can use motion-based controls to efficiently complete various tasks.

Additionally, we show that overall device comfort is not affected by age, and that older adults do not perceive motion-based game controls as more exhausting than younger adults.

When comparing controller comfort, we show that motion-based devices are more physically demanding; both user groups report higher levels of fatigue when using motion-based controllers, with the Kinect being more tiring than the Move. Participant comments showed that older adults considered the increased physical effort of motion-based controls a welcome challenge, whereas some young participants commented on physical fatigue as a negative aspect of motion-based game controls.

Yet, results investigating overall enjoyment do not show any differences between controllers, suggesting a positive player experience regardless of input device, with both groups consistently rating fun above neutral levels. In terms of overall controller preference, young adults prefer the Mouse over any other device, whereas older adults do not rank the Mouse significantly higher than the Move controller, suggesting a more positive attitude towards motion-based game controls. When looking at motion-based controllers only, the Move was consistently ranked higher than the Kinect across both groups. Participant comments show that older adults consider themselves to be most familiar with the mouse, frequently highlighting a lack of experience with the other controllers. However, they also expressed interest in novel input devices, again referring to the Move as the preferred alternative to the Mouse.

These findings have two implications. First, the performance results suggest that the impact of age needs to be considered when designing video games for older adults, as age may influence the suitability of in-game challenges. Second, the results for comfort and enjoyment show that older adults enjoy engaging with games to a similar extent as young adults, and that motion-based input devices represent a valid alternative to sedentary game controls.

4.4   Discussion

Our work explores the suitability of sedentary and motion based game controls for older adults. In this section, we discuss the implications of our results for the design of game interaction for older adults, with a focus on design considerations for motion-based games.

4.4.1   Age-Related Changes and Player Performance

Although the differences between older and younger adults found in our study do not seem to affect the overall play experience, it is important to consider two main implications of our work on player experience in a bigger context: First, it is important to consider the impact of player performance on game difficulty, as certain in-game tasks may be more challenging for

older adults than for younger audiences due to controller-related performance differences, thus *feedback frequency has to be increased and activation threshold lowered to ensure that it is encouraging for older adults*. Second, if seniors consistently perform worse in terms of overall performance, game designers have to acknowledge this fact by adapting how player performance is evaluated to provide older adults with a rewarding experience and to *balance for performance differences between older and younger players* (e.g., by applying different threshold values for positive feedback or employing approaches for player balancing [18]). To keep older adults engaged over a longer period of time and to enable competition between younger and older players, designers have to adapt games to the individual skills of older adults, carefully balancing accessibility and challenge.

4.4.2   Sedentary vs. Motion-Based Game Controls

Research has frequently highlighted the potential of motion-based game controls, and our results show that they are suitable for older adults, offering an alternative to sedentary input devices. In this context, it is interesting that *despite their awareness of the higher physical demand of motion-based input, older adults enjoy playing games using motion-based controls* as much as using sedentary input devices, some even considering the physical demand a welcome exercise. However, the choice of input device also has to be discussed with regards to the impact of age-related changes. While our study investigated the suitability of input devices for active older adults, additional design challenges arise when creating games for older adults who experience a higher level of age-related changes, e.g., nursing home residents. In this context, designers may have to address individual needs by integrating alternative input devices: While older adults experiencing decrements in fine motor skills (e.g., due to Arthritis) are likely to find using sedentary devices such as the mouse or GamePad less comfortable, it is important to keep in mind that older adults experiencing age-related changes and diseases that affect gross motor skills (e.g., Hemiplegia) may experience problems applying motion-based game controls.

4.4.3   Motion-Based Games for Older Adults

The following section discusses issues particularly related to the design of motion-based games for older adults, focusing on controller-based and hands-free interaction as well as motion-based input and physical exertion.

Within the motion-based game controls applied in our study, older adults prefer controller-based input (Move) to hands-free input (Kinect). The results show that despite a comparable interaction paradigm and a similar range of motion required for input, participants found the Move less demanding to use and ranked it higher than hands-free interaction using Kinect. Comments show that in contrast to hands-free input, the Move controller provided users with a clear reference of their location, making it easier for them to adapt their own position in relation to the camera and direct their input. Additionally, the different technologies for tracking user input make the Kinect more sensitive to differences in player posture, with the Move being more robust in terms of changing one's position during play. However, there may be situations in which hands-free input is more suitable; these considerations are similar to the trade-off between sedentary and motion-based input devices: ***While older adults may generally prefer controller-based motion-based input, hands-free input can be beneficial for persons experiencing severe motor impairments which limit their abilities of holding an input device in their hands***. Furthermore, there are situations in which hands-free input yields advantages, e.g., when designing games for nursing homes, controllers can be misplaced, and hands-free input is more sanitary.

The fact that older adults enjoy engaging with motion-based games despite physical effort has two main design implications for games. First, this shows that ***games are a useful tool to encourage older adults to be more active, making physical activity more attractive***. This opens up a variety of design opportunities, including the design of games for physical therapy and rehabilitation. Creating game-based rehabilitation routines that implement motion-based game controls offers the possibility of making tedious routines more fun, motivating users to stick with programs. On the other hand, the effect of fun on the perception of physical effort means that older adults may not notice if they overexert, ***so game pacing has to be adapted to ensure safe interaction and to prevent injury***.

4.4.4 *Motion-Based Controls Beyond Games*

The integration of motion-based controls is not limited to games, and the results of our study hold implications for design considerations that are generally applicable to HCI.

An issue that might have a big effect on controller choice among non-gamer audiences is how familiar both younger and older adults are with the mouse. This is particularly important when designing for older adults, as today's generation of seniors did not grow up with computer

technology, and had to spend time to learn how to interact with computers using a mouse. Therefore, the effort associated with adopting new technologies is likely to be higher than in younger adults, potentially discouraging older adults' willingness to work with novel input devices. Additionally, our results show that people are highly efficient using the mouse, suggesting that the device is a good choice in performance-oriented tasks. Generally speaking, ***designers should account for the extra effort required of older adults to learn to use a new input device,*** perhaps by offering a step-by-step tutorial, facilitating the learning period so that older adults can use the new device with comfort, efficiency and confidence.

4.5   Limitations and Opportunities

Our results show that older adults can apply motion-based game controls and are open to using novel input devices as an alternative to mouse input; however there are limitations and questions that need to be addressed.

Because we were interested in basic interaction differences, we used simple tasks in our evaluation. Participants were not required to complete combined actions (e.g., pointing and clicking). Therefore, we suggest the exploration of tasks requiring complex input sequences. In this context, it should be examined how the nature of in-game tasks influences players' controller preferences. Also, playing time per device was limited. To evaluate long-term differences in physical effort between younger and older adults, extended periods of play are necessary, also facilitating the evaluation of long-term motivation to determine whether the positive perception of motion-based game controls prevails over time, or if there were novelty effects. Finally, because the goal of our study was to compare motion-based controls to sedentary input, interaction only included movements of the player's hand, neglecting full-body motion-based input. To explore the full potential of motion-based interaction, it is crucial to evaluate the inclusion of the user's whole body in input, and to investigate related changes in the impact of age on interaction (e.g., changes in posture and gait). In this context, we believe that the further investigation of differences between active seniors and older adults experiencing severe age-related changes, e.g., nursing home residents, may hold additional implications for the design of video games, and have a large impact on the accessibility of motion-based game controls.

4.6   Conclusion

In this chapter, we examined game input devices with a focus on older adults, and we showed that motion-based interaction is a suitable alternative to traditional input for this audience. Our results show that motion-based game controls are accessible and enjoyable, offer opportunities for encouraging physical activity among older adults, and can be applied in domains beyond gaming. Research presented in this chapter lays a foundation for further work in the field of game design for older adults: in the following parts of this thesis, we explore the design of full-body motion-based game interaction for institutionalized older adults to gain further insights into how older adults apply motion-based game controls, and whether such games are accessible and enjoyable for persons experiencing a higher degree of age-related changes and impairments.

CHAPTER 5

FULL-BODY MOTION-BASED GAME INPUT FOR OLDER ADULTS

Related publication: Gerling, K., Livingston, I., Nacke, L., and Mandryk, R. 2012. Full-Body Motion-Based Game Interaction for Older Adults. CHI '12: Proceedings of the 30th International Conference on Human Factors in Computing Systems, Austin, TX, USA.

Research has shown that playing games can have positive effects on the emotional and physical well-being of institutionalized older adults, and can motivate them to maintain a basic level of activity [19, 84]. The latest generation of game input devices, such as Microsoft Kinect, provides an opportunity for motivating physical activity. However, commercially available games put older adults at risk of injury by failing to accommodate for their range of abilities. In addition, there are no guidelines for designing gesture-based games for this particular group, and applying traditional HCI guidelines is difficult because games require special consideration to balance the difficulty needed to bring challenge – a necessary component of games – and ease of use.

We conducted two studies exploring the suitability of full-body motion control for older adults. In our first study, we evaluated how well elderly participants could perform a set of gestures that was developed in collaboration with a physical therapist. Results suggest limitations in traditional gesture movements, and based on our findings in study one, we designed a game for institutionalized elderly using gestures for full-body motion control. In a second study we investigated how participants responded to the gestures in our game. Results from study two showed the success of our gestures, and demonstrated the positive effect of playing our game on participant mood. Our work makes three primary contributions: 1) we created a set of gestures suitable for institutionalized older adults in a gaming context, considering their range of motion, agility and strength; 2) we presented a full-body motion-controlled game for older adults and demonstrated that such games can have a positive effect on older adults' moods; influencing their well-being and providing enjoyable leisure activities; and 3) we present design guidelines for full-body motion controls to accommodate the range of abilities among institutionalized older adults. Additionally, we discuss how our findings and guidelines generalize beyond the scope of camera-based full-body motion-control games.

5.1 Related Work

Game design for older adults has focused on design guidelines and case studies. The design of exergames for the elderly has been explored, but gesture-based input for games has only explored the context of younger players.

5.1.1 Game Design for the Elderly

First considerations on game design for older adults date back to the 1980s, where Weisman [174] explored the accessibility of Apple II games among institutionalized older adults, highlighting the importance of adaptable games. More than 25 years later, the issue was addressed by Gamberini et al. [59], who focused on the impact of cognitive decrements on the use of entertainment systems, particularly addressing the design of graphical user interfaces. Likewise, Ijsselsteijn et al. [80] analyzed age-related changes and present a set of design recommendations including the creation of individually meaningful and visually adjustable games providing multimodal feedback. Considerations of the design of meaningful games [146] highlight the importance of perceived benefits for the elderly. Additionally, Flores et al. [53] address the creation of games for stroke rehabilitation, recommending visual adaptability, inclusion of therapy-appropriate movements, and suitable cognitive challenges. Different case studies have explored game design for older audiences. To motivate elderly persons to participate in rehabilitation, for example, after a stroke [12], game-based approaches have successfully been used. Often, Nintendo's Balance Board is used as an input device, for example, in various games for balance training [19]. Also, different approaches toward cognitive training for the elderly [13], and social interaction [88] have been explored. It has also been shown that institutionalized older adults enjoy playing games, but interaction challenges have to be addressed [73].

On closer examination, the design recommendations from previous work are high level, only providing small insights into the actual interaction between the older adult players and the system. Prior work has not explored the suitability of hardware game interfaces and associated interaction paradigms for older adults. Likewise, most case studies focus on game mechanics rather than addressing interaction design, frequently focusing on a limited body area. This has led to a lack of information regarding the application of full-body interaction for older adults.

5.1.2 Designing Physical Interaction in Video Games

Physical interaction in video games has been examined from the perspective of providing an exertive sports-like experience, or of exploring gesture-based interaction.

Physical Activity Motivating Games

Exergames integrate physical activity to engage the player [117]. Much work has focused on creating sports-like experiences to help fight sedentary lifestyles among younger audiences [38]. High-level considerations regarding exergames for elderly by Aarhus et al. [1] underline the importance of addressing individual differences by allowing players to adjust game speed and complexity. Further research by Gerling et al. [72] addresses the issue of game accessibility for institutionalized older adults by suggesting the support of standing and seated players to account for age-related impairments, and to avoid sudden and extensive movements. However, suitable interaction paradigms are not described. In the field of intergenerational play, it has been suggested that a design for enactive interaction and intuitive interfaces based on motor actions is required [164]. Yet, suitable gestures for game input are not provided.

Gesture-based Interaction in Games

Natural and gesture-based interaction has a history in 3D user interface design, and virtual environments [29, 77]. Existing efforts in those fields largely focus on productive tasks. However, design principles that focus on user enjoyment rather than task efficiency cannot be applied directly to the design of games. There is little research on full-body motion control in video games available. Despite the large popularity of gesture-based games, few have addressed gesture-based game control on an analytical level. For example, Payne et al. [133] discuss issues in the design of spatial 3D hand gestures in games, recommending the inclusion of tutorials, and highlighting the implementation of natural gestures. Work in full-body interaction for games has focused on the compilation of gesture recommendations and the exploration of player instruction. Norton et al. [127] provide a set of gestures for action games based on observations. Furthermore, they describe design guidelines for full-body interaction, which focus on steering and locomotion. Charbonneau et al. [36] explore player instruction and feedback visualization in dancing games. They match specific in-game actions, such as walking, with similar real-world movements. Their results show that movement visualization affects player performance, and timing is an issue in movement-based games, which is backed up by additional work by Johnston

[82]. Rice et al. [137] present an evaluation of gesture-based mini games with 36 older adults. They suggest the exploration of gesture-based gaming for institutionalized older adults with a focus on hands free input.

Given that existing literature has only begun to analyze the needs of older adults specifically in game design, further research on interaction design for institutionalized older adults is necessary. This is particularly important, as effects of age-related changes are likely to affect the suitability of full-body interaction. Additionally, there remains a lack of research on the high-level accessibility of gestures. Interaction paradigms and game mechanics are often granted a higher priority than the consideration of individual player abilities, which is appropriate when designing for younger audiences but may not suffice when designing for older adults. We believe that reversing this philosophy – prioritizing ability before mechanics – makes games accessible to a larger audience.

5.2   Full-Body Game Interaction for Older Adults

To explore full-body interaction for older adults, considerations regarding the impact of age-related changes are necessary to address the special needs of this audience.

5.2.1   Age-Related Changes and Impairments

Particularly when designing gesture-based interaction for institutionalized older adults, a number of age-related changes need to be considered with a focus on physical abilities of older adults. As outlined in the previous chapter, advanced age is associated with the reduction of muscle mass, and older adults often experience lower strength and stamina than younger persons [87]. This is frequently paired with a lack of movement control, as well as higher reaction times, and generally slower movements [39]. This leads to changes in posture and gait, and an increased risk of falls [87]. Additionally, the age-related increase in difficulties in motor learning [87], and age-related diseases (e.g., arthritis or orthopedic impairments [39]) further affect the physical abilities and the capacity to use standard approaches to human-computer interaction of older adults. All of those factors have to be considered when designing full-body interfaces for institutionalized older adults. First, the general accessibility of such interfaces has to be evaluated. Second, it is important to minimize the risk of injury due to unsuitable movements.

5.2.2 A Gesture Set for Older Adults

Based on the aforementioned considerations regarding age-related changes, we suggest a basic gesture set (Table 7) that can be used to engage older adults in full-body interaction. It was created in cooperation with a physical therapy expert to ensure that all gestures are suitable for institutionalized older adults and do not overstrain users. The set includes a total of eight simple movements, which were derived from physical therapy exercises and everyday movements that institutionalized older adults are likely able to perform without much assistance. Postures and movements were chosen based on their accessibility for persons with limited physical abilities. We assume that integrating gestures that are intuitive and can easily be explained (e.g., clapping one's hands) offers the opportunity of easing older adults without prior computer/gaming experience into the interaction process.

The gesture set is limited to four core movements to account for a lack of previous activity as well as age-related impairments among the target audience, and to limit the amount of sensorimotor learning necessary to interact. Also, most gestures can be carried out while being seated to account for decrements in physical abilities (e.g., changes in posture and gait) and for the large amount of mobility disabilities among institutionalized older adults. In the set, we differentiate between static and dynamic gestures. Static gestures require users to hold a pose – for instance raising one arm and holding it up for a few seconds. Dynamic gestures require users to repeatedly carry out movements – e.g., waving one arm instead of simply raising it. Due to the larger degree of activity required for dynamic gestures, we expected them to be more challenging.

	Static	**Dynamic**
Gesture 1	Hands together	Clap hands
Gesture 2	Raise one arm	Wave arm
Gesture 3	Arms to the side	Pretend to fly
Gesture 4	One-leg stand	Walk in place

Table 7. Overview of static and dynamic gesture sets.

5.3   Study 1: Input Gestures for Older Adults

In the first study, we investigated the suitability of the gesture set for institutionalized older adults. Furthermore, we explored performance differences between static and dynamic gestures, and the accessibility of interaction for older adults using Kinect.

5.3.1   Gesture Analysis Tool

To evaluate the feasibility of gesture-based interaction for institutionalized older adults using Kinect, we created a tool that prompts the user to perform our gesture set (Table 7). Player instruction was provided through descriptions, e.g., '*Put your hands together*' or '*Wave your arm*', and the display of a stick figure that performed the gesture. Users were provided with a green checkmark upon successful gesture completion. While users interacted with the tool, performance metrics (gesture completion, tracking quality) were logged. Gestures were tracked using relative joint positions. The tool was implemented in C# using the Microsoft Kinect SDK and Microsoft Game Studio 4.0.

5.3.2   Participants and Procedure

Fifteen institutionalized older adults (7 female) participated in the evaluation, 13 living in a nursing home, and two older adults taking part in an adult day program at the same home. The mean age was 73.72 years (SD=9.90; Range 60 to 90). Thirteen participants were in a wheelchair, one was using a cane for support while walking, and one person was able to walk independently. Six participants had experienced a stroke, leaving one side of their body paralyzed. Eight participants had played video games before, seven on a Wii. None of the participants had used camera-based systems such as Kinect before. The study was conducted at a media room of the nursing home that was equipped with a large-screen TV and offered enough space for participants to engage with the game. Participants first filled out a consent form and were informed about goals of the study. Then, demographic information was collected including information on the participant's health to ensure that the study would not put them at risk of injury. The gesture analysis tool was then introduced and participants were asked to perform the gesture set twice while being observed. Finally, participants completed a questionnaire on the suitability of the gesture set. The research protocol was approved by the research ethics boards at the University of Saskatchewan and the Saskatoon Health Region.

5.3.3 Results

In this section we provide an overview of the results of the first study including questionnaire results, performance data, and observations, and we give an overview of the main findings.

Questionnaire Results

Participants were asked to rate their interaction experience on a 5-point Likert scale. Results show an overall positive experience regarding the fun users had while performing the gestures, and relatively low values for difficulty and perceived exhaustion (Table 8). 67% of the participants were not afraid of losing balance, and 87% were not afraid of falling. 93% of the participants thought the program provided sufficient instructions, and 87% found that it provided enough feedback on gesture performance. Hand gestures were highlighted as easiest to perform, especially if movements were natural and already known from daily life, as one participant pointed out that *"Raising my arm [was easiest] because it is just natural, it is quite strong."*. Gestures that were affected by impairments were perceived as most difficult, mainly leg-based input and gestures requiring strength in both arms. Participants liked that the gestures allowed them to be active; some highlighted that they had to practice certain movements with their hands and that computer-based training might support that. Three participants stated that they did not like anything about the gestures as they were too simplistic. One participant highlighted that she would have liked to engage with a more complex system: *"The gestures were not much fun, there was not much competition."*.

Performance Metrics

Metrics were logged by the evaluation tool to track individual participant performance. The results show an overall completion rate of 54.17%. Tracking gestures was sometimes not possible due to participants' limitations in range of motion or impairments; 16.67% of gestures were not recognized although carried out correctly. We found high completion rates for static hand-based gestures while rates for dynamic gestures were lower (Figure 4).

Observations

Observations during the first study revealed interaction differences among the target audience. Some of the participants could easily perform one gesture (e.g., raising one arm) but were unable to complete similar movements (e.g., moving one arm to the side).
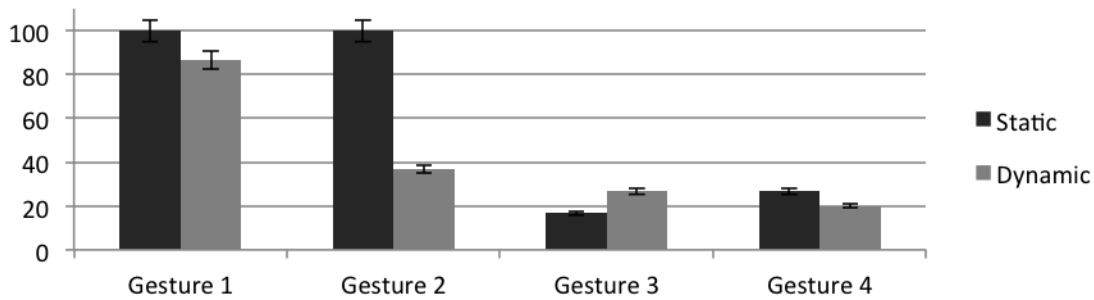
Figure 4. Completion results for gestures in percent (CI: 95%).

Item	Mean	SD
Performing the gestures was fun.	3.40	1.72
Performing the gestures was tiresome.	1.87	1.41
Performing the gestures was easy.	4.40	1.30
Performing the gestures was difficult.	2.20	1.57

Table 8. Mean results for items examining the perceived suitability of the gesture set (5 = completely agree).

The wide range of impairments led to differences in gesture performances, which decreased the accuracy of our gesture recognition. We observed highly individual interaction styles due to varying physical abilities. For example, when players lifted their arm, there was a great variance in height. The ability to hold a posture or perform a gesture for a certain time also varied. Many participants required a long time to finish each gesture while others quickly completed each stage. For some of the participants, on-screen information was not sufficient and they turned to the investigators for assistance. Further observations revealed difficulties of the Kinect system dealing with participants in wheelchairs as the SDK only supports standing interaction. However, it was always possible to calibrate the system for users in wheelchairs.

Findings

Generally, institutionalized older adults represent an extremely heterogeneous target audience, which raises the necessity of adaptable interaction paradigms that can be individually adjusted. In our study, we found large differences between participant abilities resulting in differences in participant responses to our gesture set. Ability differences included limitations in range of motion (ROM), in strength affecting the ability of holding and repeating a gesture, and overall movement speed. Although the ability of using arms and legs was limited due to

individual impairments that gesture-based interfaces need to account for, there are also main categories of institutionalized older adults ability that can be considered – specifically, the ability of participants to use limbs on both sides of their body and the presence of wheelchairs. Completion rates suggest that dynamic gestures were more challenging for institutionalized older adults, perhaps because repeated movements are more demanding than holding a posture. Also, walking gestures were difficult for participants in wheelchairs; many of the participants were not able to move their feet independently. Generally, games need to work around the issue of wheelchair tracking by using space that is not affected by the chair, such as to the sides of the player, and removing bulky parts of the chair (e.g., lowering arm rests or removing lap trays) improves tracking results. Finally, being instructed by a computer screen was an unfamiliar experience for many participants.

5.4   Study 2: Gesture-Based Game Interaction

In the second study, we explored the use of gestures in games addressing institutionalized older adults. Based on the results of the first study, we created a gesture-based game for institutionalized older adults. We then conducted a study using our game to refine gesture-based interaction for institutionalized older adults in games and to observe how the gesture-based game affected participant mood.

5.4.1   A Gesture-Based Gaming System for Older Adults

We created a gesture-based game that invites players to perform movements for growing a flower garden (Figure 5) because prior research suggested gardening themes for games for older adults [146]. The gesture system was designed to provide adaptable interaction paradigms that accommodated age-related changes, such as not being able to raise arms over a certain degree or allowing slower steady movements. The game was implemented in C# using the Microsoft Kinect SDK and Microsoft Game Studio 4.0.

Game Adjustment and Calibration

Based on our findings from study one, basic information about the player's individual physical abilities needed to be provided upon game start to determine whether seated or standing interaction is possible, and if one-handed play is required. Then, players participated in a short calibration sequence during which they were asked to reach out to small flowers displayed on the screen. First, they were asked to collect as many flowers as possible to evaluate their ROM.

Second, players had to reach to and hold certain flowers at specific screen positions to determine their strength and their ability of holding a certain pose. Player agility was calculated depending on completion time. Based on these values, players either engaged with the game via static or dynamic gestures. Threshold values for successful gesture completion and effect duration were set accordingly; if a player was assigned a low ROM value, the level of gesture precision was reduced. If players received low values for strength, game effects would remain active longer to avoid overexertion. Low agility values led to a larger time window for gesture completion.
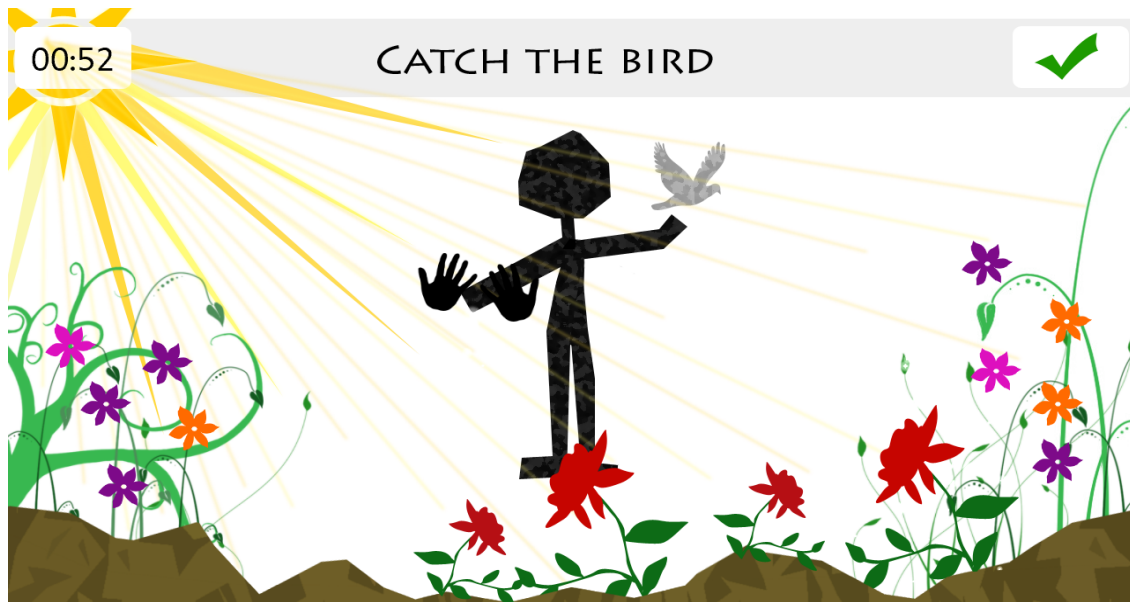
Figure 5. Screenshot of the tutorial phase of the game.

Gestures and Game Mechanics

We developed four gesture-based game mechanics related to our gardening theme. These mechanics required players to perform different full-body gestures based on their individual abilities determined through calibration.

Growing plants. Players have to stand on one leg (static) or walk in place (dynamic) to grow plants. If players are seated, plants automatically grow.

Growing flowers. Players need to lift (static) or wave (dynamic) one arm. This activates rain that spreads from the player's hand onto the foliage.

Making flowers bloom. Flowers start blooming once players manage to get a certain amount of sunshine by either extending one or both arms to the side (static) or pretending to be flying by waving both arms (dynamic).

Catching the bird. Once all flowers have grown and are blooming, a bird appears. Players have to move their hand towards it to catch it, which provides an increase in pace.

Instruction and Feedback: Guided and Free Play

The first part of the game provided a period of guided tutorial play in which the game prompted players to perform certain gestures in a predefined order. Players were instructed in this tutorial by short phrases explaining the gesture and a stick figure demonstrating the movement. In the second part players could engage in free play, where they could perform any of the available gestures at any time without detailed instruction. When players successfully completed gestures, the gesture was revealed, and players were awarded points. The game used sound to underline the completion of player tasks. Once the garden was grown, a scoring screen was shown and the game ended.

5.4.2   Participants and Procedure

Twelve institutionalized older adults (5 female), with an average age of 76.7 (SD=10.6; Range 60 to 91), living in a nursing home participated in our study. Eleven participants were in wheelchairs; only one was able to walk without assistance. Similar to our first study, six participants reported having had a stroke, leaving one side of their body paralyzed. The study was conducted in the media-room of a nursing home. Participants first filled out a demographic questionnaire. Before participants started the game, they completed a pre-game PANAS questionnaire [173] to measure their positive and negative affect states. Participants first played the tutorial and then were allowed to engage in free play for five more minutes or until they successfully completed the game. After the session, they completed a post-game PANAS and gave feedback about the gestures and game mechanics.

5.4.3   Results

Based on the abilities of our study population, static gestures were assigned to all participants, hence we do not study differences between static and dynamic interaction.

Questionnaire Results

Differences in mood as assessed by the PANAS questionnaire before and after playing were analyzed using a paired-samples t-test. There was a significant increase in positive affect after playing the game (M=3.88, SD=0.79) compared to before the game (M=3.34, SD=0.64),

t_{11}=-2.92, p<0.01. However, no changes in negative affect before (M=1.72, SD=0.78) and after the game (M=1.68, SD=0.86), t_{11}=0.28, p=0.79 were found. The questionnaires revealed that gestures were perceived as suitable, and the game was perceived as easy and fun (see **Table 9** and **Table 10**), yet we did not find any connections between player performance and these phenomena. Participants noted that the game had a positive effect on their alertness: "*I'm a little more attentive than I was before.*" Once used to the game, some participants highlighted that more feedback and more in-game options would improve their experience: "*I wish more would have happened, like every time I moved.*" The participants generally liked the graphical style and theme of the game: "*Oh, that [game] is cute.*"

Performance Metrics

The technical implementation of the Kinect game was successful as the performance logs showed no tracking failures. Completion results for hand and arm-based gestures were high (100% for raising arm, 100% for moving arm(s) to the side(s), and 92% for catching the bird), whereas only one participant was able to perform foot-based gestures. Out of the twelve participants, eleven persons participated in free play.

Observations

Observations showed that most of the participants could interact with the game. Often, participants needed additional explanations. There were a few differences between guided play during the tutorial and the period of free play that followed it. Only some participants could correctly recall interaction paradigms after the tutorial and interact with game on their own, whereas others needed assistance from the experimenters to perform correct movements. Also, some participants showed physical fatigue after interacting with the game over longer periods of time. From a technical perspective, Kinect tracking worked well despite participants sitting in wheelchairs.

Item	Mean	SD
Performing the gestures was fun.	3.08	1.62
Performing the gestures was tiresome.	2.33	1.61
Performing the gestures was easy.	3.83	1.03
Performing the gestures was difficult.	2.75	1.29

Table 9. Descriptive statistics for the perceived suitability of the gesture set used for the mini game (5 = completely agree).

Item	Mean	SD
Playing the game was fun.	3.79	0.99
Playing the game was tiresome.	2.13	1.57
Playing the game was easy.	3.71	1.48
Playing the game was difficult.	1.83	1.11

Table 10. Descriptive statistics for items examining the perceived suitability of the game (5 = completely agree).

5.4.4 Findings

Based on the results, we conclude that institutionalized older adults generally enjoy engaging in full-body interaction games, and that the garden-themed game design presented in this chapter appealed to the audience. When comparing the results of this study to those of study one, it becomes clear that providing an adaptable calibration routine largely contributes to the accessibility of full-body motion-control for institutionalized older adults and enabled participants to engage in play regardless of individual impairments. However, results also show that most participants could not participate in free play on their own. This lends itself to the conclusion that free play is not suitable for elderly without prior gaming experience. For most of our players, recalling gestures was too challenging on their own. While proper game tutorials for institutionalized older adults remain to be explored in future work, one possible solution might be to introduce longer training periods for all gestures or designing game mechanics that suggest gesture affordances. For example, picking apples from a tree would trigger a known gesture and might be an easier game mechanic. Also, some of the participants seemed to be more alert and awake during the second part of the study, while others were less engaged. Therefore, an individual gesture adaptation is not only necessary to accommodate different players but also to account for the age-related within-player variances that we have observed in these studies.

5.5   Discussion

The work presented in this chapter looks specifically at the challenges of designing full-body motion-controlled games for institutionalized older adults. In the previous sections, we have demonstrated the need for specific considerations when designing motion-based games for elderly. In this section, we discuss the significance of our observations during the studies, the

need for adaptable gestures and adaptable gesture systems, and the positive effect that gesture-based games may have on the emotional well-being of institutionalized older adults.

5.5.1 Full-Body Motion-Controlled Gaming for Elderly

With a growing number of senior citizens, games may contribute to their well-being in full-time care, as physical activity is crucial for well-being in old age. Yet, certain problems and limitations have to be considered.

Implementing Games for Older Adults Using Kinect

When we compare gesture-based interaction using the Kinect to that of other gesture-based interfaces, the Kinect has clear benefits over the competition. Compared to other devices such as the Nintendo Wii Remote or PlayStation Move controller, the lack of a handheld controller becomes a clear advantage. The use of the Kinect allows for more natural interactions, and frees designers from the worry of arthritic hands holding a controller. Players (who are not familiar with traditional handheld controllers in the case of institutionalized older adults) are able to interact with the game directly. The lack of controllers can (if designed correctly) simplify the interaction, and allow for more natural mappings, which ease the entry into play if institutionalized older adults lack gaming experience.

Motion-Based Game Design for Older Adults

Our research results show that the elderly can interact with games, enjoy playful activities and have the desire to stay more active, which can be supported by video games. However, common game design practices balance the challenge of a game around the abilities of younger players, and diverse physical and cognitive abilities of older adults make the use of commercially available games problematic. Therefore, gestures used in such games must be adaptable to facilitate all player types.

Based on the results of study one, we found that it is important to individually calibrate games according to a player's needs. Most Kinect games require players to stand, have use of two arms and legs, good vision, quick reactions, and knowledge of the interaction with video games. Therefore, current generations of full-body motion-controlled games are inaccessible not only to institutionalized older adults but to many players, e.g., children experiencing mobility disabilities. One of the main issues is that commercially available games only calibrate games according to player position to optimize tracking results. We believe that this calibration process

has to be augmented to provide an inclusive approach towards motion-based game design. By implementing a calibration routine that considers individual player abilities, we provide a means of including broad audiences in motion-based gaming. In study two, we demonstrated that this approach offers the opportunity of allowing older adults to engage with digital games, and we believe it may be useful for general audiences to adapt games to individual player skills.

5.5.2 Gesture Design and Adaptability

The results of our two studies revealed three main implications for gesture design for institutionalized older adults. 1) Static gestures were generally easier to perform and may therefore be more suitable because the movements are limited and the durations can be carefully controlled. Dynamic gestures, while still viable, put older adults at an increased risk of overexertion. Generally, both gesture types work if systems for older adults scale to their abilities. 2) Player range of motion, strength and general agility influence the interaction process. Systems need to focus on recognizing few, well-defined user actions instead of supporting a large number of gestures. Difficulties experienced by participants during our study illustrate the need for forgiving recognition mechanisms. 3) Being able to intuitively relate to everyday actions was highlighted as a positive aspect and increased the ability of participants to complete movements. It was also beneficial when describing interaction paradigms and instructing players. However, there is a risk of restricting motion controls too much. If controls are reduced too far then interaction becomes limited – insufficient motions remain to keep players from becoming bored. It falls to designers to carefully balance the needs of players and interactions.

5.5.3 Effects of Motion-Controlled Games on Older Adults

When we combine the potential cognitive and physical benefits of full-body motion controls, the large potential of games having a positive effect on institutionalized older adults is revealed. Perhaps the most valuable outcome from our studies was the positive effect playing video games had on the mood of the participants. In both studies, we found that participants enjoyed the experience of playing the game by indicating a more positive affective state. A prolonged positive affective state leads to an overall increase in positive mood [46]. Players who have a positive experience are more likely to continue to play, and return at a later point. In this context, it is important to highlight that we understand games as a means of supplementing the

life of older adults. To preserve positive effects, we recommend applying games as a gateway to new experiences rather than a replacement of other leisure activities.

5.6   Future Work

After our first investigation of motion-controlled full-body interaction for institutionalized older adults, many research questions remain to be addressed by future work. Most importantly, future work on motion-based game interaction for institutionalized older adults should investigate inclusive game design for older adults with mobility disabilities. Our studies revealed that camera-based systems such as the Microsoft Kinect sensor can be problematic for persons using wheelchairs, and that a significant group of older adults in residential care does use wheelchairs on a daily basis. To allow them to fully benefit from motion-based video game play, it is crucial to examine the design of wheelchair-accessible motion-based games that can accommodate their needs. Additionally, research should explore on-screen instruction for institutionalized older adults. Our results suggest that it is likely that institutionalized older adults will generally respond more positively to guided experiences. Future studies will explore this question in greater detail to determine whether it is possible to design games for independent play. Furthermore, an evaluation of possible benefits of engaging with full-body motion-controlled games is necessary with a focus on the investigation of positive cognitive and physical effects. In terms of game design for older adults, we plan to implement the gesture set presented in this chapter into an ad-hoc game for nursing homes designed to engage residents for a longer period of time.

5.7   Conclusion

Older adults in nursing homes frequently lead sedentary lifestyles and therefore experience a reduced quality of life leading to decreased life expectancy. Video games offer the opportunity of motivating institutionalized older adults to become more active. Over the past few years, there has been an increase in motion-controlled video games, which hold the promise of engaging users in physical activity. However, there has been little research regarding the design of motion-controlled games for diverse audiences, resulting in little understanding of how to ensure that interaction techniques are functional for older adults. Our work is a first step in this direction. Through our study of motion-control for institutionalized older adults, we have exposed the limitations of current design philosophies and highlighted design opportunities to

facilitate the creation of accessible motion-controlled video games. If full-body motion-controls are to enjoy the same acceptance as other interaction techniques, we must ensure that games and other entertainment technologies remain an accessible and enjoyable activity for all audiences, including older adults.

CHAPTER 6

WHEELCHAIR-BASED GAME CONTROLS FOR OLDER ADULTS

Related publications:

Gerling, K., Kalyn, M., and Mandryk, R. 2013. KINECTWheels: Wheelchair-Accessible Motion-Based Game Interaction. CHI 2013 Extended Abstracts, Paris, France.

Gerling, K., Mandryk, R., and Kalyn, M. 2013. Wheelchair-Based Game Design for Older Adults. Proceedings of ASSETS 2013, Bellevue, WA, USA. Best Student Paper Award.

More than half of Canadians over the age of 65 in residential care use wheelchairs [148]. Research has shown that the use of wheelchairs severely affects the functional independence of older adults, and limits their opportunity of participating in physical activity, leading to low levels of perceived health [22] and sedentary lifestyles. This puts older adults using wheelchairs at a particularly high risk of suffering from *sedentary death syndrome* [163]. To address this issue, it is important to provide physical activity and leisure activities [22], but only few remain accessible to older adults using wheelchairs. As the previous chapter has outlined, motion-based video games are a promising design opportunity for this audience: research has shown that games can provide cognitive and physical stimulation [1] and have a positive effect on the emotional well-being [68] of institutionalized older adults. However, our results also show that the accessibility of motion-based games for older adults using wheelchairs is limited (due to limitations of tracking algorithms and few upper body gestures used as input), and additional considerations are necessary to allow older adults using wheelchairs to obtain the full benefits of such games [68].

To explore the use of wheelchair-based input in motion-based games for older adults, we implemented the KINECT^{Wheels} toolkit [67], which allows us to track wheelchair movements using the Microsoft Kinect sensor. Using KINECT^{Wheels}, we then evaluated the feasibility of wheelchair-based game input in a controlled study. Based on the results, we created Cupcake Heaven, a motion-based video game designed for older adults that integrates wheelchairs. In a final study, we evaluated the accessibility of, interaction with, and resulting player experience of Cupcake Heaven with eight older adults regularly using wheelchairs. Our results show that Cupcake Heaven is accessible to them, and that they enjoy playing motion-based games,

suggesting that games are a suitable means of providing physical stimulation for older adults using wheelchairs. This part of the thesis makes three contributions: 1) we show that wheelchair movements can be recognized and interpreted as input to a game using the KINECT^{Wheels} toolkit; 2) we demonstrate that wheelchair-based interaction is suitable for older adults, and that motion-based games can be designed in a way that makes wheelchair input both accessible and enjoyable; and 3) we highlight design opportunities for wheelchair-based games for older adults and for applications beyond entertainment.

An increasing number of older adults live in nursing homes, many of whom depend on walking assistance. Providing stimulation through enjoyable leisure activities is an important step in improving their cognitive, physical, and emotional well-being. Our research can inform the work of game designers and encourage the creation of motion-based video games that address the specific needs of institutionalized older adults. On a general level, applying assistive devices as an enabling technology for game play offers the opportunity of allowing players to view their assistive device in a new light. Besides providing cognitive and physical benefits, this may encourage players to develop a positive relationship with their assistive device, focusing on its advantages rather than limitations.

6.1   Related Work

In this section, we provide an overview of previous approaches towards integrating wheelchairs in HCI, and we summarize findings regarding motion-based video games for older adults that hold implications for wheelchair-based game design.

6.1.1   HCI Research Involving Wheelchairs

Human-computer interaction has explored the use of wheelchairs from different angles. The following section gives an overview of wheelchair interaction, and wheelchair-based game controls.

Wheelchair-Based Interaction

Work in the field of wheelchair-based interaction has a strong focus on accessibility; prior research has primarily focused on how people interact with their electric wheelchairs. Felzer and Freisleben [50] present HaWCoS, a system that proposes including information on muscle contractions rather than hand-based input to navigate the environment using a wheelchair. Likewise, Hinkel [78] suggests the integration of head movements to control

electronic wheelchairs to allow for hands-free interaction with other devices. In contrast to these approaches that aim to make the wheelchair itself more accessible, another line of work focuses on applying the wheelchair as an input device to increase the accessibility of other systems, such as computers. Wobbrock et al. [178] investigate how joysticks of electric wheelchairs can be applied as text entry solutions to facilitate the interaction process by allowing persons using wheelchairs to apply their wheelchair as the input device, rather than using additional technology.

Wheelchair-Based Game Interaction

Research has also explored the integration of electric wheelchairs as a computer game input device. Rossol et al. [140] propose a framework that implements electric wheelchairs as a game input device; based on this, they design virtual training scenarios to support rehabilitation and wheelchair training by encouraging people to become more familiar with their assistive device. Hasdai et al. [75] evaluated this type of virtual environment using electric wheelchairs as the input device, and showed that wheelchair-based game input can improve participants' driving skills. They concluded that wheelchair-based game input can be valuable for supporting wheelchair navigation skills.

In contrast to these approaches that focus on the integration of electric wheelchairs into video games, the GAME^{Wheels} [52] system allows for the use of manual wheelchairs as an input device. The authors designed a custom metal structure that wheelchairs can be mounted on to track basic wheelchair movements. An evaluation of their system [128] showed that the system produced significant levels of energy expenditure, creating opportunities for physical activity. However, the two major limitations of their approach are that it requires custom-designed hardware that is not available to the general public, and that the system does not explicitly focus on the needs of older adults. In our work, we address these issues by using the Microsoft Kinect sensor to recognize wheelchair input – a commercially available, low-cost camera-based tracking system that has been shown to be a suitable input device for motion-based video games. In addition to supporting wheelchair-based input, our system supports body-based gestures to broaden the range of player input available to this particular audience.

6.1.2   Motion-Based Games for Older Adults

Motion-based game interaction for older adults has unique challenges because of the special characteristics of the target audience; this section summarizes age-related changes and impairments, as well as motion-based game design for older adults to inform the design of wheelchair-based games.

Age-Related Changes and Impairments

Particularly regarding the ability of navigating wheelchairs, it is important to consider the negative impact of age on strength and stamina [87], reduced movement control, and longer reaction and overall movement times [39]. When designing wheelchair-based controls, it is important to understand the impact that age-related decrements may have on older adults' abilities of navigating manual wheelchairs. It is not only important to ensure the general accessibility of interfaces by accommodating a variety of abilities and accounting for age-related changes that influence interaction, but it is also important to ensure that interaction paradigms are safe and do not put older adults at risk of injury from excessive strain.

Motion-Based Game Controls for Older Adults

A growing number of projects focus on the development of accessible motion-based applications for older adults with the goal of providing physical and mental stimulation [49], e.g., for people living in nursing homes. Full-body motion-based games usually require players to be able to stand without assistance and move around in the room freely. Examples include the virtual dancing environment DanceAlong by Keyani et al. [88], and motion-based mini games by Rice et al. [137]. Both games require players to be able to stand without assistance; while DanceAlong strongly focuses on foot-based input, the mini games proposed by Rice et al. primarily require upper limb interaction. In the previous chapter, we present an initial design of a motion-based game that is accessible to older adults who use assistive devices. Older adults are invited to play a gesture-based gardening game that is accessible to people playing either while standing or sitting in a chair. Likewise, many games that were designed to support physical therapy for older adults (e.g., [12]) are accessible for persons using wheelchairs as they can be played while sitting.

Research addressing full-body motion-based game controls for older adults has the challenge of how to allow for wheelchair-accessible interaction while still providing sufficient

levels of physical activity. In this context, researchers need to overcome current limitations of motion-based games for older adults by providing additional input gestures to allow players using wheelchairs to fully experience motion-based gaming and receive the exertion-related benefits of motion-based play. Our work aims to address these limitations by combining wheelchair input with upper body gestural game interaction. Using the KINECT^{Wheels} toolkit [67], we develop and evaluate Cupcake Heaven, a wheelchair-based video game for older adults that features both wheelchair-based and gestural game input.

6.2   Study 1: Developing Camera-Based Wheelchair Interaction

KINECT^{Wheels} [67] is a toolkit that facilitates the integration of wheelchair input at the development stage using the Microsoft Kinect sensor. In study one, we evaluate the feasibility of wheelchair input using our system to inform the design of wheelchair-based game controls for older adults.

6.2.1   *The KINECT^{Wheels} System*

The KINECT^{Wheels} system is a software library written in C# based on the Microsoft Kinect SDK that allows developers to easily and quickly add interactivity to their programs. KINECT^{Wheels} provides the data from the official Microsoft Kinect SDK, as well as extra gestures that help take advantage of the movements that a wheelchair can make. Data available from the Kinect SDK are all the joint positions of the skeleton and raw image data (colour and depth). The new gestures the KINECT^{Wheels} system provides include the direction the wheelchair is pointing, a gesture for quick movements to the left and right sides as well as the front and the back (**Table 11**).

	Wheelchair Input	**Body Input**
Gesture 1	Move forward	Clap hands
Gesture 2	Move backward	Raise left arm
Gesture 3	Turn left	Raise right arm
Gesture 4	Turn right	Lift legs

Table 11. Overview of wheelchair-based and body-based input supported by KINECT^{Wheels}.

As shown in **Table 11**, KINECT^{Wheels} also detects traditional full-body motion-based gestures, including: clapping hands, raising the left and right arm, and lifting the legs. Once a gesture is recognized, the toolkit allows for a variety of actions, including sending keystrokes that represent the gestures to the operating system so that third-party programs (including those implemented in Flash, OpenGL, and XNA) can be controlled using KINECT^{Wheels}.

Case Study: XNA Racing Game

In order to assess whether KINECT^{Wheels} can be used for game input, we combined the toolkit with an XNA racing game that allowed us to test basic interaction paradigms (Figure 6). In the game, players control their car using wheelchair movements (**Table 11**). Common procedures were mapped onto wheelchair movements in the following way: To speed up, the player has to move the wheelchair towards the camera. To slow down, the player has to move away from the camera. In order to steer to the left or right in the game, the player has to turn the wheelchair to the corresponding direction.

The results of preliminary user tests show that players can control the car using wheelchair input and that players enjoy the interaction process, but that a more detailed analysis of tracking rates and gesture completion times is necessary to provide insights into design requirements for wheelchair-based video games.
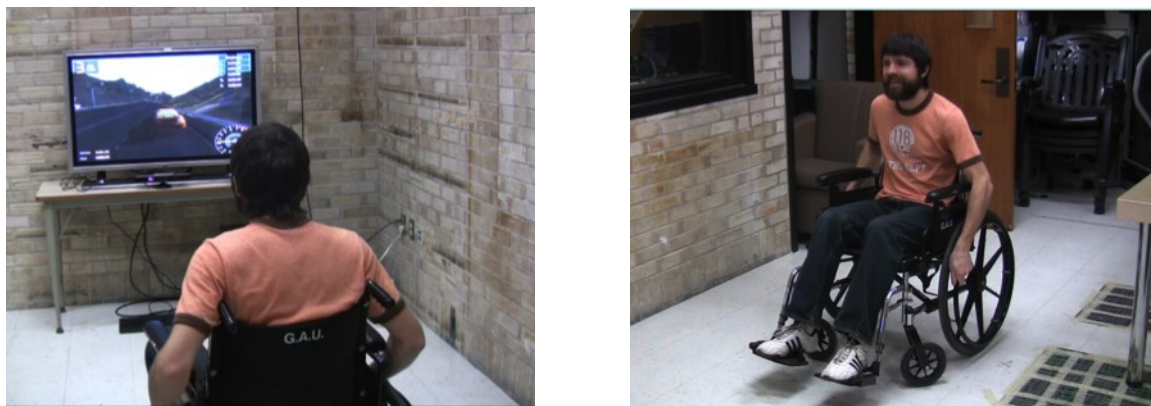
Figure 6. A person interacting with KINECT^{Wheels}.

6.2.2 System Evaluation

To determine whether the KINECT^{Wheels} gestures and their recognition rate are appropriate for game input, we integrated the gesture set into an analysis tool. We were

interested both in the general suitability of the approach, and potential differences between body-based and wheelchair-based game input.

Gesture Analysis Tool

We created a gesture analysis tool based on KINECT^Wheels in order to determine whether wheelchair-based input can be applied in an efficient and enjoyable way (**Figure 7**). Based on findings from the two studies presented in the previous chapter, we prompted users to complete wheelchair- and body-based movements (**Table 11**). Instructions were provided through images and descriptions. During the interaction process, performance metrics were recorded. Metrics include gesture type, gesture sequences, completion times, and gesture recognition rates. The analysis tool was implemented in C#, using the Microsoft Kinect SDK 1.5 and Game Studio 4.0.

Participants and Procedure

Although our goal is to design for older adults, we used younger participants in this study. Our primary interest was in the feasibility of the system (i.e., tracking and recognition accuracy); we did not want to put older adults at risk of injury using a system that had not been evaluated regarding safety concerns and physical demand (e.g., whether users could navigate the wheelchair in the small area visible by the Kinect sensor). Because the metrics of interest in this study are the relative completion time and recognition rate of different gestures, we feel confident that a preliminary investigation with younger people will help to guide an informed design that can then be evaluated with older adults. Twelve participants (6 female) with an average age of 25.67 years (SD=4.01) took part in the evaluation. All participants were right-handed and reported no motor impairments that could have influenced their ability to navigate a wheelchair. None of the participants had prior experience using a manual wheelchair, but all of them had played motion-based video games, seven having previously used the Kinect sensor.

At the beginning of the study, participants filled out a consent form and were asked to provide demographic information. Once participants felt confident using the wheelchair, they were given an overview of the recognition tool. Then, participants were asked to complete two sets of body-based and wheelchair-based input to familiarize themselves with the system. Next, participants were asked to complete two different gesture sets consisting of different combinations of wheelchair-based and body-based input. Finally, participants were asked to complete the NASA-TLX [169] and the ISO 9241-9 questionnaire on device comfort [44] to

investigate the cognitive and physical challenges when using a wheelchair as an input device as well as the differences between wheelchair-based and body-based input. The evaluation ended with open questions on participants' perception of wheelchair-based interaction.

Gesture	Tracked	Missed	%
Clap hands	53	19	73.6
Raise left arm	70	2	97.2
Raise right arm	68	4	94.4
Lift legs	35	37	48.6
Move forward	72	0	100
Move backward	72	0	100
Turn left	63	9	87.5
Turn right	62	10	86.1

Table 12. Tracking results (number of tracked, missed, percentage) per gesture (72 repetitions per gesture).

Results – Performance

We tracked performance metrics to evaluate the recognition rates and timing of wheelchair- and body-based gestures. Only the last two data sets for each participant (combination of wheelchair- and body-based input) are included in the analysis. We present descriptive statistics in this section and only perform statistical tests when warranted.

Figure 7. Screenshot of the gesture recognition tool instructing the user to turn to the left.

Participants performed a total of 576 gestures; 495 gestures were recognized correctly by the system. Hence, the overall recognition rate was 85.9%, with rates being lower for body-based gestures (78.5%) than for wheelchair-based gestures (93.4%) – see Table 12. Recognition rates for the clapping gesture and leg lift were low due to the technical difficulties of trying to recognize user input in front of participants' bodies; results for all other gestures consistently exceeded an accuracy of 85%. Completing a gesture generally took 2-3 seconds, with body-based gestures taking 2471 milliseconds, and wheelchair-based gestures requiring 2581 milliseconds – see Figure 8. To investigate whether gesture completion time was influenced by the preceding gesture, we performed a repeated-measures ANOVA and found no difference in gesture completion times (body versus wheelchair) when following a wheelchair-based gesture ($p=.081$), but that body-based gestures following a body-based gesture are faster ($p<.001$) than wheelchair-based gestures that follow a body-based gesture ($F_{1,11}=18.9$, $p=.001$, $\eta2=.632$).

Results – Questionnaires

The results of the NASA-TLX and ISO-9241-9 questionnaires provide further insights into the perceived cognitive load and device comfort. We included a post-intervention questionnaire to investigate whether participants enjoyed wheelchair interaction. Comparisons between wheelchair- and body-based gestures were made using paired-samples t-tests.

Descriptive results for all questionnaires are provided in Table 13. The composite score [74] of the NASA TLX showed that the cognitive load was significantly higher for wheelchair-based movements than for body-based input ($t_{11}=2.61$, $p=.024$). In addition, we considered the subscale for physical demand, which showed that participants perceived wheelchair-based gestures as more demanding than body-based input ($t_{11}=2.43$, $p=.034$), which is supported by results of the ISO-9241-9 questionnaire ($t_{11}=3.46$, $p=.005$), particularly when participants were asked about fatigue ($t_{11}=2.69$, $p=.021$). However, we did not find significant differences for general comfort ($t_{11}=-0.23$, $p=.082$) and ease of use ($t_{11}=-0.69$, $p=.504$). This suggests that participants consider wheelchair-based gestures more physically challenging, but are still satisfied with overall comfort. This is backed by results regarding fun that show no difference between wheelchair- and body-based input ($t_{11}=1.77$, $p=.104$).
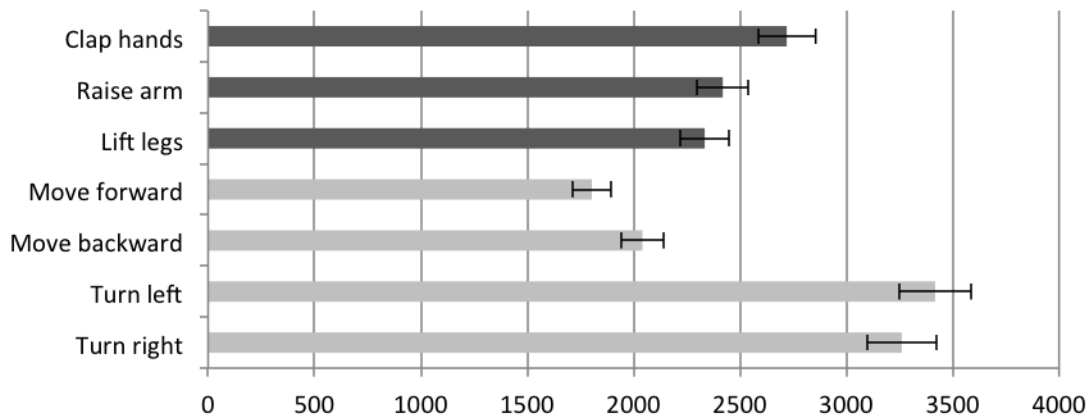
Figure 8. Average completion time per gesture in milliseconds (CI = 95%).

	Item	Wheelchair	Body
NASA-TLX	*Composite score*	51.17(21.35)	28.67(15.35)
	Physical demand	8.67(4.54)	4.50(3.75)
ISO-9241-9	*Composite score*	30.08(3.58)	25.42(3.53)
	General comfort	3.75(0.97)	3.83(1.12)
	Ease of use	4.00(0.74)	4.17(0.72)
	Fatigue	8.17(3.27)	5.50(1.17)
Post-game	*Fun*	4.17(0.94)	3.50(0.91)

Table 13. Mean (SD) results for the TLX (20 point scale, composite score 0-120), ISO (5 point scale) and post-game (5 point scale, 5 = strongly agree) questionnaires.

When asked about general problems, participants reported that raising their legs while sitting in the wheelchair was challenging: "*Lifting the legs during the body based input was physically demanding, especially while sitting in the wheel chair and trying to establish a good seating position to do the movement.*" Participants sometimes found it difficult to return to a neutral position after gesture completion: "*A large part of the stress of performing the task was trying to get back to the same position before starting the next movement*", which corresponds to experimenter observations that were made during the evaluation. In general, comments showed that participants perceived body-based input as more intuitive, but considered wheelchair-based input to be more enjoyable: "*Body based input seems to be more natural, and easier to control.*" – "*The wheelchair based input was more fun and engaging than the body based input.*".

Findings

In this section, we interpret our results, which can inform the design of wheelchair-based game controls for older adults. Our results for the KINECT^{Wheels} tracking accuracy show a trade-off between achieving high tracking rates and offering a broad gesture set; both of which can affect player experience. If tracking rates are too low, players may experience frustration, whereas a small gesture set may cause boredom. Our results suggest that body-based input was more problematic than wheelchair-based input, with recognition rates being particularly poor for gestures that were performed in front of the player's body. However, recognition rates for other types of input were acceptable, and the negative effects of lower tracking rates on player experience can be minimized by appropriate design decisions, e.g., by applying well-recognized gestures to frequent or crucial game events.

Average completion times of around 2.5 seconds per gesture show that participants were able to interact with the system, and that input was fast enough for use in an interactive system. However, designers need to consider time differences between gestures (e.g., moving the wheelchair back and forth is faster than turning it to the sides) and individual players. Our results show that the previous gesture type (wheelchair or body) affects gesture completion time; participants generally required more time when following up on wheelchair-based input as this required them to readjust their hands or deal with movement momentum that had built up. This dependence should be considered when designing input sequences: designers can either combine gestures in a way that increases challenge, or allow users to refocus by introducing sequences of easily combined gestures. Finally, games should consider how to support players when returning to a neutral position after gesture completion. This could be achieved through the inclusion of on-screen menus to help users remain within a certain range of the sensor.

When interpreting our results, it is important to consider how they would extend to usage by older adults. Based on our findings regarding full-body motion-based game interaction for older adults presented in the previous chapter, we expect that older adults would require more time to complete gestures than younger adults, and that tracking accuracies might be lower given the smaller range of motion of older adults. However, we would not expect to see different patterns in our results among older adults due to age-related changes.

6.3   Study 2: Wheelchair-Based Game Controls for Older Adults

To follow up on the results of our first study, which showed that wheelchair-based interaction is generally safe to use and suited for interactive systems, we apply the results of study one in the context of older adults to inform the design of the wheelchair-based game Cupcake Heaven. Using the game, we conduct a second study to validate the feasibility of wheelchair-based input in the context of interaction design for older adults, and explore how the gesture set can be integrated into wheelchair-based video games that are accessible and enjoyable for older adults.

6.3.1   *The Cupcake Heaven Video Game*

To investigate the feasibility of wheelchair-based game input for older adults, we created Cupcake Heaven (**Figure 9**), a game in which players are invited to collect candy and pass it on to a girl. To increase the challenge, players have to avoid collecting vegetables, and the girl changes location, either being displayed on the right or left side of the screen. The game implements body-based and wheelchair-based input; it aims to encourage users to move around in their wheelchair. We implemented the game in C# using the Microsoft Kinect SDK 1.5.1, Microsoft Game Studio 4.0, and the KINECT$^{\text{Wheels}}$ toolkit.

Wheelchair-Based Game Input

Based on the results of study one, we identified a set of wheelchair-based and body-based gestures that were well recognized by the system, and that we expect to be easy to learn for older adults.

There are two lanes in the game – one on the top of the screen and one on the bottom. Candy and vegetables flow left-to-right through the top lane and the bottom lane. In order to pick up candy from either of the two lanes, players are asked to move the wheelchair forwards and backwards, which moves the virtual hand up and down respectively. Intersecting the hand with a food item automatically picks it up. The game only allows for vertical movements to facilitate simple interaction; players are not expected to adjust their horizontal position to pick up candy. To pass on candy to the child, players have to lift their arm on the side at which the child is currently displayed; this will dispatch the item. If players wish to discard an item that they collected, they have to clap their hands. We decided to implement this gesture using an improved tracking algorithm, because results from Chapter 5 suggest that clapping is particularly easy for

older adults, and because there is little negative impact in the game if the clapping gesture is not quickly recognized.

In order to accommodate the various abilities of older adults, the pacing of Cupcake Heaven can be adapted. This includes changing the speed at which candy passes by to allow users to take more time to make a selection, as well as longer availability of the child before she moves to the other side.

6.3.2 Evaluation

In the evaluation, we applied Cupcake Heaven to examine the feasibility of wheelchair-based game input for older adults.

Participants and Procedure

We carried out our study in collaboration with Brightwater Senior Living and Sherbrooke Community Centre in Saskatoon, SK, Canada. Ten older adults (four males) participated in the evaluation. Data from two participants were removed from the study (in one case, tracking difficulties were caused by a non-removable tray mounted on the wheelchair, another participant withdrew after the introduction). The average age of the remaining participants was 75 years (SD=5.53). All participants used manual wheelchairs, with three of them having used a wheelchair for more than ten years, four having used wheelchairs for one to three years, and one participant having used a wheelchair for two months. Three participants had had a stroke that lead to hemiplegia, and one participant was diagnosed with cerebral palsy.

After giving consent, participants provided demographic information. Next, participants were given time to familiarize themselves with the wheelchair and the environment, and were introduced to Cupcake Heaven in a short tutorial. Then, participants were asked to play the game for about ten minutes, each level of the game lasting three minutes. Finally, participants were asked to complete the NASA-TLX [74] questionnaire and the portions of the ISO 9241-9 [44] questionnaire on device comfort that investigates physical fatigue to assess their experience using the wheelchair as a game input device. In addition, participants were asked to rate their overall experience with the game and answer interview questions on its content, input gestures, and the overall play experience.

Figure 9. Overview of Cupcake Heaven, a wheelchair-accessible motion-based game for institutionalized older adults.

Results

Are wheelchair-based video games suitable for older adults? Our results show that all participants were able to interact with Cupcake Heaven. During each three-minute level, players interacted with an average of 10.19 (SD=2.77) game items (candy or vegetables), picking them up and either releasing them by lifting their arm, or discarding them by clapping their hands. Out of these items, an average of 2.76 (SD=1.12) were fed successfully to the child. Other items were discarded, represented the wrong kind of item (vegetable), or were fed at a time when the child was not present. Participants reached an average score of 475 (SD=237.44). In terms of player experience, results of the post-game questionnaire show that participants reported positive levels of fun (Table 4). When asked about their detailed experience with the game and their opinions on applying a wheelchair as input device, participants pointed out that they enjoyed playing games with their wheelchair: "*It was fun. I like challenges.*" – "*I enjoyed using my motor skills.*" – "*It was mentally and physically stimulating*". Observations support the notion that participants enjoyed the game, with some players getting excited about collecting candy or moving along with the background music.

Can wheelchair-based game controls provide cognitive and physical stimulation for older adults? Findings from our study suggest that wheelchair-based game controls challenge older adults physically and cognitively, but are manageable on an overall level, suggesting that it is possible to strike a balance between challenging and thus engaging players, and keeping players from experiencing undue stress and fatigue.

	Item	Mean (SD)
NASA-TLX	*Composite score*	47.38(15.95)
	Physical demand	9.38(5.21)
ISO-9241-9	*Composite score*	13.50(1.41)
	General comfort	3.50(1.07)
	Ease of use	3.38(0.92)
	Fatigue	1.33(0.47)
Post-game	*Fun*	3.63(1.41)

Table 14. Mean (SD) results for the TLX (20 point scale, composite score 0-120), ISO (5 point scale) and post-game (5 point scale, 5 = strongly agree) questionnaires.

The results of the NASA-TLX questionnaire (Table 14) show that the cognitive load of older adults interacting with Cupcake Heaven was at an average level, and that it produced a medium level of physical demand. This is supported by results of the ISO 9241-9 questionnaire (**Table 14**) that show that the system was rated as relatively easy to use and comfortable. In contrast to the results of the NASA-TLX, items of the ISO questionnaire investigating physical fatigue report low levels of physical demand. These findings need to be interpreted along with observations that were made during the study, which contradict subjective ratings for fatigue that were made through the ISO questionnaire; many participants seemed to be challenged by the system and became increasingly tired throughout the gaming session (heavier breathing, individual comments on physical exertion). This suggests that wheelchair-based video games have the potential of providing much needed physical exertion for institutionalized older adults. Participants recognized this opportunity and highlighted the benefits of physical activity made accessible through the game. One participant pointed out that the game helped him see the wheelchair in a different light, commenting that the game gave him "*the idea that you can use the [wheel]chair for something other than sitting on it*". Other participants explicitly commented on using video games to be physically active: "*It is good for me [to be active], I did track and*

field when I was young, and I played tennis and basketball." – "If you played it for half an hour, you'd get some exercise.".

How can our results help inform future projects integrating wheelchair controls into video games for older adults? Observations and questionnaires revealed further insights into how participants interacted with Cupcake Heaven that can help inform future design efforts.

While all participants could interact with the system on a basic level, some persons experienced difficulties coordinating multiple movements when moving back and forth, and simultaneously trying to drop off candy. We observed large differences in participants' abilities of controlling their wheelchairs, and the speed at which they were able to navigate. Along these lines, some participants paid close attention to moving their wheelchair, being unable to follow simultaneous in-game events. Sometimes, participants would leave their arm up in the air after successfully discarding an item, triggering undesired input. Some participants needed frequent reminders of possible in-game actions and seemed to experience difficulties coordinating their movements.

In terms of in-game behaviour and coping with challenges, some participants showed difficulties remembering to collect candy while avoiding vegetables, sometimes leading to frustration when feeding an item to the child did not trigger the expected response. In contrast, one participant pointed out that she did not find Cupcake Heaven stimulating enough, and that she would have preferred a more complex game: "*It wouldn't be a game I'd play very often, I'd find it boring*", highlighting that it would be more fun in a multiplayer setting: "*It might be more fun to play with somebody else*". Another participant explicitly commented on the way input was integrated, stating that she "*found it tiring when [she] went back and [the avatar] didn't start moving right away*".

This outlines a core challenge future research will have to address: Although many institutionalized older adults use wheelchairs, they use the assistive device for a variety of reasons (e.g., short-term recovery from illness, life-long disabilities, or recent age-related changes), and are a diverse audience in cognitive and physical abilities, and overall familiarity with their wheelchair.

6.4   Discussion

This chapter investigates wheelchair-based game controls for older adults. In the first part of our work, we demonstrate that it is possible to integrate wheelchairs into motion-based

interaction, and we present our toolkit KINECT$^{\text{Wheels}}$. Based on the findings, we present Cupcake Heaven, a wheelchair-based game specifically designed for older adults. In the remainder of this chapter, we discuss the implications of our findings for future work and show how it can be applied to increase the quality of life of older adults.

6.4.1   Wheelchair-Based Game Controls

Designing motion-based game controls that allow for the integration of wheelchairs is a promising way of making motion-based video games accessible for people who use wheelchairs. However, there are certain limitations of the presented approach.

Wheelchair-Based Input Gestures

In our research, we demonstrate that wheelchair-based interaction can be applied in an efficient and enjoyable way, which opens up new opportunities for designers, allowing them to integrate wheelchairs as game controls. Our evaluation of the gesture set presented in section 6.2.2 holds several implications for wheelchair-based interaction design. It shows that it is possible to combine wheelchair-based input and body-based gestures to obtain a range of input gestures broad enough to allow for sufficient complexity in game design. Additionally, results show that completion times differ per gesture, suggesting that designers have to carefully consider the pacing of their games to allow players to transition between gestures (e.g., changing from wheelchair to body input) while also accounting for momentum that wheelchairs build (as our results showed that gestures following wheelchair input are generally slower than sequences of body-based interaction). Since wheelchair-based gestures require the use of the hands to move the wheelchair, designers have to take into account that wheelchair-based gestures and hand gestures cannot be performed at the same time. The fact that participants reported that wheelchair-based input was more physically demanding than body-based input, but equally comfortable as body-based gestures suggests that this may be a way of introducing physically challenging motion-based games for persons using wheelchairs.

Technical Limitations

In the design and evaluation of KINECT$^{\text{Wheels}}$ and Cupcake Heaven, we encountered several technical challenges related to the design of camera-based wheelchair interaction. A core challenge during the implementation of KINECT$^{\text{Wheels}}$ was that turning the wheelchair more than 45 degrees caused a loss in recognition. While we were able to achieve acceptable tracking

results for turning to the sides through the application of additional algorithms, turning the wheelchair backwards or spinning around is not possible using the current implementation. Additional challenges arise depending on the way designers wish to integrate KINECT^{Wheels}: because images provided by the Kinect can be noisy, including the absolute position of the wheelchair for precise player input is difficult, and designers should consider including a dead-zone similar to joysticks when working with the position of the chair. Likewise, adjustments have to be made if the system is interfacing with other applications using keystrokes; additional algorithms may need to be applied to imitate keyboard input (e.g., repeatedly pressing a button). Finally, moving around the floor space is inherent in wheelchair gestures, and designers have to create games in a way that helps keeping the user within the view of the sensor, e.g., asking players to move forward multiple times needs to be counter-acted with a move backward so that players do not leave the tracking area.

6.4.2   Wheelchair Games for Older Adults

The evaluation of Cupcake Heaven shows that older adults can successfully engage with wheelchair-based video games. This opens up new opportunities for introducing cognitive and physical stimulation to older adults using wheelchairs, particularly care home residents. Our results show that participants not only enjoyed wheelchair-based interaction, but that actively applying the wheelchair as a means of controlling a game also helped them reflect on the way they use their assistive device in daily life. Wheelchair-based games could encourage persons who have only recently started to use a wheelchair to develop a positive relationship with it, helping them to apply it to increase their quality of life rather than regarding it as a limitation of their independence. As a game input device, the wheelchair can be viewed as an enabling technology, rather than a restricting one. In the context of wheelchair-based game design, a challenge that needs to be addressed is adaptive game design for heterogeneous audiences. Even among institutionalized older adults living in the same care unit, we observed differences in cognitive and physical abilities, influencing the way these individuals approached the game. These differences extended beyond the basic accessibility of the user interface and general pacing of the game; while simplistic mechanics and a casual approach towards gaming are suitable for some players, they may not keep the interest of others.

6.4.3 *Wheelchair Skills Training for Older Adults*

In terms of applying the work presented in this paper to improve the quality of life of older adults, the development of wheelchair skills is a crucial step in encouraging older adults to embrace their assistive device and maintain a high degree of functional independence. However, many older adults only start using a wheelchair in late life, and experience difficulties in developing a positive relationship with it. Wheelchair training is a promising opportunity that has been shown to be effective with younger age groups [145]. Older adults are encouraged to participate in occupational therapy to become familiar with their wheelchair; however, this requires access to a therapist and can be tedious. Wheelchair-based game controls could provide in-home wheelchair skills training; if input gestures are designed to support therapy goals, game-based interventions could help older adults become more familiar with their wheelchair. Such games could help players' abilities of navigating their environment, increase their functional independence, and thereby improve their quality of life.

6.5 Conclusion

Our work can help designers to build upon the abilities of players using wheelchairs rather than making limited subsets of existing motion-based interaction paradigms accessible. Because of the increasing popularity of motion-based video games, it is important to encourage the inclusion of wheelchair-accessible control schemes to allow persons using wheelchairs to participate in play and obtain the full benefits of motion-based video games. In that context, we believe that wheelchair-based video games are a valuable opportunity of encouraging physical and cognitive activity among older adults. Besides the immediate benefits of playing motion-based video games, the integration of wheelchair movements has the potential of improving older adults' relationship with their assistive device, increasing their abilities of using wheelchairs to independently navigate their environment, and contributing to their quality of life.

CHAPTER 7

DESIGN GUIDELINES FOR MOTION-BASED GAME INTERACTION FOR OLDER ADULTS IN LONG-TERM CARE

This chapter summarizes findings from the previous chapters and concludes this part of the thesis by providing design guidelines for motion-based game interaction for older adults in long-term care. Based on Chapter 5, general recommendations for the implementation of motion-based game controls for institutionalized older adults are provided that can help designers wishing to gain first insights into such technologies for older adult audiences. Based on Chapter 6, the thesis provides detailed guidelines for the design of full-body motion-based game interaction in games for older adults with mobility disabilities, particularly those using wheelchairs.

The guidelines are designed to foster safe physical activity among older adults, and can help game designers to improve the accessibility of motion-based video games by mindfully designing for players with mobility disabilities and other age-related changes.

7.1 Guidelines for Full-Body Motion-Based Game Controls for Institutionalized Older Adults

The results of chapter five show that accounting for the needs of institutionalized older adults in full-body game interaction requires considerations regarding their physical and cognitive abilities on various levels.

In this section, we propose seven guidelines for the design of full-body gestures for institutionalized older adults (Table 5) to support designers when creating entertainment software for nursing home environments. Each guideline addresses a specific problem in full-body game interaction for institutionalized older adults that we found during our studies or that was derived based on findings from the studies. Along with every guideline, we provide additional information on how it relates to the individual needs of institutionalized older adults, and we suggest possibilities of addressing the biggest design challenges.

In contrast to other work in the field of guidelines for activity motivating games for institutionalized older adults by Gerling et al. [72], which addresses high-level issues, our guidelines focus on the interaction process and provide detailed information regarding the most

common interaction problems that we discovered during our studies. There are some similarities between our work and the guidelines for games for motor rehabilitation by Flores et al. [53], who recommend games that adapt to the motor skill level of players and the implementation of a therapy-appropriate range of motion. However, they do not elaborate on how those goals can be achieved, and this information is provided by the guidelines presented in our paper. Further work by Gerling et al. [73] on the design of games for institutionalized older adults highlights the importance of meaningful metaphors on a general level, which we map onto full-body gaming.

Some of our guidelines relate to those provided by Norton et al. [127], who highlight the importance of player recall of in-game interaction options as well as accounting for player fatigue in game design. The guidelines presented in this paper expand on those aspects and elaborate on how they can be applied to interaction design for older adults.

7.1.1 Guideline 1: Age-Inclusive Design

Create inclusive games by embracing age-related physical and cognitive impairments. Institutionalized older adults frequently experience ailments that prevent them from moving all of their limbs, which can severely influence the interaction process. Systems should account for this issue by including gestures that adapt to the player's individual impairments, e.g., by offering gestures that can be carried out using either one or both arms. Furthermore, the impact of cognitive changes has to be considered, e.g., by offering simpler game structures.

7.1.2 Guideline 2: ROM-Adaptability

Create interaction paradigms that adapt to individual differences in player range of motion. Institutionalized older adults often suffer from a reduced range of motion that limits their ability of engaging in full-body interaction. To account for this issue and to prevent injury, full-body interfaces for institutionalized older adults should be calibrated according to individual player abilities. Because limitations in player range of motion also lead to large differences in gesture execution, recognition in games for institutionalized older adults should feature a bigger tolerance in gesture execution instead of requiring a high level of precision for successful recognition.

7.2.3 Guideline 3: Exertion Management

Provide fatigue management and prevent overexertion by appropriate game pacing. Due to the prevalence of sedentary lifestyles, institutionalized older adults often have a reduced

stamina level and are much more prone to movement based injury and overexertion. Games need to manage player fatigue through appropriate pacing, e.g., alternation of physically intense and less challenging game periods that allow players to relax and recover. Depending on the degree of player frailty, challenging periods should be shortened while relaxing game tasks can be extended. Reminders to take a break (or shutdown of the game) depending on the player's overall level of fitness should be integrated to avoid overexertion.

7.2.4   Guideline 4: Dynamic Game Difficulty

Offer difficulty adjustments between players and individually scale challenges. Games need to adjust to a large range in ability from one institutionalized older adult to another to allow for the appropriate level of activity and challenge to keep more active players engaged while avoiding overstraining others by dynamically adjusting the level of difficulty to player ability. Also, individual performance levels of institutionalized older adults change daily. Games need to account for this individual variability by dynamically adapting challenges for returning players instead of introducing a gradual increase of in-game challenges as the game progresses.

7.2.5   Guideline 5: Easy Gesture Recall

Provide natural mappings and clear instructions that support gesture recall to empower players. Many older adults have no prior experience playing games or being instructed through a computer screen, and are dependent on other persons for assistance when engaging in play. To address this problem, all instructions should be very clear and use common language. It is important to avoid the inclusion of information that is not crucial for play, e.g., additional GUI elements. Additionally, actions should be explainable using diagrams and simple on-screen demonstrations. To further support gesture learning and recall, in-game actions should map closely to real world activities. Games should not require players to recall a gesture; instead, players should be reminded of possible actions by affordances of in-game events, e.g., raising one's arm as an item appears at the top of the screen rather than raising one's arm to trigger another action.

7.2.6   Guideline 6: Continuous Player Support

Integrate continuous tutorials and player prompting to facilitate gesture learning and interaction. Much attention must be given to the training of institutionalized older adults. Extended tutorials are required to ensure that players are given time to learn the skills needed to

play the game. This includes learning how to play the game in general and understanding how to use gestures to interact with it in particular. It is important that tutorials for gesture learning relate to previous knowledge to facilitate the acquisition of new skills and are repeated throughout gameplay to remind users of their options. Some older adults suffer from a reduced attention span that makes it difficult to follow an activity over a longer period. To grasp their attention, games should visually and audibly prompt the user if no interaction is detected. Also, it should not be assumed that players are capable of knowing when actions are required; they should constantly be prompted for correct input.

7.2.7   Guideline 7: Simple Setup Routines

Implement easy menus, startup and shutdown routines to encourage independent play. Technical knowledge cannot be assumed from either institutionalized older adults or nursing staff. Therefore, games must be easy to set up and run, but must also facilitate take down and cleanup. Due to the unfamiliarity that many institutionalized older adults have with this form of technology, the traditional traversal of a menu structure cannot be assumed as common knowledge.

7.3   Guidelines for Wheelchair-Accessible Motion-Based Games for Older Adults

While the previous set of guidelines can be applied to create generally accessible motion-based games for older adults, addressing the large group of institutionalized older adults using wheelchairs creates additional challenges. In order to create wheelchair-based video games for older adults, it is important to account for the impact of age-related changes and impairments on wheelchair-based game interaction and beyond. Based on the previous set of guidelines and findings regarding wheelchair-based game design presented in Chapter 6, we suggest three main areas in which existing guidelines should be extended to better match the design of accessible wheelchair-based game interaction for older adults.

7.3.1   Wheelchair Guideline Extension 1: Intuitive Mappings of Wheelchair Input

Easy gesture recall should be supported by full-body input through the implementation of natural gesture mappings, e.g., by building on movements that players can relate to real-world actions. In the context of wheelchair-based interaction, integrating the wheelchair in a way that helps participants relate wheelchair input to in-game actions could help facilitate gesture recall. An example of an intuitive mapping is applying the wheelchair in a racing game, encouraging

players to move forward to speed up, move back to break, and turning the chair to the sides to make turns in the game.

7.3.2   Wheelchair Guideline Extension 2: Consider Effort Required to Move Wheelchair

Adapting to player range of motion is important when designing upper body gestures to go along with wheelchair-based input. Furthermore, *adapting to player strength* is important, because the evaluation of KINECT[Wheels] showed that wheelchair input is perceived as more physically demanding than body-based input, and older adults experiencing age-related changes may experience difficulties when repeatedly using their upper body to navigate the wheelchair. *Exertion management* is another aspect that needs to be considered when integrating wheelchairs into the interaction process. Designers need to keep in mind that wheelchair movements require more effort, and are slower than body-based input; an aspect that has to be considered in the pacing of the game, and when determining the frequency at which certain types of input are required.

7.3.3   Wheelchair Guideline Extension 3: Design for Novice Wheelchair Users

Age-inclusive design is necessary to embrace special characteristics of the target audience. Regarding wheelchair-based game interaction for older adults, it is important to keep in mind that many older adults are novice wheelchair users who have limited experience with their assistive device. Designers should account for this aspect by carefully designing wheelchair-based interaction into their games, slowly increasing the difficulty and frequency of input in order to allow players to become more familiar with their assistive device.

7.4   Conclusion

This chapter provides general design guidelines for motion-based video games and an extended set of guidelines for wheelchair-based game input for institutionalized older adults. Both sets of guidelines are informed by the results of studies presented in Chapters 5 and 6.

The first set of guidelines demonstrates how interaction paradigms need to be adapted to better meet the needs of older adults, particularly persons living in long-term care who generally experience higher levels of age-related changes and impairments. They focus on general physical and cognitive abilities of this target audience and account for lower levels of technology literacy among today's older adults. Furthermore, our work shows that adapting design guidelines for

motion-based video games for older adults is possible to help inform designers who wish to create wheelchair-based games, particularly focusing on the additional challenges that older adults using wheelchairs experience when interacting with motion-based video games. In this context, results of Chapter 6 show that wheelchairs can add an additional layer of complexity, calling for careful considerations and balancing of in-game challenges during the design process beyond the application of design guidelines.

This outlines a general issue that needs to be addressed when designing for institutionalized older adults. Results of our studies show that older adults are a highly heterogeneous audience with large individual differences in physical and cognitive abilities. These differences within certain groups of older adults (e.g., persons using wheelchairs) or between individuals come with a set of unique design challenges (e.g., foot-based input being unsuitable for persons using wheelchairs) that can only be partially addressed by the guidelines presented in the first part of this chapter. The extended guidelines for wheelchair-accessible motion-based game input for older adults presented in the second part of this chapter demonstrate the extent to which general guidelines need to be adapted for special user groups; similar considerations would be necessary if designers would like to design motion-based games for other groups of older adults with special needs, e.g., persons who had a stroke earlier in their lives [12], or persons with Parkinson's disease [10, 11].

Therefore, design guidelines can only serve as a first starting point when trying to create motion-based games that meet player skills and abilities, particularly when designing for older adult audiences with little previous gaming experience and a wide range of age-related changes and impairments. In this context, following a user-centered, iterative design process that involves the target audience at an early stage of development to adapt interaction paradigms and game mechanics to their abilities is a crucial step to fully address the needs of institutionalized older adults, and to design games for them that are equally safe, accessible, and enjoyable for them.

PART III: APPLYING MOTION-BASED GAMES FOR OLDER ADULTS IN LONG-TERM CARE

This chapter aims to address core challenges outlined in chapter three (the impact of age-related changes on the physical and cognitive abilities of older adults) by building on the results of the first part of this dissertation and by examining design challenges specific to the design space of long-term care (i.e., older adults in home care, and institutionalized older adults living in care facilities). It provides an overview of two research projects designed to investigate motion-based game design for older adults, each of which addresses one of the challenges: The first study presents results of a long-term study examining the integration of motion-based video games in different types of long-term care facilities, comparing how older adults living in senior residences, and institutionalized older adults in care homes approach video games. The second project builds on the social benefits of video game play. It synthesizes findings suggesting that games encouraging social interaction have a positive effect on the emotional well-being of older adults, and combines it with the work presented in this thesis by focusing on the application of motion-based video games in the caregiving context to improve the relationship between older adults and their caregivers.

CHAPTER 8

LONG-TERM PLAYER MOTIVATION IN MOTION-BASED GAMES

Related publication: Gerling, K. and Mandryk, R. Considerations for the Long-Term Deployment of Motion-Based Games in Residential Care. Submitted to TACCESS.

The study presented in this chapter investigates whether older adults consider video games an enjoyable leisure activity over a longer period of time, which is an important step towards assessing their suitability as interventions in physical therapy and rehabilitation. Building on one of the core challenges identified in Chapter 3, the study compares two populations of older adults; one group living at a senior residence, and one group living in a long-term care facility. Results suggest that age-related changes in cognitive and physical abilities of older adults have a strong impact on their interaction with motion-based games, their preferred context of play, and the amount of assistance they require during setup and gameplay. Based on these findings, this chapter provides strategies for the design and deployment of video games for older adults in long-term care.

While a wide range of work focusing on motion-based video games for older adults is available (see Chapter 2), much work in human-computer interaction explores motion-based games for older adults with a focus on accessibility and short-term player experience (see Chapter 3). As a result, little is known about the long-term engagement of older adults with video games. This issue is partially addressed by long-term studies looking at potential benefits of video games for older adults that often require participants to play games over several weeks (e.g., [8] and [154]). Researchers tend to conclude that games may provide older adults with a stimulating leisure activity that can be carried out independently [123], which means that it could be conducted for a low cost and without requiring significant personnel investment from the care facility due to the self-directed nature of play. Because many of these studies are carried out within a tightly controlled research context, their ecological validity in terms of providing insights into how older adults would engage with games outside the research context – i.e., without encouragement of investigators, and without the continuous support of staff – is limited. If games are to benefit older adults in senior residences and care homes in the long run, it is crucial to understand how games can be adapted to be deployed in residential care facilities, and

how they can be designed to encourage the independent participation of residents. This would allow older adults to benefit from play as an activity that is not dependent on the availability of staff, potentially empowering them and encouraging them to regain independence, rather than introducing new access barriers that might lead to negative experiences.

In our work, we approach the issue by studying how older adults play video games 'in the wild'. We develop four motion-based mini-games specifically addressing the needs of institutionalized older adults, and we introduce weekly video gaming sessions over a period of three months to older adults in two representative environments – at a senior residence and at a care home. We invite residents to play our custom games, along with commercially-available motion-based video games, in a group setting, and we investigate how both groups of older adults engage with the games and the other residents participating in the sessions.

Our results contrast previous research suggesting that commercially available video games may be an easy means of providing self-directed cognitive and physical stimulation for broad groups of older adults. Instead, we show that cognitive and physical abilities within the group of older adults living in residential care have a large impact on the way they adopt video games, that instruction and support are essential for fostering an enjoyable gaming experience, and that not only games, but also the gaming context, needs to be adaptable to suit older adults with a wide range of cognitive and physical abilities. In this context, our results suggest that considerations beyond the accessibility of games and their short-term player experience are necessary to provide meaningful mental, physical, and social stimulation for institutionalized older adults that can keep them engaged over a longer period of time. While our study shows that video game play can be enjoyable and engaging for older adults regardless of cognitive and physical abilities, it also outlines that gaming experiences for older adults in residential care need to be carefully crafted towards individual needs to allow players to truly benefit from video game play outside the research context.

Studying how older adults interact with video games beyond tightly controlled research settings in an important step towards developing a more realistic view on the potential benefits and risks of video gaming in residential care. This is necessary to ensure that games deployed in residential care meet the needs of players and have the potential to increase quality of life.

8.1 Related Work

Related work has examined interactive technologies for older adults from different perspectives. In this section, we summarize existing research efforts addressing the deployment of interactive technologies in residential care, and we examine video games that were tested with or designed for institutionalized older adults.

8.1.1 Deploying Technology in Residential Care

The deployment of information technology in residential care has previously been examined regarding its potential of supporting older adults and their caregivers [105], and providing entertainment for older adults in nursing home environments [25, 122].

Technology to Facilitate Caregiving and Assisted Living

Regarding the deployment of technologies for older adults who receive care, technologies to facilitate caregiving and to support assisted living are an important area. Much work in the field of human-computer interaction has focused on improving the caregiving process [37], for example, by deploying information technology to monitor older adults and thereby support caregivers [92], or the development of systems in the field of ambient-assisted living that aim to help older adults maintain independence, e.g., applications to help them follow medication routines [90].

Technology to Connect and Entertain

In contrast, other researchers have focused on the deployment of technology to improve the quality of life of older adults in residential care by fostering mental, physical and social activity. Blythe et al. [25] report on the deployment of four interactive interventions in a care home in the UK that were designed to stimulate older adults by enhancing their awareness of their surroundings, such as Video Window, a monitor connected to a camera on the roof of the home to give residents new views on the building and the areas around it. The authors show that playful applications can foster socialization between older adults and across generations by providing *tickets to talk* (i.e., opportunities for people to talk), and they outline the importance of carefully exploring the design space by spending time in the care home environment to better adapt technical solutions to the needs of residents. Along these lines, Müller et al. [122] highlight the importance of accounting for the care home context and report on a qualitative study addressing the deployment of a large-screen display in a German care home. Their findings

support results by Blythe et al. [25], suggesting that technology can help older adults connect with each other and staff members, however, they also outline core challenges, such as carefully exploring the care facility to design appropriate interventions. Finally, Lindley et al. [105] present a literature review that specifically explores the potential of technology to support social relationships of older adults. In their work, they show that information technology can be applied to help older adults maintain relationships with family members and friends, and they outline play as one of the main areas of interest in human-computer interaction for older adults.

8.1.2   *Video Games for Institutionalized Older Adults*

Building on the promising design opportunities that playful interaction could offer for older adults in residential care, first efforts have been made to investigate the use of video games for this audience. In this context, deploying video games in residential care has been approached from three perspectives: (1) looking at how older adults interact with commercially available games; (2) the design of video games particularly addressing the needs of institutional older adults from the perspective of human-computer interaction; and (3) the deployment of video games for older adults with goals beyond entertainment, e.g., in physical therapy and rehabilitation.

Deploying Commercially Available Games

Regarding the deployment of commercially available games in care facilities, researchers have focused on potential benefits of video game play on the emotional well-being of institutionalized older adults. A six-week study by Jung et al. [84] in which 45 institutionalized older adults participated in gaming sessions showed that video game play had a significantly higher positive impact on participants' overall well-being than traditional board games. Marston et al. [110] present a review of long-term studies that deploy commercially available video games in residential care. Their summary shows that such games have the potential of fostering social interaction and improving the emotional well-being of older adults in residential care despite problems related to the usability and accessibility of commercially available games. In this context, previous studies (e.g., [69]) also bring up problems regarding the accessibility of games that were initially designed for younger players, suggesting that further research is needed to create games that older adults can engage with regardless of the impact of age-related changes and impairments.

Creating Accessible Game Interaction

Research in human-computer interaction has addressed game design for older adults in residential care. In Chapter 5, we investigate the design of motion-based game interfaces for older adults, focusing on full-body gesture-based input for institutionalized older adults; in Chapter 6 we examine wheelchair-accessible game controls. While the work provides insights regarding the short-term player experience of institutionalized older adults as well as general considerations associated with game design for older adults in long-term care – e.g., the prevalence of age-related changes and impairments and its impact on motion-based interaction – the evaluations provide little insights into the long-term use of motion-based games among older adults in residential care.

Games for Therapy and Rehabilitation

A research area that partially bridges this gap is the application of video games for therapy and rehabilitation. Among others, Alankus et al. [5] and Balaam et al. [12] explore the application of games and game technologies in stroke rehabilitation. Results of user studies spanning several weeks suggest that games have the potential of increasing exercise motivation among older adults. Likewise, Smeddinck et al. [154] show that game-based approaches are a valuable means of engaging older adults with Parkinson's disease in phyiscal therapy over a longer period of time, and research by Anguera et al. [9] shows that long-term engagement with video games can improve cognitive functioning in older adults. In these studies, older adults' continued engagement with games is likely influenced by the research context (and resulting focus on the potential benefits of video game play), therefore giving limited insight into how players would interact with games beyond participation in a research study, and how older adults in residential care would gain access to these games without the support of researchers.

On a general level, previous work has paid little attention to special design considerations that are necessary if technologies are to be deployed in residential care over a longer period of time [25, 105]. Additionally, little is known about the long-term gaming behaviour of institutionalized older adults in less controlled environments, raising the question of whether they would be willing to play video games over a longer period of time outside a tightly controlled research setting. However, this is a core question that needs to be answered to assess the overall value of video games for institutionalized older adults, as continuous engagement

with games without substantial support of nursing staff or researchers is an important step towards independently gaining the benefits of play.

In our work, we aim to address this issue by exploring how older adults in residential care approach video games in an in-the-wild setting to obtain information on how they interact with games, what their long-term gaming behavior looks like, and how designers can best accommodate the needs of institutionalized older adults wishing to play video games by accounting for age-related changes as well as the special characteristics of long-term care facilities.

8.2 Long-Term Gaming Behaviour of Older Adults in Residential Care

To study long-term gaming behaviour of older adults in residential care, we created a set of motion-based casual games for older adults and selected two commercially available motion-based games to examine their use in a long-term study following an in-the-wild approach, in which we deployed our games in a less controlled setting at care facilities to examine whether and how older adults would integrate games into their daily lives.

8.2.1 Games to Study the Long-Term Gaming Behaviour of Older Adults

Both the custom-designed and commercially available video games are motion-based, using the Microsoft Kinect sensor as the input device.

Custom-Designed Mini-Games

We created four mini-games to be included in our study. Games were designed to be accessible to older adults without prior gaming experience, and are based on real-world activities that players were likely to be familiar with.

Design rationale. Research on casual exergames [61] and casual games for health [65] has shown that simplistic, easily accessible game concepts are particularly suited for audiences with little gaming experience and in gaming situations where players cannot engage with games over a longer period of time, which are aspects that are also relevant when designing games for older adults in residential care. This goes along with considerations for the design of motion-based games for institutionalized older adults presented in Chapter 7 of this dissertation, highlighting the importance of accounting for age-related changes and the development of accessible interaction paradigms. Furthermore, De Schutter and Vanden Abeele [146] outline the importance of creating games that relate to experiences from the daily lives of older adults.

Graphical design decisions are in line with research by Smeddinck et al. [153], suggesting that casual games that provide short chunks of play for older adults need not feature elaborate graphics, which is in line with findings on graphical fidelity in games for other audiences [64].

Overview of the games. Based on these considerations, we developed four motion-based mini-games. *Candy Kids* and *Prairie Hunter* are games that require pointing input and in which players have to make time-based input, e.g., moving the crosshair over an animal in *Prairie Hunter*. *Cooking Challenge* and *Harvest Time* are gesture-based games in which players can complete in-game challenges by applying a set of three gestures. All games can be played in single-player mode or competitive multiplayer mode.

Figure 10. Screenshots of the games applied in this study: Prairie Hunter (top, left), Candy Kids (top, right), Harvest Time (bottom, left), and Cooking Challenge (bottom, right).

In *Candy Kids*, players have to feed a child different types of candy: items move across the upper area of the screen and can be fed to the child by moving the player avatar (represented by a virtual hand) over the food at the same time. Challenge is created by switching the location of the child after each round of feeding, and by including items of different value. *Prairie Hunter* invites players to set out on a virtual animal hunt. In order to increase their score, they have to hunt as many animals as possible. This is achieved by moving the crosshair over of the animal. Challenge is created as animals appear in different locations and at different times: bigger

animals result in a greater score, but they appear less frequently, while smaller animals appear repeatedly for a short time. Both Candy Kids and Prairie Hunter use *pointing input*, where the player's hand controls an avatar within the game.

In *Cooking Challenge*, players have to prepare a salad. Ingredients are presented in the central area of the screen and have to be cut into pieces by imitating chopping movements and then pushed into the bowl by extending one's hand to the front. Once all ingredients are added, they have to be mixed, which can be achieved by the imitation of a mixing gesture. *Harvest Time* invites players to cut down an apple tree using the same chopping gesture as in the previous game, then shake the tree by moving one's hand left and right until an apple drops, and handing the apple to a girl who appears on screen by extending one's arm to the front. Both Cooking Challenge and Harvest Time implement gesture-based input that tries to mimic some of the real-world actions associated with the content of the games.

All games were implemented in C# using Microsoft XNA Game Studio 4.0, and are played using the Microsoft Kinect. Our implementation invites players to use their strong hand to perform gestures and pointing actions to control the avatar. Games were designed to start up automatically once one or more players approach the screen to reduce setup routines.

Commercially Available Games

We included two commercially available games in our study. Both games are played on the Microsoft Xbox 360 and use the Kinect sensor as input device. Games were selected to represent casual Kinect gaming, and because the utilized input paradigms were likely to be partially accessible to older adults.

Kinect Sports. Kinect Sports offers a range of mini games that are based off traditional sports. In our study, we included Kinect Sports Bowling, a bowling simulation that is controlled by imitating real-world motions associated with bowling, e.g., swinging one's arm back and to the front to throw the ball. The game supports up to four players and allows for quick turn-taking similar to the actual sport.

Kinect Adventures. Kinect Adventures is a full-body motion-based video game that consists of a number of mini-games in which players are invited to apply their whole body to overcome in-game challenges in outdoor and fantasy settings. Games can be played in single player mode or with a partner; gameplay usually lasts for a couple of minutes.

Both games use the Microsoft Kinect sensor as input device, if games are controlled with hand gestures, users are invited to use their strong hand.

8.2.2 Case Study: Exploring the Long-Term Gaming Behaviour of Older Adults in the Wild

We conducted a field study to investigate how older adults in residential care apply video games in their daily lives.

Study Design

The presented study is a long-term approach towards understanding the gaming behaviour of older adults in residential care. It was conducted with the support of two care facilities: (1) a senior residence where older adults receive some assistance in their daily lives (e.g., optional meal plans) and are given the opportunity of participating in organized activities (e.g., fitness classes and excursions), but where residents are generally independent and active. (2) a nursing home that provides extensive care for its residents (full-care environment including meal plans, organized activities, and personal care) and caters to older adults experiencing severe age-related changes and impairments.

At each of the facilities, we offered a weekly supervised gaming session over the course of three months. In total, older adults had the opportunity of participating in twelve supervised gaming sessions. In addition, we invited participants to engage with the games outside the gaming sessions to understand how video games could be deployed in an unsupervised context, and whether games could serve as self-directed activity. At the senior residence, supervised gaming sessions were paused for a month after the first two months to study whether older adults would still engage in weekly play regardless of the availability of an instructor. We had planned to follow the same scheme at the nursing home, but were unable to do so because of the level of support required by participants. At the beginning of the study, we assessed the cognitive and physical fitness of participants and collected demographic information. At the end of each month, older adults participated in a focus group interview to reflect upon their gaming experience.

Participants and Setting

At the senior residence, gaming sessions were hosted in a community room first and moved into the fitness room during the course of the study. Games were displayed on a 40" TV

screen, player input was tracked using the Kinect sensor. Participants played the games without using assistive devices to support their mobility. At the nursing home, gaming sessions were hosted in a media room. Games were displayed on a 46" TV screen, player input was tracked using the Kinect sensor. All participants played the games while sitting in wheelchairs.

Sixteen older adults (nursing home: six participants, one female, senior residence: ten participants, 7 female) participated over the course of the study. Participants were recruited with the help of staff (social director and volunteer coordinator). At the nursing home, the average participant age was 73.5 (SD=4.18). All participants required walking assistance and were using wheelchairs. Average scores for the Mini Mental State Exam (MMSE) were at 13.3 points (SD=1.86), suggesting that all participants experience significant cognitive impairments. Only two participants had prior video game experience, mainly focusing on casual games. At the senior residence, the average participant age was 79.2 (SD=4.80). Four participants used walkers, however, all of them were able to play the games without assistance. One participant used a wheelchair. Average MMSE scores of 27 (SD=2.33) showed that none of the participants experienced significant cognitive impairments. Two participants had prior gaming experience playing casual games on the computer or iPad.

Measures

We included a range of measures to study how older adults interacted with the games, what their perceptions of the gaming sessions were, and how their cognitive and physical abilities influenced their participation in gaming sessions.

Session attendance and game use. We tracked how many gaming sessions older adults participated in, and whether they engaged with any of the games outside the supervised gaming context.

Performance logging. We logged player scores throughout the study to gain insights into the development of player performance over time, and to compare performance of players at the senior residence and nursing home.

Assessment of Physical Fitness and Cognitive Abilities. Physical fitness of participants was assessed based on their ability of walking independently, and the use of mobility assistance (canes, walkers, wheelchairs). Cognitive abilities were assessed using the Mini-Mental State Exam (MMSE) [54], a test designed to assess the cognitive abilities of an individual. It includes questions about the participant's current location, time, and date (e.g., "What is today's date?"

and "What city are we in?"), spelling and counting (e.g., spelling the word "world" backwards), the recall of information (e.g., recalling three previously mentioned words), as well as drawing and writing tasks (e.g., copying two intersecting pentagons, and spontaneously writing a sentence).

Player Experience Measures. Focus group interviews addressed the accessibility and usability of the games as well as player experience in the context of residential care. Questions were designed to investigate the perceptions of video games among older adults (e.g., "What are your thoughts on our four games that you played during the past month? Did you enjoy playing them, or was there anything that you did not like?"), and to examine which factors encouraged continued participation in weekly gaming sessions (e.g., "Did you mostly play the games by yourself, or did you play with others?").

Research Questions

By applying the following measures, we try to answer the following research questions:

1. Were the gaming sessions suitable for all participants?
2. Are there differences in session attendance between older adults living in senior residences and nursing homes?

We include these questions to investigate whether our games and the gaming context was accessible for all study participants. Furthermore, we are interested in the level of assistance that is necessary to allow older adults to participate in video game play.

3. What are older adults' motives for continued participation in gaming sessions?
4. What are reasons for dropping out of gaming sessions?

We ask these questions to investigate which characteristics of the participants and features of our games led to continued participation in gaming sessions to provide insights into video games that are suited for players in residential care.

8.2.3 Results

We organize our results based on our research questions. We report both quantitative and qualitative results and then provide explanations of our findings. Qualitative results (interviews and observations) were analyzed using a coding scheme focused on the research questions.

Were the gaming sessions suitable for all participants?

Choice of games. We included both commercially available as well as custom-built games in our study to investigate their suitability for older adults in residential care. Performance metrics for the set of custom-designed mini-games suggest that all games were accessible to both groups of players. Players at the nursing home were unable to gain access to the set of commercially available games due to the impact of age-related changes (e.g., use of assistive devices, hemiplegia) and the complexity of games, which is in line with findings reported by [69]. Participants at the senior residence were able to interact with both Kinect Sports Bowling and Kinect Adventures independently after short periods of instruction and only required assistance during setup (e.g., help navigating through menu structures).
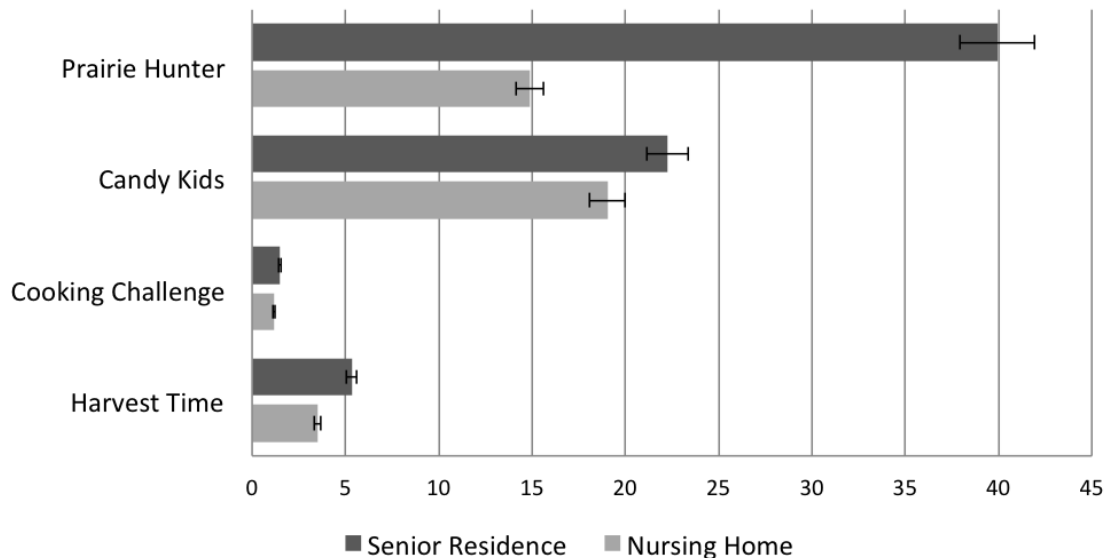
Figure 11. Average player scores for the custom-designed mini-games (CI=5%). Scoring systems are adapted to each of the games, Prairie Hunter and Candy Kids yield higher scores by design.

Regarding the appeal of the games included in the study, participants generally found them enjoyable and appealing, pointing out that "*it's fun to do something physical*" (P2, senior residence). When asked about differences between the games, players at the senior residence pointed out that the custom-designed mini-games were appropriate to get more familiar with video games, but that the long-term appeal of more complex commercially available applications was bigger, which is also reflected by their choice of games throughout the gaming sessions

where participants increasingly requested to play Kinect Sports Bowling. This suggests that the benefits of specifically designing games for older adults in residential care increase along with the impact of age-related changes and impairments experienced by players, but that games need to provide enough depth to keep players engaged over a longer period of time.

Group setting of gaming sessions. Gaming sessions were held in a group setting to give participants the opportunity to experience multiplayer games. Attendance rates (**Figure 12**) and interview results suggest that this format generally appealed to residents of the senior residence: Participants highlighted that they enjoyed the opportunity to meet other residents, and that competing with other players added interest to the gaming sessions, pointing out that "*it's being involved that feels good*" (P8, senior residence) and that "*it's good fun to be together and participate*" (P3, senior residence). In this context, some participants noted that they would have been more comfortable learning how to play games without the presence of others, stating they felt as if "*everybody was watching, you know they are there*" (P3, senior residence); however, learning to play in a group had the advantage that more experienced players frequently offered help for less experienced players.

In contrast to this generally positive perception, the group setting caused major problems for participants living at the nursing home: participants found it extremely difficult to learn how to play games in front of a group and were self-conscious about their ability to play games, suggesting that you "*gotta work your way into the games, then it's okay [to play with others]*". Additionally, all players were using wheelchairs and had difficulties independently navigating the room, therefore, swapping between players required more time and sometimes caused frustration among waiting participants, with two participants specifically pointing out that they would prefer individual gaming sessions. Finally, communication between participants at the nursing home was limited as a result of different age-related impairments (e.g., hearing difficulties among some participants and the inability to speak clearly among others), which may have further increased the generally negative view on group gaming sessions. To address this issue, we adapted the layout of gaming sessions at the nursing home for the second and third month of the study, offering individual opportunities to play games instead of group sessions.

Duration of gaming sessions. Group gaming sessions were scheduled to last one hour; participants at the senior residence reported that the length was appropriate and sometimes continued playing after the supervised session ended because it fit into the overall schedule at the

residence (e.g., participating in another round of bowling before lunch). Participants at the nursing home pointed out that they found it difficult to maintain interest in gaming sessions for a full hour (see previous section). Individual gaming sessions during the second and third month at nursing home lasted an average of 14 minutes (SD=5.59) with participants being invited to play for a maximum of twenty minutes. Observations and participant comments suggest that individual sessions led to higher levels of fatigue due to the physical nature of the games; in this context, turn-taking in group settings may be an advantage as it introduces breaks from play.

Are there differences in session attendance between older adults living in senior residences and nursing homes?

Development of attendance of supervised gaming sessions over time. Figure 12 shows attendance rates at both institutions. As with previous studies [110], we show that initial participation rates are high. In the first few weeks, attendance rates for the nursing home were over 80%. However, the results also show that participation rates drop after an initial spike in participation during the first month when residents were invited to play. In contrast to developments at the nursing home where participation stagnated in the last month, participation rates at the senior residence remain stable during months two and three, with about 50% of the initial number of participants being present at the sessions. Overall, participants at the senior residence attended an average of 7 out of 12 gaming sessions (SD=4.51). Participants at the nursing home attended an average of 5 out of the 12 sessions that were offered (SD=3.27). At both facilities, we observed a fluctuation of participants, with participants dropping out for one or more sessions, but attending at least two sessions a month. At the senior residence, two participants only joined the group after the first month, having learned about the activity from other residents.

Support needed to participate in gaming sessions. To understand the level of support participants required to successfully attend gaming sessions, we analyzed three different aspects of the gaming sessions. Regarding basic session attendance, participants at the senior residence needed no assistance other than readily available information on the schedule (i.e., advertisements of the sessions in the monthly program), and occasional reminders that a session was about to start. In contrast, participants at the nursing home needed extensive assistance to be able to attend the gaming sessions.
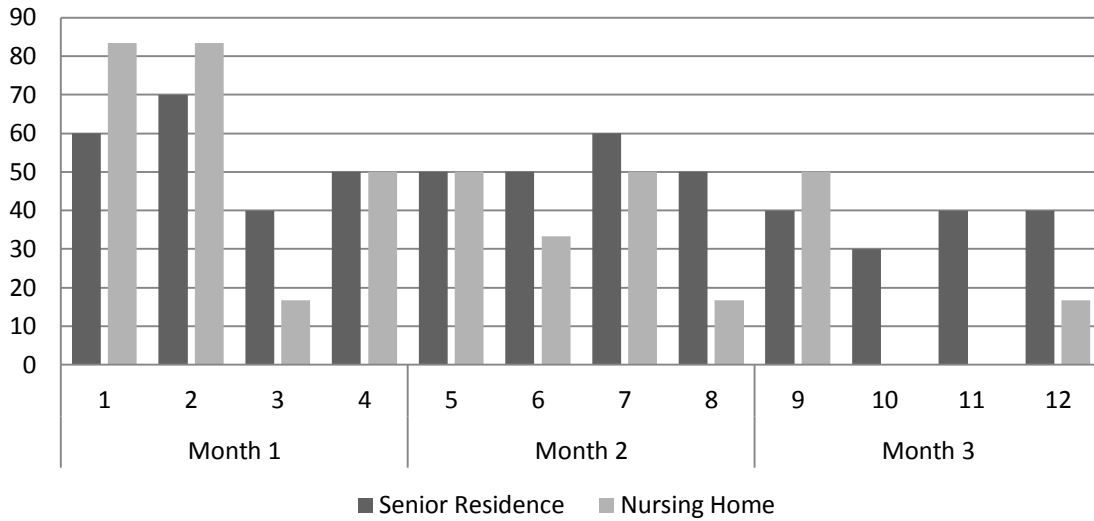
Figure 12. Attendance rates of supervised gaming sessions (in percent per week) at the senior residence and nursing home. Note that between month two and three, participants at the senior residence engaged in a month of unsupervised play.
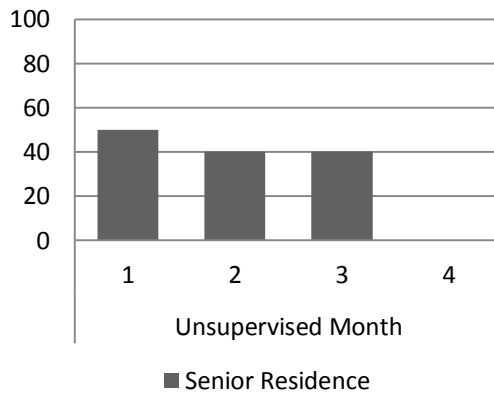
Figure 13. Attendance rates of unsupervised gaming sessions (in percent per week) at the senior residence, held between month two and three of the supervised sessions.

Apart from reminders prior to session start, staff needed to be available to help participants make their way to the media room; sometimes, participants needed help transferring into their assistive device to be able to leave their room. In terms of setting up games, both groups of participants needed assistance starting the gaming systems and navigating game menus. While participants at the nursing home also needed continuous help during gameplay (e.g., reminders of available interactions, or the rules of the game), players at the senior residence

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were able to recall how to interact with different games after an introductory period in the first month of the study, one participant explicitly stating that "*if [the game] is on, we're good to go*".

Engagement with games outside the context of supervised sessions. At the senior residence, we offered one month of unsupervised gaming sessions (between the second and third month of supervised play) where participants were invited to play games without the assistance of a facilitator in order to explore the potential of games to serve as a self-directed leisure activity. Figure 13 shows that participation rates remained near 50% during the month of unsupervised play if gaming sessions were advertised on the monthly program, and games were set up by a staff member (3/4 sessions). However, participants did not attend if nobody was available to assist (1/4 sessions). At the nursing home, this part of the study was omitted due to the level of support needed by participants to attend gaming sessions. At both facilities, games were made available to study participants outside the context of scheduled gaming sessions that were facilitated by a researcher; participants were informed that staff members were available to help if they required assistance in setting up games. However, there was only one occasion on which a participant at the senior residence approached staff to play Kinect Sports Bowling.

What are older adults' motives for continued participation in gaming sessions?

Entertainment. Residents at both facilities agreed that participating in gaming sessions was an enjoyable leisure activity that provided participants with a novel experience that stood out from other activities usually offered at the homes.

Social context of gaming sessions. While participants at the nursing home did not enjoy playing video games in a social context, participants at the senior residence highlighted the group setting as one of the biggest factors that encouraged them to participate in gaming sessions over a longer period of time. Participant quotes support this notion, e.g., one participant stated "*I like the people here*" (P3, senior residence), and another one highlighted that she wished "*there were more people coming*" (P2, senior residence).

Perceived health benefits. Several participants commented on the mental and physical effort required to play both the set of custom-designed mini games as well as the commercially available games included in this study, stating that playing games was "*a good opportunity to learn*" where you had to "*use your brain [and] think ahead*" (P2, senior residence). Along these lines, one participant pointed out that she did not believe games could replace traditional

physical activity, but could be an interesting addition to the regular programming at residential care facilities, diversifying the sometimes monotonous daily life.

Appeal of games. Interestingly, only three participants (one at the nursing home, two at the senior residence) specifically commented on the appeal of video games as a factor that encouraged their continued participation in gaming sessions. Two of these participants were players with prior gaming experience (playing casual games such as Solitaire on their personal computer or iPad) and pointed out that the gaming sessions provided them with an opportunity of learning about motion-based games, a genre of video games they had no prior experience with. In this context, many participants at the senior residence explained that they enjoyed playing video games that simulated real-world activities they can no longer participate in.

What are reasons for dropping out of gaming sessions?

Health. At both facilities, health issues were a barrier to continued participation. While some participants only experienced minor health problems (e.g., feeling tired or seasonal illness) that caused them to miss single sessions and allowed them to join up with the group after their recovery, three participants who showed great interest in the initial gaming sessions (one at the nursing home, two at the senior residence) permanently dropped out due to major health problems (e.g., long-term hospitalization).

Loss of interest in games. Many participants who permanently dropped out of the gaming sessions pointed out that they simply lost interest in playing video games. One participant stated she found out "*it simply wasn't my cup of tea*" (P5, nursing home), another one outlined she felt she could "*do better things with my time*" (P7, senior residence). In this context, one player at the nursing home stated that he lost interest in playing games because he did not feel that he "*could ever get the hang of it*" (P3, nursing home).

Other appointments and commitments. Residents who only sporadically participated in the gaming sessions pointed out that they had other appointments and commitments that were of higher priority, such as doctor's appointments or family visits. Additionally, one participant pointed out that playing video games was "*a winter activity*" that she would "*like to pick up again when the weather is getting worse*" (P8, senior residence).

Social context of gaming sessions. In contrast to participants at the senior residence, older adults at the nursing home did not find the social context of the gaming sessions appealing. Two participants specifically commented on other participants being the reason for them

dropping out during the first month because "*people are taking a long time to play the games*" and "*waiting for others to finish is boring*" (P1, nursing home). Likewise, one participant who continued to participate in individual gaming sessions outlined that he enjoyed playing games on his own, because he could play at his own place and "*not worry about what others are doing*" (P2, nursing home). Along these lines, several participants at the senior residence mentioned that they sometimes felt pressured to do well in the game because others were watching.

Lack of support. Our results show that participants who experience higher levels of age-related changes and impairments require additional assistance to attend gaming sessions. Particularly at the nursing home, residents were dependent on the support of staff to attend gaming sessions. If staff was unavailable due to other tasks (e.g., supervising community outings or supporting individuals who had to attend appointments outside the nursing home), residents did not receive help transferring into their wheelchairs and moving to the media room and could therefore not participate in gaming sessions.

8.3 Core Challenges in the Deployment of Video Games for Older Adults in Residential Care

Based on the findings, this section provides insights into the core challenges related to the long-term deployment of video games in residential care facilities, with a focus on player preferences and contextual challenges.

8.3.1 Understanding the Ambiguity of Social Play

Our results suggest that playing games in a social setting introduces both challenges and opportunities for older adults. While the opportunity to socialize with other residents represented one of the biggest pulls to participate in gaming sessions for persons at the senior residence, having to play games in a group created additional barriers for players at the nursing home. In this context, it is important that game designers understand the ambiguity of social play: On the one hand, it is an opportunity for older adults to come together as a group where games can serve as a *ticket to talk* [25, 122]; creating an audience can also be interesting for persons not actively participating in play [149], serving as a *ticket to be silent* [25], allowing older adults to enjoy the company of others while watching them play. Additionally, playing with a group provides active players with an opportunity to share successes, and potentially a source of support. On the other hand, social play and the presence of others can turn into a barrier for persons who experience

higher levels of age-related changes and impairments, have little confidence in their ability to play games, or are not comfortable being observed when learning how to play.

While a lot of research highlights potential benefits of social play, particularly in the context of games for older adults (e.g., by catering to observers and players alike [149]), and spectators can contribute to the experience of the individual in performance games (e.g., commercially available motion-based games such as Wario Ware: Smooth Moves), it is important that designers understand the risk of games increasing the vulnerability of institutionalized older adults by exposing the impact of age-related changes. In this context, game developers need to re-think traditional design principles: challenging players and pushing limits in multiplayer settings may be appealing for younger players, but can turn into a major barrier for players with different abilities [70] who are simultaneously challenged to adapt to cognitive and physical changes that come with late life.

8.3.2 Recognizing Challenges of Motion-Based Interaction

Benefits of playing video games are often associated with their physical nature. Our study shows that despite the efforts of making motion-based games accessible for audiences with special needs (see Chapter 6), implementing physical activity using camera-based systems that require players to accurately position themselves within the gaming area can create additional access barriers in certain situations, e.g., if players are using wheelchairs and games are to be played in multiplayer setting. Therefore, designers should consider offering alternative interaction paradigms for audiences that might experience problems using full-body motion-based input, e.g., by working with controller-based motion-based game interaction rather than relying on hands-free input. Finally, if the goal of gaming sessions in residential care is to provide mental stimulation and an opportunity to meet other residents, game developers should also consider sedentary game input.

8.3.3 Adapting Games to the Reality of Residential Care

Previous work presented in this dissertation has looked at the challenges related to game design for institutionalized older adults from the perspective of human-computer interaction, focusing on accessible user interfaces and simple setup routines (see Chapter 7). This study shows that the long-term deployment of games in residential care facilities requires considerations that take into account aspects of daily life in residential care facilities, particularly

the fluctuation among players and the importance of staff to support residents in attending gaming sessions.

On a general level, our study showed a high level of fluctuation among players, with new participants joining the group after learning about the gaming sessions, persons dropping out for various reasons, and some participants taking a break from playing to attend to other responsibilities. This creates a number of challenges for game designers: First, if games offer multiplayer functionalities, they should accommodate a flexible number of players and facilitate quick turn-taking if many participants are present. Second, games should offer an easy entry into play that allows novice players to quickly catch up to the group, while the overall level of complexity of games needs be high enough to maintain the interest of players frequently attending gaming sessions. This implies that games for residential care should focus on mechanics- rather than story-driven game design, which would allow players to return to gaming sessions at any time without missing information required to play the game.

In addition, adapting games to the reality of residential care means recognizing the importance of support staff beyond setting up gaming systems. Previous studies have looked at the role of staff with a focus on allowing them to secure the basic upkeep of games; however, our study shows that, depending on the group of older adults, help beyond this level is necessary. This contradicts research highlighting the benefits of video games over other leisure activities due to the self-directed nature of play: as the impact of age-related changes and impairments grows, older adults require extensive assistance to gain access to games. In this context, the opportunity of the game development community to facilitate the participation of older adults in play is limited, and efforts beyond creating accessible games that can easily be set up in a care home environment are necessary: if older adults require the support of staff to be able to attend gaming sessions, care facilities need be aware that they must provide higher levels of assistance for gaming sessions to turn into accessible and successful leisure activities for their residents.

8.4 Discussion

This paper presents an exploratory long-term study of the gaming behaviour of older adults in residential care, with a focus on differences and similarities between persons living in nursing homes and older adults living in senior residences. Our results show that increased age-related changes and impairments have an impact on engagement with games beyond game accessibility, influencing how older adults view the context of play and how much assistance

they require to be able to play games, limiting the potential of games to serve as a self-directed leisure activity. In this section, we discuss the implications of our findings. We summarize main aspects of designing video games to be deployed in residential care, and we comment on the role of games in the lives of institutionalized older adults.

8.4.1   Designing for Older Adults in Residential Care

In this section we discuss the implications of our findings for the deployment of games in residential care, with a focus on design requirements for different care home environments and the role of games in the care context.

Game Design Considerations for Residential Care Settings

The results of our study show that previous considerations are not sufficient to provide a positive gaming experience over multiple gaming sessions. While prior work suggested that accessible games for institutionalized older adults can be created by accounting for age-related changes and impairments (Chapter 7), findings from this study show that a more comprehensive approach is necessary when designing games for residential care: age-related changes and impairments do not only influence whether basic gameplay is accessible, but also have an effect of how older adults view themselves in the gaming context, and how they perceive the participation of others, which needs to be reflected by game concepts. Therefore, game developers need to be aware of the specific group of institutionalized older adults they are designing for to best adapt their games to their individual skills and abilities. Even among older adults in residential care, the range of skills and abilities among players is wide; to be successful, games need to accommodate most of them, which may mean that games have to be tailored towards specific groups of older adults in residential care.

The Role of Games in the Lives of Older Adults

In the past, the deployment of video games in residential care has often been viewed as a simple solution to provide physical and mental stimulation that can help foster communication between older adults [84, 88]. The findings of our study suggest that we need to develop a more differentiated perspective on games for older adults in residential care, and that it is important to understand the role games can fulfill in their lives. In this section, we discuss core findings that need to be considered when offering gaming sessions for institutionalized older adults. Depending on the level of age-related changes and impairments experienced by older adults, the

deployment of games becomes increasingly challenging and requires extensive support of nursing staff prior to play and during gaming sessions. This needs to be considered when evaluating the benefits of games compared to other supervised leisure activities offered by care facilities; if older adults experience high levels of age-related changes and impairments, games are not an independent activity that they can participate in without the support of others.

On a general level, these results suggest that games offer an opportunity of diversifying leisure activities made available to older adults in residential care, but that the research community needs to be aware of their limitations regarding the support older adults require to be able to engage in play, and the aspects that contribute to their long-term engagement with games. This is particularly important when evaluating the value of the application of games for older adults with a purpose beyond entertainment, such as their deployment in therapy and rehabilitation.

8.5   Limitations and Future Work

There are several limitations to the work discussed in this paper. Our study is of an exploratory nature and only includes a small number of participants at both care facilities; our findings presented in this paper should be viewed in this light and replicated in other environments. Additionally, while the in-the-wild approach was beneficial to give more realistic insights into how older adults approached video games, it also introduced challenges and possible confounds as the research context was less controlled, e.g., we had no influence on the level of support older adults at the care home received to attend gaming sessions, how other programming at the home influenced their participation, and what effects social relationships had on group gaming sessions.

This study provides several opportunities for future work. First, studying the long-term gaming behaviour of older adults in a bigger context would be valuable to confirm the findings of our exploratory study. In this context, addressing the question of how games could be designed to facilitate the involvement of staff, and how care facilities could best be supported in the deployment of games is an important step towards supporting care facilities wishing to turn video games into a valuable leisure activity for their residents. Additionally, conducting research with a detailed focus on social aspects of play among institutionalized older adults – for instance, the role of competition among players – could provide further insights into how games can be applied to strengthen social relationships among older adults in residential care.

8.6   Conclusion

Understanding how older adults in residential care approach video games in an in-the-wild context is important to identify the role of games in their lives, and arrive at a better understanding of how games can be applied to benefit older adult players. Our study provides first insights into the long-term gaming behaviour of older adults in different contexts of care, highlighting challenges and opportunities that need to be addressed by the research community. Studying how older adults interact with video games beyond tightly controlled research settings in an important step towards developing a more realistic view on potential benefits and risks of video gaming in residential care. This is necessary to ensure that games deployed in residential care meet the needs of players and have the potential of increasing their quality of life.

CHAPTER 9

MOTION-BASED GAMES TO CONNECT OLDER ADULTS AND CAREGIVERS

Related publication: Gerling, K. and Mandryk, R. Supporting Caregiving for Older Adults Through Play. Submitted to ASSETS 2014.

Building on the results of the previous chapter, this part of the dissertation explores how games can be integrated into the daily lives of older adults, particularly focusing on the caregiving context: older adults who experience increasing levels of age-related changes and impairments often struggle to take care of their daily needs, and may at some point have to rely on others for care. Often, close relatives are involved in providing in-home care for older adult family members [83], causing a shift from a usually reciprocal relationship to asymmetry. This creates challenges for both members of this caregiving dyad: older adults have to adapt to depending on others to take care of personal needs, and this affects the way they perceive themselves [105]. At the same time, caregivers often struggle with a lack of personal freedom as the result of spending significant time on caring for their family member. These challenges often put stress on the relationship, which can lead to fragility and isolation in the dyad. These negative outcomes then put further pressure on the emotional and physical well-being of older adults and caregivers, weakening, rather than strengthening their relationship over time [57, 63]. To improve the situation of caregiving dyads, human-computer interaction researchers have focused on the design of interventions that facilitate the caregiving process. Current work aims to provide support for the tasks of caregiving (e.g., reducing caregiver burden through applications that enable caregivers to communicate with healthcare professionals [106]), or to assist older adults to live independently (e.g., applications to help them keep track of medication [90]). Although relieving the burden of the caregiver while empowering the older adult is essential for managing the caregiving relationship, the potential of interactive technologies to directly address the *quality of the relationship* in a caregiving dyad has been largely unexplored. Alongside the need to facilitate the giving and receiving of care, interactive technologies have the potential to

support relationships by creating joint experiences that foster affection and promote closeness [160].

In our work, we explore the potential of motion-based video games to foster closeness in relationships burdened by caregiving. Motion-based games are a promising design opportunity because they have been shown to have a positive impact on the emotional well-being of older adults [84], the physical dimension may be leveraged to increase the satisfaction of relatedness [76], and they offer the opportunity of fostering social interaction through play, thereby contributing to the relationship between players [97]. In addition, games have been shown to be a way of importing affect through experienced competence in a risk-free environment [144], and provide an enjoyable activity for players to focus on, thus binding the players' attention and cognition, leaving few resources to ruminate on the cares and worries of daily life [95]. We apply principles from casual and intergenerational game design to create two multiplayer mini-games suited for older adults and caregivers without extensive gaming experience, that encourage interaction between players, and that can be integrated into daily life in short chunks of play. In particular, we employed game mechanics that encourage the players to cooperate to solve a goal, where each member of the team has an equal and essential task or role. Results of an exploratory study where ten dyads of older adults and their caregivers played our games and a detailed analysis of the experience of two dyads show that caregiving dyads enjoy playing games, but that special dynamics of the relationship require careful design considerations. Our work makes three contributions: (1) We provide a first example of how interactive technologies can be applied to engage caregiving dyads in joint activity. (2) We show that motion-based games have the potential of fostering communication between older adults and caregivers. (3) We identify challenges and opportunities in game design for the caregiving context, and outline strategies to support designers wishing to create games for caregivers and older adults.

Connecting caregiving dyads through shared experiences is an important step toward increasing the emotional and physical well-being of older adults and caregivers. Interactive interventions such as video games that connect people have the potential of supporting this goal by providing a joint leisure activity, fostering the development of positive relationships through communication and shared experiences, and may contribute to the quality of life of older adults and caregivers.

9.1 Related Work

In this section, we outline the importance of meaningful relationships in caregiving, and show how interactive technologies have been applied to support this goal.

9.1.1 Need to Belong, Relatedness, and Caregiving

Baumeister and Leary [20] define the *need to belong* or *relatedness* as a "need to form and maintain at least a minimum quantity of interpersonal relationships", and they identify two main aspects that help fulfill that need: people require repeated interaction with the same person to develop a relationship; and that relationship can only be meaningful if both people care about the other.

Literature reports various negative effects of a lack of meaningful relationships, ranging from decreased emotional well-being (e.g., [143]) to negative effects on health [161]. In their work, Baumeister and Leary [20] provide a detailed discussion of potential consequences of the deprivation of meaningful relationships on the individual. Based on their definition of the need to belong, they identify two kinds of partial deprivation that are particularly interesting in the context of caregiving, *interaction without a bond of caring*, and *relatedness without interaction*. The issue of *interaction without caring* is relevant in caregiver-patient dyads with a professional caregiver. Although patients and caregivers spend extensive amounts of time with each other, the relationship often remains superficial [20], leading to partial deprivation among both patients and caregivers. *Relatedness without interaction* refers to a situation in which individuals share a bond of caring, but are not given an opportunity to strengthen their relationship through interaction. In caregiving, we identified the following two situations that can lead to this kind of deprivation. First, age-related changes may limit older adults' opportunities of social participation. Second, if people with a previously established bond of caring become involved in caregiving – e.g., if an adult child takes care of their elderly parent – the act of caring may take up time that was once reserved for social interaction [57], reducing the relationship to its practical aspects. Additionally, the shift from reciprocal relationships to asymmetry in late life influences the way older adults perceive themselves, having a negative impact on their emotional well-being [105].

Fulfilling the *need to belong* among patients and caregivers can contribute to the overall quality of care both for older adults in professional care and for those who are cared for by a loved one. To improve the situation of older adults and caregivers, it is important to establish a positive relationship in caregiving dyads [63]. Creating a positive bond can reduce burden and

stress [134], and positively influence the well-being of caregivers to improve the caregiving process.

9.1.2 Supporting Relationships Through Technology

Interactive technologies have previously been applied to satisfy the *need to belong* and increase *relatedness* among different groups, e.g., persons in romantic relationships, among families, and close friends. Much work in this field has focused on intimate relationships. In a 2012 review, Hassenzahl et al. [76] examined 143 artifacts designed to support romantic relationships. Examples of technologies to support romantic relationships are digital artifacts such as the Lover's Box by Thieme et al. [159] that aims foster the emotional development of romantic relationships, applications such as Hug over a Distance by Vetere et al. [168] that aims to facilitate physical intimacy over a distance, or the application of video chat to connect persons in long-distance relationships [126]. Additionally, research exploring the potential of technology to support relationships has increasingly started to focus on connecting families. Research by Kirk et al. [93] suggests that families apply video chat to connect to members in remote locations; Forghani et al. [55] discuss how the technology is applied to connect grandparents and grandchildren. Along these lines, Davis et al. [41] present Virtual Box, an application designed to connect children and grandparents in play to help mediate family intimacy, highlighting the potential of engaging persons in playful interaction.

9.1.3 Applying Interactive Technologies in Caregiving

Researchers have also created technologies that support caregiving by addressing caregiver and patient needs.

Technologies to Support Caregivers or Patients

Various technologies have been designed to support the caregiving process. Chen et al. [37] review main challenges that need to be addressed to reduce caregiver burden, and identify the design opportunities of applications that support caregivers that help cope with emotional stress and management of caregiving as core design opportunities. In this context, Yamashita et al. [181] highlight the importance of social networks, and Liu et al. [106] show that mobile technologies can help connect caregivers with other family members and healthcare professionals to facilitate caregiving, and applications have been developed to help caregivers manage the caregiving process, e.g., talk scheduling [99]. Likewise, research has addressed

supporting the needs of patients, e.g., by providing applications to help older adults keep track of medication [90]. There has also been significant work done to facilitate older adults' 'aging in place' – an area related to caregiving. Benefield and Beck [21] suggest the implementation of different technologies to facilitate aging in place, e.g., allowing family caregivers to remotely monitor the health status of the older adult patient, whereas the Aware Home Initiative at Georgia Tech [92] focuses on supporting the needs of older adults aging in place and the peace of mind of their family members. For the most part, current approaches integrating technology in caregiving aim to resolve practical problems (e.g., scheduling and monitoring) rather than focusing on the emotional well-being of individuals involved in caregiving.

Games for Health

Games for Health are an area of game design concerned with the development of video games to increase the physical and emotional well-being of players. Many design efforts in this field have focused on encouraging healthy behaviour and achieving disease prevention (e.g., the HIV prevention game Pamoja Mtaani [170]), or informing patients to increase their compliance and self-efficacy (e.g., Bronkie the Bronchiasaurus, a game for children with asthma [100]) to improve therapy outcomes. Initial design efforts have been made to facilitate the caregiving process through video games. Patel and Salata [131] applied video games to improve communication between children with dysarthria and their caregivers by increasing the verbal abilities of patients through play. Gerling et al. [65] showed that caregivers of children with cancer regarded video games as a means of initiating communications between patients, parents, and medical staff, a factor that is crucial to increase social support for patients [100]. However, none of these games directly connect patients and caregivers through play; in all cases, patients engage with the game and benefits are expected to carry over into the relationship with their caregivers.

Despite these design efforts addressing the challenges of caregiving from different perspectives, no applications are available that specifically address the idea of supporting the process of caregiving by directly connecting patients and caregivers, creating common ground in asymmetrical relationships, and increasing relatedness between both parties. In our work, we investigate whether interactive technologies can be applied to support older adult-caregiver relationships. We believe that connecting older adults and caregivers through video games can foster the development of meaningful relationships through interaction, leveraging the fact that

play often is symmetrical and reciprocal [105]. This would allow caregiving dyads to have joint experiences on common ground, and could help family caregivers and older adults engage in a new shared activity.

9.2   Designing Video Games for Caregiving Dyads

In this section, we present the design rationale for our two motion-based games *Prairie Hunter* and *Candy Kids*. Furthermore, we present design probes and discuss how different caregiving dyads engage in play, and how the characteristics of each dyad influence their experience playing our games.

9.2.1   Design Rationale

To adapt our games to the needs of older adults, caregivers, and the caregiving context, we built on prior work addressing casual game design and intergenerational play.

Existing Design Guidelines

Research on casual exergames [61] and casual games for health [65] has shown that simplistic, easily accessible game concepts are particularly suited for audiences with little gaming experience and in gaming situations where players cannot engage with games over a longer period of time, aspects that are also relevant in a caregiving context. This goes along with considerations for the design of motion-based games for older adults [68] highlighting the importance of accounting for age-related changes and the development of accessible interaction paradigms. Additionally, caregiving often involves cross-generational dyads, e.g., if adults care for older adult parents. Work in the field of intergenerational play has shown that video games are a means of creating common ground in asymmetrical relationships [105], can connect people across generations [171], and can change the way people feel about another age group [158]. Furthermore, research has addressed the issue of creating video games that are suited for the needs of players of different age groups and gaming backgrounds: Vanden Abeele and de Schutter [164] outline the importance of creating games that relate to experiences from daily life, and recommend the integration of competition in games to foster social interaction. Likewise, Rice et al. [137] suggest that intergenerational play can support interaction between different groups of players, and they highlight that moderate physical effort yields additional health benefits for players. Research has shown that cooperative play is suited to improve empathy within dyads [47]. Furthermore, we aim to integrate design considerations for technologies to

increase relatedness that were identified by Hassenzahl et al. [76]. Their work suggests that the integration of physicality as well as joint actions can lead to higher levels of relatedness among people. Both aspects are inherent to cooperative motion-based game play. Thereby, we aim to provide a new kind of opportunity for shared activity that can help facilitate social interaction between older adults and caregivers.

Challenges Specific to Caregiving Dyads

The special nature of the caregiving relationship in late life poses unique design challenges. In this section, we identify three core challenges that need to be addressed when designing video games for the caregiving context.

Challenge 1: Supporting a wide range of caregiving dyads. Research on motion-based games for older adults shows that older adults in long-term care are a heterogeneous target audience, and that it is important to accommodate a wide range of physical and cognitive abilities [68]. Additionally, a challenge specific to game design to connect caregivers and older adults is the likelihood of the composition of the caregiving dyad influencing game interaction: when younger caregivers (e.g., adult children) are involved, they can be expected to have prior computer experience, which may facilitate the entry into play. In contrast, in dyads where members do not have extensive computer and/or gaming experience (e.g., if spouses are involved in caregiving), we expect it to be more difficult for dyads to gain access to video games. Particularly when designing for caregiving dyads with limited technology literacy, or dyads where one member has extensive prior gaming experience, *creating enjoyable games that offer an adequate level of challenge* is important. Besides offering tutorials and other supportive materials [68], striking the right balance between challenge and player skills for players of different ability and experience is crucial.

Challenge 2: Preventing the caregiving relationship from being affected by poor playing performances. Research on player balancing in multiplayer exergames has demonstrated that poor player performance can have an impact on self-esteem and the relationship between players [70]. This is a challenge for motion-based video games for the caregiving context, as negative emotions associated with poor playing performances could carry over into the caregiving relationship if they prevail in the long run; particularly affecting older adult players who are more likely to experience gameplay problems due to the impact of age-related changes and impairments. To overcome this challenge, designers have to *move the player focus from*

individual in-game performance to the joint experience. In terms of game design, this could be accomplished by putting a bigger emphasis on joint efforts, e.g., by rewarding joint actions rather than the result of one single player action. Furthermore, individual player scores should be avoided and integrated into team scores to emphasize the importance of the performance of the caregiving dyad.

Challenge 3: Facilitate shared ownership of games to avoid reinforcement of existing roles. To avoid the reinforcement of existing roles within the caregiving dyad (e.g., the caregiver being responsible for daily needs of the older adult), it is important for video games for caregiving dyads to *encourage shared ownership*, offering common ground for older adults and caregivers, and creating a space where older adults can actively contribute to the success of the dyad. This can be accomplished in two ways. First, in-game skill balancing can be applied to assist weaker players, thereby reducing obvious skill differences within the caregiving dyad. Second, games can be designed to build on the strengths of older adults, allowing them to be independent players and offering them the opportunity of assisting their caregivers. This can either be done by integrating challenges that appeal to their age group (e.g., specifically integrating game content that relates to their past), or by offering asymmetric player roles to allow older adults to choose an interaction paradigm and/or in-game role that suits their needs. Applying both strategies would allow older adults to make an independent contribution to the game, potentially increasing their confidence in their abilities of participating in the game, and would create common ground for the caregiving dyad.

9.2.2 Game Concepts

Based on these considerations, we adapted two games deployed in the context of the long-term study, *Candy Kids* and *Prairie Hunter*, two motion-based casual games that provide easily accessible game controls, simple game mechanics, and short chunks of play. In order to allow for caregiving dyads to engage in joint interaction, we adapted both games to invite collaborative in-game interaction. In *Collaborative Candy Kids*, players work together to feed a child different types of candy and vegetables: items moves across the upper area of the screen and can be fed to the child by moving both player avatars (represented by virtual hands) overtop of the food at the same time. Challenge is created by switching the location of the child after each round of feeding, and by including items of different value. *Collaborative Prairie Hunter* allows players to support each other when hunting wild animals. In order to increase their score,
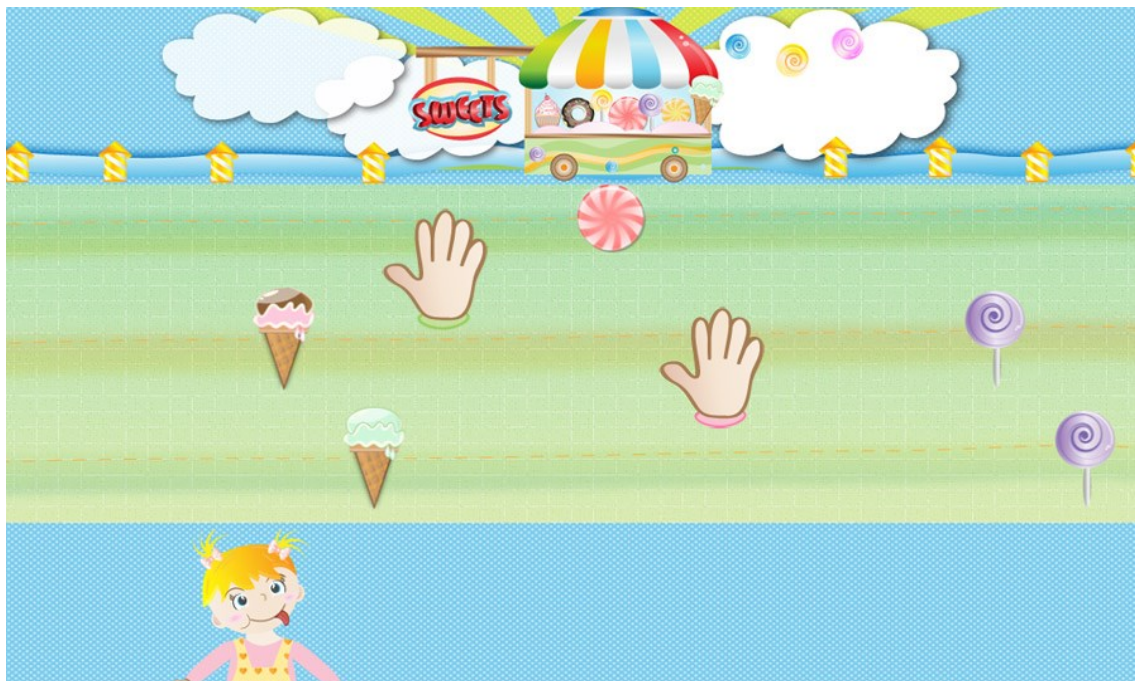
Figure 14. Collaborative Candy Kids, a motion-based casual game for older adults and caregivers.
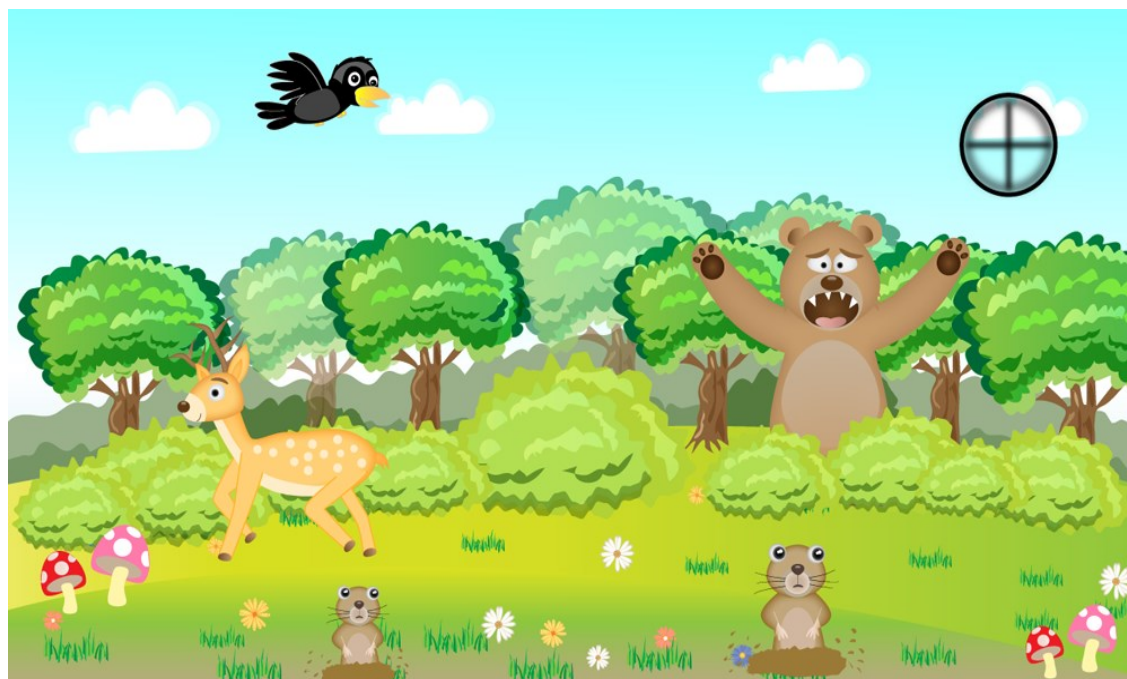
Figure 15. Collaborative Prairie Hunter, a motion-based hunting game for older adults and caregivers.

they have to hunt as many animals as possible. This is achieved by moving the avatar represented by a crosshair and controlled by one player overtop of the animal. Once the avatar is in the right position, the other player has to perform a pushing gesture to fire the gun. Challenge is created as animals appear in different locations and at different times: bigger animals result in a greater score, but they appear less frequently, while smaller animals appear repeatedly for a short time.

Both games are played using the Microsoft Kinect. Our implementation invites players to use their strong hand to perform gestures and pointing actions to control the avatar. Although both games are cooperative, *Collaborative Candy Kids* is symmetric (both players perform the same action), whereas *Collaborative Prairie Hunter* is asymmetric (players have different roles).

9.3   Exploring How Caregiving Dyads Engage in Play

In this part of our work, we explore how caregiving dyads approach *Candy Kids* and *Prairie Hunter* through case studies with a focus on how different characteristics of caregivers and older adults influence the way they engage in play.

9.3.1   *Participants and Procedure*

Ten pairs of caregivers and older adults participated in the evaluation. All caregiving dyads included older adults and a family caregiver (e.g., adult daughter or son, or a spouse). The average age of older adults (7 female) was 81.50 (SD=6.36); caregivers (8 female) had an average age of 58.70 (SD=10.89). Only one older adult had prior computer experience (that person had also played video games before); all caregivers had used a computer, and three of them were familiar with video games. Regarding age-related changes and impairments, four older adults reported age-related mobility impairments that restricted their independence, and one participant was diagnosed with dementia. None of the older adults lived in residential care; six older adults lived in their own apartment and were visited regularly (at least two times per week) by their caregiver. Four participants reported that they lived with their caregiver. We assessed caregiver burden using the Caregiver Burden Scale [112]. Results show that objective caregiver burden was within a normal range (average score: 19; scores above 23 are considered high).

The case studies were carried out in the home of the older adult to allow participants to remain in a familiar environment. At the beginning, written consent (caregivers) and oral assent

(older adults) was obtained. To better understand the background of the dyads, participants were asked to provide demographic information, including questions about their relationship with the other person. Additionally, caregivers answered a questionnaire on caregiver burden [112]. Participants then received an introduction to the games and played two rounds using of each of them. Afterwards, they answered a questionnaire on their player experience (PX) [137] that examines joint video game play on the dimensions *Cooperation*, *Communication*, *Partner Preference*, *Ease of Use*, and *Competence*, and participated in a structured interview that further explored their perceptions of motion-based games as a shared activity. Each session lasted about 90 minutes.

9.3.2   *Quantitative Results*

In this section, we present the results of the evaluation and discuss our findings regarding the design of motion-based video games for caregiving dyads. Between-group comparisons for player experience were made using one-way ANOVA. Pre- and post-play affect were compared using Wilcoxon Signed Rank Test. Qualitative data was coded with a focus on the research questions.

Are motion-based games accessible and usable for caregiving dyads?

Our results show that both games were playable by caregiving dyads. On average, caregiving dyads scored 30.44 points (SD=15.97) in Prairie Hunter, and 11.71 points (SD=10.88) in Candy Kids; large standard deviations outline performance differences between dyads. Questionnaire results for PX metrics for ease of use (Figure 3) show that both older adults and caregivers found the games usable and accessible. A one-sample t-test showed that the ratings for ease of use were significantly higher than neutral (t_{17}=3.5, p=.003). We also found no significant differences in the ease of use ratings between groups (older adults and caregivers) ($F_{1,16}$=0.03, p=.866). In addition, both older adults and their caregivers expressed their competence with the game and we did not find any difference between the groups (M_{OA}=3.16, SD_{OA}=0.55; M_{CG}=3.18, SD_{CG}=0.70; $F_{1,18}$=0.01, p=.944). These results show that the games were generally accessible to caregivers and older adults.

Observations during gameplay back up these findings and provide a greater insight into how caregiving dyads approached our games. Generally, caregivers had a higher level of computer and video game experience and were more comfortable with the idea of playing video

games. Often, this caused caregivers to take the lead during the first moments of play, and instruct the older adult on how to complete in-game challenges. Except for one caregiving dyad, this behaviour diminished as the gaming session progressed. Generally, caregivers with gaming experience seemed to be more enthusiastic about playing games with their loved one, and needed less help when learning how to play. Observations and quotes show that caregiving dyads consisting of two older adults (e.g., if the caregiver was a spouse) found it more difficult to learn how to play the games, e.g., "*we are too old to learn this*" (caregiver, D5). Despite these comments on a lack of experience, ratings for ease of use and competence suggest that older adults were generally able to play the games with motion-based input.

How do caregiving dyads feel about playing motion-based games together?

Questionnaire results for PX show that caregiving dyads generally had a positive experience, and that they collaborated well. Ratings for both cooperation and communication were significantly higher than neutral (Coop: t_{17}=2.4, p=.027; Comm: t_{18}=4.0, p=.001). This is backed by interview results showing that both members of the dyad generally enjoyed playing motion-based games with the other person, stating that "*playing games is a great joint activity*" (older adult, D3) and that "*it is nice to be able to play together*" (caregiver, D2). There were no significant differences in the ratings between the groups (Cooperation: $F_{(1,16)}$=0.04, p=0.848; Communication: $F_{(1,17)}$=0.02, p=0.895, Partner Preference: $F_{(1,16)}$=0.25, p=0.626), suggesting that older adults and caregivers had similar experiences. In some cases, interviews revealed comments regarding partner preference that had a negative connotation, e.g., "*my partner *tried* their best*" (caregiver, D5).

When questioned about the value of joint video game play, nine out of the ten caregiving dyads highlighted that they were able to help each other in the games, and that they felt that the other person contributed to their success. In contrast, one dyad outlined that they did not enjoy playing games together (D5; caregiver was unhappy with his partner's contribution), and that their engagement with our games confirmed this perception. The physical dimension of the games was perceived as a means of providing mental and physical stimulation; as one participant highlighted, "*you spend time together, you get a little bit of exercise, [and] you can train your hand-eye coordination*" (older adult, D3). Additionally, observations show that the physicality of the games caused caregiving dyads to coordinate their actions (e.g., instructing the other person where to place their hand), and sometimes led to affectionate touch where one player would

gently squeeze another player's hand or arm during the course of the game, or hug the other person after finishing a round of playing. Finally, participants commented on the potential of the games to initiate discussions, with one dyad stating that "*games are good to foster communication*" (caregiver, D2) and can help "*bring up memories*" (older adult, D2).
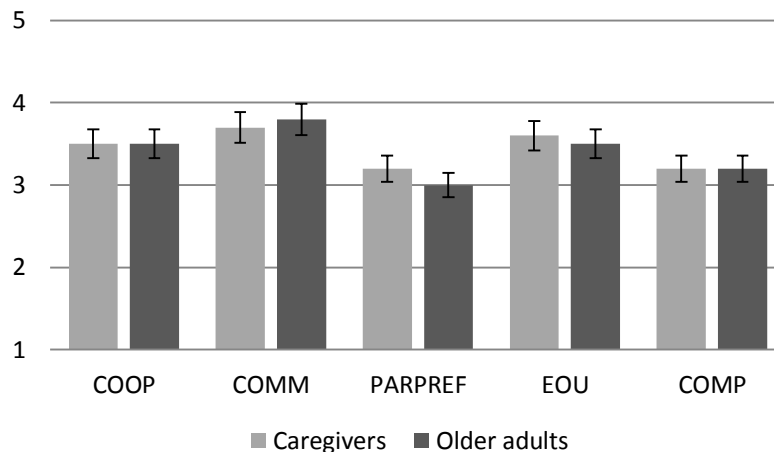
Figure 16. Player experience results (COOP = Cooperation, COMM = Communication, PARPREF = partner preference, EOU = Ease of Use, COMP = Competence). Results were provided on a 5-point Likert scale (higher = better; CI=5%).

When interpreting these results, two main areas should be discussed regarding their potential of supporting caregiving relationships: (1) The application of games to foster communication between older adults and caregivers, and (2) potential benefits of joint interaction with a physical dimension. However, the results also suggest challenging aspects in the sense that the experience of playing video games greatly differed for individual caregiving dyads (e.g., results regarding partner preference, Figure 16 and Figure 17). In this context, it is important to acknowledge design requirements that emerge from the individual characteristics of caregiving dyads; for the successful deployment of games, it is not only important to create positive experiences for the majority of dyads, but also to ensure that shared video game play does not harm individual relationships.

9.3.3 Qualitative Enquiry: Case Studies

In this section, we analyze the individual experiences of two caregiving dyads (names changed) with different backgrounds to expose factors that may either hinder or facilitate the perception of shared video game play as a positive experience.

The Experience of Emma and Andrew: Effects of Cognitive Impairments on Joint Play

Emma and Andrew (both 83 years old) are married and have lived together for almost 60 years. Before retiring, Andrew worked an office job with managerial responsibilities; Emma was a housewife and took care of their children. Recently, Emma was diagnosed with early stage dementia, which increasingly limits her independence. While she still takes care of some of the household chores, Andrew faces the growing responsibility of organizing her daily life; however, when questioned about caregiver burden, he reported low objective burden (score: 14) suggesting that his personal life is not severely affected by caring for his wife. Regarding joint leisure activities, Emma and Andrew report traveling together, as well as reading and listening to music, but do not play card- or board games regularly. Additionally, they do not have extensive experience using computers, and they have never played video games before.

Playing video games as shared leisure activity. Since Emma and Andrew had not played video games before, we were interested in how they approached our games, and whether Emma's cognitive abilities would influence their experience. Generally, our observations show that Andrew found quick access to the games, whereas Emma found the concept of motion-based game interaction difficult to understand. While playing our games, she was continuously instructed by Andrew, who was very focused on success. Instead of addressing Emma's needs (e.g., answering her questions about the goal of the game), we observed that Andrew tried to push her to simply complete actions required for them to be successful within the game. Over the course of the games, comments show that Andrew got increasingly frustrated with Emma, exclaiming that there was "*no point in trying this with you [Emma]*" after she had repeatedly asked similar questions about the game. When asked about the contribution of his partner in the follow-up interview, he reflected on their score and pointed out that Emma "*tried her best*", but that her help was "*not enough to be successful*". In contrast, Emma pointed out that she appreciated Andrew's help, and that she thought they worked well together as a team. This is also reflected by their questionnaire responses investigating game experience (Figure 17, left). Regarding synchronous and asynchronous input, Emma stated that she found it easier to play Candy Kids (using synchronous input), because it allowed her to imitate Andrew's actions. Regarding their general perception of joint motion-based play, Emma and Andrew agreed that "*it is positive to work together*", but that they do not consider playing video games an interesting leisure activity.
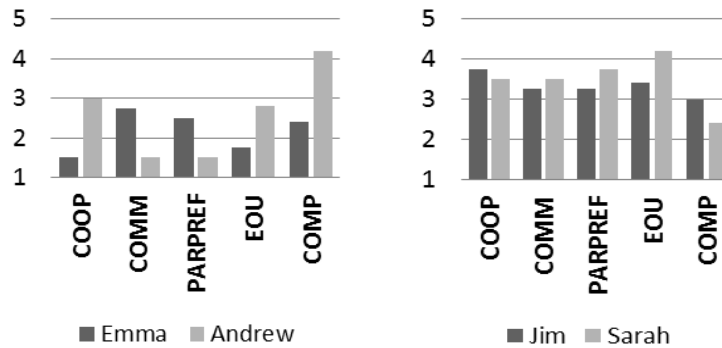
Figure 17. Player experience results for Emma and Andrew (left) and Jim and Sarah (right). COOP = Cooperation, COMM = Communication, PARPREF = partner preference, EOU = Ease of Use, COMP = Competence. Results were provided on a 5-point Likert scale (higher = better).

The impact of their individual characteristics on their gaming experience. Emma and Andrew are an example of an older adult-older adult caregiving dyad where one member experiences cognitive impairments, and the spouse is transitioning into the role of the caregiver. This comes with a set of unique challenges (e.g., the loss of reciprocity in a formerly symmetric relationship) that influenced the way Emma and Andrew experienced joint motion-based play: while the games were generally accessible to Andrew, our results show that additional considerations are necessary to allow persons with Emma's background to engage in play, which includes designing games in a way that would give the caregiver enough space to help their family member accomplish in-game goals while still being able to succeed in the game on a personal level.

The Experience of Jim and Sarah: Connecting Gamers Through Shared Motion-Based Play

Jim (80 years old) was diagnosed with polyneuropathy, a condition that affects the nervous system and has a negative impact on his mobility. He experiences problems walking and relies on a walker as a mobility aid. Before retiring, he worked as firefighter. His daughter, Sarah (50 years old), is a professional caregiver and assists Jim in his daily life, taking care of many household chores (e.g., laundry and grocery shopping). They do not share the same home, but see each other multiple times a day; Sarah gradually transitioned into the role of Jim's caregiver after his wife died three years ago. Interview results show that Jim is thankful for his daughter's help, and that Sarah appreciates being able to support her father. Both of them have previous experience using computers and playing video games, with Jim being an avid gamer, pointing

out that he "*plays video games every morning after breakfast*". They play card and board games with friends and family, and they have also played movement-based games, such as Wii Sports Bowling.

Playing video games as shared leisure activity. Observations showed that Jim and Sarah could build on previous experience when approaching our games, and quickly developed an encouraging, reciprocal approach to play where both players occasionally instructed the other person and gave feedback on their performance. Sarah pointed out that she "*dominated in the beginning but he [Jim] quickly figured out how to play*". In this context, observations showed that Sarah was patient and gave Jim room to learn how to play our games. Regarding joint play, Jim pointed out that "*[...] it wasn't bad at all to be able to help Sarah [...]*" and that he enjoyed working together with his daughter, stating that he would like one of his friends to try the games with him. They generally found the asymmetric interaction in Prairie Hunter more interesting, but pointed out that both games were fun to play. When comparing our games to card- and board games they had played before, they pointed out that being able to observe the other person's facial expression was a dimension not included in video games as both players generally focus on the screen, which they thought might have contributed to their experience. In general, both Jim and Sarah agreed that playing games together was an interesting joint activity where "*everybody had to contribute their share*" (Sarah). This perception is also reflected by their questionnaire results (Figure 17, right), which show very balanced, above-average results for both members of the caregiving dyad on all scales investigating joint play.

The impact of their individual characteristics on their gaming experience. Jim and Sarah are an example of a daughter-father caregiving dyad where both members have computer experience, and the older adult is enthusiastic about playing video games. Interview results shows that both Jim and Sarah had detailed perception of the games and were able to communicate preferences regarding interaction paradigms and game mechanics. This creates interesting opportunities for game designers wishing to follow a participatory design approach where caregiving dyads with previous gaming experience could provide detailed feedback on game concepts beyond high-level personal preferences and accessibility considerations. However, the experience of Jim and Sarah also shows that it may be necessary to develop more complex, challenging gaming experiences to keep caregiving dyads with gaming experience engaged over a longer period of time, adding another layer of complexity to the development

process, as these games may not be suitable for caregiving dyads with lower levels of technology literacy.

Comparing the Results

The differences in the experience of Jim and Sarah and that of Emma and Andrew expose characteristics of caregiving dyads that may contribute to the adoption of games as a positive shared activity. When comparing the two case studies, we observed large differences in their experience (see different player experience results, Figure 16 and Figure 17), and we identified the following characteristics that might have affected the adoption of games and should be investigated by future work.

Status and type of the caregiving dyad. Jim and Sarah are a well-established caregiving dyad with clearly defined roles that are accepted by both members. In contrast, Emma and Andrew are transitioning into caregiving; issues associated with this process (e.g., accepting that a family member can no longer take care of her own needs) may have carried over into their gaming experience. Additionally, Emma and Andrew are a caregiving dyad where a spouse takes care of his partner – a relationship that is usually symmetric and highly reciprocal, which may further complicate transitioning into caregiving. Along these lines, the differences in age-related changes (cognitive vs. mobility impairments) had a different impact, as Jim could easily access our games, whereas the visibility of Emma's cognitive impairments was increased by the gaming situation. In this context, having to approach a new activity (e.g., video games) may reinforce existing issues within the caregiving dyad instead of providing an enjoyable shared leisure activity.

Previous gaming experience and player personalities. In contrast to Emma and Andrew, Jim and Sarah had a positive perception of games, and could build on previous experience playing video games when interacting with our games. This facilitated their access to our games and allowed them to focus on playing games together instead of solely coordinating their own actions. In this context, comments during play showed that Sarah was more concerned with their shared experience than the overall outcome of the game, whereas Andrew was highly ambitious (e.g., commenting on their scores) and therefore perceived Emma's problems in learning how to play the games as hindrance to being successful in the game. In this context, providing combined scores for caregivers and older adults may have been a disadvantage, showing the importance of arriving at a better understanding at how game designers can create enjoyable shared experiences

that allow both caregivers and older adults to experience success regardless of their player personalities.

These considerations suggest that research should explore a third area when addressing game design for caregiving dyads: focusing on design challenges that arise from individual characteristics of caregiving dyads (e.g., the nature of the caregiving dyad or previous gaming experience among older adults) is not only an important step toward creating enjoyable games, but also crucial to ensure that shared play does not harm burdened relationships.

9.3   Discussion

This chapter looks at how motion-based video games can be leveraged to help support relationships between caregivers and older adults. We present design considerations that can be applied to ensure that motion-based games are generally accessible and enjoyable for caregivers and older adults, and we discuss individual characteristics that may influence the shared experience of playing games. In this section, we discuss our findings with a focus on design opportunities and challenges for future work in this area.

9.3.1   Shared Play as an Opportunity to Connect Caregiving Dyads

There are various opportunities for interactive technologies to support relationships. In this section, we outline how our findings regarding video games for caregiving dyads can be leveraged to connect caregiving dyads.

Fostering Communication Through Play

Our study shows that games are a potential means of scaffolding conversation among players. While participants were generally focused on in-game events during gameplay, many dyads reflected upon their gaming session once they finished playing. Interestingly, even participant pairs who did not consider themselves avid video game players trailed off into discussions of other topics related to the games (e.g., one older adult commented on how they would offer their grandchildren candy to make them eat their meals, which initiated more storytelling about the past among older adult and caregiver). This aspect could be leveraged in the context of mini games that can serve as conversation starters between persons in caregiving relationships. Drawing from positive memories of both members of caregiving dyads would be an interesting design opportunity to connect older adults and their caregivers; design efforts in this field could draw from previous work that investigated game topics suitable for older adults

[164]. Additionally, this concept easily extends beyond caregiving for older adults, and could be applied for other people in difficult situations as demonstrated by [65].

Interaction With a Physical Dimension

Our study shows that the physical dimension of co-located play connects older adults and caregivers, and findings suggest two aspects of joint interaction that could be leveraged to foster closeness. First, joint interaction naturally encourages verbal coordination; this can serve as a vehicle to connect players through conversation, giving purpose to communication through the means of in-game challenge, thereby helping to facilitate conversation in difficult situations. In our study, we observed that discussing how to interact with the game and helping each other often served as an 'icebreaker' that allowed both members to get familiar with the game and negotiate their in-game roles. Second, we observed that the physical dimension of the game sometimes led to affectionate touch between players, e.g., one player would gently squeeze another player's hand or arm during the course of the game, actions which may further contribute to increased levels of relatedness between players. This aspect could be strengthened through interaction design: while our games only required joint interaction within the game (e.g., connecting avatars in the game), a carefully designed physical dimension – e.g., using player proximity as input, or encouraging players to join or clap hands – might be an interesting means of fostering closeness.

9.3.2   *Risks and Challenges of Shared Play Within Burdened Relationships*

Our work exposes risks and challenges that need to be addressed when engaging caregiving dyads in shared motion-based video game play. Our analysis of two case studies – the experiences of Emma and Andrew as well as Jim and Sarah – shows that both status and type of the caregiving dyad as well as their general approach to video games greatly influences the perception of games as a shared experience. Particularly when looking at the experience of Emma and Andrew, it becomes clear that design considerations extending beyond the initial challenges outlined in section 9.2.1 are necessary to avoid games harming caregiving dyads by reinforcing existing challenges within the caregiving relationship. In this context, it is important to recognize the vulnerability of caregivers: our initial design considerations strongly focused on the needs of the older adult to ensure their access to our games. However, results of the case studies suggest that shared activities may also burden the caregiver if they expose the impact of

age-related changes on the older adult, e.g., if shared in-game goals put pressure on the caregiver and faces them with the conflict of consolidating their own ambitions within the game with their task of supporting their loved one. Therefore, future work should further explore ways of mitigating the risk of increasing the vulnerability of caregiving dyads through shared play, and provide recommendations that can help inform the work of designers wishing to create video games for caregivers and older adults experiencing high levels of age-related changes, burden and stress – dyads that could benefit the most from enjoyable shared leisure activities.

9.4   Limitations

Our results show that motion-based games are generally accessible for caregiving dyads and that they enjoy shared play; however, there are certain limitations that need to be discussed. On a general level, caregiving is a sensitive topic: some dyads seemed to be afraid of giving off a wrong impression, or hurting the other person with their statements. We observed that older adults and caregivers in our study would seek affirmation of the other person on answers regarding their relationship. Also, some caregivers tried to influence the way older adults responded to questions related to the caregiving process. The setup of our study – inviting caregivers and older adults to participate at the same time in their own homes – was not ideal, and future work investigating this topic should consider interviewing caregivers and older adults separately. Additionally, future work should investigate long-term effects of video games on caregiving dyad; while the work presented in this paper provides first insights into challenges and opportunities, it is important to arrive understand how repeated video game play affects caregivers and older adults, and whether positive effects of games prevail over a longer period of time and lead to an improved caregiving process.

9.5   Conclusion

Caregiving for older adult family members is a challenging task that changes the nature of relationships, and may expose the caregiving dyad to high levels of stress. Our work is a first step towards the application of interactive technologies to directly connect caregivers and older adults instead of focusing on one member of the caregiving dyad, and it exposes both design opportunities as well as challenges that need to be addressed by researchers and designers. Our findings highlight that caregivers and older adults enjoy engaging with motion-based video games as a shared activity, and that games encourage communication, potentially fostering

closeness within the caregiving dyad. This highlights the potential of video games to support positive relationships among caregiving dyads: integrating interactive technologies into the caregiving process may not only provide an enjoyable leisure activity for caregiving dyads, but also offer a novel way of promoting positive relationships in difficult situations, thereby contributing to the quality of life of older adults and caregivers.

PART IV: DISCUSSING MOTION-BASED GAMES FOR OLDER ADULTS

This part of the thesis summarizes the work presented in this dissertation. It discusses how results tie back to the core challenges identified in chapter three, and how findings regarding motion-based game interaction and game design can be combined with research results from other areas of video games for older adults (e.g., findings regarding older adults' preferences in terms of graphical fidelity) to create better video games for older adults in long-term care. Furthermore, this chapter demonstrates how findings generalize beyond older adult audiences to increase the overall accessibility of motion-based video games (e.g., balancing between players of different skills and abilities), their implications for the design of motion-based interfaces beyond games, and how they can be applied in the context of future work.

CHAPTER 10
DISCUSSION

This dissertation examines the design of motion-based games for older adults with a focus on the accessibility of motion-based game controls, the creation of suitable game design concepts, and potential application areas for motion-based games for older adults in long-term care. The first part of this thesis provides an overview of common age-related changes and existing efforts in the field of motion-based games and formulates three core challenges that have to be addressed by research on motion-based game design for older adults: (1) making commercially available game input devices accessible for active older adults and older adults in residential care; (2) creating accessible game mechanics and adapting game concepts to the needs and preferences of institutionalized older adults; and (3) designing for the caregiving context to allow older adults in residential care to benefit from motion-based video game play. In the remainder of the thesis, these challenges are addressed in the context of different research studies. The third part of this thesis addresses motion-based game interaction for older adults and summarizes findings from three studies. The first study was designed to examine the suitability of motion-based game controls for older adults by comparing them to sedentary input devices and their use by younger audiences, the second study investigates full-body motion-based game controls for older adults, and the third study evaluates the feasibility of wheelchair-based game input for older adults. Based on these studies, design recommendations for motion-based game controls for older adults are provided. Building on these results, the fourth part of the thesis

addresses the application of motion-based games in the lives of older adults and presents results of two studies that were conducted with a focus on older adults in long-term care. The first study investigates long-term player engagement of older adults living in senior residences and nursing homes; the second study looks at whether games can be applied to improve the relationships between older adults and family caregivers.

On a general level, the results of this dissertation show that motion-based game controls can be designed in a way that is accessible for older adults, and that motion-based games can be an appealing leisure activity for older adults in residential care, but that there are also challenges to this context that need to be considered and addressed. This chapter of the dissertation provides a critical review of the core challenges outlined in the first part of the thesis, and discusses whether the work presented in this dissertation helps address these challenges. Furthermore, it outlines how findings can be generalized to other application areas beyond games, and can help inform the design of games for other audiences with special needs, for example, persons with disabilities.

10.1 Have the Core Challenges in Motion-Based Game Design for Older Adults Been Addressed?

This section looks at the core challenges in motion-based game design for older adults that were identified in Chapter 3 of this dissertation. It discusses how the work presented in this thesis can help overcome the challenges, and outlines its contributions and limitations.

10.1.1 Challenge 1: Designing Accessible Motion-Based Game Interaction for Institutionalized Older Adults

Many commercially available motion-based games are not fully accessible for older adults because they were designed for younger audiences with healthy bodies and previous gaming experience, and therefore do not meet the needs of older adults, particularly those experiencing age-related changes and impairments. The first part of this dissertation addresses this issue by examining the accessibility of motion-based game controls for older adults, and shows that it is generally possible to design motion-based game input in a way that is accessible for both active older adults as well as persons who experience a wide range of age-related changes and impairments: Older adults can generally interact with motion-based game controls in a safe, accessible, and enjoyable way, and are sufficiently efficient at applying motion-based

controls for them to be used in the context of game design (Chapter 4: Sedentary vs. Motion-Based Game Controls). Regarding the choice of input device (controller-based motion-based game controls or hands-free camera-based input), our findings suggest that either kind of motion-based game control is associated with certain advantages and disadvantages (e.g., controller-based input being more tangible, but hands-free input being more sanitary in multiplayer settings); on a general level, both types of input device were accessible to older adults. Following up on these findings, our results on the suitability of interaction paradigms beyond input devices show that camera-based full-body motion-based game controls can be designed in a way that is accessible for institutionalized older adults (Chapter 5: Full-Body Motion-Based Game Input for Older Adults); however, special considerations are necessary if older adults are using wheelchairs (Chapter 6: Wheelchair-Based Game Controls for Older Adults) as currently available camera-based systems are not fully accessible for persons using wheelchairs. In this context, results of our long-term study on the gaming behaviour of older adults in residential care (Chapter 8: Long-Term Player Motivation in Motion-Based Games) back up these findings, showing that institutionalized older adults experience difficulties when trying to play commercially available games, but that they can participate in custom-designed motion-based games. In contrast, results also show that active older adults can play certain commercially available games (e.g., games with simple hand- and arm-based interaction paradigms, such as Kinect Sports Bowling).

This suggests that considerations regarding the design of accessible motion-based game controls become increasingly important as the impact of age-related changes and impairments grows, and that it is crucial to consider the specific limitations that come with certain age-related changes (e.g., mobility disabilities and the use of wheelchairs and their prevalence among institutionalized older adults). In this context, our work provides design guidelines (Chapter 7: Design Guidelines for Motion-Based Game Interaction for Older Adults in Long-Term Care) that can help inform the work of researchers and game developers wishing to create accessible motion-based applications for older adults experiencing a wide range of age-related changes and impairments. However, it is important to note that such design guidelines can only serve as a starting point in the design of motion-based game controls for older adults, and that a user-centered design process is necessary to select appropriate input devices (e.g., deciding whether to use controller-based or hands-free motion-based game input) and to adapt games to the specific

requirements of the target audience (e.g., working with persons using wheelchairs or designing accessible interaction paradigms for persons with hemiplegia).

This shows that it is possible to design accessible motion-based game controls for older adults regardless of the impact of age-related changes and impairments; however, due to the complexity of games, the creation of suitable interaction paradigms can only be considered a first step towards the creation of motion-based video games for older adults. Additional considerations regarding the suitability and appeal of game mechanics and game topics as well as the application context and the living situation of institutionalized older adults are necessary to allow them to fully benefit from motion-based video game play.

10.1.2 Challenge 2: Understanding the Player Experience of Older Adults

Following the design of accessible motion-based game interaction, the next challenge to be addressed in this thesis was whether motion-based games can be designed in a way that is beneficial for and appeals to older adults in long-term care. In this context, it is important to arrive at a detailed understanding of the player experience of older adults, investigating how different aspects of motion-based games, such as game mechanics, topics or graphics affect how older players perceive these games.

Besides investigating the design of accessible game controls, the second part of this dissertation provides first insights into the player experience of older adults: the evaluation of full-body motion-based game controls for institutionalized older adults (Chapter 5: Full-Body Motion-Based Game Input for Older Adults) using a gardening game as example shows that older adults generally enjoy playing motion-based games, and that engaging with such games has a positive effect on their mood. These findings are supported by evaluation results of the wheelchair-accessible motion-based game Cupcake Heaven (6.3 Study 2: Wheelchair-Based Game Controls for Older Adults), again highlighting that institutionalized older adults enjoy playing motion-based games. Along these lines, results of the third part of this dissertation investigating game design for older adults and caregivers (Chapter 9: Motion-Based Games to Connect Older Adults and Caregivers) show that older adults enjoy playing video games with their caregivers, and that games can increase relatedness within caregiving dyads. A limitation of these studies is that their primary focus is on aspects other than player experience, and that they only evaluate games in the context of a single gaming session and their implications regarding the long-term player experience of older adults is limited. These shortcomings are partially

addressed by the long-term study included in this dissertation (Chapter 8: Long-Term Player Motivation in Motion-Based Games). It shows that depending on the kind of motion-based game and the level of age-related changes and impairments experienced by players, motion-based games have the potential of engaging older adults over a longer period of time. In this context, our results confirm design recommendations regarding suitable topics video games for older adults provided by IJsselsteijn et al. [80] and De Schutter and Vanden Abeele [146], showing that older adults do enjoy engaging with games that are designed around topics of daily life, such as cooking or gardening, and that they find games particularly appealing if they mimic real-world activities, such as bowling.

However, all of these studies only provide high-level insights into the player experience of older adults, and little is known about how different game elements influence their player experience. We begin to address this issue in another research project examining the impact of graphical fidelity on player experience. In a study investigating the relationship between visual complexity, player experience, performance, and perceived exertion in motion-based games for older adults [153], we found that older adults prefer game graphics that convey premise over stylized visuals (e.g., they prefer being able to recognize game objects instead of seeing abstract shapes) and report a more positive player experience. However, the level of graphical fidelity beyond stylized graphics does not have a significant impact on player experience. These findings are backed up by results of a study examining the impact of graphical fidelity on the player experience of younger adults [64], showing that graphical fidelity is less important in easily accessible casual games and only has an impact on player experience as the level of difficulty of in-game challenges rises. However, our findings regarding the impact on visual complexity of motion-based games do show that the level of visual fidelity affects perceived exertion, suggesting that high-quality game graphics reduce perceived exertion among older adult players. This effect can be beneficial when trying to encourage players to push through periods of challenging gameplay; however, it also puts older adults at the risk of overexertion and injury if motion-based games create high levels of immersion and reduce the focus on responses of their own bodies to in-game challenges.

Arriving at a detailed understanding of the way older adults experience motion-based video games is particularly important if games are to be applied to improve the well-being of institutionalized older adults, or to serve in therapy and rehabilitation: Researchers and game

developers need to be aware of both opportunities and challenges associated with the use of video games among older adults; particularly when applying games over a longer period of time, it is crucial to be aware of potential risks of the use of motion-based video games regarding the emotional and physical well-being of institutionalized older adults.

10.1.3 Challenge 3: Motion-Based Video Games for Older Adults in Long-Term Care

The results of this dissertation show that the awareness of special requirements of the context in which motion-based video games for older adults are deployed is equally important as accounting for age-related changes and impairments to make motion-based games accessible for older adults. Our findings suggest that special design considerations are necessary to adapt games to the caregiving context, particularly daily life in residential care, and that the prevalence of age-related changes and impairments among residents of care facilities can result in additional requirements for the design and deployment of games that extend beyond the basic accessibility of motion-based game interaction.

Our findings suggest that when working with older adults, the context in which games are played needs to be considered as it affects how older adults perceive video game play, and how they reflect upon their own skills and abilities. Particularly when trying to encourage older adults to engage with games in a social context, it is important to be aware of the effects that other players might have on their experience. While research results looking at video games as a socialization aid are generally positive (e.g., [84] and [88]), the results of this dissertation suggest that there may be negative effects of playing video games in a social setting on older adults in long-term care that need to be considered: our study on long-term player engagement among older adults in residential care (Chapter 8: Long-Term Player Motivation in Motion-Based Games) shows that older adults may feel intimidated by the presence of others when trying to learn how to play games, and that they are aware of their in-game accomplishments in relation to those of other group members. In this context, our results regarding the deployment of motion-based games to connect older adults and caregivers (Chapter 9: Motion-Based Games to Connect Older Adults and Caregivers) show that the relationship of the caregiving dyad can be improved through joint interaction in collaborative motion-based game play, which highlights the great potential of video games for older adults as a means of socializing with other persons. However, the results also show that large differences in players' abilities of learning how to interact with the games and their in-game performance might lead to a reinforcement of stereotypical roles

and may have caused some older adults to reflect upon the changes in physical and cognitive abilities that they experienced as a result of the aging process. These findings need to be considered because research results suggest that playing games in a social setting affects how we perceive ourselves: another study that we conducted to investigate how balanced and unbalanced competition in motion-based games affects the player experience and self-esteem of younger adults [70] shows that player performance has a significant effect on the relationships between players, the overall player experience, and players' self-esteem. Results suggest that a bigger performance gap between weaker and stronger players leads to a decreased experience of both participants; furthermore, results of an exploratory study comparing competition between able-bodied persons and players with mobility disabilities show that the experience of able-bodied players is affected in a negative way if they feel that they have an unfair advantage over a person with a disability. These findings have implications for game design for older adults in residential care: our results show that this audience is an extremely heterogeneous player group with a wide range of skills and abilities. Particularly as the impact of age-related changes and impairment grows, games need to be adapted to a wide range of players, and games allowing for competition between players should be able to accommodate enjoyable and encouraging competition between players of different skill levels, particularly when older adults engage in play with younger family members or caregivers. In this context, it is necessary to further explore the impact of competition and collaboration on the player experience of older adults under special consideration of the impact of age-related changes and impairments on the accessibility of video games and the perception of competition between players. Only if researchers and game development consider the special needs of older adults in residential care in the design process, is it possible to mitigate the risk of negative effects and allow older adults to obtain the physical, cognitive and emotional benefits that are associated with playing motion-based video games.

This aspect also needs to be considered in the deployment phase: creating enjoyable gaming experiences for older adults does not end with accessible and adaptive game development; efforts to support older adults in residential care wishing to play video games need to be extended into daily routines at care facilities to ensure that residents are able to obtain access to video games regardless of age-related changes. In this context, our studies on the deployment of motion-based games for older adults in long-term care (Chapter 8: Long-Term Player Motivation in Motion-Based Games; Chapter 9: Motion-Based Games to Connect Older

Adults and Caregivers) show that caregivers of older adults often function as gatekeepers. On the one hand, they are important stakeholders in the deployment of video games, because they have the opportunity of introducing new activities to older adults. On the other hand, they have to be supportive during the deployment phase if older adults need assistance in playing games that cannot be addressed by game design considerations (e.g., if older adults with mobility disabilities need assistance to attend gaming sessions). This highlights the importance of working with experts from the field of gerontology and nursing care in the development and deployment of video games for older adults to ensure that applications do not only meet the needs of older adult players, but can also convince other stakeholders of their great potential in the lives of older adults living in residential care and ensure that they are willing to support older adults' continued access to video game play.

On a general level, the results of this dissertation show that it is possible to overcome the main challenges in the design of motion-based video games for older adults, and to create motion-based games that are accessible for older adults regardless of age-related changes and impairments. Additionally, the results show that it is possible to integrate games into the lives of older adults. To accomplish this goal, it is crucial to make careful considerations during the design process, work closely with the target audience to adapt games to their preferences and needs, and to include other stakeholders, such as nursing staff, if games are to be deployed in residential care.

10.2   Generalizing the Findings Beyond Game Interaction for Older Adults

This section discusses the implications of the findings of this dissertation beyond motion-based video games for older adults, with a focus on their application for older adult audiences in a broader context, and how they extend to other audiences with special needs.

10.2.1 Applications Beyond Games

With information technology becoming pervasive in daily life, it is important to ensure the accessibility of new technologies for older adults. In this dissertation, we have demonstrated that motion-based controls can be applied in an accessible and enjoyable way, and our results can help inform the implementation of motion-based interaction beyond games, for instance to facilitate user interaction in home entertainment or to support ambient-assisted living solutions.

In the context of ambient-assisted living, Chapter 4 suggests that differences between controller-based and hands-free input solutions are likely to play a bigger role: while controller-based interaction offers additional input options through buttons, it always requires active participation of the user. In contrast, hands-free systems offer the possibility of augmenting the interaction process by including passive input, which can be obtained by sensing user location, posture, and the changes therein. Further research should explore the development of senior-friendly gestures and input methodologies to foster the integration of motion-based controls beyond gaming.

Additionally, gestures and guidelines as proposed in Chapters 5, 6, and 7 can be applied in other areas where older adults are required to interact with information systems and generally contribute to facilitation of their interaction with information technology. For instance, the implementation of gestures in ambient-assisted living has the potential of supporting older adults when interacting with information systems in their home environment. Tasks such as the motion-based control of home electronics (e.g., controlling lights or television) could greatly facilitate everyday life. In this context, applying appropriate interaction paradigms, e.g., the gesture set provided in this thesis, can support the independence of older adults and allow them to continue living in their home environment even when experiencing age-related changes. Furthermore, institutionalized older adults might benefit from gesture-based interaction in daily life if routine tasks such as opening or closing doors can be augmented by motion-controlled interaction.

10.2.2 Extending Our Findings to Other Audiences

Certain aspects of the work presented in this dissertation extend to other audiences with special needs. Creating motion-based game interfaces that can accommodate a wide range of skills and abilities does not only improve their accessibility for older adults, but also for other individuals with cognitive disabilities or mobility disabilities. In this context, one particularly interesting design opportunity is the creation of wheelchair-accessible motion-based video games for audiences beyond older adults.

The gestures and guidelines we have presented in Chapter 5 and Chapter 7 are specifically designed to aid designers to build games for older adults who experience a wide range of physical and cognitive age-related changes. However, the same gestures and guidelines can be applied, in a general way, to games that are designed with full-body motion control in mind. If our guidelines are used in the development of any game, then players with other

impairments will be able to enjoy these games. For example, players in wheelchairs or who experience other physical limitations would still be able to participate in these games. Also, games for young children with little motor control would benefit from simple gesture-based controls.

Additionally, our results particularly addressing wheelchair-based game controls can be applied to keep motion-based video games accessible for players of all ages with mobility disabilities. The evaluation of the KINECT^{Wheels} toolkit presented in Chapter 6 show that younger able-bodied people enjoy wheelchair-based controls, and consider the use of a manual wheelchair to interact with video games an interesting experience. In this context, wheelchair-based game controls could also be leveraged to raise awareness for topics such as wheelchair accessibility of public places and foster understanding of problems that people using wheelchairs experience, e.g., by creating mini games that illustrate the inaccessibility of different areas of life. Such games could be applied to educate the general public by inviting them to experience the world from someone else's perspective [27]. In this context, wheelchair-based games are a great opportunity for engaging students, and encouraging them to consider challenges that their peers who use wheelchairs have to face on a daily basis, thus fostering an understanding of accessibility issues. A major limitation of many motion-based video games that address younger audiences and implement camera-based input devices such as the Microsoft Kinect is that they are not fully accessible to players using wheelchairs; although some games can be calibrated to work for players sitting on a chair, players using wheelchairs will not be able to engage with motion-based video games that require players to move around in the room. The KINECT^{Wheels} toolkit that was developed as part of this dissertation can be applied to create motion-based video games for children and teenagers using wheelchairs that encourage physical activity beyond simple upper body movements. Results of our work on balancing video games for players of different skills and abilities [70] suggest that persons using wheelchairs enjoy playing motion-based games using their wheelchair as input device. This suggests that it is possible to embrace the abilities of the target audience [177] rather than making limited subsets of interaction paradigms of existing games accessible, thus allowing persons using wheelchairs to obtain the full benefits of exergame play.

Motion-based games have a wide range of benefits on the cognitive, physical and emotional well-being of players. This dissertation examines the design, implementation, and

deployment of motion-based games with a focus on allowing older adults in long-term care to obtain these benefits. The results show that motion-based game interaction can be designed in a way that is accessible and enjoyable for older adults. Furthermore, findings demonstrate that motion-based video game play is beneficial for this audience, highlighting the large potential of video games to contribute to the quality of life of audiences with special needs.

While these findings address the basic challenges outlined in Chapter 3 of this dissertation, the results also raise new questions and provide opportunities for additional research, hence a number of exciting challenges for future work remain.

CHAPTER 11
CONCLUSION AND FUTURE WORK

This dissertation investigates the design of motion-based video games for older adults in long-term care with a focus on game interaction, game design and the application of games in a care context. It demonstrates that it is possible to make motion-based game controls accessible for older adults, and that game concepts can be designed in an engaging and empowering way. However, it also highlights the importance of accounting for individual player characteristics and circumstances, and raises additional questions regarding opportunities in motion-based game design for older adults. In this chapter, we discuss two main areas for future work: the design of games beyond entertainment with the goal of improving the quality of life of institutionalized older adults, and further decomposing the player experience of older adults.

11.1 Designing Motion-Based Games to Improve the Lives of Institutionalized Older Adults

Our findings suggest that older adults particularly enjoy engaging with games if they can benefit from video game play beyond being entertained, for instance, if games can contribute to their physical, cognitive, or emotional-well being. In this context, previous work has explored the application of video games in therapy and rehabilitation (e.g., [4], [10], and [12]) and cognitive training (e.g., [8]), but relatively little is known about designing games for older adults specifically addressing their quality of life, and aiming to improve their emotional well-being. In this context, the results of this dissertation outline several opportunities for future work.

Chapter 5 demonstrates that playing motion-based video games has positive effects on older adults' mood. This effect of motion-based video games could be leveraged to improve the emotional well-being of older adults throughout the day; future work should examine how to design casual games to foster emotional well-being among older adults that can be integrated into daily routines of institutionalized older adults in multiple short chunks of play, similar to work on casual exergames by Gao and Mandryk [61]. Additionally, research needs to explore which game elements contribute to an increase of positive affect among older adults, whether this effect can be maintained over time, and how it can be achieved on a larger scale.

In terms of the emotional well-being of older adults, relationships with other people play an important role [84], and results of this dissertation suggest that motion-based games specifically addressing the challenge of connecting players are a promising design opportunity. Chapters 8 and 9 demonstrate the potential of games to connect older adults with peers and caregivers; in this context, future work should explore how the design of games can contribute to relationships between players, and how relationships between older adults and caregivers develop over time if they jointly engage with motion-based video games.

Finally, Chapter 6 on wheelchair-based game input for older adults shows that motion-based games can be applied to improve older adults' relationship with their assistive device. This highlights another opportunity of applying motion-based games to benefit institutionalized older adults: motion-based video games could serve as vehicles to encourage them to become more familiar with their assistive devices, e.g., wheelchairs, to improve their mobility, encourage them to maintain physical independence, and thereby increase their quality of life. Future work in this area should explore the integration of motion-based video games in physical activity routines at residential care facilities. In this context, games could be a valuable design opportunity in wheelchair skills training for older adults: if wheelchair-controlled motion-based games would integrate movements that older adults need to learn to be able to navigate their wheelchairs, this could contribute to their ability of independently navigating their environment.

However, if games are implemented in residential care with the goal of becoming part of the daily lives of older adults, it is also important to arrive at a detailed understanding of how games affect institutionalized older adults and further explore challenges and opportunities in their deployment.

11.2   Decomposing the Player Experience of Older Adults

In the context of applying motion-based games to improve the quality of life of institutionalized older adults, understanding how they interact with games, and how this interaction and their overall experience with the game affects them, is an important step towards the design of games that fully meet the needs of this audience. Therefore, researchers should aim to further decompose the player experience of older adults to understand challenges and opportunities in the design of motion-based games for this audience.

This issue needs to be addressed from two different perspectives. First, it is important to further examine how older adults perceive motion-based games in the short run, and how

features of games directly affect their experience, e.g., understanding whether highly immersive games may increase the risk of injury for players who do not pay sufficient attention to reactions of their bodies during play, examining how certain elements of games such as graphics, input gestures, or sound can contribute to a positive player experience, and exploring how the context of play (e.g., participating in single player vs. multiplayer games) affects the appeal of video games. Second, research has to examine long-term effects of engaging with motion-based games beyond the physical and cognitive benefits, with a focus on how games can influence how players perceive themselves, e.g., by examining whether competition between institutionalized older adults has effects on the self-esteem of players and their relationships with other persons.

When designing for older adults, it is important to keep in mind that the lack of previous gaming experience is only true for the current generation of older adults. Once younger generations who grew up playing video games age, new considerations regarding game concepts are necessary, as prior experience with games is likely to have an impact on players' understanding of games, as well as preferences in terms of game genres and expectations regarding the complexity and depth of games. Therefore, future work has to explore how an increase in previous experience with games affects older adults' perceptions of video games in late life, the ability of dealing with complex game concepts, and how this affects player experience. In this context, combining the results of this dissertation regarding the accessibility of motion-based game controls for older adults with new opportunities in game design is an exciting opportunity that researchers and game developers need to address.

11.3   Designing Video Games for Caregiving Environments

Finally, future work should further explore game design opportunities associated with the development of video games for caregiving environments. This dissertation gives some insights into the special requirements of motion-based video games for the deployment in residential care; however, our results also show that further research is necessary to adapt games to the requirements of care settings. It is important to consider how the living environment of older adults affects their engagement with video games, and how caregivers, nursing staff and other stakeholders can be integrated into the design and development of games to encourage their continued involvement once games are deployed in residential care. To foster the integration of caregivers and staff, researchers should work closely with these audiences; a starting point for future work would be a detailed analysis of their opinions on motion-based video games for

institutionalized older adults, and their perspectives on requirements for games to be deployed in residential care beyond accessibility considerations. In this context, research results could extend beyond older adults and hold implications for other audiences, e.g., children and teenagers who are hospitalized for longer periods of time, or adults with disabilities who live in long-term care.

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