RollAbility: A Case Study of Aligning the Design of Game-Based Wheelchair Skills Training with Clinical Protocols and Player Experience Goals

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Interactive technology and games provide promising methods for wheelchair skills training. This paper introduces RollAbility, a rehabilitative game for powered wheelchair skills training aimed at children and teenagers with complex movement disorders. The game combines clinical best practices and standardized training protocols with player experience goals. Developed through an iterative process with rehabilitation experts and game designers, RollAbility utilizes the Wheelchair Skills Training Program *[Kirby et al. '23]* and integrates key insights from Aufheimer's *[CHI '23]* motivation studies in physical therapy to ensure both therapeutic and engaging gameplay. Evaluated through exploratory sessions with children, therapists, and clinical experts, results show that RollAbility effectively merges clinical protocols with an engaging game format. However, balancing player autonomy and therapist guidance remains a critical consideration. This work offers a blueprint for designing therapeutic games that align clinical protocols with engaging player experiences.

CCS Concepts: • **Human-centered computing → Empirical studies in accessibility**; • **Software and its engineering → Interactive games**.

Additional Key Words and Phrases: Powered Wheelchair Skills Training, Game-based Rehabilitation, Interdisciplinary Design, User Study, Qualitative Research

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1 Introduction

Interactive technology and games are a promising means of delivering wheelchair skills training. For example, there have been attempts to leverage Virtual Reality simulation to provide powered mobility skills training [23], Augmented Reality has been employed in prototypes exploring training

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of manual wheelchair skills [36], and there are tablet-based approaches that guide users through real-world exercises [38]. However, particularly in the context of wheelchair skills training for children and teenagers, additional considerations may be necessary. In particular, previous work has highlighted the need for adaptation and positive encouragement that moves beyond the state-of-the-art [7, p. 12], that games can be leveraged to re-introduce patient autonomy into physical therapy , as well as recognition that therapist involvement is crucial for therapeutic success [7, p. 12]. Likewise, previous work [5, 36] has highlighted the relevance of building upon clinical training protocols, but has not yet provided a clear process for their integration, an aspect that also remains unaddressed by frameworks and recommendations for the design of serious games (e.g., [97]).

In light of these gaps, we contribute RollAbility, a rehabilitative game that supports wheelchair skills training among children and teenagers with complex movement disorder. Through design and exploratory evaluation of the artifact, we seek to answer the following two research questions (RQs):

- ***RQ1:*** *How can we design games for wheelchair skills training that align with clinical best practices and validated training protocols while maintaining player experience goals?*
- ***RQ2:*** *What is the practical experience of the children and their therapists with RollAbility, and what potential do clinical experts see?*

We translated these questions into a two-step research process: In the first step, We designed and developed RollAbility, a rehabilitative game for powered wheelchair skills training. This game allows users to control a virtual wheelchair on screen using their actual powered wheelchair in stationary mode. The development process followed an interdisciplinary approach, involving iterative collaboration among therapists, rehabilitation experts, and game designers. From a therapeutic perspective, our game integrates a validated wheelchair skills training program - the Wheelchair Skills Training Program (WSTP) [56], which is highly tailored to personalized wheelchair controls and steering systems, and can be adjusted to player abilities by therapists in real time by means of a companion mobile app. In terms of game design, key insights from Aufheimer et al. [7] analysis of motivation in physical therapy were used to underpin the design of RollAbility, ensuring that player experience and engagement are prioritized alongside therapeutic goals. In the second step, we carried out an exploratory evaluation of RollAbility at a Flemish rehabilitation centre that examined player experience from the perspective of children and teenagers taking part in wheelchair skills training (N=6) as well as the perspectives of the young people's guiding therapists on the game (N=4). Additionally, the game was also presented to clinical experts (N=5) to review their professional perspective on the player experience. Through this step, we sought to gain first insights into whether player experience and clinical goals of RollAbility were met as a result of the design process.

Our results show that the integration of clinical protocols and practice through interdisciplinary collaboration is possible, but that design processes need to be adapted to enable clinical experts to adequately map clinical protocols onto game mechanics. Specific to our application context – wheelchair skills training – we also show that careful adjustment of many aspects of the game are necessary to support therapeutic outcomes, ranging from enabling players to engage with the game using their everyday wheelchair control hardware to realistic in-game physics with respect to wheelchair behaviour and even to careful and detailed mapping of real-world exercises onto gameplay. At the same time, we restate previous findings stating that game design needs to be mindful of providing an engaging player experience. Here, evaluation results suggest that RollAbility has potential to engage young people but that the balance between enabling autonomous play for an engaging player experience and maintaining therapeutic control for clinical relevance directly conflicts each other.

Overall, our work makes the following three main contributions: (1) We provide a blueprint for a design process that supports integration of clinical evidence into games for therapy, and show that the Wheelchair Skills Training Program (WSTP) [57] is a viable protocol for developing game designs. (2) Through RollAbility, a fully playable game for powered wheelchair skills training combined with a companion app, we make artifact contribution that encapsulates the key insights highlighted by Aufheimer et al. [7]. (3) The balance between player autonomy and therapist guidance is a key area for further refinement. While the game effectively engages children and teenagers in wheelchair skills training, the presence of therapists, though essential for therapeutic relevance and accessibility, can limit player autonomy. This tension between enabling autonomous play for engagement and maintaining therapeutic control for clinical relevance highlights the need for a more nuanced approach.

2 Related Work

In this section, we give an overview of relevant related work. First, we present current approaches to wheelchair skills training from the perspective of rehabilitation science. Second, we outline existing efforts to develop interactive systems to facilitate wheelchair skills training. Finally, we highlight how our research expands on this body of work.

2.1 Wheelchair Skills Training: Purpose and Approaches in Rehabilitation Science

Wheelchair skills training serves various purposes, which we discuss in the following section. Additionally, we give an overview of previous approaches to wheelchair skills provision, focusing on efforts to provide clinically validated training protocols.

2.1.1 The Purpose of Wheelchair Skills Training. Wheelchair skills training instructs patients on how to operate manual or powered wheelchairs more effectively through a motor skill learning process [36, 56]. This process results in the improvement of movement precision, both spatially and temporally, as a result of practice [99]: Learning occurs through repetition of movement and variations in difficulty, with each incremental change contributing to improved performance [51, 58]. Feedback is crucial for this learning, and the tuning of motor control processes happens outside of conscious awareness [99]. Thus, improving one's ability to interact with powered wheelchair input devices is expected to translate into intentional, more accurate wheelchair movement. Here, there is evidence that improved wheelchair skills result in enhanced independent mobility [12, 50] and quality of life [22, 50]: As wheelchair skills increase, individuals tend to use their wheelchairs more frequently [49], cover greater distances while driving [59], gain confidence in handling [91], and participate more actively in social activities [41, 50, 61]. Also, concerning acquired disabilities, wheelchair training facilitates return-to-work rate [98]. Additionally, among children using manual or powered wheelchairs, improved wheelchair skills positively impact cognitive and psychosocial development [42].

The primary goal of wheelchair skills training is to enhance patients' quality of life by promoting independent mobility. This recognition is underscored by the World Health Organization (WHO), which emphasizes the significance of wheelchair skills assessment and training for overall health and well-being [54, 100]. WHO emphasizes that training is not merely a recommendation for improved quality of life but a fundamental right under the United Nations Convention on the Rights of Persons with Disabilities. Article 20, Section C specifically highlights the obligation to ensure personal mobility with the utmost independence through the provision of mobility skills training [70].

2.1.2 Approaches to Wheelchair Skills Training. Various approaches to wheelchair skills training exist, and the organizations providing skills training may differ depending on the healthcare system in a given country or area. Best et al. [9] conducted an online survey to investigate the current practices of manual wheelchair skills training in Canadian rehabilitation centres and concluded that the implementation of validated wheelchair training programs is limited and suggests that innovative training methods could ease the burden on clinicians. A similar survey by Mathis and Gowran [64] carried out an analogous survey, focusing on the practices in Irish rehabilitation centres and came to a similar conclusion. Further, the authors emphasize the need to enhance health professionals' knowledge of advanced mobility skills training[64]. In some countries (e.g., in the UK [39, 55, 96]), wheelchair skills training is provided by charitable organizations in, whereas in other parts of the world, formal training remains largely inaccessible [28].

2.1.3 Wheelchair Skills Training Program. Wheelchair Skills Training Program (WSTP), is the most widely used validated program [9, 64]. Practically, the WSTP describes both wheelchair literature, which explains the correct execution of wheelchair skills, and principles of motor learning, which describe the methods for teaching these skills [10, 56]. The program includes 32 exercises addressing four different skill levels suitable for manual and powered wheelchair users. The WSTP exercises address a range of issues, including wheelchair maintenance and adjustment of settings, but also extending to movement exercises such as rolling forward and turning in place, interactions like reaching for objects and navigating through hinged doors, and techniques for challenging driving conditions. Each exercise description includes a rationale, setup instructions and scoring criteria for therapists, and tips and special considerations for different user groups (e.g., children, powered wheelchair users). Please refer to the respective subsections for details on two exemplary exercises relevant for our work, forward roll (Section 3.3.1) and turn in place exercise (Section 3.3.2).

In comparison with other training approaches, WSTP follows a task-based approach, where participants perform a series of individual tasks focused on perfecting specific skills [57]. This differs with programs like the Assessment of Learning Powered mobility use (ALP), which follows a process-based approach, assessing participants based on their learning process [71]. Additionally, WSTP is continuously being adapted to meet the specific needs of different patient groups. In a study conducted by Sawatzky et al. [88], WSTP was specifically modified for children, demonstrating its flexibility and effectiveness in paediatric applications. Similarly, in an intervention study by Naaris et al. [69], WSTP was tailored to cater to children with Cerebral Palsy (CP) using powered wheelchairs, ensuring that the program addresses their unique challenges and requirements.

2.1.4 Barriers for Implementing Wheelchair Training Programs. Regarding practical considerations, the primary obstacles for implementing validated wheelchair training programs include a lack of time and resources, uncertainty about how to apply the programs, and the cost associated with them [9]. Additionally, lack of adequate space, uncertainty regarding professional training, and the unsuitability of the clinical setting for such programs creates significant barriers to anchor the programs into therapy [9]. These findings highlight the challenges rehabilitation centres face in adopting standardized training methods and underscore the need to address these barriers to improve training practices. Finally, patient motivation is an essential aspect in wheelchair skills training [7, 63], particularly given that many protocols require patient participation over longer periods of time. Here, Maclean et al. [63] note that the patients' motivation related to personal traits and social factors affects the engagement in therapy and contributes significantly to the therapeutic outcomes. Adjacently, Aufheimer et al. [7] examined strategies therapists use to sustain patient motivation, particularly focusing on the implications for therapeutic game design, a perspective that we leverage in the design of RollAbility (see section 3.2).

2.2 Interactive Systems to Support Wheelchair Skills Training

Interactive systems have the potential solution to address the challenges in implementing wheelchair skills training. A significant body of work has demonstrated that these systems can be effective in therapy [3, 11, 17–19, 89] and can motivate patients [26, 62, 84]. Previous work has provided evidence for transfer of digitally acquired skills to real-world wheelchair use, with studies by Archambault et al. [6], Gefen et al. [33], and Faure et al. [25] confirming effectiveness for various user groups. Likewise, Cooper et al. [20] and Hernandez-Ossa et al. [47] explored the development of alternative interfaces for powered wheelchairs. While their focus was on the input systems, their findings also support transfer of virtual skills to real-world scenarios. By examining previously implemented simulations and games for wheelchair training therapy, we can identify potential challenges and opportunities to enhance their implementation.

2.2.1 Simulations for Wheelchair Skills Training. Previous research has developed simulators to virtualize wheelchair operation, aiming to replicate wheelchair behaviour in virtual environments (VEs). Genova et al. [34] created an accurate simulator for both powered and manual wheelchairs using the Gait Real-time Analysis Interactive Lab (GRAIL by Motek, NL)[13], integrated into a motion analysis lab for upper limb motion analysis. Similarly, Sonar et al. [92] developed a VR simulation with a head-mounted display and powered wheelchair joystick, providing realistic haptic feedback. The Virtual Environment Mobility Simulator (VEMS) [2] uses a standard screen and rollers to detect wheelchair movement for training in domestic environments. Herrlich et al. [48] used game engine technology to develop a virtual powered wheelchair simulation with the PhysX [72] physics engine of Unreal Engine 3 [32], though it had limitations in accuracy for training steering and turning skills. Rodriguez [82] created a VR training simulator for children with motor and cognitive impairments, focusing on simplicity and clarity. Rossol et al. [83] introduced a customizable platform for training powered wheelchair skills on a PC, using mouse and keyboard inputs, with a sensing algorithm to evaluate dexterity and confidence. Most research focuses on technical aspects, often missing the involvement of clinical experts or wheelchair users to identify relevant behaviours for successful and enjoyable training.

2.2.2 Game-Based Wheelchair Skills Training. Using games for rehabilitation enhances therapy enjoyment [84]. For example, Geometry Wheels [36], an Augmented Reality (AR) game, trains mobility skills in manual wheelchair users through camera-tracked movements and therapeutic tasks. Studies show interactive systems engage users but face challenges in balancing difficulty with skill levels. Research on movement-based games for powered wheelchair users highlights the influence of cognitive and physical abilities on performance and the importance of considering emotional expression in game design [35]. Hernandez et al. [45] developed six exergames for children with Cerebral Palsy (CP), through a year-long participatory design process and an eight-week home trials, finding that games for children with CP can be designed by simplifying level geometry, reducing error consequences, and balancing for differing abilities. Drisdelle et al. [23] created a VR wheelchair skills training game with a reward system, multiple camera angles, and real-time performance metrics. Lastly, Gerling et al. [37] studied creating wheelchair-controlled video games through participatory design, comparing contributions from young wheelchair users and game design experts, revealing that experts provided more detailed specifications, while wheelchair users offered high-level ideas about meaningful and enjoyable design.

2.3 Identifying the Research Gap

While wheelchair skills training positively impacts independent mobility [12, 50], quality of life [22, 50], and cognitive and psychosocial development [42], its current implementations often face barriers. Frequently, these systems do not concern validated training programs [9, 64]. The landscape of wheelchair simulation has made substantial progress over the recent years (cf. 2.2.1). However, many systems have been only examined from a technical point of view, and an embedding into actual therapy programs or an evaluation of their effectiveness is missing. Furthermore, although research on interactive systems has shown the importance of therapist involvement [2, 83], motivation [26, 62, 82, 84], adaptability [83], clinical expertise [2, 23, 36, 37], and wheelchair user experience [36, 37], maintaining patient motivation [7, 63] and adapting to specific patient groups [9, 69, 88] are ongoing challenges. In this work, we aim to overcome these limitations through a holistic design procedure that builds upon the existing wheelchair simulations, implements a standardized training protocol, iteratively evaluates our design with therapy experts, and embeds the simulation in a motivational game setting that is further evaluated with children who are conducting wheelchair skill training.

3 RollAbility: A Game to Train Powered Wheelchair Skills

In this section, we give an overview of the design and development of RollAbility. The core idea behind the game is to facilitate wheelchair skills training by allowing direct integration of the physical wheelchair as game controller. By using the control system of their wheelchair (e.g., joystick or head-foot steering system), players control a virtual wheelchair. RollAbility directly maps onto clinical exercises [57], situating them in a gameful setting that can be adjusted using a mobile app for real-time customization of exercise difficulty. Thereby, we ensure that therapists can adapt the exercises as required by the therapeutic context and the individual situation of their patients. In this section, we first elaborate on our design process. Then, we give an overview of our game design, addressing how training exercises were embedded in the game, the implementation of game controls, and we describe the companion app for therapists.

3.1 Design Process: Interdisciplinary and Iterative Design Involving Rehabilitation Experts

RollAbility was designed in interdisciplinary collaboration with experts in rehabilitation science, an endeavour that has been described as challenging due to conflicting goals and opportunities offered by games for therapy [78]. We iteratively worked with two rehabilitation experts with extensive experience in physical therapy and wheelchair skills training, meeting weekly over the course of six months. The design process was structured in three phases: (1) Development of Shared Design Goals, (2) Development of Virtual Exercises to Guide Discussion, and (3) Embedding of Exercises Into Game Design. Thereby, we sought to balance design requirements both from the perspective of game design and training requirements, and to build a game that could be embedded into existing skills training sessions.

3.1.1 Phase 1: Development of Shared Design Goals. At the beginning of the design process, the research team negotiated overarching design goals. As a result, there was emphasis on the relevance of following clinical training protocols, while also acknowledging the relevance of engaging gameplay and a positive player experience to achieve the motivational pull [84] that therapeutic games wish to draw upon. We agreed to build upon the Wheelchair Skills Training Program (WSTP) [57], and selected the following six exercises: roll forward, turn in place, sideways, ascend/descend ramp, open hinged door, and turn while moving forward. The selection was made to ensure high similarity to WSTP structure. Iterative discussions focused on exercise descriptions and practical implementation, eliminate failure states, incorporate adaptability of exercise difficulty parameters, and the recording of performance data based on the WSTP grading criteria. The rationale behind the selection process was that the exercises should be relevant to the training program, address different skill areas within the training, and be versatile, allowing for varied gameplay. Additionally, the research team agreed on the need for each exercise to be controllable using the player's individual wheelchair control system, thereby allowing for customization to their preferred mode of interaction, and also the one that would be used for real-world wheelchair driving.

3.1.2 Phase 2: Development of Virtual Exercises to Guide Discussion. Early on in the design process and in continuous consultation with rehabilitation experts, we developed a testbed environment to simulate the exercises in Unity, which we intended to use for game development. This was done to accurately translate the WSTP exercises into the virtual world (e.g., in terms of distances and error margins), and help root conversations in practical examples of how the WSTP exercises could be virtualized, highlighting opportunities and constraints of technology in the translation process. Using the testbed environment, we iteratively implemented virtualized exercises in rapid development cycles with continuous feedback loops among the collaborators. With this agile development paradigm, we were able to address issues and opportunities arising from prototype testing. For example, the turn in place exercise requires a patient to turn in a very confined space. During the creation of the virtual exercise, we found that the movements needed to turn the wheelchair did not match real-life wheelchair operation. The existing movement model was too unrealistic for the exercise. Consequently, we developed an improved model that more accurately replicated wheelchair turning behaviour, enabling correct steering during the exercise.

3.1.3 Phase 3: Embedding of Exercises Into Game Design. In the final step, we focused on integrating the virtual exercises into a complete game design. The objective was to balance game engagement with clinical validity. To support patient motivation, the game design integrates Aufheimer et al. [7]'s Key Lessons for the design of games for therapy and rehabilitation, which suggest active involvement of the therapists, flexible reconfiguration of the exercises, and avoidance of failure during gameplay to facilitate enjoyable experiences that are applicable in real-world therapeutic contexts. In terms of theme and visuals we further build on existing work that already explored gaming preferences of children and young power wheelchair users [35, 46], for example in the context of participation in physical activity [40]. With this, the game aims to reflect young people's gaming preferences, and to accommodate for the diversity of individual needs to avoid patients' frustration (cf. [27]). Furthermore, to address the need to keep therapists in the loop (also see [7]) and to enable effective adaptation, we agreed to develop a companion app that would allow therapists to make adjustments to the game at runtime. As in the previous design phase, we iteratively developed the game concept in close collaboration with the rehabilitation researchers and in adherence to the WSTP manual [57], ensuring that the design remains aligned with therapeutic goals and practice. Key points at this step of the design process included defining a coherent game design that is as flexible and adjustable as regular therapy, incorporating Aufheimer et al. [7]'s key insights for motivation in therapeutic contexts, and creating an engaging design for each exercise while ensuring the exercise mechanics from the previous step are maintained. Additionally, we focused on designing an app that balances maximizing therapeutic control with minimizing direct impact on the player experience.

In the following section, we describe the resulting game design in detail.

3.2 Game Design

RollAbility is a Caribbean-themed open-world game in which players can freely explore and initiate missions. The gameplay loop involves driving around, starting a mission, completing the required tasks (which are WSTP exercises translated into in-game challenges), and then returning to free exploration mode. The design of the overall narrative builds upon previous work examining the preferences of young wheelchair users regarding movement-based play [35], and integrates

Fig. 1. Fisherman NPC (left) and Player character (right)

previous work addressing game design for children with disabilities that highlights the relevance of in-game action[45]. The game is controlled using the individual control scheme of one's wheelchair (see section 3.2.2); therapists have the ability to configure the game throughout a play session by means of a companion app (see section 3.2.3). For implementation, we switched to the Godot 4.x engine [60]. One of the reasons for this switch was Godot 4's support for .NET 6 and higher [86, 87], which allowed us to leverage modern C# features and tools that were inaccessible in Unity at the time of development[1]. The models used in the game are part of the art pack POLYGON - Pirate Pack from Synty [93]. The companion app was also implemented using the Godot 4.x engine.

3.2.1 Game World, Player Representation and Non-Player Characters. **Game World.** The game is set on a tropical island, where players can explore a small town implemented as virtual 3D environment (see Figure 2). The island setting indicates the playable area, with the land area being navigable and the water area serving as a natural boundary. This allows a design without the need for artificial constraints that disruptively limits movement autonomy when exploring freely. The design of the town revolves around a central square at which missions (incorporating training exercises) can be selected, reducing the difficulty of finding points of interest, and aiming to minimize the need for external intervention from the therapist to guide the player. Both aspects emphasise *"Key Lesson 3: games as an opportunity to increase patient self-determination"* from the motivation analysis [7, Table 1].

Player Representation. Within this game world, the player is represented as a smiling younger person in a powered wheelchair as depicted in Figure 1 on the right. By default, the game is intended to be played from a first-person perspective. This teaches players to perform exercises from the same field of view as in real life. In addition, the game supports a third-person view, allowing the player to learn more about the physical presence of the wheelchair when performing manoeuvres. The gameplay from third-person perspective is depicted in Figure 4. The therapist controls the perspective, enabling them to decide which insight is more educational, highlighting *"Key Lesson 4: recognizing the limitations of game-based physical therapy and the unique value of human-led approaches"* [7, Table 1], which points out that current technology is not able to reach the same quality in terms of adjusting to individual patients , e.g., accurately addressing their emotional experience and skill level in real-time.

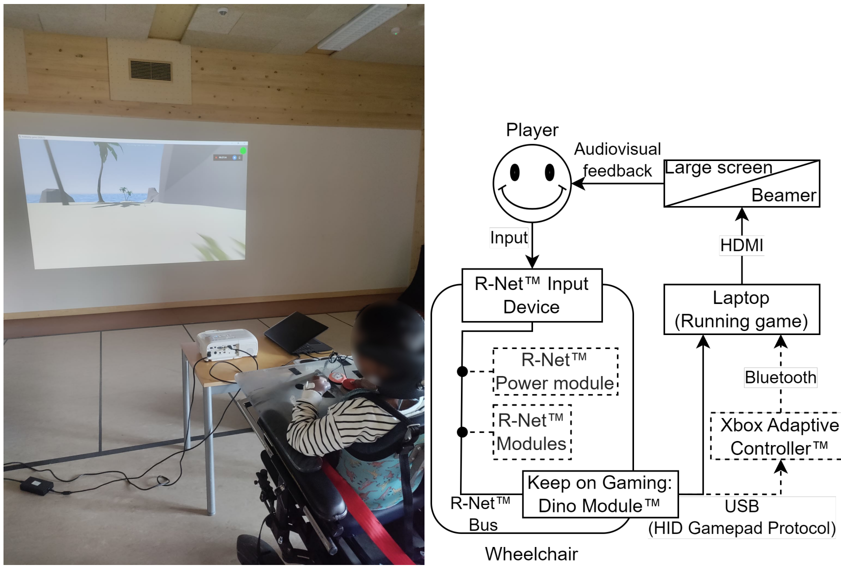
[1]Unity 2021.x only supports .NET Standard 2.1 and .NET 4.x [66]

Fig. 2. A screenshot of the game world

Non-Player Characters. The island is filled with non-player characters (NPCs) such as the fisherman on Figure 1 on the left, approachable for interaction, and as a means to contextualize the therapy exercises through in-game missions. Engaging with townspeople by parking the wheelchair in a highlighted zone in their proximity triggers a mission that unfolds within the same island setting. These missions represent multiple repetitions of physical therapy exercises and integrate them into a playful format. For example, driving up and down a fishing pier to assist an elderly fisherman represents the roll forward exercise (also see Section 3.3.1). The narrative aspect of these missions aims to add meaning to the exercises addressing *"Key Lesson 3: games as an opportunity to increase patient self-determination"* [7, Table 1]. Additionally, missions are designed to ensure the player cannot fail. Invisible walls confine movement to the relevant area, and trigger zones advance mission progression. Progress is based on *when* the player reaches the next point, not *if*, eliminating any fail states. This is directly derived from *"Key Lesson 2: viewing player performance through the lens of vulnerability"* [7, Table 1]. In section 3.3, we discuss the translation of the exercises into the game world in more detail.

3.2.2 Game Controls. The game is controlled by moving a virtual wheelchair using the input interface from a real powered wheelchair. All interactions are managed through virtual wheelchair movement, eliminating the need for additional controls. Since not all wheelchair interfaces support driving backwards, no interactions strictly require it.

From a technical perspective, this approach to game controls requires the establishment of a direct connection between the powered wheelchair and the game. As shown in figure 3b, we employ a Dino module by Keep On Gaming [73], an additional operational mode that can be installed on a powered wheelchair using the R-net system [94]. This modification allows us to input control signals into the Dino device, which converts R-net control signals into USB-HID joystick commands [29]. These commands are then sent over a USB cable to the host PC or through an Xbox adaptive controller [65]. This setup enables customized input configurations using the controller's input ports for buttons and joysticks. The wheelchair's signals are reassigned to mimic the left joystick on the Xbox controller and transmitted via USB cable or Bluetooth to the host PC. This setup requires that every in-game action can be executed through direct 2-axis joystick control or virtual wheelchair's movements, allowing the player to operate the game solely with their wheelchair input controls, thereby emphasizing their autonomy during gameplay, as highlighted in Key Lesson



(a) A child playing the game using their own powered wheelchair controls.

(b) A schematic overview of the setup and control scheme.

Fig. 3. An image and schematic of the game setup

3 of the motivational analysis [7], which highlights that games may re-introduce autonomy in typically restrictive therapeutic environments.

3.2.3 Therapist Involvement Through a Companion App. Following Aufheimer et al. [7]'s Key Lesson 4 of the motivational analysis, which suggests that designing games as supplementary technology for therapeutic practice rather than as a replacement for therapy, the therapist is actively involved in the game setup. The presence and involvement of therapists also help to overcome the limitations of computational assessment and adaptation. Further, in alignment with Key Lesson 1, which emphasizes that rehabilitative technology needs to factor in personal characteristics of patients along with situational aspects to holistically approach adaptation in games for physical therapy [7, Table 1], therapists can access a broader and more complex range of assessment techniques. Such assessments involve, for example, judgment based on individual personality traits or preferences, understanding patients' emotions, and perceiving other environmental factors [7].

To provide therapists with control over the exercises, RollAbility features a mobile companion app that allows for the adjustment of exercises in real-time and the creation of custom training sessions. Further, the app displays performance data, such as precise distance measurements or the duration of an action, which virtual approaches can assess more easily than their physical counterparts.

While the child is playing the game, the therapist can manage the training session through an app. The app is used to configure a custom training session specifically for the child. Creating a session involves selecting which exercises are available, setting preconditions for exercises (e.g., the sideways exercise can only be played after completing the roll forward and incline exercises), and determining the number of repetitions. Further, for each exercise, its parameters, such as exercise dimensions or error margins, can be adjusted for each exercise repetition.

Fig. 4. RollAbility game: third person view during turn-in-place exercise

Once the training session is set up, the therapist can send the configuration to the game and enable the exercises or missions. During gameplay, the therapist can still modify the training session but with several limitations: (i) no exercises can be added or removed unless their preconditions haven't been met; (ii) no iterations of an exercise can be added or deleted once the exercise is chosen by the player; and (iii) the parameters of the currently performed iteration cannot be altered. These limitations are introduced to conceal any changes from the player. Adjusting the training during runtime allows therapists to tailor the exercises based on their current observations, an important feature for *"Key Lesson 1: development of a more holistic perspective on adaptation in games for physical therapy"* [7, Table 1]. This feature is further emphasized by showing performance measurements based on the WSTP performance criteria description after each exercise iteration, providing therapists with information on the child's progress.

3.3 Translation of WSTP Exercises into the Game

As mentioned in section 3.1, six exercises from the WSTP were selected for inclusion in the game. This selection was informed by extensive discussions with engineering and rehabilitation researchers regarding the feasibility of virtualizing these exercises. The decision took into account the technological limitations in providing specific feedback and the critical role of these exercises in physical therapy. Virtual versions of these physical therapy exercises were subsequently proposed, following the descriptions outlined in the WSTP manual [57]. Following this, interdisciplinary collaboration led to adjustments in the design of the virtualized exercises, incorporating practical considerations from clinical practice, leveraging opportunities offered by the new virtual medium, and identifying parameters for adjustments by therapists similar to their practical interventions. In a third design step, the virtual exercises were implemented into the game as discussed in section 3.1.3.

To exemplify how the exercises are transferred into the game, we describe the two exercises *forward roll* and *turn in place* in more detail. We first describe the physical exercises, then, we depict the virtual twin in the testbed simulation, and finally, we explain how the exercise is implemented in the game setting.

3.3.1 Forward Roll.

Physical Exercise. The *forward roll* exercise in the WSTP manual trains fundamental indoor skills for manoeuvring narrow spaces [57, p. 113]. In this exercise, the trainee is required to move on a 1.5 m wide straight path from a starting line to the finish line, which lie 10 m apart from each other. The starting line should be visible by the trainee, while the finish line should only be visible to the therapist, a target object 1.5 m behind the finish line indicates the end of the path to the trainee. Therapists can adjust the width and distance of the path to vary the difficulty and may introduce random stops during the movement to assess stopping reaction time. The schematic of the exercise is illustrated in figure 5a. The exercise is assessed based on 3 scoring criteria: (i) did the trainee travel the requested distance (e.g., 10 m)?; (ii) did wheels stay within road width (e.g., 1.5 m)?; and (iii) did the wheelchair stop in a controlled manner? The execution of the exercise is shown in the instructions video of the wheelchair skill program [15].

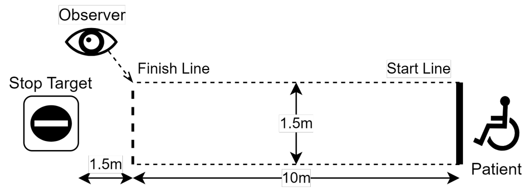
Virtual Exercise. In alignment with the manual, our virtualized forward roll exercise features a dynamically adjustable path that defaults to 1.5 meters in width and 10 meters in length, as well as the sudden stop prompting. When performing the exercise, the driver gets instructions on the screen to drive over the path toward the target location on the other side of the path. With the random stop enabled, a sudden message will prompt the driver to stop immediately. Once the driver has stopped, the program returns to the interrupted forward roll exercise. A screenshot of the virtual exercise is shown in figure 5b. When the exercise is performed, the offset from the target is measured, when the wheelchair goes into the margin zone (see yellow zone in fig. 5b) is detected, and the time along with distance travelled after a stop are registered.

Game Implementation. The *forward roll* exercise requests the player to drive to a target while staying on the path during the movement. To embed the exercise into the game context, the task is given by a fisherman NPC who asks the player for help and gives them the mission to catch fish at the end of the pier. This narrative element enhances the Aesthetics by providing a meaningful and engaging story. To spark curiosity, we made the targeted box at the end of the pier visually distinctive by applying an overlay shader that generates glowing, moving lines over the box. This further enhances the Aesthetics by making the game visually appealing and intriguing.

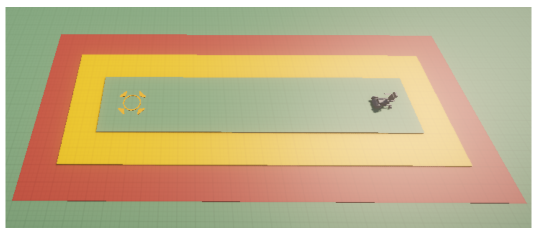
The Mechanics of the exercise remain unchanged, as the player still needs to drive to a target while staying on the path. However, the Dynamics are enriched by the added context of helping the fisherman and catching fish, which provides a clear goal and motivation for the player. These adjustments transform the exercise into a task to reach a target that is integrated into the game's narrative, making the experience more immersive and enjoyable. This transformation is illustrated in Figure 5c. All these changes are made without altering the original mechanics of the exercise.

3.3.2 Turns in Place.

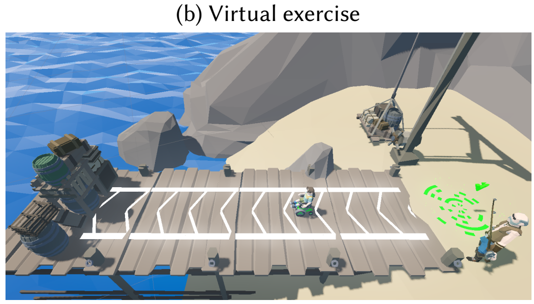
Physical Exercise. In the *turns in place* exercise, the driver learns to turn the wheelchair in the tightest space possible [57, p. 132]. The type and dimensions of the wheelchair significantly impact the ease of this exercise. Wheelchairs with casters make it easier by allowing yaw rotation around the upward axis, and their positioning on the wheelchair influences the turning behaviour. The setup includes a level surface with two intersecting perpendicular lines. On each of the resulting lines four marks such as coloured dots should be applied to visualize the distances from the centre (e.g., at $0.5m$, $1.0m$, and $1.5m$). Measuring tools like a protractor, goniometer, or magnetic compass measure the angle of the wheelchair's turn. The therapist adjusts the difficulty of the exercise by requesting the driver to stay within the 0.5, 1.0, and 1.5-meters radius marks. The scoring criteria for the turn in place exercise are: (I) Has the trainee parked within the angle margins (for



(a) A schematic overview of the roll forward exercise described in the WSTP manual.



(b) Virtual exercise



(c) Fishing mission

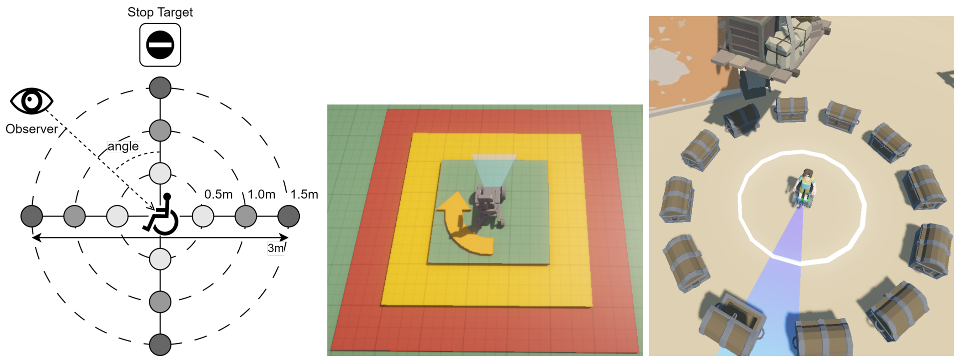
Fig. 5. Visual representation of the design steps of the forward roll exercise

180° it defaults at 20°.)?; (ii) Were any of the wheels outside the distance circle?; and (iii) Was the turn performed with minimal displacement from the starting point? The schematic of the setup is illustrated in figure 6a, and the activity is depicted in a video by the wheelchair skill program [16].

Virtual Exercise. At the beginning of the exercise, the driver is prompted to turn in the direction indicated by an arrow on the ground. The exact displacement and turning angle are measured using the coordinates and transform properties of the virtual wheelchair. Additionally, the implementation of the virtual wheelchair was modified to represent the turning behaviour expected with casters. A screenshot of the virtual exercise is shown in figure 6b. The acceptable region to manoeuvre is indicated by the green region, which can be adjusted in real-time by the therapist.

Game Implementation. The *turn in place* exercise teaches the trainee angular movements with the wheelchair. Within the game, the task is performed in the context of assisting a merchant in sorting his goods into the correct chests. The chests are arranged in a circle around the player, and the target chests are strategically placed at the different turning angles that the therapist wants the player to navigate to (figure 6c).

3.3.3 Remaining Exercises. The remaining four exercises follow a similar approach. The *ascends and descends inclines* exercise [57, p. 204 - 219] trains users to navigate up and down ramps as



(a) WSTP schematic overview (b) Virtual exercise (c) Sorting mission

Fig. 6. Visual representation of the design steps of the turns in place exercise

shown in a video by the Wheelchair Skills Training Program (WSTP) [74]. The virtual exercise consists of a large slope with an invisible wall to prevent the player from falling off, and a visual waypoint on the opposite side indicating to drive over the slope. Therapists can adjust the width and angle of the slope using the companion app. This exercise is integrated into the game as a mission where the trainee assists an unlucky driver in retrieving their belongings stuck behind a broken-down horse wagon.

The next game mission combines two exercises *manoeuvring sideways* [57, p. 152] and *going through a hinged door* [57, p. 196]. *Manoeuvring sideways* teaches the trainee to move sideways in small hallways while *going through a hinged door* trains how to park correctly in front of a hinged door before opening it. These two exercises are shown in videos [14, 76] by the WSTP. We merged these two exercises into a single mission because the *manoeuvring sideways* exercise needed an indoor setting to create the feeling of a narrow space, and the *going through a hinged door* exercise required a context for why the player must go through the door. Combining them addressed both issues. In the game mission, the player helps a priest clear the church hallways of weeds and opens a door at the end of the hallway.

The *turns while moving forward* exercise [57, p. 139] involves driving forward while turning left and right around a row of obstacles, as shown in a WSTP video [75]. This exercise is implemented in the game world as the initial virtual testbed but has not yet been developed into a narrative-based mission. Additionally, we introduced a variation of the *turns while moving forward* called the *U-turn* exercise, which involves making a 180° turn around a single obstacle. Although not directly described in the WSTP manual as a separate exercise, a WSTP video [77] demonstrates it. This exercise was identified as requiring separate implementation during collaboration sessions with engineering and rehabilitation researchers. Like the original exercise, the *U-turn* is currently implemented only as the virtual testbed in the game world and is planned for future development into a narrative-based mission.

4 Step 2: Exploratory Evaluation of RollAbility

After formulating a design and creating a prototype through interdisciplinary collaboration and an iterative design process as described in section 3, evaluating the design with the target audience is an important step in order to further examine the potential of game-based wheelchair training therapy. By collecting input from children and teenagers, therapists, and other clinical experts, we address RQ2 (section 1).

4.1 Method

We employed a qualitative research approach that predominantly relied on semi-structured interviews to examine participant experience. These were tailored to each of the groups involved in the exploratory evaluation:

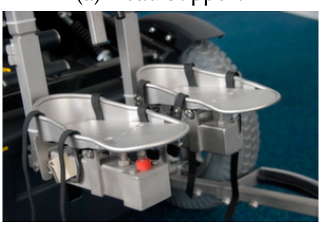
Clinical experts were interviewed using open questions inspired by the Player Experience Inventory (PXI) [1] and the miniPXI [43] to operationalize player experience within the interview format and cover all relevant aspects. The questions from the miniPXI [43] were translated into the local language and rephrased as open-ended questions. For instance, the statement *"The game gave clear feedback on my progress towards the goals."* was translated and rephrased to *"Did the game, in your opinion, give clear feedback about your progress towards the goals? How did you notice that?"* Children and teenagers were interviewed using a similar approach, with the open questions adjusted for better comprehension. For example, *" Did the game show you how well you were doing? How could you see or notice that?"* Therapists of children and teenagers were also interviewed in a similar format, with questions translated to Dutch and tailored to their perception of the children's experience during the session. For example, *"Did the game, in your opinion, give clear feedback to the child about his or her progress? What made you think that the child did or did not receive clear feedback?"* Additionally, we observed behaviours during gaming sessions, such as the children's reluctance to stop playing the game or the frequency and duration of their gaze shifting away from the game. These observations were used to further contextualize and explain our findings.

4.2 Participants

We recruited a total of 16 participants to take part in the exploratory evaluation. This included six children and teenagers who were powered wheelchair users, five of whom were students at the Flemish school where the study took place. Another child joined the study through a referral. The children and teenagers were joined by four assigned therapists who are responsible for providing wheelchair training therapy at the school. For the child joining through referral their parent stood in as observer. The children were aged between 8 and 19 years, with an average age of 14.67 years (SD = 3.64). Here, we want to note that this broad age spread is not unusual at schools for disabled children, and is also routine in therapy, where young people of a broad age range participate in similar therapeutic protocols. In terms of physical ability to control their wheelchair, the Gross Motor Function Classification System (GMFCS) [95] levels of the children ranged from IV to V, and the Manual Ability Classification System (MACS) [24] levels ranged from I to IV. Wheelchair experience ranged from one to eleven years (M = 5.5, SD = 3.86). Four participants controlled their wheelchair using a joystick, one participant used 3 coloured buttons (figure 8), and another participant used an Adremo head-foot steering system [30, p. 2] [79] (figure 7). The last two devices restricted wheelchair movement, only allowing users to turn to the sides and drive forward.

In addition, we recruited five clinical experts. Expert 1 is a postdoctoral researcher specializing in adapted physical activity for 10 years, with 7 years of prior experience as a therapist focusing on manual wheelchair skills training. Expert 2 is a paediatric neurologist with 24 years of experience, who has worked with cerebral palsy for 29 years and has 11 years of experience with serious games. Expert 3 is a postdoctoral researcher in paediatric neuropsychological rehabilitation for 3 years, with 7 years of experience in cerebral palsy and serious games. Expert 4 is a postdoctoral researcher in rehabilitation sciences for 6 years, with 6 years of experience in cerebral palsy and 4 years in wheelchair skills training. Expert 5 is a postdoctoral researcher and occupational therapist with 10 years of experience in paediatric rehabilitation, focusing on wheelchair adjustment and training.

(a) Head Support



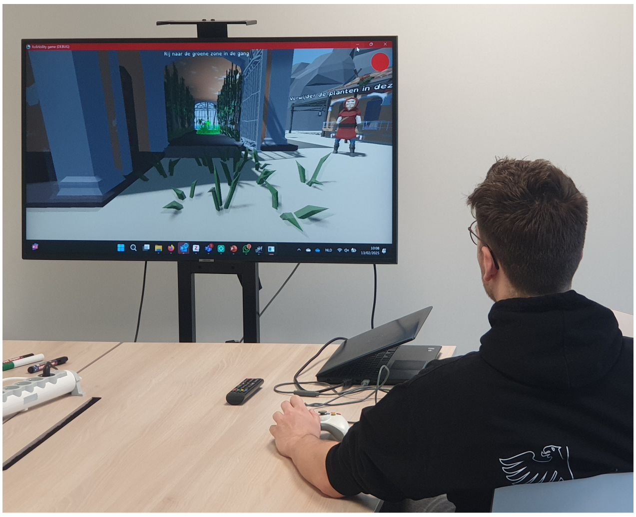
(b) Feet Support

Fig. 7. Adremo head-foot steering system using a) head support with sensor arrays for steering and b) feet support pressure peddles for accelerating and breaking. Images from Gakopoulos et al. [30, p. 2]

Fig. 8. Coloured buttons with stickers of different animals used for controlling forward acceleration and left and right turning of the (virtual) powered wheelchair.

4.3 Procedure

The training session setup involves as described in section 3.2.2 and shown in figure 3, a powered wheelchair connected to a computer which runs the game and displays this on a big screen or through a projector. A therapist, for this experiment a researcher from rehabilitation with therapeutic experience, stands next to the powered wheelchair and guides the player through the game. For the approach with children and their therapists, the children used their own powered wheelchairs and thus used the control scheme (see section 4.2) they also use for driving the wheelchair. The therapists who are normally responsible for the children's wheelchair training observed the game-based training session from the side. For the approach with clinical experts, a wired Xbox controller was used instead of a powered wheelchair to control the game. The controller was placed on a table to the left or right of the participant, based on their preference, simulating the joystick position on a powered wheelchair. Figure 9 illustrates this setup. A predefined session, containing all the virtual exercises split in three phases was used during the training. This approach did not allow for the adaptation of exercises, thus the adaptable aspect of the game system was not evaluated. However, using a consistent set of exercises enabled comparisons of the same tasks performed by different participants, highlighting variations in exercise difficulty among them. At the beginning of each session, information on the research was provided and participant were given room to ask questions. In the case of child participants, we obtained written assent from children and informed consent from legal guardians (e.g., parents). For adult participants, we obtained written consent. The research protocol was approved by the Ethics Committee Research UZ / KU Leuven, reference number S67860.



(a) Experimental Setup for clinical experts that did not use wheelchair input.

(b) Left hand positioning

(c) Right hand positioning

Fig. 9. a) Shows the experiment setup with clinical experts using a Xbox controller and large screen to test the game. The Xbox controller is put on the table to simulate a mounted joystick on a powered wheelchair. Depending on the preferred hand the Xbox controller was hold like b) for left handed control or like c) for right handed control.

4.4 Data Analysis

Audio recordings for all participant groups were transcribed by the first author, who then repeatedly read the transcripts to thoroughly familiarize himself with the data. Afterwards, we employed Framework Analysis, a structured method of thematic analysis [31], utilizing a deductive coding approach. Given our interest in the experience that RollAbility provided, we leveraged the theoretical framework of the Player Experience Inventory (PXI) [1] as lens which underpinned our codebook. This model provided two broad areas of player experience—functional and psychosocial consequences—and ten specific categories that describe these dimensions: Ease of Control, Goals and Rules, Challenge, Progress Feedback, Audiovisual Appeal, Meaning, Curiosity, Mastery, Immersion, and Autonomy. The data were coded according to these categories. During analysis, we coded data from all participant groups together (i.e., that of children and teenagers, therapists, and clinical experts), and we highlight these roles when presenting results. The first author engaged in several rounds of coding, discussing their progress and resulting themes with another member of the research team. The full set of themes was then appraised within the entire research team.

5 Results

In this section, we present the findings structured around the two core categories of the PXI [1], functional and psychosocial consequences for player experience. Therein, we discuss detailed aspects of the player experience provided by RollAbility from the perspectives of young people, their therapists, and other clinical experts.

5.1 Functional Consequences

The functional consequences of player experience are defined as *"the immediate, tangible consequences, experienced as a direct result of game design choices."* by Abeele et al. [1, p. 2], and encompass *ease of control*, *progress feedback*, *audiovisual appeal*, *clarity of goals*, and *challenge*.

5.1.1 Ease of Control. Ease of Control is defined as *"the extent to which a player finds the actions to control the game clear and intuitive"* in [1, p. 5]. With respect to RollAbility, this sub-theme covers how the wheelchair controls and their translation into in-game movement impacted the player experience. Here, the **control of the virtual wheelchair was regarded as an enjoyable and natural experience**, with one of the children pointing out that *"the driving, I find quite nice"* (C1), while an expert noted that based on their observations, *"The combination of trying to master the control of the steering device and seeing the immediate results on the screen was particularly enjoyable."* (E1). Another aspect that was highlighted with respect to *Ease of Control* was that **there is a similarity between children's driving behaviour in the real world and within the game**. To illustrate, one of the therapists commented that *"What stands out is that how he drives here and how he drives in real life have similarities. For example, if he turns too far, we would go back, but he makes a whole turn. He does the same thing here in the game. That was quite remarkable."* (T2). This suggests that the controls map onto wheelchair control in the real world, which is relevant for any training tool seeking to achieve transfer of driving skills.

5.1.2 Goals and Rules. As defined by [1, p. 5], *"The extent to which the overall objective and rules are clear to the player."* This sub-theme captures the player's experience in understanding how to perform the game missions and the actions within those missions. Children, therapists, and experts highlighted **the importance of therapist guidance throughout sessions**. For instance, one child commented that *"Yes, [I understood goals] partially through help of the therapist and also because I could see where I had to drive to."* (C1), which was further emphasized by the therapist. Similarly, another child stated, *"Yes, I could do quite a lot of exercises. Well, except for one, this one [U-turn exercise (see section 3.3.3]) had to be explained, otherwise I didn't know what to do."* (C4). A therapist added, *"He needs that guidance, right? On the other hand, once you've [therapist] explained it, it's clear, and he does carry it out, of course."* (T6). The need for guidance was echoed by experts, who highlighted that the **reusing game elements provided structure and recognizable elements, which is similar to what they used in physical therapy**, e.g., the use of green circles of target areas. However, there also were instances of **difficulty finding the green circles if they were out of sight**. For example, one child mentioned that *"Going back to the green zones was difficult,"* (C5), and their therapist elaborated, *"It wasn't always very clear that she had to go back to the green circles."* (T5).

5.1.3 Progress Feedback. Progress feedback is defined as *"The extent to which it is clear to the player how well he or she is doing in the game"* by [1, p. 5]. This sub-theme emphasizes the player's awareness of session, exercise, and action progression, as well as their understanding of the quality of their performance in these activities. Here, we want to note that the answers we received from the children indicated that the question was unclear to them. However, experts noted that **relying only on positive feedback, as discussed in section 3.2.1, can make the game confusing when actions are performed incorrectly**, e.g., one expert stated, *"when you go into the arrow and wait, it makes a sound, which clearly indicates that you've finished that part and need to start something else. However, when an error is made, the feedback isn't as clear."* (E3). In this context, another expert pointed out that **the therapist provided feedback when the feedback in the game was lacking**, commenting that *"[...] the feedback within the game itself could be optimized, but* *it becomes clearer with someone providing support alongside."*, once more underscoring the relevance of therapist support.

5.1.4 Audiovisual Appeal. Audiovisual appeal [1, p. 5] refers to *"the extent to which a player appreciates the audiovisual styling of the game."* This sub-theme addresses how the player experienced the low poly art style, the audio-visual effects within the missions, and the responsive audio from the wheelchair controller. Children, therapists and clinical experts agreed that the game looked visually attractive. One child commented that *"I find that beautiful"* (C2), and another pointed out *"I liked the landscape."* (C1). One of the experts also emphasised that *"I think* ***there is a nice balance in the visuals - they're not too overwhelming, but still a bit exciting****. I also find the sound effects to be quite pleasant."* In contrast, one therapist was concerned about visual distraction, stating that *"I definitely think it was visually appealing, but I also noticed that he always wanted to look somewhere else."* (T2).

5.1.5 Challenge. Challenge describes [1, p. 5] *"the extent to which the specific challenges in the game match the players' skill level."* This sub-theme is particularly difficult to measure since all tests were conducted with a predefined session setup, as mentioned in section 4.3. Consequently, none of the exercises were adjusted to individual skill levels. As a result, **the overall perception of the game was that it was not challenging enough, except for the sideways exercise** (see section 3.3.3). *"That last assignment is incredibly difficult [referring to the sideways exercise]. I have to say that. The rest was actually quite simple."* (C1), and another pointed out that *"[i]t could have been a bit more challenging"* (C4). Similarly, T1 commented: *"I think except for that last assignment, it was quite easy for her. But it's not that she was bored."* (T1). Experts agreed with this notion, e.g., *"The last task was particularly challenging for me [sideways park], while the others didn't seem as hard."* (E1). Experts also pointed out that **removing danger also removes challenge and teachable experiences**. Here, one expert mentioned, *"If you don't want the child to drive off the bridge, it's not clear whether you should put some kind of barrier at the beginning and then remove it at some point in the levels. This could subconsciously teach them to avoid certain things like hitting the wall. [...] Of course, you don't want to make them feel like they've failed, so it's a bit difficult to find the balance with failure."* (E3).

5.2 Psychosocial Consequences

The psychosocial consequences of player experience are defined as *"the emotional experiences, as a second order response to game design choices."* [1, p. 2]. We leverage this concept to explain how players experienced RollAbility. Following the structure of the PXI [1], this theme consists of five sub-themes, *Mastery*, *Curiosity*, *Immersion*, *Autonomy*, and *Meaning*.

5.2.1 Mastery. Mastery [1, p. 5] refers to *"a sense of competence and mastery derived from playing the game"*. It describes how players experience their ability to perform the exercises presented in the game. Here, **most children indicated that they felt they were good at playing RollAbility**. With respect to specific parts of the game and the challenge they provided, there was consensus that the game facilitated mastery; however, one child highlighted that *"Parking in circles was easy, but others were more difficult, and then I thought, what am I doing here?"* (C1). This suggests that specific players may find certain parts of the game more challenging. In terms of mitigation strategies to maintain a sense of mastery, **therapists helped with encouragement and restored confidence**. For example, T6 stated that *"I think that's where the frustration came in again. So not the full 100%, but I think with the necessary encouragement and us saying 'you're doing well,' it will sink in that 'okay, I am doing well here.'"*. Likewise, one child pointed out that **alternating between difficult and simple actions improved the feeling of achievement**, saying, *"You have a sense of achievement* *because it's quite easy to get into those circles and then do the more difficult things. A good balance."* (C1).

5.2.2 Curiosity. Curiosity [1, p. 5] refers to *"a sense of interest and curiosity roused by the game"*. This sub-theme describes to which extent players were interested in what the RollAbility game has to offer, specifically regarding game content and setup and execution of exercises. With respect to the game environment, results show that **some participants were drawn to the game to explore the virtual world in an open-ended way**. For example, therapists and experts commented on children's in-game behaviour, e.g., *"He wants to discover what he sees"* (T2). In contrast, **other participants showed interest in exploring what missions they could complete in the game**. For example, T6 mentioned, *"The fact that he wanted to continue means that he was wondering what was going on"*, and one of the experts pointed out that *"I was curious about what exercise would come next"*.

5.2.3 Immersion. Within the PXI, immersion [1, p. 5] is defined as *"a sense of immersion and cognitive absorption, experienced by the player"*, describing how the player becomes cognitively involved and experience their presence within the game world. Overall, our result suggest high levels of immersion. Here, multiple participants mentioned that **immersion in the game led to higher focus on the exercises than on real-life counterparts**. For example, a child noted that *"When I drive in everyday life, I look around everywhere instead of looking ahead. But the focus, now I really focused on the game"* (C1). Similarly, a therapist observed, *"He is generally easily distracted, but now that I see him here and compare it to how he is in my sessions, he is much more focused."* (T2). One of the parents shared this observation, stating that *"the focus was there. For [C4], there was definitely a lot of focus"*. **Experts highlighted intentionally increasing or decreasing immersion as a design opportunity**. In particular, they saw potential to support easily distracted patients, with E4 highlighting that *"maybe it's possible to choose whether or not to hear those sounds [like dogs barking]"*. This was echoed by E5, pointing out that *"You might almost have to set that up, because it's different for each child. Also, sounds like those of a barking dog might actually work for some children, because you might want to teach them how to continue with their training despite environmental noise"*. We further discuss differences in distraction in terms of transferability and validity, as well as the adaptation of game-based wheelchair skills training in section 3.2.3.

5.2.4 Autonomy. Autonomy [1, p. 5] is defined as *"a sense of freedom and autonomy to play the game as desired"*. This sub-theme describes whether players felt in control of how they engaged with RollAbility. Overall, results draw a mixed picture: Regarding wheelchair movement, some players indicated that **they felt free to drive their own way**, e.g., *"Yes, just like driving fast, I do that myself through the hallways. And I always find that liberating."* (C1). Similarly, C4 mentioned, *"Yes, spinning around like that, and I always drive at the fastest speed, but mom thinks it's too fast"*. Other participants **felt more restricted in playing the game**. For example, C3 compared their experience to other games they played, pointing out that *[...] I always walk a bit sideways in Roblox, so to speak, and that doesn't cause any problems, but in this game, there was a red wall"*, reaching the boundaries of the game world and noting differences in degrees of freedom with respect to movement. Similarly, a therapist mentioned, *"She has to control herself, but I think she couldn't do much else other than follow the instructions"* (T3), which was also echoed by experts, e.g.,*"I could have driven a few more laps before I felt comfortable, but I always go straight to my goal. So I was very duty aware, so I had no freedom, right? I could only do what I had to do, right?"* (E1), highlighting the trade-off between following therapeutic protocols and enabling free exploration. This was also highlighted as **a challenge with respect to therapist involvement, which therapists and experts considered necessary, yet a limitation of autonomy**. For example, one therapist pointed out that *"I think he needs a bit of guidance, so it's more difficult for him in that regard because he needs some direction and also on time, as he wanted to go very fast"* (T6). Likewise, E3 added, *"If [children are] given too much free time and you only have a one-hour session with the child, you might not get to do everything you wanted. So, maybe a bit more guidance would be helpful."*

5.2.5 Meaning. Meaning [1, p. 5] refers to *"a sense of connecting with the game, resonating with what is important"*. This sub-theme describes how players make meaning of RollAbility as a tool for therapy and skill development. Overall, our results show that **players found the game meaningful because it allowed them to practice wheelchair skills**. For example, one child highlighted that *"But the feeling that you can practice better, I do like that driving."* (C1). Likewise, therapists found the game meaningful but were wondering about children's perspectives, e.g., *"For me, it is meaningful, but is it the same for the child? I don't know, but I hope so. Because these are skills that are useful for daily life."* (T4). Likewise, E4 noted, *"I can see that if you are in a wheelchair, this is meaningful. For better mobility"*. Along these lines, one of the children commented that *"[the game is fun] because it is based on an electric wheelchair"* (C3), suggesting that **representation of protagonist driving a wheelchair was considered a part of the game that made it meaningful to them on an individual level**.

6 Discussion

In our paper, we designed and evaluated RollAbility, a game to train powered wheelchair skills. Here, we first provide answers to our two research questions. Then, we draw upon our findings to reflect upon the player experience goal of autonomy and whether it is attainable in games for therapy and rehabilitation.

6.1 RQ1: How can we design games for wheelchair skills training that align with clinical best practices and validated training protocols while maintaining player experience goals?

Overall, our work contributes RollAbility as a design case study that demonstrates the feasibility of creating evidence-based games for therapy. However, our work also shows that the design of rehabilitation games that integrate clinical protocols does not only require reconciliation of design goals, but also necessitates design approaches and tools that enable rehabilitation experts and game designers to effectively discuss and negotiate key design decisions. While integration of the Wheelchair Skills Training Program (WSTP) [57] appeared straightforward at surface level, accurate implementation of details (e.g., adjustment of task difficulty) required discussion, and mapping onto gameplay was challenging due to conflicting goals (e.g., autonomy and engagement [26, 84] versus performance and protocol adherence [9, 56, 64]). To facilitate this process, we introduced a three-step design process with an intermediate step in which WSTP exercises were virtualized (see Section 3.3) to contribute abstract representations of real-world exercises for discussion with rehabilitation experts. Our work suggests that these helped ground discussion, and allowed for more effective translation into in-game tasks in the next step of the design process. Likewise, the iterative collaboration with clinical experts at an early stage in the design process was instrumental in aligning gameplay with clinical considerations, enabling a shared understanding of design goals that guided decisions throughout development.

Here, we built upon Aufheimer et al.'s key lessons [7] for the design of motivating games for therapy. Throughout design and implementation, the lessons were helpful in guiding our overarching design choices (e.g., the integration of a companion app to allow for direct assessment (Key Lesson 1, [7, Table 1]) and human-in-the-loop adaptation (Key Lesson 4, [7, Table 1])) and provided a reference point for discussion within the research team. However, the evaluation of

RollAbility showed that the lenses themselves should be presented with more nuance as our results suggest that avoiding instances of failure (Key Lesson 2, [7, Table 1]) can potentially mitigate challenge and teachable experiences in the game, which otherwise has the potential to improve motivation and learning [44]. Furthermore, the player autonomy (Key Lesson 3, [7, Table 1]) remains a challenge when practically deploying games, an aspect which we discuss further in Section 6.3.

6.2 RQ2: What is the practical experience of the children and their therapists with RollAbility, and what potential do clinical experts see?

Our results suggest that RollAbility provided a positive experience for children, who appreciated the control scheme that goes beyond the state of the art in game-based wheelchair skills training (see Section 2.2) and directly integrated their individual, real-world powered wheelchair controls. Likewise, children were engaged by the game and appreciated the audiovisual design and being able to immerse in interesting in-game tasks. Hence, RollAbility appealed to players both on the level of functional and psychosocial consequences for player experience. With respect to therapeutic value, therapists noted similar wheelchair behaviour to real life, appreciated the structured approach of the game, and saw improved engagement with session content compared to physical therapy, while potential impact of RollAbility for long-term patient engagement still need to be studied [53]. However, both children and therapists expressed interest in more advanced in-game tasks, and there were some instances in which therapist feedback and intervention throughout the playing session negatively impacted player autonomy. Likewise, clinical experts were ambivalent regarding the abundance of positive feedback (which we designed in line with Aufheimer et al.'s key lessons [7]), and the relative removal of risk from the game. This implies a need for more nuanced strategies for the provision of in-game feedback and more advanced in-game challenge. Finally, clinical experts saw value in RollAbility as it immersed patients, shielding them from real-world distractions when first entering into play, which is in line with anecdotal evidence from exergames research in sensitive settings [90]. This showcases an opportunity to further explore how to adjust immersion depending on the type of challenge and stage of training.

6.3 Autonomy as a Challenge for Game Design for Therapy and Rehabilitation

Games for therapy are frequently viewed as a means of increasing patient motivation [62]; in particular, Aufheimer et al.'s work [7] that we have built upon in the design of RollAbility proposes to use games as a means of re-introducing autonomy in the context of physical therapy and rehabilitation of children and young people, who are often afforded little choice pertaining to their participation in and the structure of therapy.

While our results suggest that young people thought that RollAbility provided them with in-game autonomy (see Section 5.2.4), therapists and rehabilitation experts were acutely aware of practical and temporal constraints of therapy (see Section 5.2.4), and sought a moderating role in player engagement with the games (see Sections 5.1.2 and 5.1.3). This adds further nuance to previous research by Jung et al. [52], which highlighted that free choice of games can lead to conflict between patient and therapist, with patients striving to maximize their enjoyment and therapists focused on clinical outcomes. Here, previous work has noted that the design of games for therapy should not distract from the therapy goals [4], and work on exergames [80] has suggested hat player autonomy inherently conflicts with the requirements of training programs, introducing challenges for game design.

Providing the most detailed exploration of player autonomy to date, the *Integrated Model of Contextual Autonomy Support in Leisure Play Contexts* highlights the relevance of players being able to *"choose whether, when, what, how long and how to play"* (p. 3938) and the importance for play to be *"shielded from outer demands and public observers"* (p. 3938) [21]. Our study provides designerly

Table 1. Comparison of findings from the design and evaluation of RollAbility with Deterding's [21] integrated model of contextual autonomy support.

Condition for the experience of autonomy according to Deterding [21]	**Characteristics and deployment context of RollAbility**
(1) Choosing whether to play and *(2) what to play*, i.e., engaging with a game at one's own volition, and selecting a game that alings with one's current motive for engagement	RollAbility is embedded into wheelchair skills training that children and teenagers have to attend. Therapists may allow choice over whether to play the game (or whether to engage in traditional skills training exercises instead), and may leave patients a degree of choice regarding the selection of tasks. However, in comparison with leisurely play, player autonomy is restricted.
(3) Choosing when to play and *(4) how long to play*, i.e., being free to determine the moment in the day when to engage, and having control over the length of the gaming session	RollAbility is to be played during skills training sessions that are scheduled during school hours. These sessions are of fixed length. Children and teenagers do not have control over this schedule.
(5) Choosing how to play, i.e., being able to make one's own choices regarding in-game interactions and playstyle	RollAbility offers a degree of freedom regarding driving style within the game, and participants appreciated this this during the evaluation (see Section 5.2.4). However, therapists may choose to recommend a specific in-game driving style.
(6) Minimizing social and material consequence of gameplay, i.e., play being separate from the real world	For RollAbility to be successful, there must be a transfer between in-game wheelchair skills to real-world wheelchair skills. Hence, play is inherently linked with the real world. Additionally, in-game performance may be communicated to other stakeholders, e.g., parents.
(7) Being shielded from outer demands and observers, or being able to play in a situation where one feels comfortable and not under pressure from outside factors	Given that RollAbility is intended to be played in the presence of the therapist (and with their support), playeres are not shielded from observers. We anticipate that the impacts on player experience depends on the relationship between patient and therapist. Our evaluation also showed that there are instances in which their presence is beneficial (Section 5.1.3 and 5.2.1).

and empirical evidence how these aspects are impacted in a therapeutic context: RollAbility violates many of the conditions for players to experience true autonomy (see Table 1). In particular, we note a conflict with Aufheimer et al.'s [7] work: If games are not leveraged to replace therapy (e.g., to support additional exercises at home) but are used to augment it, the presence of the therapist will inevitably influence how players experience the game (7). Likewise, many characteristics of therapy limit choice (1-5), reducing the likelihood for games to satisfy an individual's need for autonomy in the context of therapy.

These challenges emphasize an inherent frustration of basic psychological needs [8] in games for therapy. Previous work has suggested that frustration of one need could be compensated by the satisfaction of another [67, 81], which aligns with Aufheimer's observation of therapists, who emphasize competence and relatedness to compensate for the lack of autonomy [7]. However, if games for therapy are not suited to re-introduce autonomy, this raises the question whether they offer motivational advantages over traditional approaches. Likewise, this suggests that the HCI games research community needs to pick up on past discussion of player autonomy in serious settings (e.g., see [80]), and the potential of games to satisfy basic psychological needs therein.

7 Limitations and Future Work

There are a few limitations and opportunities for future work associated with our research. Concerning the design of RollAbility, we implemented on only a front-wheel-driven wheelchair to demonstrate the complete user-centric development cycle. However, this limitation excludes a plethora of techniques exercise and movement behaviours. Hence, in future work, we will implement front-, mid-, and back-wheel-driven configurations to match a variety of patient's wheelchair models [68]. Additionally, we only translated a small number of WSTP exercises into in-game tasks to demonstrate feasibility, and will create a broader set in the future. Regarding the user study, our work was qualitative and only featured a small sample. While our findings provide valuable initial insights, the findings require empirical validation with a larger test group, and in the context of clinical trials that also examine effectiveness across multiple sessions (cf. Naaris et al. [69], Zhang et al. [102]). In terms of therapist involvement, our work suggests that it creates challenges for player autonomy that need to be managed. Here, approaches taken by previous work that actively involve therapists through in-game roles (e.g., the rehabilitation game Percussion Hero [85] represents the therapist as an active participant within the game) might be a promising avenue that could facilitate and streamline moderation. For example, this could support co-play, modelling driving behaviour, or directly giving feedback from within the game rather than stepping out of it [101]. Finally, while the visual design and evaluation of the companion app was not the focus of our work presented here, we want to investigate suitable visualisation strategies, therapists' perceptions of the app, and implications for the design of therapy sessions in the future. In particular, we look forward to exploring new pathways toward balancing control over therapy sessions between therapists and patients.

8 Conclusion

This paper contributes RollAbility, a game for powered wheelchair skills training that combines clinical protocols with engaging gameplay, integrating individual, real-world powered wheelchair controls. Our interdisciplinary and iterative design approach allowed us to create a game that aligns with clinical training protocols [57] while considering game design recommendations for patient motivation in physical therapy [7]. The design process proved valuable for the game development while adhering to the clinical training protocols, allowing therapists, experts and game designers to develop a common ground to holistically conceive an engaging and effective therapy. The qualitative evaluation revealed that the game was well-received by children. However, the evaluation also revealed that despite our interdisciplinary design process, tensions between therapeutic goals and engaging gameplay remain. In particular, therapists intervened throughout gameplay in ways that affected player autonomy, suggesting that when therapists are present when patients play, they shape player experience and may restrict autonomy. Thus, our results also raise the question of whether games for therapy can really serve as a tool to increase patient autonomy. This highlights a key challenge for game-based rehabilitation, and we hope that our work can contribute to ongoing discourse on the role of player autonomy in games for therapy.

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