Designing Interactive Manual Wheelchair Skills Training for Children

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ABSTRACT

Access to wheelchair skills training is important for the mobility and independence of wheelchair users, but training rates are low - particularly among young people. In this paper, we present *Geometry Wheels*, a movement-based experience prototype to explore the potential of interactive technology to support basic wheelchair skills training for manual wheelchair users, designed with the support of occupational therapists. Results of an evaluation with 15 participants (10 young wheelchair users and 5 parents) show that interactive systems can deliver engaging and challenging activities that encourage wheelchair navigation and activity. However, the project also revealed challenges in designing for individual differences in physical abilities, in conflicts between children's and parents' perceptions of ability, and barriers to home use. We outline strategies for the design of rehabilitative technology to help young people with disabilities build physical abilities.

CCS CONCEPTS

• **Applied computing** → **Computer games**;

KEYWORDS

Games, movement-based interaction, occupational therapy

ACM Reference Format:
Kathrin Gerling, Kieran Hicks Olivier Szymanezyk, and Conor Linehan. 2019. Designing Interactive Manual Wheelchair Skills Training for Children. In *Designing Interactive Systems Conference 2019 (DIS '19), June 23–28, 2019, San Diego, CA, USA*. ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3322276.3322281

DIS '19, June 23–28, 2019, San Diego, CA, USA

ACM ISBN 978-1-4503-5850-7/19/06…$15.00
https://doi.org/10.1145/3322276.3322281

1 INTRODUCTION

Building navigational skills and engaging in basic physical activity are both crucial for the independence and mobility of wheelchair users [28]. However, access to wheelchair skills training is challenging. For example, less than 20% of young people in the UK who transition to wheelchair use receive training [39]. Existing training opportunities are often created by the charitable sector, for example, *WhizzKids* and *Go Kids Go*, and despite being offered in many locations across the UK, availability is sporadic and associated with long travel. Games and interactive systems have previously been leveraged to deliver affordable and accessible physical rehabilitation and physiotherapy (e.g., [40]), and to encourage wheelchair users to engage in physical activity [23]. We therefore suggest that games and game technology can support easily accessible wheelchair navigation training.

In this paper, we present work carried out in collaboration with Go Kids Go! that aims to engage young wheelchair users in physical activity, and encourage them to build wheelchair skills. We report on a requirements establishment process that involved observation of, and participation in, wheelchair skills training sessions provided by Go Kids Go!, to supplement recommendations derived from literature, along with expert input. We describe the design of *Geometry Wheels*, an experience prototype designed to support the acquisition of basic wheelchair skills and rehabilitative exercises for manual wheelchair users. We provide insights from an evaluation of that prototype with 15 participants (10 young wheelchair users and 5 parents), which focuses on understanding the accessibility, usability and experience provided by Geometry Wheels, as well as barriers and facilitators for the potential home use of interactive wheelchair skills training systems.

Our results show that Geometry Wheels was generally suitable for young wheelchair users. However, while the system successfully engaged them in training of core wheelchair skills, participant feedback revealed conflicting perspectives on how well the prototype supported individual preferences and abilities with respect to challenge and physical activity. Additionally, children's perspectives often differed fundamentally from those of their parents. Results suggest that parents saw value of interactive training interventions for their children, but also raised concerns regarding cost and space requirements should such systems be designed for home use. Building on our findings, we contribute a discussion of challenges for interactive wheelchair skills training, by connecting results of requirements establishment and end-user evaluation (including the role of social interaction in rehabilitative settings). Finally, we reflect on conflicts in user-centred research into playful interactive systems with multiple stakeholders.

Our work examines the role of technology in a sensitive setting, and contributes to our understanding of challenges and opportunities that go along with the shift toward self-directed, technology-mediated tools to encourage physical activity and rehabilitation.

2 RELATED WORK

In this section, we review previous research on the use of interactive technology to support therapy and rehabilitation with young people, and discuss traditional and technology-based approaches toward wheelchair skills training.

Technology-Supported Occupational Therapy and Rehabilitation

Interactive technology is increasingly leveraged to support therapy and rehabilitation, offering an opportunity to engage end-users in otherwise tedious activity [14, 22], and delivering occupational therapy at scale [40]. In this context, movement-based technologies in general, and playful systems in particular, have been applied in a range of settings and targeted a range of audiences. For example, previous work has demonstrated the benefit of movement-based games to support stroke rehabilitation and increase player mobility [1], to deliver falls prevention exercise among older adults [41], or to engage individuals with Parkinson's disease in occupational therapy [34]. Application settings range from institutional (e.g., technology-supported physical stimulation for older adults in long-term care [18]) to home use (e.g., as a means of encouraging community-based care [41]). A number of playful systems have been developed that aim to provide opportunities for physical stimulation specifically for wheelchair users [12, 19]; however, this work has predominantly focused on understanding and improving player engagement and experience, and has not explored the rehabilitative potential of such systems.

Game-Based Interactive Rehabilitative Systems for Young People. A number of systems have been designed specifically to support occupational therapy and rehabilitation for young people with special needs. For example, Waddington et al. [42] used a bespoke game to provide engaging rehabilitative exercises for young people with neurological vision impairment, finding a significant and measurable transfer of skills from game context to a day-to-day object recognition task. Moving into the space of movement-based systems, Hernandez et al. [22] were the first to design game-based physical therapy for children with cerebral palsy, using exercise bikes as input devices for a range of challenging and enjoyable mini games. Kourakli et al. [30] show that movement-based Kinect games can improve motor skills of children with special educational needs. Finally, Gerling et al. [15] demonstrate the potential of custom-designed Kinect games to empower young wheelchair users through play; they conclude by suggesting that systems can successfully challenge players through carefully balanced competition.

Wheelchair Skills Training

Successfully maneuvering a wheelchair is a complicated motor co-ordination task, and skills training programmes have been designed as an important step toward establishing independence for wheelchair users. Here, we summarize common approaches, and outline current challenges.

Traditional Approaches. Wheelchair skills training is a form of motor skill learning. Better skills improve an individual's ability to negotiate and adapt to changing environments, and their quality of life [24]. Training programmes cover a wide breadth of skills, ranging from effective pushing techniques to safely utilizing a wheelchair in traffic. A variety of training programmes have been devised. For example, high-level recommendations are provided by the World Health Organisation [26, 27], and include basic elements such as moving the wheelchair forward and turning, along with more advanced tasks such as dealing with slopes, curbs, and stairs. These recommendations are also reflected by guidelines produced by researchers, e.g., [29]. More detailed, validated programmes exist for adult wheelchair users, most prominently the Wheelchair Skills Training Program (WSTP) [25], which includes elements such as basic propulsion, turning, breaking, and managing curbs, but also skills that require a combination of movements, e.g., obstacle avoidance, reaching for objects, and maneuvering doors. Specifically targeting children, Sawatzki et al. [8] provide a revised version of the WSTP, adjusting instructions such as reaching height to younger persons. However, despite the availability of validated training programmes with documented effectiveness [35], a recent survey by Best et al. [7] revealed that they are not widely used.

Interactive Wheelchair Skills Training. First attempts have been made to support wheelchair skills training through computer programs. For example, the EPIC Wheels [20] program aims to support home-based wheelchair skills training for older adults. The system uses a tablet computer that is strapped to the wheelchair user's thigh to issue instructions. While this offers a hands-free and mobile solution, it also requires users to shift attention between body, wheelchair, and tablet to follow exercise instructions, and does not provide any feedback on user performance. With respect to powered wheelchairs, some attempts have been made to develop joystick-controlled training environments that assess performance (e.g., [4, 5]), demonstrating the general feasibility of interactive environments to support skills training along with their effectiveness. Targeting manual wheelchair users, the GAMEWheels system [13, 37] uses a custom designed mechanical platform that supports the tracking of propulsion, and uses this as input to virtual environments. The system was designed specifically for athletes. Finally, previously discussed wheelchair-related games research by Gerling et al. [15, 16] explores the integration of wheelchair movement through camera-based approaches and effectively provides real-time feedback, but does not consider exercises relevant in the context of skills training.

Building on the research presented in this section, our tool aims to present relevant exercises in a playful and interactive manner, allows users to focus on their own movement along with wheelchair navigation, and provides real-time feedback on exercise completion.

3 GEOMETRY WHEELS: AN EXPERIENCE PROTOTYPE TO EXPLORE INTERACTIVE WHEELCHAIR SKILLS TRAINING

Geometry Wheels is an interactive system combining movement-based user input with immediate feedback using gaming technology. Because the design challenge in this project is largely a physical one (i.e., we need to understand the interaction of the system with participants' physical capabilities) physical prototyping was a necessary step in the design process. Through this phase of design, we were specifically interested to create a system to help us capture preferences and experiences (e.g., see [43]) of end-users. Here, we describe the process through which the system was designed.

Requirements Establishment

In the first phase of the project, we engaged in an extensive requirements establishment phase, building (1) an overview of commonly used wheelchair exercises suitable for interactive skills training, (2) expert perspectives on additional requirements for interactive solutions for children, and (3) an exploration of existing in-person skills training session to examine which characteristics should be integrated in our system. Based on these three elements, we provide considerations to inform the design of interactive wheelchair skills training for younger users. In this stage, we build on expert input rather than engaging end-users in the design process because the selection of exercises clearly needs to be guided by therapists' perspectives. This is not to devalue participatory design (PD) approaches which are well-documented in the context of accessibility research (e.g., [15]), but to reflect the fact that this stage of the development process leaves little room for end-user input (who we plan to engage in the future; for discussion see Limitations and Future Work).

Part 1: Summary of Commonly Used Exercises. We identified academic guidance on skills training [7, 29] along with recommendations for practitioners [27]. Kirby [29] categorizes skills into **basic (B), intermediate (I) and advanced (A) categories**, which we adopt here for structure.

Basic. *B.1 Pushing* [27, 29]. Moving the wheelchair forward or backward while covering short distances. *B.2 Turning* [27, 29]. Turning the wheelchair to both sides while in a fixed location, or while moving. *B.3* Reaching and picking up [29]. Reaching objects from the wheelchair (e.g., high up), and picking up items from the floor while seated. **Intermediate.** *I.1 Pushing over distances* [29]. Moving the wheelchair forward while covering long distances. *I.2 Navigating incline* [29]. Moving the wheelchair forward and backward while also navigating an incline. *I.3 Avoiding moving obstacles* [29]. Moving the wheelchair to avoid moving obstacles (e.g., avoiding pedestrians in traffic). *I.4 Moving through hinged doors* [29]. Combining basic skills (pushing, reaching, also pulling) to move through door. **Advanced.** *A.1 Wheelie* [29]. Tilting the wheelchair and holding balance, lifting the front wheels to lay foundation for navigation of obstacles (e.g., curbs). *A.2 Navigating steep incline* [27, 29]. Moving the wheelchair forward and backward while also navigating an incline. *A.3 Navigating steps and gaps* [27, 29]. Performing a wheelie; holding the wheelie while moving the wheelchair. *A.4 Entering and exiting the chair* [27, 29]. Using upper body strength to enter and leave the wheelchair (e.g., to facilitate transfer to vehicle, or to support independence at home.

Part 2: Expert Input. Expert input was solicited from project partner Go Kids Go! through Skype interviews during which they were asked to detail their training routines, and was generally in line with existing recommendations for wheelchair skills training, highlighting the importance of basic wheelchair skills such as propulsion to allow wheelchair users to gradually build more complex skills (skills B.1 and B.2). Particularly regarding training for children, expert input highlighted the importance of contextualizing exercises and combining physical with cognitive challenge, e.g., encouraging children to carry out wheelchair movement in busy situations to prepare them for more complex situations such as navigating traffic (comparable to skill I.3), where they do not only need to be able to navigate their own wheelchair, but also simultaneously need to monitor the behaviour of other actors. Experts also commented that certain elements of wheelchair skills training require the user to move the wheelchair and/or their bodies into positions that are only safe with assistance, for example, when shifting balance to move the chair into a backward leaning position, thereby lifting the front wheels ('wheelie'; skill A.1). With the use of anti-tippers, this activity was considered low-risk, however, the experts commented this would be a concern when carrying out exercise without professional support.

Part 3: Participation in Skills Training Sessions. Two members of the research team attended two wheelchair training courses held in gymnasiums of local schools in the East Midlands, UK. The team participated in the sessions as students to gain first-hand insights into the structure of the events, and observe the experience of attendees. Researchers recorded their experiences via a combination of written field notes and photos for research purposes where appropriate; the work was approved by the University of Lincoln College of Science ethics board.

Sessions were facilitated by two trainers, and began with introductions that involved all attendees (also parents and in some cases siblings). It was clear that skills training was provided through two types of activities that are well-aligned with principles for educational game design [32]; 1) quick skill-and-drill sessions intended to establish proficiency at core skills, and 2) playful activities that required the integration of those core skills. Throughout the courses, trainers demonstrated and actively participated in all activities to provide role models for the children [11]. We observed that trainers also made big efforts to provide individual feedback to participants, inviting them to participate in quick one on one sessions if they struggled with a particular skill, e.g., the trainer offering extra support when one of the participants struggled to tilt the wheelchair backwards as the first step of learning how to complete a wheelie. Additionally, we observed how trainers and parents balanced encouragement with challenging children to push their boundaries [17]. The day was broken up by a lunch break; during this time many of the children were observed playing, and parents socialized. Sessions concluded with a playful activity such as wheelchair basketball, which required performance of a range of cognitive and physical navigation skills previously addressed in the workshops.

Considerations for the Design of Technology to Support Wheelchair Skills Training Among Young People. Here, we summarize the four most important design considerations that we derived from the range of requirements establishment processes that we used.

1) Teach basic wheelchair skills first Basic skills training should allow wheelchair users to familiarize themselves with the operation of their assistive device. During this phase of training, an emphasis should be placed on exploration rather than quick completion of tasks, ensuring that the initial contact is positive (in line with game design recommendations such as [31]). Simple wheelchair movement (propulsion, turning; *skills B.1 and B.2*) along with upper body movement (e.g., reaching while seated; *skill B.3*) should be included in this phase, creating a foundation for further training.

2) Foster the development of intermediate and advanced wheelchair skills. Once basic wheelchair skills are trained to mastery, more complex skills can be encouraged. Importantly, performing complex skills often requires the combination of a number of previously learned simple skills, as well as the execution of those skills under time pressure, or under circumstances that require increased physical exertion. Indeed, this extends to the combination of physical and cognitive challenges, for example, executing a chain of actions in a short time frame (e.g., waiting for the lift to open, pushing the wheelchair to enter, and choosing a floor; *skills I.3 and I.4*).

3) Integrate play. The training sessions that we observed very clearly demonstrated how games and playful activities worked as an engaging context in which to practice and improve wheelchair skills. This approach allows wheelchair users to apply a combination of different skills in the types of challenging situations that they will encounter in day to day activities. For example, when playing wheelchair basketball, it is crucial to be able to navigate one's wheelchair, but also carry out upper body movements (e.g., throw the ball). Technology-based interventions should preserve this approach, while ensuring that players are challenged appropriately to maintain a balanced play experience.

4) Encourage safe system use and/or enforce assistance where necessary. Certain elements of wheelchair navigation (e.g., wheelies) can be a risk to the user unless they are well-practiced or have access to safety equipment. Therefore, interactive technology in this space needs to be aware of health and safety requirements, and integrate steps to protect users from harm (in line with existing guidelines on general movement-based play [36]). For example, this could mean that these elements are avoided entirely, that users are asked about the availability of safety equipment, or that systems are able to sense whether support is available (e.g., another person to support a wheelie; *skill A.1*). Systems also need to consider the space required for wheelchair movement, and how to encourage individuals to remain aware of their surroundings.

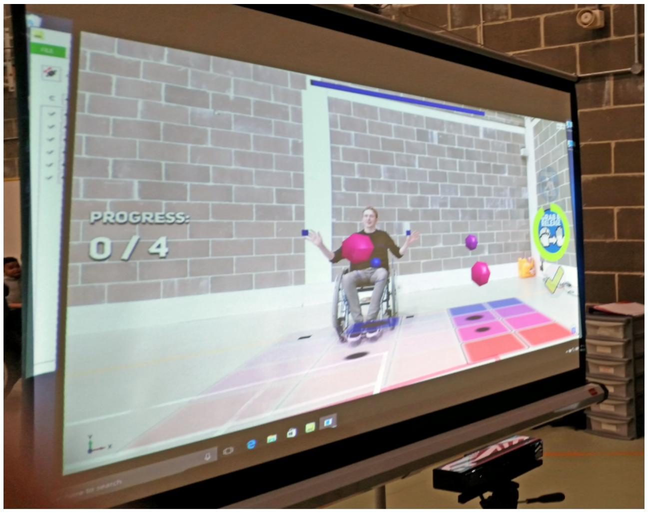

Figure 1: Demonstration of a Grab and Drag task.

Figure 2: Physical setup demonstrated in lab environment.

Design and Implementation

Geometry Wheels is an augmented reality (AR) system to support wheelchair skills training among young people. The system utilizes camera-based user input, and records a video stream that is displayed on screen and augmented with a number of virtual objects that guide the user (Figure 1). Wheelchair and body movement are integrated using an extended version of the KINECTWheels toolkit [16] that builds on the Kinect One camera, offering more reliable tracking quality. The system supports tracking of basic wheelchair movement (moving forward, backward, and turning to the sides) along with the position of the upper body, arms, and hands; the position of the user's hands is communicated through a visual effect (Figure 1; also see video figure). The general Geometry Wheels system is implemented using C++ and Windows Presentation Foundation (WPF), Helix 3D Toolkit, and the Kinect 2.0 SDK.

Training Structure. Skills training follows a two-part structure. First, users are admitted into a training sequence where they are introduced to each of the tasks, and given the opportunity to explore without time limit. Afterwards, users are asked to engage in training, where tasks are presented sequentially with short resting periods. Each task has a time limit of 60 seconds to reflect temporal requirements of the real world; exercises were designed with the intention to be completed within 30-45 seconds The system integrates four training tasks each relating to one or more wheelchair skills.

Task 1: Reaching. During this task, the system projects increasingly difficult to reach spheres onto the video stream. Users need to engage in upper body movement, and later on wheelchair movement to be able to reach all objects. In the final stage of this task, objects move to challenge users to plan and adapt their path in real time. *Relevant wheelchair skills: B.1, B.2, B.3, I.3.* **Task 2: Grabbing and dragging.** Building on the previous task, users need to grab rather than just reach for spheres (signaled to the system by closing their hand). Once grabbed, objects need to be dragged onto increasingly distant target areas, in the last stage requiring the user to navigate the wheelchair while simultaneously holding on to the object. *Relevant wheelchair skills: B.1, B.2, B.3.* **Task 3: Following a path.** During this task, a path is projected onto floor tiles. Users need to follow the path from beginning to end to complete the exercise. *Relevant wheelchair skills: B.1, B2.* **Task 4: Avoiding areas.** Here, certain floor tiles need to be avoided at short notice, challenging users to respond quickly to a changing environment. *Relevant wheelchair skills: B.1, B.2, I.3.*

Training Environment. *Geometry Wheels* combines a video stream with virtual objects (3D geometric shapes) [29]. We opted for an AR system inspired by Physio@Home, reported by Tang et al. [40], leveraging the combination of virtual and real elements to support users in following their own movement along with maintaining awareness of their surroundings. We colour code virtual objects along with a grid of floor tiles, and include shadows to allow users to explore depth (Figure 1). Instructions are provided through pictograms using a heads-up display similar to those integrated in gaming environments that many young people already are familiar with (see Figure 1). We integrate user instruction with core mechanics, e.g., placing arrows on floor tiles to indicate how users should move, thereby reducing the need for textual information unsuitable for younger children. We deliberately maintained a simple graphical style using geometric shapes to use the system as a tool to elicit potential themes and graphical styles from participants throughout evaluation. The physical setup for the Geometry Wheel requires floor space of at least 2.80x2.80m; input from the charity partner and a related survey [33] suggest that this space would be available in the homes of most wheelchair users. The Kinect sensor is placed in front of a large display, facing the user (see Figure 2).

4 EVALUATION

The evaluation of Geometry Wheels was carried out together with Go Kids Go!, and involved parents and young wheelchair users.

Research Questions

The user study was intended to assess whether the prototype system was accessible and usable in the context of skills training, and to facilitate further refinement of the system with end-users. There were three main research questions. **RQ1.** Is Geometry Wheels suitable for young wheelchair users? **RQ2.** Does the system challenge users to engage in a range of relevant wheelchair navigation skills? **RQ3.** What challenges must be addressed to develop Geometry Wheels into a standalone system for home-based rehabilitation?

Participants and Procedure

We recruited ten children at wheelchair skills training workshops in the UK facilitated by Go Kids Go! (age range: 4 to 11, 5 female) and five (2 female) parents to participate in the evaluation. All children used manual wheelchairs; some had only recently started to use a wheelchair while others were more experienced (3+ years of wheelchair use). The evaluation took place in conjunction with two wheelchair skills workshops hosted by Go Kids Go!. At the beginning, the goals of the research were explained to children and parents, and participants gave informed consent. For children, we followed an oral assent protocol along with written consent by their guardians. Then, children received a short introduction to the control scheme and core mechanics of Geometry Wheels. Afterwards, they interacted with the system. Throughout use, performance data was automatically logged. Parents and the research team observed the engagement of participants with Geometry Wheels; the researchers took notes of their observations. Following this stage, we carried out semi-structured interviews lasting between five and fifteen minutes with children and parents to explore perceptions of the system and to obtain basic demographic information. While we aimed to interview parents and children separately to account for power relationships, some children were interviewed in the presence of their parents; in these instances, we asked parents not to interfere unless necessary to support their child. At the end of each session, all participants were thanked for their time and given the opportunity to ask questions. The research was approved by the University of Lincoln College of Science ethics board.

Measures

The evaluation comprises qualitative and quantitative measures, performance data automatically logged by the system, observations made throughout interaction, and semi-structured interviews to explore participant perceptions.

Performance data. The system logged the overall interaction time of each participant, time spent on each task, and the number of tasks attempted and whether a task was successfully completed.

Observations. Observations were manually recorded on paper and focused on children's interaction with the system. They were made in two categories: Technical aspects of the interaction (e.g., tracking issues, or system-side problems engaging with the tasks), and user experience (e.g., children's emotional response to the system expressed through comments and facial expressions).

Semi-structured interviews. Interviews sought to understand the participants experience of using the system, issues concerning challenge and the physical and mental effort required (e.g., "Did you feel that you were exercising while using the system?"), along with children's and parents' perception of the visual style and possible themes (e.g., "What are your thoughts on the style of the system?", "Can you think of any themes or topics that would make it more exciting for you?"), and thoughts on long-term engagement in the home (e.g., "What other elements would you like to see in the system?", "How would the system fit into your home?").

Data Analysis

Quantitative data (performance data) were descriptively analyzed using SPSS. Qualitative data obtained through interviews were analyzed following a Thematic Analysis approach as detailed by Braun and Clarke [9, 10]. Interviews were first transcribed, and these texts were subsequently analyzed by the research team. The three research questions were used as a framework through which to interpret the data. The analysis was carried out from a critical realist position [21]. Specifically, in carrying out the analysis, we were interested in understanding participants reports of their own experience in interacting with Geometry Wheels. We accept participants' statements as valid reports of their experience, but do not assume that participants are fully conscious of all the factors that may influence their experience, or their reporting of that experience. Thus, the researcher must understand and interpret participants statements through the frame of their scholarly expertise on the topic, while being critical of their own values and their own experiences regarding the topic.

In the first stage of coding 93 codes were assigned to a total of 564 data points (at paragraph level). After all stages had been completed, four main themes (*Understanding Usability and Accessibility of Geometry Wheels*, *Balancing Challenge and Physical Effort*, *Reconciling Children's and Parents' Values*, and *Identifying Barriers and Facilitators for Home Use*) and seven sub-themes were decided upon.

Results

Here, we discuss the four main themes that best explained the data, exploring both children's and parents' perspectives on Geometry Wheels.

Theme 1: Understanding Usability and Accessibility of Geometry Wheels. In carrying out any user study of any prototype system, it is essential to establish first whether that system supports its intended task, in an appropriate context, with an appropriate group of users. The first theme describes participants' reflections on whether Geometry Wheels supported wheelchair skills training in a usable and accessible manner. Sub-themes focus on the **accessibility of Geometry Wheels**, the **challenge of conveying depth information** and the opportunity for **increasing inclusion through wheelchair controls**. Participants suggested that the system was both accessible and usable for young wheelchair users. Specifically, with successful use of wheelchair and body for system control, and positive feedback on the general interaction paradigm. For example, one participant highlighted the quality of wheelchair controls, commenting that *"it worked really well, [...] I actually thought it worked better because of the way it was set up"* (P6, child). Furthermore, data shows that the system was accessible for young people, suggesting that they understood the goals and enjoyed interaction (e.g., we observed smiles and laughter throughout evaluation sessions). This is reflected in parent feedback, suggesting that the playful nature of our approach engaged their children, e.g., *"I think it's really good, like I guess they are doing things without realising that they're doing it because it's their favourite game"* (P14, father). This is also reflected in participant feedback, e.g., one child stated that *"it was awesome, it was interesting"* (P10, child).

However, a prominent theme related to accessibility and usability was the challenge of conveying depth information. While participants could generally interact with the system and many understood the idea of using the depth of the room for interaction, feedback suggested that cues provided by the system (colour coding and shadows) were not sufficient for all users. For example, one participant stated that *"[...] there was no way, you did not know how far forward or backwards the ball was."* (P12, child). This was backed by observations of participants requiring assistance when first interacting with the system, reminding them of depth cues. Likewise, one parent suggested that working with depth might be an accessibility barrier, indicating that her daughter cannot perceive depth, outlining a challenge for training systems that to some extent depend on the third dimension to fully convey skills (also backed by low task completion rates for this participant; 37.5% compared to an average of 84% across participants).

Table 1: Average (Med) task completion times (s), minimum and maximum completion times, success rates.

Task	AvgTime	MinTime	MaxTime	%Success
All	43	9	60	84
Task 1	43	12	60	84
Task 2	40	10	60	69
Task 3	44	9	60	81
Task 4	44	11	60	100

The final sub-theme related to usability focuses on the positive impact of wheelchair controls on user experience, and their potential to increase inclusion and foster physical activity. There was broad consensus that wheelchair controls were beneficial. For example, one participant commented that *"I liked it how it's not just a person who could walk normally, I liked how wheelchair users could do it"* (P10, child). Likewise, parents outlined that *"it's good that someone is actually thinking about wheelchair users"* (P9, father). Finally, our results show that Geometry Wheels encouraged participants to reflect on physical activity, e.g., one participant commented that wheelchair integration *"was pretty cool, made me actually think about moving and stuff"* (P6, child). Data logs of participant interaction with the system support the notion that Geometry Wheels was generally accessible and usable for the participants, showing an average task completion time of 43 seconds which is within the initially anticipated time frame. Further, the overall success rate of 84% (see table 1 for breakdown per task) suggests that participants could generally accomplish the training goals, while only 16% of attempts were not completed within the 60 second time limit, with Task 2 (Reaching and Grabbing) being most challenging (69% success rate).

Theme 2: Balancing Challenge and Physical Effort. This theme focuses on the participants' **perception of challenge and physical effort** during their interaction with the system. In terms of challenge (i.e., the tasks included in Geometry Wheels), feedback was mixed, with some participants noting certain tasks were too easy (e.g., simply reaching for spheres). However, younger participants in particular expressed profound frustration about the level of difficulty of tasks that required combination of wheelchair skills (e.g., moving the wheelchair and reaching for a sphere). For example, one participant stated that he *"can't move forward onto the fucking square, had to go backwards [to grab a sphere] and it was quite difficult to move your hands and to grab it"* (P15, child) after only making a short attempt to complete the task, the choice of words underlining his frustration. Likewise, another participant recognized the challenging nature of some tasks, e.g., *"some bits were a little bit tricky, like trying to dodge squares"*, but concluded that the overall level of difficulty was *"just right"* (P11, child). Similarly, another participant highlighted potential for scaffolding, suggesting that *"it was very fun and then you do the things that were a bit more complicated"* (P4, child). This suggests that the individual perception of and psychological approach towards dealing with challenge differs, and needs to be considered as an additional factor for balancing (besides the physical abilities of users).

Feedback on physical effort required to engage with the system was similarly mixed. One participant explained that they did not enjoy Geometry Wheels *"because I did not like the moving around"* (P12, child). In contrast, another participant highlighted that the combination of wheelchair movement and interactive system facilitated the process, stating *"[...] it doesn't feel like you're having to move, like when I have to do normal exercises it feels like I'm forced to do it, with the game it feels like I'm doing it because I want to."* (P6, male). Parents' feedback on physically challenging their children through Geometry Wheels was exclusively positive. For example, one parent outlined that *"[their children] play wheelchair basketball, so the grabbing and pushing movement is something they need to develop"* (P8, father), suggesting a good mapping between our tasks and challenges in the real world. Taking this idea further, another parent suggested to directly include real-world tasks in the system to increase the level of challenge and encourage their children to push through difficult situations, *"[...] getting through a doorway or something like that, moving with the chair at the same time, that's quite difficult, when you gotta push it and pull it"* (P9, mother).

Theme 3: Reconciling Children's and Parents' Values to Design Engaging Wheelchair Skills Training Systems. The third theme predominantly reflects participants' **conflicting opinions** regarding necessary improvements for Geometry Wheels, along with our **observations of problematic participant interaction** throughout the interviews. In terms of features and themes, both children and parents provided input. Here, we observed a number of similarities and differences between children and parents, hinting at different values and perspectives. For example, a common feature brought up by participants of all ages was the idea of playing with others, e.g., capabilities for co-located interaction: *"It would also be good if I could play with other people as well, it's more involved if you can do it with other people rather than just at home."* (P6, child). However, children predominantly raised the idea as a means of improving their experience, whereas parents were focused on encouraging their children to develop social skills. Likewise, the importance of educational features was a common theme, but was brought up exclusively by parents, e.g., *"They need to learn, even though they're at school all day, they need to learn at home and stuff, and sometimes that encourages the learning."* (P13, mother), This was accompanied by comments such as *"I don't like them playing on games all the time for the sake of playing."* (P13, mother), suggesting that the participant viewed our system as a game that needed additional 'serious' content to be considered valuable. This was also reflected in suggested themes, with parents focusing on adding value beyond play such as teaching sports, and children explored a broad range of topics, e.g., unicorns, superheroes, and nature-themed experiences. Generally, there was little overlap in thematic preference among children, suggesting a need for flexible solutions to accommodate a broad range of users.

The last and perhaps most surprising subtheme was that of parental intervention, when parents were present during their children's interviews, and interrupted the process to offer (unsolicited) input. This included comments on children's preferences and abilities: for example, in terms of features and themes, a father commented that his son liked animals, but the child continued to address his initial idea of a fantasy theme, *"I've got a good one, Lego one while playing in unicorn world!"* (P10, child). Likewise, a mother pointed out that an educational feature would be desirable (while the question was directed at her child), and her child openly contradicted her: *"Mom [loudly], I don't want it to be educational."* (P3, child). In other instances, however, children went along with suggestions of their parents, e.g., after the mother stated that *"She don't play games"*, the participant confirmed *"I don't like play [...]"* (P4, child). In a similar vein, there were instances of parents commenting on their children's abilities, e.g., *"She can't, she hasn't got the depth, she hasn't got the skills."* (mother of P3), despite her daughter trying to engage in play. Finally, we observed parents interrupt their children to complete their answers, but also to help direct attention.

Theme 4: Importance of Barriers and Facilitators for Home Use. The final theme is summarizing participants' **reflections on barriers and facilitators for home use**. There were two prominent sub-themes, the first one being the **space requirements** of the system, and the second being **system cost**. In terms of space requirements, parent feedback in particular revealed that this could either act as a barrier or facilitator, with some parents commenting that they would easily be able to create enough free space in their home, and others suggesting that even after moving furniture, their lounge would not be big enough, contradicting previous findings and assumptions made during the design process. Likewise, system cost was problematic for some parents even when using off-the-shelf hardware (and also picked up by children) with one mother pointing out that *"it all comes to costing"* (P3, mother). In contrast, other parents commented that they had previously invested in comparable gaming technology (e.g., the Nintendo Wii). If we interpret room available in the home in the context of finances, this suggests that cost is an important barrier towards broader uptake of home-based rehabilitative technology that needs to be considered when designing such systems.

5 DISCUSSION

This paper reports on the design and evaluation of *Geometry Wheels*, a system to support wheelchair skills training among young wheelchair users. Our results show that the system was accessible and usable, and provided a positive user experience **(RQ1)** (Theme 1). However, user feedback on task difficulty and building towards complex movements **(RQ2)** was mixed (Themes 2 and 3), suggesting that some participants struggled with the amount of physical effort required for interaction. This shows that further support is necessary to enable all users to combine simple into more complex forms of wheelchair navigation. Finally, our results show that a number of design challenges need to be addressed to develop the system into a standalone solution for home-based rehabilitation **(RQ3)**: Most importantly, effective scaffolding strategies need to be implemented to facilitate complex skill development (Theme 2). Furthermore, the integration of elements to connect players and facilitate social exchange was important to prospective users (Theme 3), along with the reduction of space requirements to facilitate broader access to home deployment (Theme 4). In this section, we summarize the most important insights from our study, and discuss implications for interactive rehabilitative applications beyond wheelchair skills training. Finally, we also discuss methodological challenges that arise when engaging young people with special needs and their parents in research, contributing to our understanding of how to involve these audiences.

Interactive Wheelchair Skills Training

Interactive systems can be leveraged to engage wheelchair users in skills training, encouraging them to participate in physical activity, and providing a sense of inclusion by making off-the-shelf hardware accessible. We contribute a system that does not only encourage gesture-based interaction with a two-dimensional environment as implemented in many games for rehabilitation (e.g., [38, 41]), but truly leverages the third dimension of game and physical space to adequately represent challenges that need to be addressed by wheelchair users. Thereby, we demonstrate that the design approach originally suggested by [40] (using simultaneous camera streams showing two perspectives on the user's body) can be integrated into a single perspective and applied in more complex settings. However, we also note that understanding depth was challenging for some wheelchair users, suggesting additional research into movement guidance (e.g., [2] is necessary to effectively communicate this aspect to end users with broad ranges of cognitive abilities.

Challenges for Interactive Rehabilitative Systems

Here we discuss the four main challenges that emerged during the development phase and/or evaluation (see reference to themes within each challenge) of Geometry Wheels, and we discuss the broader context of these issues.

Challenge 1: Rethinking Challenge in Interactive Systems for Therapy and Rehabilitation. Balancing - matching challenge and player skill - is a core concern in movement-based game development to facilitate positive player experiences [19], and is highly relevant in the context of this project (see Theme 2). When creating interactive experiences for vulnerable audiences, this match is especially important to avoid instances of vulnerability, particularly when engaging players with mobility impairment in activity that has a physical component [17]. While games increasingly apply algorithmic approaches such as Dynamic Difficulty Adjustment (DDA) [3], continuously adapting challenge to user skill in rehabilitative systems that facilitate motor skill learning may be more complex. The benefits of DDA for player experience are well-established [3], however, little is known about the impact of DDA on skill development. Thus, systems that aim to teach tangible skills required for independent living might have less leeway for the dynamic adjustment of challenge. Alternatively, exploration of scaffolding in games and the potential of common approaches (e.g., [31]) for rehabilitative systems could offer solutions, breaking down tasks into smaller, more manageable chunks rather than reducing overall task difficulty, thereby reflecting recommendations for traditional wheelchair skills training [29].

Challenge 2: Moving Beyond Functional Elements: The case of Multi-User Features and Social Support. Our findings echo that of many other studies into rehabilitative technology, suggesting that multi-user features can serve as an element to engage patients (see Theme 3). Likewise, our observations of in-person training sessions show that wheelchair skills training events did not only serve the purpose of skills provision, but also offered parents the opportunity to connect with other people in similar situations, thereby facilitating social support. This highlights one of the key challenges for the development of effective rehabilitative technology: many systems (including ours) focus on the provision of functional skills, failing to replicate the wider delivery context of traditional therapy and rehabilitation. To this end, system designers can draw from research into games for audiences with special needs (e.g., [22]) that have demonstrated how to effectively address the concern in a research setting. However, the biggest challenge - bringing together users from small groups at the right time to facilitate social experiences - still remains to be addressed in the wild.

Challenge 3: Moving From the Lab into the Home. While the evaluation presented in this paper was not carried out in people's homes, we received valuable feedback outlining challenges for future integration (see Theme 4). While camera-based systems for rehabilitation are commonly designed with the intention of home use (e.g., [40]), our findings suggest that such systems in some cases exceed the space available in the home (echoing findings by Axelrod et al. [6] on technology interventions for older adults), turning this means of providing therapy and rehabilitation into an option only available to individuals with spacious homes. This suggests the re-introduction of socioeconomic barriers to the access of care; in our work this is further reflected by participants voicing concerns regarding system cost (even when using off-the-shelf gaming hardware). Therefore, research needs to explore alternative approaches that integrate technology already widely available to end-users (e.g., smartphones and accelerometry), or investigate ways in which system cost can be shifted to healthcare providers rather than the individual.

Challenge 4: Understanding Risks of Design by Proxy. Our results show that parents and children had different and sometimes conflicting perspectives on design elements to be integrated in the system (e.g., parents suggesting further educational elements, and children directly objecting to the idea; see Theme 3). While the involvement of proxies has generally been successfully applied in the design of assistive technology (e.g., with children with limited communication [2]), our results suggest that this approach needs to be applied with care. Particularly when involving parents in the design of technology for their children, it is important to explore differences in values (e.g., education over entertainment), how these affect design suggestions, their overall impact on the nature of the resulting system, and whether they might ultimately reduce motivation of the children to engage with the system. Likewise, we observed instances where parents commented on their children's (in)abilities. While we do recognize the pivotal role of parents as carers and close partners of their children, we previously observed instances where experts underestimated the abilities of young people with disabilities [42], suggesting that parent's comments on children's limitations need to be backed with careful observation, and, if possible, their own input.

6 LIMITATIONS AND FUTURE WORK

There are a number of limitations that need to be considered when interpreting the work presented in this paper. Most importantly, we only report on the first stage of our project and engagement of broader audiences in PD practices are required as a next step to develop the experience prototype into games. Building on this step, long-term investigations of user experience and effectiveness of resulting training applications are necessary. Furthermore, we would like to follow up on the role of feedback: while our system does inform users about successful task completion, there is potential to develop more fine-grained feedback mechanisms to scaffold motor learning (e.g., assessing propulsion technique in addition to tracking whether a user moved their wheelchair at all). Finally, future work should address the provision of social support, in line with participant suggestions to integrate multi-user features in our system, reflecting a core element of in-person training.

7 CONCLUSIONS

Interactive wheelchair skills training offers the opportunity of engaging bigger numbers of children in exercises that help build wheelchair skills, which are an important contributor to independence, wellbeing, and quality of life. Our work contributes to the development of such systems by outlining core challenges along with opportunities that playful interactive systems offer in such settings; we show that it is possible to engage young people in activity that contributes to the development of wheelchair skills, but also highlight that feedback provision and user encouragement is one of the most challenging areas for system design. Further, we reflect on financial implications of shifting technology-supported rehabilitation into the home, highlighting the need for affordable and easily deployable solutions to provide truly accessible interactive rehabilitative systems.

8 ACKNOWLEDGMENTS

We would like to thank Go Kids Go! and all participants for supporting our research. The work was funded by EPSRC EP/N023129/1, An Interactive Training Platform to Improve Manual Wheelchair Skills.

REFERENCES

[1] Gazihan Alankus, Amanda Lazar, Matt May, and Caitlin Kelleher. 2010. Towards Customizable Games for Stroke Rehabilitation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 2113–2122. https://doi.org/10.1145/1753326.1753649

[2] Fraser Anderson, Tovi Grossman, Justin Matejka, and George Fitzmaurice. 2013. YouMove: Enhancing Movement Training with an Augmented Reality Mirror. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST '13)*. ACM, New York, NY, USA, 311–320. https://doi.org/10.1145/2501988.2502045

[3] Dennis Ang and Alex Mitchell. 2017. Comparing Effects of Dynamic Difficulty Adjustment Systems on Video Game Experience. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '17)*. ACM, New York, NY, USA, 317–327. https://doi.org/10.1145/3116595.3116623

[4] Tao G. Torkia C. Boissy P. Lemay M. Reid D. Routhier F. Ryan S.E. Woodhouse J. Archambault, P.S. 2013. Development of a new virtual environment for a power wheelchair simulator: a user-centered approach.. In *Proc. of International Conference on Virtual Rehabilitation 2013, Philadelphia*.

[5] Cachecho S Routhier F Archambault PS, Tremblay S and Boissy P. 2012. Driving performance in a power wheelchair simulator. *Disab Rehabil: Assist Tech* 7 (2012), 226–233.

[6] Lesley Axelrod, Geraldine Fitzpatrick, Jane Burridge, Sue Mawson, Penny Smith, Tom Rodden, and Ian Ricketts. 2009. The reality of homes fit for heroes: design challenges for rehabilitation technology at home. *Journal of Assistive Technologies* 3, 2 (2009), 35–43. https://doi.org/10.1108/17549450200900014 arXiv:https://doi.org/10.1108/17549450200900014

[7] Krista L. Best, William C. Miller, and FranÃğois Routhier. 2015. A description of manual wheelchair skills training curriculum in entry-to-practice occupational and physical therapy programs in Canada. *Disability and Rehabilitation: Assistive Technology* 10, 5 (2015), 401–406. https://doi.org/10.3109/17483107.2014.907368 arXiv:https://doi.org/10.3109/17483107.2014.907368

[8] Sawatzky Bonita, Rushton Paula W., Denison Ian, and McDonald Rachael. 2012. Wheelchair skills training programme for children: A pilot study. *Australian Occupational Therapy Journal* 59, 1 (2012), 2–9.

[9] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706qp063oa arXiv:https://www.tandfonline.com/doi/pdf/10.1191/1478088706qp063oa

[10] Virginia Braun and Victoria Clarke. 2013. *Successful Qualitative Research: A Practical Guide for Beginners.* SAGE.

[11] John O. Cooper, Timothy E. Heron, and William L. Heward. 2007. *Applied Behavior Analysis.* Pearson.

[12] Stephen Cuzzort and Thad Starner. 2008. AstroWheelie: A Wheelchair Based Exercise Game. In *Proceedings of the 2008 12th IEEE International Symposium on Wearable Computers (ISWC '08)*. IEEE Computer Society, Washington, DC, USA, 113–114. https://doi.org/10.1109/ISWC.2008.4911599

[13] Shirley G. Fitzgerald, Rory A. Cooper, Emily Zipfel, Donald M. Spaeth, Jeremy Puhlman, Annmarie Kelleher, Rosemarie Cooper, and Songfeng Guo. 2006. The development and preliminary evaluation of a training device for wheelchair users: The GAMEWheels system. *Disability and Rehabilitation: Assistive Technology* 1, 1-2 (2006), 129–139. https://doi.org/10.1080/09638280500167639 arXiv:https://doi.org/10.1080/09638280500167639

[14] David R. Flatla, Carl Gutwin, Lennart E. Nacke, Scott Bateman, and Regan L. Mandryk. 2011. Calibration Games: Making Calibration Tasks Enjoyable by Adding Motivating Game Elements. In *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology (UIST '11)*. ACM, New York, NY, USA, 403–412. https://doi.org/10.1145/2047196.2047248

[15] Kathrin Gerling, Kieran Hicks, Michael Kalyn, Adam Evans, and Conor Linehan. 2016. Designing Movement-based Play With Young People Using Powered Wheelchairs. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 4447–4458. https://doi.org/10.1145/2858036.2858070

[16] Kathrin Gerling, Michael R. Kalyn, and Regan L. Mandryk. 2013. KINECTwheels: Wheelchair-accessible Motion-based Game Interaction. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13)*. ACM, New York, NY, USA, 3055–3058. https://doi.org/10.1145/2468356.2479609

[17] Kathrin Gerling and Conor Linehan. 2014. Exploring Player Abilities to Create Challenging Games: When Participatory Design Exposes Vulnerability. In *CHI 2014 Workshop on Participatory Design for Serious Game Design: Truth and Lies*.

[18] Kathrin Gerling, Regan L. Mandryk, and Conor Linehan. 2015. Long-Term Use of Motion-Based Video Games in Care Home Settings. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 1573–1582. https://doi.org/10.1145/2702123.2702125

[19] Kathrin Gerling, Matthew Miller, Regan L. Mandryk, Max Valentin Birk, and Jan David Smeddinck. 2014. Effects of Balancing for Physical Abilities on Player Performance, Experience and Self-esteem in Exergames. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2201–2210. https://doi.org/10.1145/2556288.2556963

[20] Edward M. Giesbrecht, William C. Miller, Ian M. Mitchell, and Roberta L. Woodgate. 2014. Development of a Wheelchair Skills Home Program for Older Adults Using a Participatory Action Design Approach. *BioMed Research International* (2014). https://doi.org/10.1155/2014/172434

[21] David J. Harper. 2011. Choosing a qualitative research method. In *Qualitative research methods in mental health and psychotherapy*, David J. Harper and A.R. Thompson (Eds.). Wiley-Blackwell.

[22] Hamilton A. Hernandez, Zi Ye, T.C. Nicholas Graham, Darcy Fehlings, and Lauren Switzer. 2013. Designing Action-based Exergames for Children with Cerebral Palsy. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 1261–1270. https://doi.org/10.1145/2470654.2466164

[23] Kieran Hicks and Kathrin Gerling. 2015. Exploring Casual Exergames with Kids Using Wheelchairs. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '15)*. ACM, New York, NY, USA, 541–546. https://doi.org/10.1145/2793107.2810304

[24] Shahla M. Hosseini, Michelle L. Oyster, R. Lee Kirby, Amanda L. Harrington, and Michael L. Boninger. 2012. Manual Wheelchair Skills Capacity Predicts Quality of Life and Community Integration in Persons With Spinal Cord Injury. *Archives of Physical Medicine and Rehabilitation* 93, 12 (2012), 2237 – 2243. https://doi.org/10.1016/j.apmr.2012.05.021

[25] Laura Keeler, R. Lee Kirby, Kim Parker, Katie D. McLean, and Jill A. Hayden. 2018. Effectiveness of the Wheelchair Skills Training Program: a systematic review and meta-analysis. *Disability and Rehabilitation: Assistive Technology* 0, 0 (2018), 1–19. https://doi.org/10.1080/17483107.2018.1456566 arXiv:https://doi.org/10.1080/17483107.2018.1456566 PMID: 29616832.

[26] Chapal Khasnabis and Kylie Mines (Eds.). 2012. *Basic Level Wheelchair Service Training Package.* World Health Organization.

[27] Chapal Khasnabis and Kylie Mines (Eds.). 2012. *Wheelchair Service Training Package: Trainer's Manual.* World Health Organization.

[28] O. Kilkens, M. Post, A. Dallmeijer, F. van Asbeck, and L. van der Woude. 2005. Relationship between manual wheelchair skills performance and participation of persons with spinal cord injuries 1 year after discharge from inpatient rehabilitation. *Journal of Rehabilitation Research Development* 42, 3 (2005), 65–74.

[29] R. Lee Kirby. 2016. *Wheelchair Skills Assessment and Training.* CRC Press.

[30] Maria Kourakli, Ioannis Altanis, Symeon Retalis, Michail Boloudakis, Dimitrios Zbainos, and Katerina Antonopoulou. 2017. Towards the Improvement of the Cognitive, Motoric and Academic Skills of Students with Special Educational Needs Using Kinect Learning Games. *Int. J. Child-Comp. Interact.* 11, C (Jan. 2017), 28–39. https://doi.org/10.1016/j.ijcci.2016.10.009

[31] Conor Linehan, George Bellord, Ben Kirman, Zachary H. Morford, and Bryan Roche. 2014. Learning Curves: Analysing Pace and Challenge in Four Successful Puzzle Games. In *Proceedings of the First ACM SIGCHI Annual Symposium on Computer-human Interaction in Play (CHI PLAY '14).* ACM, New York, NY, USA, 181–190. https://doi.org/10.1145/2658537.2658695

[32] Conor Linehan, Ben Kirman, Shaun Lawson, and Gail Chan. 2011. Practical, Appropriate, Empirically-validated Guidelines for Designing Educational Games. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11).* ACM, New York, NY, USA, 1979–1988. https://doi.org/10.1145/1978942.1979229

[33] Liam Mason, Kathrin Gerling, Patrick Dickinson, and Antonella De Angeli. 2019. Design Goals for Playful Technology to Support Physical Activity Among Wheelchair Users. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '19).* ACM, 12.

[34] Roisin McNaney, Madeline Balaam, Amey Holden, Guy Schofield, Daniel Jackson, Mary Webster, Brook Galna, Gillian Barry, Lynn Rochester, and Patrick Olivier. 2015. Designing for and with People with Parkinson's: A Focus on Exergaming. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15).* ACM, New York, NY, USA, 501–510. https://doi.org/10.1145/2702123.2702310

[35] Anita D. Mountain, Cher Smith, and R. Lee Kirby. 2010. Are wheelchair-skills assessment and training relevant for long-standing wheelchair users? Two case reports. *Disability and Rehabilitation: Assistive Technology* 5, 3 (2010), 230–233. https://doi.org/10.3109/17483100903391145 arXiv:https://doi.org/10.3109/17483100903391145 PMID: 20131977.

[36] Florian Mueller and Katherine Isbister. 2014. Movement-based Game Guidelines. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '14).* ACM, New York, NY, USA, 2191–2200. https://doi.org/10.1145/2556288.2557163

[37] Thomas J O'Connor, Shirley G Fitzgerald, Rory A Cooper, Tricia A Thorman, and Michael L Boninger. 2001. Does computer game play aid in motivation of exercise and increase metabolic activity during wheelchair ergometry? *Medical Engineering Physics* 23, 4 (2001), 267 – 273. https://doi.org/10.1016/S1350-4533(01)00046-7

[38] Jan David Smeddinck, Marc Herrlich, and Rainer Malaka. 2015. Exergames for Physiotherapy and Rehabilitation: A Medium-term Situated Study of Motivational Aspects and Impact on Functional Reach. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15).* ACM, New York, NY, USA, 4143–4146. https://doi.org/10.1145/2702123.2702598

[39] John M. Stewart, G. Donaldson, and Bob J. Sapey. 2004. *The Social Implications of Increases in Wheelchair Use.* Lancaster University, Department of Applied Social Science. 33Social Work and Social Policy Administration.

[40] Richard Tang, Xing-Dong Yang, Scott Bateman, Joaquim Jorge, and Anthony Tang. 2015. Physio@Home: Exploring Visual Guidance and Feedback Techniques for Physiotherapy Exercises. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15).* ACM, New York, NY, USA, 4123–4132. https://doi.org/10.1145/2702123.2702401

[41] Stephen Uzor and Lynne Baillie. 2014. Investigating the Long-term Use of Exergames in the Home with Elderly Fallers. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14).* ACM, New York, NY, USA, 2813–2822. https://doi.org/10.1145/2556288.2557160

[42] Jonathan Waddington, Conor Linehan, Kathrin Gerling, Kieran Hicks, and Timothy L. Hodgson. 2015. Participatory Design of Therapeutic Video Games for Young People with Neurological Vision Impairment. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15).* ACM, New York, NY, USA, 3533–3542. https://doi.org/10.1145/2702123.2702261

[43] Peter Wright and John McCarthy. 2010. *Experience-Centered Design: Designers, Users, and Communities in Dialogue.* Morgan and Claypool Publishers.