Wheelchair-Based Game Design for Older Adults

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ABSTRACT
Few leisure activities are accessible to institutionalized older adults using wheelchairs; in consequence, they experience lower levels of perceived health than able-bodied peers. Video games have been shown to be an engaging leisure activity for older adults. In our work, we address the design of wheelchair-accessible motion-based games. We present KINECT^Wheels, a toolkit designed to integrate wheelchair movements into motion-based games, and Cupcake Heaven, a wheelchair-based video game designed for older adults using wheelchairs. Results of two studies show that KINECT^Wheels can be applied to make motion-based games wheelchair-accessible, and that wheelchair-based games engage older adults. Through the application of the wheelchair as an enabling technology in play, our work has the potential of encouraging older adults to develop a positive relationship with their wheelchair.

Categories and Subject Descriptors
K.4.2 [Computers and Society]: Social Issues – Assistive technologies for people with disabilities, Handicapped persons/special needs; K.8.0 [Personal Computing]: General - Games.

Keywords
Accessibility, games, entertainment, older adults, wheelchairs.

1. INTRODUCTION
More than half of Canadians over the age of 65 in residential care use wheelchairs [22]. Research has shown that the use of wheelchairs severely affects the functional independence of older adults, and limits their opportunity of participating in physical activity, leading to low levels of perceived health [3] and sedentary lifestyles. This puts older adults using wheelchairs at a particularly high risk of suffering from *sedentary death syndrome* [23]. To address this issue, it is important to provide physical activity and leisure activities [3], but only few remain accessible to older adults using wheelchairs. In this context, motion-based video games are a promising design opportunity: research has shown that such games can provide cognitive and physical stimulation [1] and have a positive effect on the emotional well-being [15] of institutionalized older adults. However, results also show that the accessibility of motion-based games for older adults using wheelchairs is limited (due to limitations of tracking algorithms and few upper body gestures used as input), and additional considerations are necessary to allow older adults using wheelchairs to obtain the full benefits of such games [11].

To explore the use of wheelchair-based input in motion-based games for older adults, we implemented the KINECT^Wheels toolkit [10], which allows us to track wheelchair movements using the Microsoft Kinect sensor. Using KINECT^Wheels, we then evaluated the feasibility of wheelchair-based game input in a controlled study. Based on the results, we created Cupcake Heaven, a motion-based video game designed for older adults that integrates wheelchairs. In a final study, we evaluated the accessibility of, interaction with, and resulting player experience of Cupcake Heaven with eight older adults regularly using wheelchairs. Our results show that Cupcake Heaven is accessible to them, and that they enjoy playing motion-based games, suggesting that games are a suitable means of providing physical stimulation for older adults using wheelchairs. This paper makes three contributions. 1) We show that wheelchair movements can be recognized and interpreted as input to a game using the KINECT^Wheels toolkit. 2) We demonstrate that wheelchair-based interaction is suitable for older adults, and that motion-based games can be designed in a way that makes wheelchair input both accessible and enjoyable. 3) We highlight design opportunities for wheelchair-based games for older adults, for applications beyond entertainment, and for children and teenagers using wheelchairs.

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

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

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

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2.1.1 Wheelchair-Based Interaction

Work in the field of wheelchair-based interaction has a strong focus on accessibility; prior research has primarily focused on how people interact with their electric wheelchairs. Felzer and Freisleben [8] present HaWCoS, a system that proposes including information on muscle contractions rather than hand-based input to navigate the environment using a wheelchair. Likewise, Hinkel [14] suggests the integration of head movements to control electronic wheelchairs to allow for hands-free interaction with other devices. In contrast to these approaches that aim to make the wheelchair itself more accessible, another line of work focuses on applying the wheelchair as an input device to increase the accessibility of other systems, such as computers. Wobbrock et al. [26] investigate how joysticks of electric wheelchairs can be applied as text entry solutions to facilitate the interaction process by allowing persons using wheelchairs to apply their wheelchair as the input device, rather than using additional technology.

2.1.2 Wheelchair-Based Game Interaction

Research has also explored the integration of electric wheelchairs as a computer game input device. Rossol et al. [20] propose a framework that implements electric wheelchairs as a game input device; based on this, they design virtual training scenarios to support rehabilitation and wheelchair training by encouraging people to become more familiar with their assistive device. Hasdai et al. [13] evaluated this type of virtual environment using electric wheelchairs as the input device, and showed that wheelchair-based game input can improve participants' driving skills. They concluded that wheelchair-based game input can be valuable for supporting wheelchair navigation skills.

In contrast to these approaches that focus on the integration of electric wheelchairs into video games, the GAME^{Wheels} [9] system allows for the use of manual wheelchairs as an input device. The authors designed a custom metal structure that wheelchairs can be mounted on to track basic wheelchair movements. An evaluation of their system [18] showed that the system produced significant levels of energy expenditure, creating opportunities for physical activity. However, the two major limitations of their approach are that it requires custom-designed hardware that is not available to the general public, and that the system does not explicitly focus on the needs of older adults. In our work, we address these issues by using the Microsoft Kinect sensor to recognize wheelchair input – a commercially available, low-cost camera-based tracking system that has been shown to be a suitable input device for motion-based video games. In addition to supporting wheelchair-based input, our system supports body-based gestures to broaden the range of player input available to this particular audience.

2.2 Motion-Based Games for Older Adults

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

2.2.1 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 the ability of older adults to interact with computers and video games [5]. Age also leads to a reduction of muscle mass, which causes decrements in strength and stamina [16], resulting in a lack of movement control and higher reaction and movement times [5]. Furthermore, older adults are likely to be affected by age-related diseases (e.g., arthritis or orthopedic impairments [5]), which affect their physical abilities and their capacity to use standard interfaces. Particularly when designing wheelchair-based controls, it is important to understand the impact that age-related decrements may have on older adults' abilities of navigating manual wheelchairs. It is not only important to ensure the general accessibility of interfaces by accommodating a variety of abilities and accounting for age-related changes that influence interaction, but it is also important to ensure that interaction paradigms are safe and do not put older adults at risk of injury from excessive strain.

2.2.2 Motion-Based Game Controls for Older Adults

A growing number of projects focus on the development of accessible motion-based applications for older adults with the goal of providing physical and mental stimulation [7], e.g., for people living in nursing homes. Full-body motion-based games usually require players to be able to stand without assistance and move around in the room freely. Examples include the virtual dancing environment DanceAlong by Keyani et al. [17], and motion-based mini games by Rice et al. [19]. Both games require players to be able to stand without assistance; while DanceAlong strongly focuses on foot-based input, the mini games proposed by Rice et al. primarily require upper limb interaction. Gerling et al. [11] present an initial design of a motion-based game that is accessible to older adults who use assistive devices. Older adults are invited to play a gesture-based gardening game that is accessible to people playing either while standing or sitting in a chair. Likewise, many games that were designed to support physical therapy for older adults (e.g., [2]) are accessible for persons using wheelchairs as they can be played while sitting.

Research addressing full-body motion-based game controls for older adults has the challenge of how to allow for wheelchair-accessible interaction while still providing sufficient levels of physical activity. In this context, researchers need to overcome current limitations of motion-based games for older adults by providing additional input gestures to allow players using wheelchairs to fully experience motion-based gaming and receive the exertion-related benefits of motion-based play. Our work aims to address these limitations by combining wheelchair input with upper body gestural game interaction. Using the KINECT^{Wheels} toolkit [10], we develop and evaluate Cupcake Heaven, a wheelchair-based video game for older adults that features both wheelchair-based and gestural game input.

3. STUDY ONE: DEVELOPING CAMERA-BASED WHEELCHAIR INTERACTION

KINECT^{Wheels} [10] is a toolkit that facilitates the integration of wheelchair input at the development stage using the Microsoft Kinect sensor. In study one, we evaluate the feasibility of wheelchair input using our system to inform the design of wheelchair-based game controls for older adults.

3.1 The KINECT^{Wheels} System

The KINECT^{Wheels} system is a software library written in C# based on the Microsoft Kinect SDK that allows developers to easily and quickly add interactivity to their programs. KINECT^{Wheels} provides the data from the official Microsoft Kinect SDK, as well as extra gestures that help take advantage of the movements that a wheelchair can make. Data available from the Kinect SDK are all the joint positions of the skeleton and raw image data (colour and depth). The new gestures the KINECT^{Wheels} system provides include the direction the wheelchair is pointing, a gesture for quick movements to the left and right sides as well as the front and the back (Table 1). As shown in Table 1, KINECT^{Wheels} also detects traditional full-body motion-based gestures, including: clapping hands, raising the left and right arm, and lifting the legs. Once a gesture is recognized, the toolkit allows for a variety of actions, including sending keystrokes that represent the gestures to the operating system so that third-party programs (including those implemented in Flash, OpenGL, and XNA) can be controlled using KINECT^{Wheels}.

Table 1. Overview of wheelchair-based and body-based input supported by KINECT^{Wheels}.

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

3.2 System Evaluation

To determine whether the KINECT^{Wheels} gestures and their recognition rate are appropriate for game input, we integrated the gesture set into an analysis tool. We were interested both in the general suitability of the approach, and potential differences between body-based and wheelchair-based game input.

3.2.1 Gesture Analysis Tool

We created a gesture analysis tool based on KINECT^{Wheels} in order to determine whether wheelchair-based input can be applied in an efficient and enjoyable way. Based on prior work on full-body motion-based game interaction for older adults [11], we prompted users to complete wheelchair- and body-based movements (Table 1). Instructions were provided through images and descriptions. During the interaction process, performance metrics were recorded. Metrics include gesture type, gesture sequences, completion times, and gesture recognition rates. The analysis tool was implemented in C#, using the Microsoft Kinect SDK 1.5 and Game Studio 4.0.

3.2.2 Participants and Procedure

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

At the beginning of the study, participants filled out a consent form and were asked to provide demographic information. Once participants felt confident using the wheelchair, they were given an overview of the recognition tool. Then, participants were asked to complete two sets of body-based and wheelchair-based input to familiarize themselves with the system. Next, participants were asked to complete two different gesture sets consisting of different combinations of wheelchair-based and body-based input. Finally, participants were asked to complete the NASA-TLX [24] and the ISO 9241-9 questionnaire on device comfort [6] to investigate the cognitive and physical challenges when using a wheelchair as an input device as well as the differences between wheelchair-based and body-based input. The evaluation ended with open questions on participants' perception of wheelchair-based interaction.

3.2.3 Results – Performance

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

Participants performed a total of 576 gestures; 495 gestures were recognized correctly by the system. Hence, the overall recognition rate was 85.9%, with rates being lower for body-based gestures (78.5%) than for wheelchair-based gestures (93.4%) – see Table 2. Recognition rates for the clapping gesture and leg lift were low due to the technical difficulties of trying to recognize user input in front of participants' bodies; results for all other gestures consistently exceeded an accuracy of 85%.

Completing a gesture generally took 2-3 seconds, with body-based gestures taking 2471 ms, and wheelchair-based gestures requiring 2581 ms – see Figure 1.

Table 2. Tracking results (number of tracked, missed, percentage) per gesture (72 repetitions per gesture).

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

To investigate whether gesture completion time was influenced by the preceding gesture, we performed a repeated-measures ANOVA and found no difference in gesture completion times (body versus wheelchair) when following a wheelchair-based gesture (p=.081), but that body-based gestures following a body-based gesture are faster (p=.000) than wheelchair-based gestures that follow a body-based gesture ($F_{1,11}$=18.9, p=.001, $\eta 2$=.632).

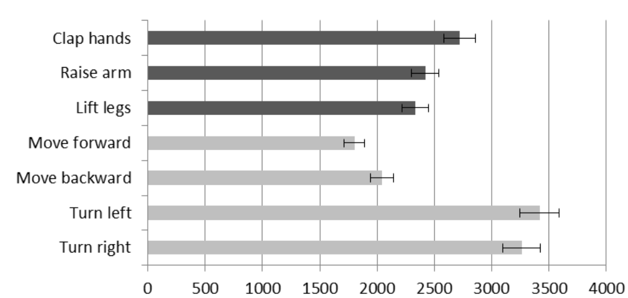

Figure 1. Avg. completion time per gesture in ms (CI=95%).

3.2.4 Results – Questionnaires

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

Table 3. Mean (SD) results for the TLX (20 point scale, composite score 0-120), ISO (5 point scale) and post-game (5 point scale, 5 = strongly agree) questionnaires.

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

Descriptive results for all questionnaires are provided in Table 3. The composite score [12] of the NASA TLX showed that the cognitive load was significantly higher for wheelchair-based movements than for body-based input (t_{11}=2.61, p=.024). In addition, we considered the subscale for physical demand, which showed that participants perceived wheelchair-based gestures as more demanding than body-based input (t_{11}=2.43, p=.034), which is supported by results of the ISO-9241-9 questionnaire (t_{11}=3.46, p=.005), particularly when participants were asked about fatigue (t_{11}=2.69, p=.021). However, we did not find significant differences for general comfort (t_{11}=-0.23, p=.082) and ease of use (t_{11}=-0.69, p=.504). This suggests that participants consider wheelchair-based gestures more physically challenging, but are still satisfied with overall comfort. This is backed by results regarding fun that show no difference between wheelchair- and body-based input (t_{11}=1.77, p=.104).

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

3.2.5 Findings

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

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

When interpreting our results, it is important to consider how they would extend to usage by older adults. In particular, we expect that older adults would require more time to complete gestures than younger adults, and that tracking accuracies might be lower given the smaller range of motion of older adults [11]. However, we would not expect to see different patterns in our results among older adults due to age-related changes.

4. STUDY TWO: WHEELCHAIR-BASED GAME CONTROLS FOR OLDER ADULTS

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

4.1 Wheelchair Input for Older Adults

In order to create wheelchair-based video games for older adults, it is important to account for the impact of age-related changes and impairments on game interaction. Based on a summary of common age-related changes (section 2.2.1) and design recommendations for full-body motion-based game interaction for older adults [11], we identified issues that are relevant to wheelchair-based interaction for older adults.

Easy gesture recall should be supported by full-body input through the implementation of natural gesture mappings, e.g., by building on movements that players can relate to real-world actions [11]. In the context of wheelchair-based interaction, integrating the wheelchair in a way that helps participants relate wheelchair input to in-game actions could help facilitate gesture recall. An example of an intuitive mapping is applying the wheelchair in a racing game, encouraging players to move forward to speed up, move back to break, and turning the chair to the sides to make turns in the game. ***Adapting to player range of***

motion [11] is important when designing upper body gestures to go along with wheelchair-based input. Furthermore, ***adapting to player strength*** is important, because the evaluation of KINECT^{Wheels} showed that wheelchair input is perceived as more physically demanding than body-based input, and older adults experiencing age-related changes may experience difficulties when repeatedly using their upper body to navigate the wheelchair. ***Exertion management*** [11] is another aspect that needs to be considered when integrating wheelchairs into the interaction process. Designers need to keep in mind that wheelchair movements require more effort, and are slower than body-based input; an aspect that has to be considered in the pacing of the game, and when determining the frequency at which certain types of input are required. ***Age-inclusive design*** [11] is necessary to embrace special characteristics of the target audience. Regarding wheelchair-based game interaction for older adults, it is important to keep in mind that many older adults are novice wheelchair users who have limited experience with their assistive device. Designers should account for this aspect by carefully designing wheelchair-based interaction into their games, slowly increasing the difficulty and frequency of input in order to allow players to become more familiar with their assistive device.

In the following section, we will highlight how Cupcake Heaven builds on these design considerations as well as the results of study one to provide accessible and safe interaction for institutionalized older adults.

4.2 The Cupcake Heaven Video Game

To investigate the feasibility of wheelchair-based game input for older adults, we created Cupcake Heaven (Figure 2), a game in which players are invited to collect candy and pass it on to a girl. To increase the challenge, players have to avoid collecting vegetables, and the girl changes location, either being displayed on the right or left side of the screen. The game implements body-based and wheelchair-based input; it aims to encourage users to move around in their wheelchair. We implemented the game in C# using the Microsoft Kinect SDK 1.5.1, Microsoft Game Studio 4.0, and the KINECT^{Wheels} toolkit.

4.2.1 Wheelchair-Based Game Input

Based on the results of study one and the design requirements in section 4.1, we identified a set of wheelchair-based and body-based gestures that were well recognized by the system, and that we expect to be easy to learn for older adults.

There are two lanes in the game – one on the top of the screen and one on the bottom. Candy and vegetables flow left-to-right through the top lane and the bottom lane. In order to pick up candy from either of the two lanes, players are asked to move the wheelchair forwards and backwards, which moves the virtual hand up and down respectively. Intersecting the hand with a food item automatically picks it up. The game only allows for vertical movements to facilitate simple interaction; players are not expected to adjust their horizontal position to pick up candy. To pass on candy to the child, players have to lift their arm on the side at which the child is currently displayed; this will dispatch the item. If players wish to discard an item that they collected, they have to clap their hands. We decided to implement this gesture using an improved tracking algorithm, because results from [11] suggest that clapping is particularly easy for older adults, and because there is little negative impact in the game if the clapping gesture is not quickly recognized.

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

Figure 2. Overview of Cupcake Heaven.

4.3 Evaluation

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

4.3.1 Participants and Procedure

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

After giving consent, participants provided demographic information. Next, participants were given time to familiarize themselves with the wheelchair and the environment, and were introduced to Cupcake Heaven in a short tutorial. Then, participants were asked to play the game for about ten minutes, each level of the game lasting three minutes. Finally, participants were asked to complete the NASA-TLX [12] questionnaire and the portions of the ISO 9241-9 [6] questionnaire on device comfort that investigates physical fatigue to assess their experience using the wheelchair as a game input device. In addition, participants were asked to rate their overall experience with the game and answer interview questions on its content, input gestures, and the overall play experience.

4.3.2 Results

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

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

Table 4. Mean (SD) results for the TLX (20 point scale, composite score 0-120), ISO (5 point scale) and post-game (5 point scale, 5 = strongly agree) questionnaires.

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

The results of the NASA-TLX questionnaire (Table 4) show that the cognitive load of older adults interacting with Cupcake Heaven was at an average level, and that it produced a medium level of physical demand. This is supported by results of the ISO 9241-9 questionnaire (Table 4) that show that the system was rated as relatively easy to use and comfortable. In contrast to the results of the NASA-TLX, items of the ISO questionnaire investigating physical fatigue report low levels of physical demand. These findings need to be interpreted along with observations that were made during the study, which contradict subjective ratings for fatigue that were made through the ISO questionnaire; many participants seemed to be challenged by the system and became increasingly tired throughout the gaming session (heavier breathing, individual comments on physical exertion). This suggests that wheelchair-based video games have the potential of providing much needed physical exertion for institutionalized older adults. Participants recognized this opportunity and highlighted the benefits of physical activity made accessible through the game. One participant pointed out that the game helped him see the wheelchair in a different light, commenting that the game gave him "*the idea that you can use the [wheel]chair for something other than sitting on it*". Other participants explicitly commented on using video games to be physically active: "*It is good for me [to be active], I did track and field when I was young, and I played tennis and basketball.*" – "*If you played it for half an hour, you'd get some exercise.*".

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

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

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

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

5. DISCUSSION

This paper investigates wheelchair-based game controls for older adults. In the first part of our work, we demonstrate that it is possible to integrate wheelchairs into motion-based interaction, and we present our toolkit KINECT^{Wheels}. Based on the findings, we present Cupcake Heaven, a wheelchair-based game specifically designed for older adults. In the remainder of this paper, we discuss the implications of our findings for future work and show how it can be applied to increase the quality of life of older adults. Furthermore, we outline how wheelchair-based interaction can increase the accessibility of interactive technologies for other audiences, and demonstrate the relevance of this work beyond game design for older adults.

5.1 Wheelchair-Based Game Controls

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

5.1.1 Wheelchair-Based Input Gestures

In our research, we demonstrate that wheelchair-based interaction can be applied in an efficient and enjoyable way, which opens up new opportunities for designers, allowing them to integrate wheelchairs as game controls. Our evaluation of the gesture set presented in section 3.1 holds several implications for wheelchair-based interaction design. It shows that it is possible to combine wheelchair-based input and body-based gestures to obtain a range of input gestures broad enough to allow for sufficient complexity in game design. Additionally, results show that completion times differ per gesture, suggesting that designers have to carefully consider the pacing of their games to allow players to transition between gestures (e.g., changing from wheelchair to body input) while also accounting for momentum that wheelchairs build (as our results showed that gestures following wheelchair input are generally slower than sequences of body-based interaction). Since wheelchair-based gestures require the use of the hands to move the wheelchair, designers have to take into account that wheelchair-based gestures and hand gestures cannot be performed at the same time. The fact that participants reported that wheelchair-based input was more physically demanding than body-based input, but equally comfortable as body-based gestures suggests that this may be a way of introducing physically challenging motion-based games for persons using wheelchairs.

5.1.2 Technical Limitations

In the design and evaluation of KINECT^{Wheels} and Cupcake Heaven, we encountered several technical challenges related to the design of camera-based wheelchair interaction. A core challenge during the implementation of KINECT^{Wheels} was that turning the wheelchair more than 45 degrees caused a loss in recognition. While we were able to achieve acceptable tracking results for turning to the sides through the application of additional algorithms, turning the wheelchair backwards or spinning around is not possible using the current implementation. Additional challenges arise depending on the way designers wish to integrate KINECT^{Wheels}: because images provided by the Kinect can be noisy, including the absolute position of the wheelchair for precise player input is difficult, and designers should consider including a dead-zone similar to joysticks when working with the position of the chair. Likewise, adjustments have to be made if the system is interfacing with other applications using keystrokes; additional algorithms may need to be applied to imitate keyboard input (e.g., repeatedly pressing a button). Finally, moving around the floor space is inherent in wheelchair gestures, and designers have to create games in a way that helps keeping the user within the view of the sensor, e.g., asking players to move forward multiple times needs to be counter-acted with a move backward so that players do not leave the tracking area.

5.2 Wheelchair Games for Older Adults

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

Our work shows that adapting design guidelines for motion-based video games for older adults (section 4.1) is possible to help inform designers wishing to create wheelchair-based games. However, our results also show that wheelchairs can add an additional layer of complexity, calling for careful considerations and balancing of in-game challenges during the design process.

6. DESIGN OPPORTUNITIES

Based on the work presented in this paper, we identified areas in which wheelchair-based interaction can be applied in a way that can contribute to quality of life.

6.1 Wheelchair Training for Older Adults

The development of wheelchair skills is a crucial step in encouraging older adults to embrace their assistive device and maintain a high degree of functional independence. However, many older adults only start using a wheelchair in late life, and experience difficulties in developing a positive relationship with it. Wheelchair training is a promising opportunity that has been shown to be effective with younger age groups [21]. Older adults are encouraged to participate in occupational therapy to become familiar with their wheelchair; however, this requires access to a therapist and can be tedious. Wheelchair-based game controls could provide in-home wheelchair skills training; if input gestures are designed to support therapy goals, game-based interventions could help older adults become more familiar with their wheelchair. Such games could help players' abilities of navigating their environment, increase their functional independence, and thereby improve their quality of life.

6.2 Beyond Older Adult Audiences

Wheelchair-based game controls can be applied to keep motion-based video games accessible for people who use wheelchairs; our results can extend to audiences beyond older adults. The evaluation of KINECT^{Wheels} in study one showed that younger able-bodied people enjoyed wheelchair-based controls, and considered the use of a manual wheelchair to interact with the gesture recognition tool an interesting experience. In this context, wheelchair-based game controls could be leveraged to raise awareness for topics such as wheelchair accessibility of public places and foster understanding of problems that people using wheelchairs experience, e.g., by creating mini games that illustrate the inaccessibility of different areas of life. Such games could be applied to educate the general public by inviting them to experience the world from someone else's perspective [4]. In this context, wheelchair-based games are a great opportunity for engaging students, and encouraging them to consider challenges that their peers who use wheelchairs have to face on a daily basis, thus fostering an understanding of accessibility issues. A major limitation of many motion-based video games that address younger audiences and implement camera-based input devices such as the Microsoft Kinect is that they are not fully accessible to players using wheelchairs; although some games can be calibrated to work for players sitting on a chair, players using wheelchairs will not be able to engage with motion-based video games that require players to move around in the room. KINECT^{Wheels} can be applied to create motion-based video games for children and teenagers using wheelchairs that encourage physical activity beyond simple upper body movements. Thereby, it is possible to embrace the abilities of the target audience [25] rather than making limited subsets of interaction paradigms of existing games accessible, thus allowing children and teenagers using wheelchairs to obtain the full benefits of exergame play.

7. CONCLUSION

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

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