Is Movement Better? Comparing Sedentary and Motion-Based Game Controls for Older Adults

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ABSTRACT

Providing cognitive and physical stimulation for older adults is critical for their well-being. Video games offer the opportunity of engaging seniors, and research has shown a variety of positive effects of motion-based video games for older adults. However, little is known about the suitability of motion-based game controls for older adults and how their use is affected by age-related changes. In this paper, we present a study evaluating sedentary and motion-based game controls with a focus on differences between younger and older adults. Our results show that older adults can apply motion-based game controls efficiently, and that they enjoy motion-based interaction. We present design implications based on our study, and demonstrate how our findings can be applied both to motion-based game design and to general interaction design for older adults.

Keywords: Older adults, games, entertainment, design.

Index Terms: H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous; K.8.0 [Personal Computing]: General - Games

1 INTRODUCTION

Industrialized countries face the challenge of providing for a growing group of older adults. Sedentary lifestyles among seniors have a negative impact on life expectancy [32]; however, increasing age reduces the number of activities accessible to older adults. Exploring opportunities for engaging seniors physically, cognitively, and socially through leisure activities is of growing importance. 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 [18] or to motivate older adults to participate in physical therapy and rehabilitation [1]. While research has shown that motion-based games have positive effects on the emotional [18], physical [36] and cognitive [3] 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 [34], and research on motion-based game controls for older adults suggests that full-body interaction creates additional difficulties for older adults who experience age-related changes in gross motor skills [15].

In our work, 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 ol der 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.

Our work 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. 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.

Motion-based games have the capacity to provide cognitively stimulating, physically invigorating, and socially engaging leisure opportunities for a growing number of seniors, making video games increasingly popular among older adults. As such, it is important to ensure the accessibility of this novel game control. Our work can inform the design of motion-based video games for seniors, and extends beyond play by providing insights into general interaction design for older adults.

2 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.

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2.1 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. [24] explore performance of pointing and dragging tasks using a mouse, trackball and stylus/tablet, and show 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. [8] 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 [4] 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 [11] 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. [13] analyze 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. [9] 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. [34] supports 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. [7] examine motion-based TV input and conclude that older adults prefer direct mappings (i.e., using the hand to point).

2.2 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).

2.2.1 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. [19] 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 [5]. Klochek and MacKenzie [21]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 [17] 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. [26] 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. [27] 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. [14] 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. [22] 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. [23] 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 [27].

2.2.2 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. [30] 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 [15] has shown that the devices are generally accessible if interaction paradigms are designed particularly addressing the needs of older adults. Pham and Theng [29] 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.

3 GAME INTERACTION FOR OLDER ADULTS

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

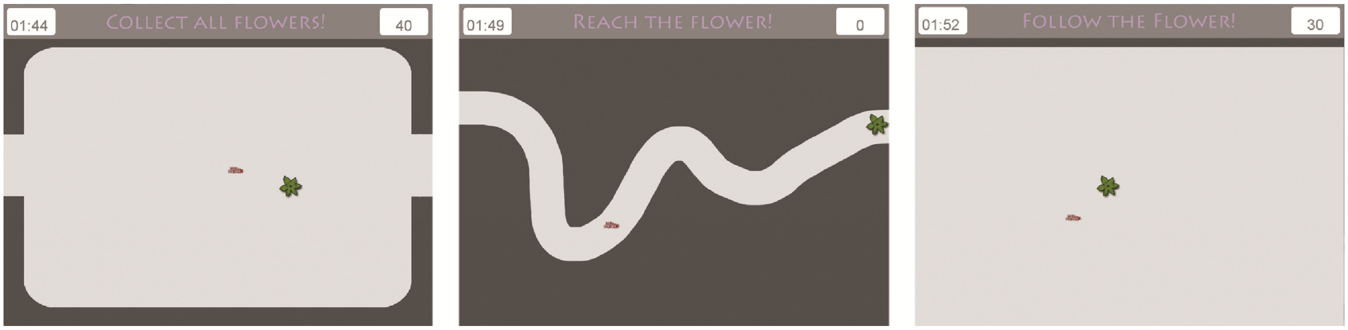

Figure 1: (1) Pointing, (2) steering, and (3) tracking tasks involving the collection of flowers.

3.1 Age-related Changes and Impairments

Age-related changes such as decreases in sensory acuity, (particularly vision and hearing), and changes in memory and attention, affect older adults' ability of interacting with computers and video games [11]. Age also leads to a reduction of muscle mass, which causes decrements in strength and stamina [20], resulting in a lack of movement control and higher reaction and movement times [11]. Additionally, the elderly often experience a decline of force control [20]. Age is suspected to cause difficulties in motor learning [20], which needs to be accounted for when designing gesture-based interaction. Furthermore, older adults are likely to be affected by age-related diseases (e.g., arthritis or orthopaedic impairments [11]), which affect 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 [35]. 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 [10], and that there are difficulties among older adults in carrying out complex point-and-click tasks [31].

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.

3.2 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.

3.2.1 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.

3.2.2 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 [9]. 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 (Figure 1) 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 [24]. 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.

3.2.3 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 STUDY

Using our test bed game, we explored the suitability of different game input devices for older adults.

4.1 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 report spending five to ten hours per week using the computer, older adults report two to five hours a week. Participants in both groups do 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 [12] and NASA-TLX [33] 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.

4.2 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 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 α=.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.

4.4 Results

4.4.1 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 1 for descriptive results. For the pointing task, there was a main effect of group ($F_{1,20}$=26.4, *p*=.000, η^2=.468) on completion time, showing that older adults perform worse than young adults regardless of input device (Table 1). Additionally, we found a main effect of controller ($F_{3,60}$=119, *p*=.000, 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*=.000, η^2=.507) and collisions ($F_{3,60}$=10.5, *p*=.000, η^2=.343). Pairwise comparisons for completion time showed that the using the Mouse was faster than the Kinect (*p*=.003) and the GamePad (*p*=.035). Move was faster than Kinect (*p*=.008). 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

Table 1: Mean results for younger (Y) and older (O) adults for the Kinect (KI), Move (MV), Mouse (MS) and GamePad (GP).

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

Table 2: 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).

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

Table 3: 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).

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

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 2). Additionally, we found a main effect of controller ($F_{3,60}$=39.0, p=.000, 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=.000), 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.

4.4.2 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 [16]. Descriptive results are presented in Table 2 and Table 3. 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=.000, 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=.000, η^2=.301). Pairwise comparisons showed that within the motion-based controllers, the Move was perceived as more comfortable than the Kinect (p=.000). 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 3) showed no main effect of group ($F_{1,29}$=0.8, p=.368, η^2=.028), but did show a main effect of controller ($F_{3,87}$=33.0, p=.000, η^2=.532). 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, η^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.*"

4.4.3 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=.000) and older adults (χ^2_3=27.49, p=.000). Pairwise comparisons using the Wilcoxon Signed Rank test revealed that young adults rank the Mouse significantly higher than Kinect (z=-3.60, p=.000), Move (z=-3.60, p=.000) 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

Table 4: Average ratings for Fun (SD) and controller rankings (Med) per group (Y = Younger Adults, O = Older Adults).

	Fun		Ranking	
	Y	*O*	*Y*	*O*
KI	3.35(1.41)	3.36(1.08)	4.00	4.00
MV	3.71(1.16)	3.86(0.86)	2.00	2.00
MS	3.35(1.00)	4.00(1.04)	1.00	1.00
GP	3.59(1.06)	3.79(0.89)	3.00	3.00

revealed that they rank the Mouse significantly higher than GamePad (z=-3.70, p=.000) and Kinect (z=-3.49, p=.000), 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).

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.*"

4.5 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 average 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.

5 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. Furthermore, we generalize our results beyond gaming and for all audiences.

5.1 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 [6]). 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.

5.2 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, research has shown 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 [15].

5.3 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***. This aspect is in line within findings on work on the design of motion-based games for older adults in nursing homes [15].

5.4 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 for older adults can use the new device with comfort, efficiency and confidence.

With information technology becoming pervasive in daily life, it is important to ensure the accessibility of new technologies for older adults. 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, 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 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.

6 LIMITATIONS AND OPPORTUNITIES

Our results show that older adults can apply motion-based game controls and are open towards 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.

7 CONCLUSION

In this paper, 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 paper lays a foundation for further work in the field of game design for older adults, e.g. games for rehabilitation, and games for older adults in nursing homes. Due to the combination of cognitive and physical stimulation that is provided by motion-based video games, they can be applied to foster well-being in old age by fighting sedentary lifestyles that severely reduce seniors' life expectancy. Because motion-based video games have the potential of contributing to the quality of life of older adults, it is particularly important to ensure their accessibility through increased research efforts in this area.

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