Custom-designed motion-based games for older adults: A review of literature in human-computer interaction

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K. Gerling, R. Mandryk, Custom-designed motion-based games for older adults: A review of literature in human-computer interaction, Gerontechnology 2014;12(2):68-80; doi:10.4017/gt.2013.12.2.001.00 Many older adults, particularly persons living in senior residences and care homes, lead sedentary lifestyles, which reduces their life expectancy. Motion-based video games encourage physical activity and might be an opportunity for these adults to remain active and engaged; however, research efforts in the field have frequently focused on younger audiences and little is known about the requirements and benefits of motion-based games for elderly players. In this paper, we present an overview of motion-based video games and other interactive technologies for older adults. First, we summarize existing approaches towards the definition of motion-based video games – often referred to as exergames – and suggest a categorization of motion-based applications into active video games, exergames, and augmented sports. Second, we use this scheme to classify case studies addressing design efforts particularly directed towards older adults. Third, we analyze these case studies with a focus on potential target audiences, benefits, challenges in their deployment, and future design opportunities to investigate whether motion-based video games can be applied to encourage physical activity among older adults. In this context, special attention is paid to evaluation routines and their implications regarding the deployment of such games in the daily lives of older adults. The results show that many case studies examine isolated aspects of motion-based game design for older adults, and despite the broad range of issues in motion-based interaction for older adults covered by the sum of all research projects, there appears to be a disconnect between laboratory-based research and the deployment of motion-based video games in the daily lives of senior citizens. Our literature review suggests that despite research results suggesting various benefits of motion-based play for older adults, most work in the field of game design for senior citizens has focused on the implementation of accessible user interfaces, and that little is known about the long-term deployment of video games for this audience, which is a crucial step if these games are to be implemented in activity programs of senior residences, care homes, or in therapy.

Keywords: video games, exergames, physical activity, older adults

Many older adults, particularly persons living in senior residences and care homes, lead sedentary lifestyles, despite the importance of physical and cognitive activity for well-being in old age. Decreased activity adversely affects an individual's life expectancy, frequently leading to sedentary death syndrome[1]. Care facilities face not only the challenge of providing medical care and accommodation, but also the responsibility of encouraging older adults living in nursing homes to participate in leisure activities. Despite various efforts[2], few activities remain accessible to institutionalized older adults, and it is difficult to motivate them to remain cognitively and physically active as the impact of age-related changes grows. Therefore, many older adults do not meet recommended levels of physical activity – a mix of about two hours of aerobic exercise in combination with muscle and strength training twice a week[3-5].

Research has frequently highlighted the potential of motion-based video games for this audience, but also pointed out that video games need to be designed with senior audiences in mind[6]: It has been shown that older adults enjoy playing video games[7,8] and it has been demonstrated in different studies that motion-based games have positive effects on the emotional[9], cognitive[10], and physical[11] well-being of older adults. However, concerns regarding the usability and accessibility of motion-based applications for older adults have been brought up by a range of studies[12], and most work focusing on the design of motion-based interactive technologies has addressed the creation of sports-like experiences to help fight sedentary lifestyles among younger audiences.

In this paper, 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. 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.

EXERCISE GAMES THEORY
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[13]. 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[14] to acute cognitive benefits[15], an increase in social interaction[16] and emotional well-being[9]. Additionally, exergames can be applied to help address the problem of childhood obesity in Western societies[17], 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[18].

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. Among others, Bogost[19] defines exergames as "games that combine play and exercise", and "that use physical input devices". Likewise, Lieberman et al.[20] 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.[21] define exergames as games "in which the outcome is predominantly determined by physical effort". Silva and El Saddik[22], introduce 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. In a review of exergame definitions, Oh and Yang[23] 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".

In order to provide a classification of exergames in this paper, 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[22] and the ideas promoted by Oh and Yang[23]: 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[24], 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 paper, 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.[25] 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 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.

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[26], 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.[7] builds on insights gained through the implementation and evaluation[27] of the research tool SilverBalance, which was designed to explore the use of foot-based user input in exergames for senior citizens. Results of an evaluation including qualitative and quantitative measures 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. An evaluation in a single session using standardized questionnaires to assess player experience 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.[28] 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
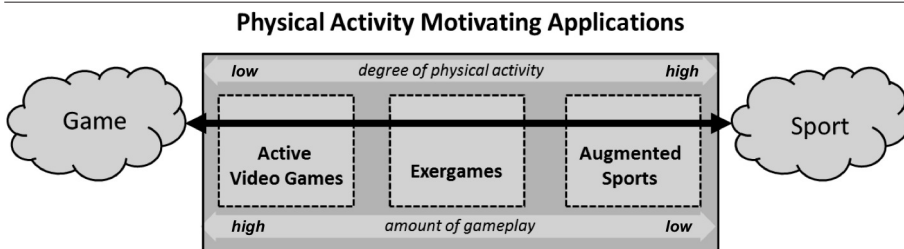

Figure 1. Distinction between applications that motivate physical activity based on the integration of exertion and gameplay

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 qualitative 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.

Gerling et al.[18] present a gardening game for institutionalized older adults that implements Microsoft's Kinect sensor in order to track user movements. Based on an exploration of senior-friendly interaction paradigms for full-body motion-control games, the game features four main challenges incorporating static or dynamic gestures: In order to grow plants, players have to stand on one leg or walk in place (if players are seated, plants automatically grow). To grow flowers, players activate rain by lifting or waving one arm. Extending one or both arms to the side or pretending to be flying gathers sunshine that allows flowers to start blooming. 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. To account for age-related changes and impairments, the system can be adjusted to meet individual player requirements (e.g., by allowing players to sit or stand while playing, and offering support for two- and one-handed play). Furthermore, it supports calibration routines that adapt input gestures to the player's range of motion, strength and speed. An evaluation with twelve institutionalized older adults showed that the game was accessible even though many participants were severely affected by age-related changes and impairments. Furthermore, the game was enjoyable, and led to a significant improvement of the participants' affective state, suggesting that exergames may have benefits regarding the emotional well-being of older adults. Measures included standardized questionnaires, performance metrics, and qualitative interviews. Likewise, Rice et al.[8] 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, combining questionnaires and observations. 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.[29,30] present the exergame Flowie, which aims to increase the number of daily steps taken by the players in a way which is similar to game concept Fish'n'Steps by Lin et al.[31]. 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 pilot user study combining qualitative and quantitative measures 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[16]. 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 where older adults participated in short chunks of gaming and post-play interviews 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 summarized in this paper (e.g., Gerling et al.[18] and Rice et al.[8]), 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

Different approaches towards game-based physical therapy for older adults have been made in the past; focusing on physical activity to prevent injury and the treatment of chronic conditions among older adults. The commercially available rehabilitation system SilverFit[32] 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 and 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[33]. 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[34] 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[35].

To address this issue, different custom software applications using foot-based gaming hardware as the input device have been designed. Young et al.[36] 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. However, an evaluation of mini games that were developed based on the system only showed a partially significant improvement of clinical measures of standing balance. Follow-up interviews with participants revealed that they were highly motivated to use the system due to the appeal of game elements. Kerwin et al.[37] 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.[27] 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.[38,39] 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[40], which allows for the direct assessment of player progress and was designed to support the application of motion-based game interfaces in physical therapy. While the system was tested in the context of a usability evaluation, the authors do not provide details on its value in a clinical context. Smith et al.[35] 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 focus on performance metrics only and show that stepping interfaces are suitable for balance training and falls prevention in the sense that all users were able to interact with the system; 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.[41,42] 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. A case study investigating the use of the game among older adults with Parkinson's disease revealed that the game appealed to players and encouraged their continuous participation in therapy.

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. Uzor et al.[43] present a game-based approach toward falls rehabilitation for older adults. Their results show that video games are a suited to encourage stroke rehabilitation among this audience; comments of older adults showed a positive response to game-based rehabilitation compared to traditional approaches such as the use of booklets. Alankus et al.[44] 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 qualitative 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. Baalam et al.[45] 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 these user studies suggest that it is important to individually adapt rehabilitation measures to user preferences for therapy to be successful. In this context, Gouaïch et al.[46] present a first approach toward dynamic difficulty adaptation in games for older adults who had a stroke. Overall, the authors concluded that the augmentation of stroke rehabilitation with information technology represents a valuable design opportunity.

Exertion

In contrast, Carmichael et al.[47] 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.[48] 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.[49], 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.[50] present Spark, a pedometer-based system similar to Flowie[29]; however, instead of combining pedometer input with a game, they provide visualizations of user activity. A three-week qualitative evaluation during which participants used the system and participated in interviews showed that people 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. On a general level, little distinction is made between the different kinds of physical activity that can be provided through games. While many applications designed for physical therapy and rehabilitation focus on coordinative training, applications with a focus on exertion aim to foster muscle workouts and overall fitness.

SUMMARY AND DISCUSSION

The overview of motion-based applications in this paper shows that a growing number of projects have the goal of addressing or exploring the needs of older adults. In this context, the overview 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. 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 the remainder of this paper, we discuss the limitations of existing research on motion-based input for interactive technologies for older adults. Based on the overview of motion-based applications for older adults in this paper, we highlight open research questions with a focus on input technologies and evaluation results, and outline areas for future work.

Closing the gap

The case studies presented in this paper cover a variety of aspects of motion-based game design for older adults; the overviews of their main characteristics and evaluation approaches (*Table 1*) show the broad range of problems 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. On a general level, research in human-computer interaction is very enthusiastic about motion-based games for older adults; little consideration is given to potential negative effects of game-based physical activity, as for instance the risk of injury through overexertion, or other disadvantages that are inherent when playing games.

In this context, we outline challenges that need to be addressed by future work in order to facilitate the deployment of motion-based video games in the daily lives of older adults.

Input devices

Many of the case studies presented in this paper 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 (*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 Microsoft Kinect sensor. Furthermore, many of the case studies shows 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 future work, it might be valuable to further explore the application of full-body motion-based input to explore additional opportunities for designers.

What do evaluation results really tell us?

The overview of evaluation results shows that a majority of studies looks at results of single ses-

sions, short intervention times, and small sample sizes (*Table 1*); 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 paper were in-home studies in which participants were encouraged to use the system on their own. Finally, because of the exploratory nature of many studies, they do not include control groups of users participating in alternative activities. 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, the scope of research is too small to investigate the long-term appeal of such games, and the lack of control conditions restricts statements regarding the benefits of games compared to other interventions, which all are crucial factors for consideration 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[10] featuring a three-month study with 79 participants showing positive effects of cybercycling on older adult cognition, or research by Aarhus et al.[11] 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: (i) investigators encourage participation in intervention sessions and represent an additional incentive that may not be present in unsupervised play; (ii) investigators and instructors can provide technical support to lower entry barriers to the use of interactive technologies;

and (iii) 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 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'
The core 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 (e.g., Alankus et al.[44]; Gerling et al.[18]); 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.[51]), 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 long-term deployment among the target audience to validate and further refine existing design recommendations. In that context, it might be valuable to explore attitudes towards interactive technologies among older adults who choose not to integrate them in their life (e.g., care home residents

Table 1. Overview of applications to foster physical activity among older adults, and their evaluation routines; M=mean

Year	Application			Evaluation					Reference
	Title: description	Input device	Audience	Routine	Duration	n	Age, yrs	Venue	
Active video games									
2008	Walk2Win: tabletop game with active part in which players search the room	Mobile phone	Older adults	2 Hour session, group discussion, observations; descriptive analysis only	Single session	8	M=71	Community centre	28
2012	SilverPromenade: players can participate in virtual walks and play mini games	Nintendo Wii remote, Balance board	Institutionalized older adults	15 Minute intervention, standardized questionnaires, observations, metrics; descriptive analysis only	Single session	18	M=80.5	Care home	7
Exergames									
2005	DanceAlong: application in which users dance along with famous movie scenes	Custom-designed camera system	Older adults	1 Hour intervention, interview; descriptive analysis only	Single session	12	56-83	Community centre	16
2009	Flowie: daily steps are measured and represented in game environment	Pedometer	Older adults	Round-the-clock intervention, metrics, standardized questionnaires	11 Days; 5 sessions	2	65 & 73	Participant home	29
2012	Gesture-based gardening game: players perform full-body gestures to grow plants	Microsoft Kinect	Institutionalized older adults	10-15 Minute intervention, metrics, observations, standardized questionnaires	Single session	12	M=76.7	Care home	18
2012	Gesture-based mini games: players perform full-body gestures	Custom-designed camera system	Older adults, family members	2 Hour session with 6 participants, custom questionnaires and observations	Single session	36	55-70	Community centre	8
Augmented sports / activity: As therapy									
2009	SilverFit: commercially available system, mini games to support physical therapy	Custom-designed camera system	Older adults	No published evaluation					32
2010	Mini games: balance training using foot-based input	Nintendo Wii balance board	Older adults with increased fall risk	1 Hour intervention, standardized scales and questionnaires	8 Weeks; 40 sessions	14	M=69.2	Hospital	38
2010	Research tool: designed to determine user balance using foot-based input	Nintendo Wii balance board	Older adults, researchers	20 Minute sessions, standardized scales and questionnaires	4 weeks / 10 sessions	6	M=84.1	Not reported	36
2011	WuppDi!: mini games using upper body gestures to support physical therapy	Custom-designed camera system	Persons with Parkinson's disease	Metrics, standardized questionnaires, interviews; descriptive analysis only	Single session	13	M=70	Not reported	41,42

Year	Description	Device	Population	Method	Duration	N	Age	Setting	Ref
2011	Research tool: designed to help examine user balance in foot-based interaction	Nintendo Wii balance board	Older adults, researchers	10 Minute intervention, standard questionnaires, metrics, observations; descriptive analysis only	Single session	8	M=82	Laboratory	27
2011	Simplified version of the commercial stepping game Dance Dance Revolution	Dance mat	Older adults with increased fall risk	Metrics	3 Single sessions	20, 21, 26	M: 78.9	Not reported	35
2012	Mobile dancing game: players dance along with music	Accelerometer	Older adults with increased fall risk	Usability testing; interviews, observations; descriptive analysis only	Single session	10	68-89	Not reported	37
Augmented sports & activity: For rehabilitation									
2010	Gesture-based mini games: e.g., catching a baseball	Custom-designed camera system, Nintendo Wiimote	Older adults in stroke rehabilitation	Weekly meeting with therapist; interview, metrics; descriptive only	6 weeks; 30 sessions	1	62	Participant home	44
2011	Applications for stroke therapy: e.g., e-book reader combining hand-based input	Custom-designed haptic input	Adults in stroke rehabilitation	Interview, metrics; descriptive analysis only	6 Weeks–7 months, multiple sessions	2	70s	Participant home	45
2013	Game-based applications: for falls rehabilitation	Accelerometer	Adults in falls rehabilitation	Interview, metrics, questionnaires	Multiple sessions	11	70s	Participant home, laboratory	43
Augmented sports & activity: For exertion									
2010	TV-based exercise application: to encourage full-body input	Custom-designed camera system	Older adults	60-90 Minute sessions, standardized scales and questionnaires, interview	Single session	19	M: 62.5	Laboratory	47
2010	TV-based exercise application building on Otago Exercise Programme: to encourage full-body input	Custom-designed camera system	Older adults with increased fall risk	Usability testing; observations, think-aloud; descriptive analysis only	Single session	12	NA	Hospital	48
2011	Tai Chi simulation: full-body input through the imitation of poses	Accelerometer	Older adults	No published evaluation					49
2012	Spark: different visualisations of daily steps	Pedometer	Older adults	Round-the-clock intervention, interviews; descriptive analysis only	3 Weeks	3	58-71	Participant home	50

who choose not to participate in research studies) to gain further insights into barriers to the use of motion-based applications that might be lowered by alternative design approaches.

CONCLUSION AND FUTURE DIRECTIONS

In this paper, we present an overview of the field of exergames for older adults. First, theoretical approaches towards games that motivate physical activity are examined in order to provide a working definition of exergames. In the context of this paper, we suggest to distinguish between active video games, exergames, and augmented sports and activity. The fundamental differentiating factor between these categories is the prioritization of exertion or gameplay in the design of the system. Based on these categories, case studies are discussed with a focus on applications for older adults. Different case studies have addressed the creation of games that motivate physical activity for older adults, frequently focusing on an exploration of senior-friendly interaction paradigms and the application of games in therapy. Our distinction between active video games, exergames and augmented sports provided in the first part of this paper was used to categorize existing studies of games that motivate physical activity. Determining the degree of physical activity required to play was difficult for some case studies as only few details on gameplay were provided, and future work should explore ways in which games and applications that motivate physical activity can be classified more accurately.

Many of the approaches towards active video games and exergames that were presented in this paper provide short chunks of gameplay to examine the suitability of different approaches towards game interface design and to investigate short-term player experience, e.g., how fun or engaging certain approaches are. However, little research has addressed the creation of game mechanics particularly suited for exergames, and therefore little information on the long-term appeal of certain game features is available. If we expect users to benefit from to long-term effects of regular physical exercise, additional investigation is required to create exergames that engage users over a longer period of time, rather than supporting short sessions of play for a short period. Specifically, long-term evaluations of game projects and studies designed to examine behavioural change are necessary to provide insights into the effects of certain game mechanics and features. Many case studies presented in this paper include user studies, but provide only superficial findings, e.g., stating that most participants enjoyed engaging with such games during a single evaluation session. To draw conclusions regarding player experience and potential benefits of these case studies, research needs to focus on long-term player engagement. This is supported by others, e.g., by Wiemeyer et al.[52] who examine health benefits of serious games for older adults.

Apart from these general considerations, this paper shows that only few exergame case studies addressing older adults have been designed. 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. It is particularly important to conduct research to investigate the benefits and risks of older adults regularly engaging with exergames. Further collaboration between the fields of gerontology, psychology, sports medicine and computer science could largely contribute to the quality of research investigating potential benefits of exergames for older adults: experts on gerontology and psychology can help arrive at a better understanding of the needs of older adults and the effects age-related changes at early stages of the game development process. Researchers in sports medicine can ensure that the integration of healthy kinds and levels of movement into video games for older adults, while computer scientists can focus on the integration of senior-friendly user interfaces and game mechanics. Ultimately, this would foster the creation of enjoyable, accessible and safe gaming experiences for older adults.

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