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Article

Gamified Shoulder Wheel: Enhancing Pediatric Engagement and Data Collection

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Abstract

Shoulder wheels are commonly used in upper limb rehabilitation, yet their repetitive nature often results in low engagement, particularly among pediatric patients. This study aimed to develop a low-cost, gamified rehabilitation system by integrating a tablet-based serious game with a gyroscope-equipped shoulder wheel to guide exercise rhythm, track movement, and provide real-time visual feedback. Specifically, the study addressed two research questions: (RQ1) what are the benefits of integrating gamification into shoulder wheel therapy, and (RQ2) which clinically relevant objective measurements can be recorded during therapy. A mixed-methods feasibility study was conducted, involving three focus groups with medical professionals to iteratively inform design decisions and assess clinical relevance, followed by a pilot study with pediatric participants and clinicians that combined quantitative engagement measures with qualitative feedback to assess engagement, usability, and perceived therapeutic value. The results indicated higher engagement ratings during interactive gameplay, demonstrated the system's ability to capture clinically relevant movement data via embedded sensors, and suggested that the system could be integrated into existing rehabilitation protocols with minimal disruption. Unlike virtual reality or wearable-based solutions, this approach retrofits familiar rehabilitation equipment with embedded tracking and serious game mechanics, offering a low-cost and scalable alternative for pediatric rehabilitation settings. Overall, the findings suggest that gamified shoulder wheel therapy has the potential to support patient motivation and enable objective performance tracking, with clinicians indicating perceived suitability particularly for children aged 8–12. These findings are preliminary and based on an exploratory, small-scale feasibility study, and further controlled and longitudinal research is required to evaluate therapeutic efficacy.

1. Introduction

Shoulder injuries are a common concern across diverse populations, resulting from repetitive strain, trauma, or neurological conditions. Rehabilitation programs frequently incorporate shoulder wheels as a key therapeutic tool to restore upper limb function, improve range of motion, and build muscle strength [1]. While effective, these exercises are often highly repetitive, which can lead to low patient engagement and adherence, particularly among pediatric and long-term rehabilitation patients. Lack of motivation in therapy can negatively impact recovery, as consistent and active participation is crucial for optimal outcomes.

To address these challenges, researchers have explored the integration of technology into rehabilitation to enhance patient engagement and clinical data collection. Among these advancements, serious games have emerged as a promising tool, merging interactive digital environments with physical therapy. By incorporating mechanics such as rewards, real-time feedback, and goal-based progression, serious games have been explored as a means to support motivation, engagement, and the collection of performance-related data [2, 3, 4], with reported effectiveness in stroke rehabilitation, multiple sclerosis management, and neuromotor disorders [5]. However, many gamified rehabilitation technologies have focused on entirely new systems such as VR-based exergames, wearable motion sensors, and robotic tools. While these approaches provide interactive and data-rich experiences, they are often costly, complex to set up, and lack sufficient clinical validation, limiting their accessibility and integration into standard rehabilitation protocols.

A notable research gap exists in the gamification of existing rehabilitation tools, such as the shoulder wheel. Retrofitting traditional rehabilitation devices with gamification features could provide a cost-effective, scalable, and clinically viable alternative, ensuring easier adoption in therapy settings. This study aims to bridge this gap by developing a gamified shoulder wheel that integrates a tablet-based game with an embedded gyroscope to track movement and guide exercise rhythm. By focusing on cost-effectiveness, clinical relevance, and ease of use, this approach examines the feasibility of integrating gamification into an existing rehabilitation device within routine clinical practice. To address these challenges, this study explores the following research questions:

- **RQ1**: What are the benefits of integrating gamification into shoulder wheel therapy?
- **RQ2**: What clinically relevant objective measurements can be recorded during therapy?

To address these research questions, this paper is structured as follows. Section 2 reviews the literature on the evolution of rehabilitation technologies, focusing on the role of shoulder wheels in therapy, the integration of serious games to enhance patient engagement and barriers to the adoption of gamified rehabilitation tools. Section 3 outlines the methodology, detailing the design and development of the gamified shoulder wheel, including the integration of a gyroscope-based tracking system, the serious game interface, and the iterative refinement process based on clinical feedback. Section 4 presents the results of the study, incorporating feedback from both child participants and clinicians. Section 5 discusses the key findings, including considerations around engagement, data tracking, and system adaptability. Finally, Section 6 concludes the paper and outlines directions for future research, including the expansion of gamification to other rehabilitation devices, the refinement of motion-tracking techniques for enhanced assessment and therapy personalization, and the potential for real-time data visualization to support individualized rehabilitation planning.

2. Background & Motivation

Rehabilitation technologies have rapidly evolved, offering new ways to enhance patient engagement and improve clinical outcomes. Serious games across modalities such as VR, wearable sensors, and robotics provide engaging therapeutic experiences while generating performance metrics for clinicians. Vision-based systems like Microsoft Kinect, VR exergames, and Nintendo Wii have been widely explored in upper limb therapy. These systems enable gesture-controlled exercises that enhance motor coordination and movement recovery, with some studies reporting higher muscle activation and engagement than traditional therapy [6, 7]. To further improve motion tracking accuracy, wearable sensors such as Inertial Measurement Units (IMUs) have been introduced, allowing for precise monitoring of movement and adherence [8], and hybrid solutions combining IMUs with vision-based tracking have been proposed to capture subtle movements [9].

Recent years have also seen the emergence of a wide range of gamified rehabilitation systems that illustrate the diversity of current approaches. For example, MILORD integrates Leap Motion tracking with analytics and engagement dashboards [10], while EMG-controlled systems use muscle activity to guide repetitive finger exercises in stroke rehabilitation [11]. Mixed-reality platforms [12] deliver interactive games without requiring additional sensors, and the FLOAT exoskeleton [13] combines robotic support with gamified repetition exercises for shoulder therapy. Other mobile and home-based solutions, such as MoEvGame [14] and NeuroGame Therapy [15], extend gamified rehabilitation to fine motor assessments and EMG-controlled home therapy.

Despite these advances, widespread adoption in clinical practice remains limited due to high costs, complex setup requirements, challenges with wearability, and insufficient clinical validation. As a result, traditional rehabilitation tools such as the shoulder wheel continue to be widely used because of their simplicity, accessibility, and therapist familiarity. However, these conventional methods often lack interactivity and objective feedback, leading to reduced patient engagement and limited quantitative assessment of progress. The integration of gamification principles and motion-tracking technology into established rehabilitation tools presents a promising approach to improving therapy adherence and clinical monitoring, while addressing limitations in existing rehabilitation systems.

2.1 Barriers to Adoption of Medical Rehabilitation Systems

Despite the promise of serious games, VR-based rehabilitation, and wearable sensors, their integration into standard rehabilitation practice remains limited due to several practical and clinical barriers. A review by Elgert et al. [16] found that applications for shoulder rehabilitation, ranging from mobile apps to robotic systems, face multiple challenges that render them unsuitable for clinical use. Many lack clinically relevant data, standardized outcomes and clinical quality, which limits clinicians' ability to make informed decisions. The involvement of clinicians in the design process is therefore crucial to ensure that technological solutions align with clinical needs and practices. While serious games offer potential for real-time feedback and quantitative assessment, limitations persist. Steiner et al. [17] noted that many rehabilitation games fail to consider patient-specific characteristics, and most exergames are designed for outpatient rather than inpatient rehabilitation. The lack of standardized protocols for serious games and the limited knowledge of therapists in VR-based rehabilitation further complicate clinical adoption [18].

In addition, although metrics such as range of motion, movement speed, accuracy, and reaction time are essential for evaluating upper limb progress, only about 65% of studies report collecting these measures [4]. Technological and methodological constraints, including the absence of finegrained motion tracking and standardized clinical assessment protocols, hinder precise data collection and analysis, resulting in a lack of evidence-based practices [19]. Moreover, high costs, complex setup requirements, and the need for specialized knowledge continue to pose significant barriers, particularly for smaller clinics and home-based therapy programs [20, 21]. These factors limit the feasibility for independent use and often require additional clinical staff training, further delaying widespread clinical integration.

2.2 Role of the Clinician in Rehabilitation Therapy

The increasing focus on tele-rehabilitation and self-use rehabilitation equipment aims to minimize the role of physical therapists, limiting their involvement to minor equipment adjustments and remote assessment of patient outcomes. However, existing literature highlights that physical therapists play a crucial role not only in technical assistance but also in providing emotional support, ensuring patient adherence, and optimizing therapeutic outcomes [22].

A study on a robotic arm rehabilitation system, which integrates sensors and motors with memory, color, pattern, and puzzle-based serious games for stroke recovery, found that clinical supervision was necessary to ensure patient safety and maximize therapeutic effectiveness [23]. Similarly, home-based rehabilitation systems such as MERLIN (hoMEcare aRm rehabiLItatioN), while promising for physical rehabilitation, face multiple challenges related to user experience, technical support, and adherence [24]. Several barriers affect the feasibility of home-based rehabilitation without medical supervision, including ergonomic discomfort, repetitive gameplay, complex game mechanics, and the need for assistance in operating the system. Additionally, the lack of technical support for software and hardware issues, as well as competing household responsibilities, can lead to reduced adherence to therapy [22]. Studies by [22, 24] further indicate that patients often prefer direct clinician interaction, even in home-based settings, underscoring the importance of human connection in the rehabilitation process.

Specialized rehabilitation systems, such as Hocoma's Armeo Spring, offer precise movement tracking and targeted therapy for patients recovering from stroke or traumatic brain injury. However, these systems are expensive, less accessible for home-based rehabilitation, and require complex setup, making them difficult to implement outside of clinical environments [25]. Research also suggests that emotional, behavioral, and cognitive factors significantly influence rehabilitation outcomes, particularly in pediatric populations [26, 27]. Additionally, children may prioritize game mechanics, such as scoring and competition, over therapeutic objectives, reinforcing the need for well-designed rehabilitation tools and therapist guidance.

The cognitive abilities of elderly patients also present challenges in self-administered rehabilitation, often necessitating clinical and technical support [28]. Moreover, a specialized medical team is essential for monitoring mental stress, anxiety, muscle fatigue, and pain due to incorrect posture, as these factors can contribute to spasticity, reduced mobility, and impaired therapy outcomes [29]. While advanced robotics and neurorehabilitation technologies offer innovative solutions for addressing physical, cognitive, psychological, and social aspects of disabilities, they remain insufficient on their own. Caregivers and therapists must also address patients' emotional and physiological needs, particularly in younger populations, where social interaction and communication play a vital role in rehabilitation [30].

2.3 The Role of Serious Games in Rehabilitation

Serious games have gained attention as a rehabilitation tool due to their potential to enhance patient engagement and provide structured therapy. However, despite their therapeutic benefits, they are often perceived as less engaging than commercial video games, primarily due to their simpler graphics and limited interactivity [31]. Unlike commercial video games, which prioritize entertainment, serious games are developed with specific therapeutic objectives but often lack the high-quality graphics and interactivity of commercial games, which can reduce their appeal [31]. A key challenge is the absence of standardized design guidelines, yet research has identified important considerations: tasks should match patients' cognitive abilities, and games should incorporate features that support visual-motor coordination, memory, and problem-solving [32].

In pediatric contexts, continuous feedback and frequent rewards are especially important to sustain motivation. Elements such as auditory feedback, colorful graphics, interactive animations, and personalized adjustments help maintain engagement, though moderation is needed to avoid overstimulation [33, 34]. Despite these insights, many serious games are developed with limited input from therapists, which risks producing tools that are misaligned with clinical needs, particularly in pediatric patients, where cognitive, emotional, and behavioral strongly influence outcomes [26, 27].

While VR- and Kinect-based serious games offer engaging environments, their high costs, technological complexity, and motion tracking limitations continue to hinder adoption in clinical practice. To address these challenges, this study proposes the gamification of an existing rehabilitation tool, the shoulder wheel, by embedding non-invasive motion tracking and interactive feedback. This approach preserves the familiarity and accessibility of conventional therapy while incorporating game-based mechanics to improve engagement and enable objective measurements of rhythm, speed, and position, without interfering with normal equipment use.

3. Methodology

This study was designed as a mixed-methods feasibility study with four complementary methodological components, each serving a distinct purpose. First, a co-design phase involving clinician focus groups was conducted to identify clinically relevant requirements and iteratively refine the system's hardware, software, and therapeutic parameters. Second, a single-session feasibility and usability evaluation was conducted with pediatric patients to explore engagement, perceived ease of use, and willingness to use the system during rehabilitation. Third, structured clinician evaluations were used to assess perceived therapeutic value, usability, and potential integration into routine clinical practice. Fourth, the system's technical data capture capabilities were examined descriptively to illustrate the type of objective movement data that could be recorded during use. These components were intended not to test clinical efficacy, but to assess the system's practical feasibility, acceptability, and clinical relevance in a real rehabilitation context.

3.1 Participants & Ethics

This study was conducted at the Center for Child Rehabilitation and Inclusion (CRIT) in Morelia, Mexico, which provides interdisciplinary care for children with neuromuscular and musculoskeletal conditions. Two groups of participants were involved. First, three clinicians (two physicians and one physical therapist) participated in focus groups to iteratively inform the design and clinical relevance of the gamified system. Second, eight pediatric patients undergoing shoulder rehabilitation at CRIT took part in a single-session feasibility trial. In addition, two clinicians (one physician and one physical therapist) provided structured evaluations of the system during the trial. The study protocol was reviewed and approved by the CRIT Ethics Committee. Informed consent was obtained from parents or legal guardians prior to participation, and assent was obtained from children when appropriate. To comply with CRIT's privacy and security protocols, no identifiable demographic or medical data were recorded for this study. Although the system interface included fields such as patient name/identifier, age, and gender as part of the intended design for future clinical use, these fields were not completed or retained as part of the research dataset during the present study. In addition, no video or photographic recordings were permitted. Only authorized medical staff were present during therapy sessions, ensuring that data collection and observations were conducted exclusively by qualified personnel within the facility.

3.2 Study Design and Procedure

The study followed a two-stage design. In the first stage, clinicians participated in focus groups that identified clinically relevant metrics, ensured alignment with rehabilitation practices, and informed iterative refinements to the hardware, software, and game mechanics. In the second stage, pediatric participants completed a single-session feasibility trial. Each child was already familiar with the conventional shoulder wheel from their ongoing therapy. To enable direct comparison, participants were asked to complete at least a few repetitions with the standard device before using the gamified version. The trial session was administered by CRIT clinicians, with session duration and intensity adapted to the child's daily predisposition (e.g., fatigue, pain, medication, behavioral state). Data collection followed a mixed-methods feasibility approach, combining quantitative engagement and usability ratings from pediatric participants, with structured qualitative and quantitative evaluations from clinicians. To ensure accessibility for pediatric users, the questionnaire was developed collaboratively with CRIT clinicians using simplified language and emoji-based response options. The questionnaire was completed by the eight pediatric participants and was designed to assess three primary constructs relevant to this feasibility study: (1) engagement and enjoyment during gameplay, (2) motivation and willingness to participate in the exercise, and (3) usability and clarity of interaction with the system. Responses were recorded on a five-point emoji Likert scale, coded numerically for analysis as follows: 1 = very negative, 2 = negative, 3 = neutral, 4 = positive, and 5 = very positive. The questionnaire was administered immediately after the therapy session within the clinical setting. Depending on the child's age, comprehension, and clinical condition, items were completed either independently or with assistance from a clinician, who could read the questions aloud or clarify wording when needed, while avoiding leading or interpretive prompts. While efforts were made to minimize response bias through neutral administration, potential influences such as novelty effects, clinician presence, and social desirability cannot be fully excluded in this exploratory setting. This design allowed children to express their experience intuitively while supporting quantitative comparison of engagement-related outcomes. As the questionnaire was developed specifically for this exploratory feasibility study, it was intended as a descriptive measure of participant experience rather than a standardized validated instrument. Clinicians, in parallel, provided structured evaluations of the system, rating its therapeutic value, usability, and ease of integration into clinical practice.

3.3 Game Design and Development

Serious games were selected as the foundation for the gamified shoulder wheel because they provide structured, interactive therapy while maintaining patient engagement. Research indicates that pediatric patients, in particular, benefit from game-based rehabilitation, as it increases motivation, participation, and adherence to therapy regimens [2]. However, prior studies have highlighted key challenges, including difficulty maintaining engagement, lack of personalization, and insufficient real-time feedback mechanisms, particularly in pediatric patients who may lose interest in repetitive tasks [33]. The "Rhythm Ship Adventure" game integrated real-time feedback, adaptive difficulty adjustments, and interactive visual elements to encourage controlled movement, while being guided by therapeutic objectives to ensure that clinical requirements dictated the game mechanics rather than purely recreational features. The design of the game was informed by established principles commonly discussed in serious games and gamification research. Specifically, the system incorporated continuous feedback through visual and auditory cues, positive reinforcement through treasure-based rewards, and adaptive challenge through therapist-adjustable difficulty and rhythm settings. These mechanics were intended to support engagement, sustained participation, and controlled movement during repetitive rehabilitation exercises, aligning with commonly recognized gamification constructs such as feedback, reinforcement, and challenge adjustment.

Maintaining optimal difficulty levels is critical for long-term engagement and therapeutic effectiveness, particularly in pediatric rehabilitation contexts where motivation and perceived competence strongly influence participation. The game incorporated dynamic difficulty adjustment (DDA) mechanisms based on prior research [33], which suggests that modulating challenge levels based on patient performance supports motor skill acquisition and a sense of competence. Some techniques considered included increasing difficulty after three consecutive successful attempts or decreasing it after two consecutive failures [32]. However, since rehabilitation success is influenced by emotional and cognitive factors, difficulty was not solely adjusted based on performance scores. Instead, therapists retained the ability to modify game parameters based on individual patient needs, allowing challenge levels to be aligned with the child's capabilities and daily condition. To support sustained engagement and clear action–feedback loops, auditory and visual feedback mechanisms were embedded, including sound effects, background music, and animated rewards such as treasure collection, which have been shown to reinforce correct movement execution and goal-oriented behavior [34]. Reward pacing was intentionally moderate, aligning feedback with successful task execution rather than rapid completion, in order to encourage precision and sustained attention rather than speed alone. To further accommodate pediatric patients or those with neurological impairments, the system included personalization settings that allowed therapists or caregivers to adjust speed and required movements as needed [35]. The implementation of comprehensive disability guidelines within game development frameworks is imperative to ensure accessibility and inclusivity for diverse users [36], ensuring that patients with varying motor abilities and cognitive conditions can engage with the system at an appropriate and motivating challenge level.

3.4 Prototype Development

Prior to the first focus group, clinicians completed a short structured questionnaire to provide their initial perspectives on gamification in rehabilitation and the integration of such systems into clinical practice. This allowed to capture baseline feedback before engaging clinicians in more detailed design discussions. The "Rhythm Ship Adventure" game simulates a ship navigating the sea, collecting treasures as the patient moves the shoulder wheel. Unlike traditional rehabilitation exercises, where rewards are provided only upon reaching a specific position, this game continuously rewards the patient as long as movement is maintained at a steady speed, encouraging sustained engagement and controlled motion. The initial game interface consisted of three screens. The patient information screen required only the patient's name and ID. The therapy configuration screen offered three preset speed options and allowed users to specify the number of rotations for the session. The gameplay screen displayed real-time movement tracking, where the player's wheel-controlled ball had to match the movement of a target ball to collect treasures.

3.5 Sensor System and Hardware Integration

The system measured orientation angles using an MPU6050 inertial measurement unit (IMU), which communicated with an ESP32 microcontroller via the I^2C protocol. Sensor data were sampled at 600 Hz and processed with an Arduino library implementing a complementary filter that fused accelerometer and gyroscope readings. This approach balances the gyroscope's accurate high-frequency response, which is prone to drift, with the accelerometer's more stable lowfrequency reference, which can be affected by vibration and noise. The processed inclination angle was transmitted via Bluetooth to a tablet, where the game application updated ball positioning in real time. During early development, the engineering team initially assumed that shoulder wheels were exclusively used for full rotations, leading them to design a system that counted complete revolutions. However, clinical feedback revealed that many patients have restricted movement, requiring a more adaptive tracking mechanism, based on partial movements rather than only full cycles. In terms of measurement reliability, the complementary filter reduces drift and noise but still results in an expected error of approximately 1–3° under typical conditions, with higher accuracy during slow and controlled movements. Short-term tests during pilot sessions showed stable data transmission and responsive game control without noticeable lag.

3.6 Focus Groups and Iterative Development

The focus groups were used descriptively to inform iterative system design rather than as a standalone qualitative dataset. To support accurate documentation of clinician input, all focus group sessions were audio recorded with participant permission, and the recordings were reviewed to capture key design suggestions, clinically relevant observations, and illustrative comments.

3.6.1 Focus Group 1: Initial Feedback and Modifications

The first focus group identified several limitations in the initial design, leading to key modifications to enhance usability and clinical relevance. Focus group input was used descriptively to guide these iterative design decisions and support clinical relevance. To refine data collection, additional fields were added to the patient input screen for recording age and gender. Additionally, clinicians emphasized that exercises should not be limited to full rotations. Instead, therapy should focus on gradually increasing these ranges. Consequently, two input fields were added to capture the starting and ending angles for each repetition, allowing for individualized adjustments based on patient needs.

A critical insight from the focus group was the significance of maintaining a consistent movement rhythm during therapy. Clinicians explained that rhythmic control could benefit patients with conditions such as spastic hemiparesis, who often struggle with fine motor coordination despite intact cognitive abilities. As one clinician noted, *"It's beneficial that it's a rhythmic movement, not just about moving the wheel quickly but maintaining control of the speed"*.

The initial design, which offered only three speed options, was deemed insufficient to accommodate diverse patient needs. To address this limitation, an additional field was introduced to allow for the specification of the time required for a complete movement cycle. The prototype initially supported only full rotations in a single direction. However, based on feedback, it was recommended that the system indicate the direction of rotation, with the target ball adjusting accordingly. This feature is essential, as different muscle groups (agonist and antagonist) are activated depending on the direction of movement. The ability to specify rotation direction enables targeted therapy for specific muscle groups requiring rehabilitation.

Discussions also addressed whether therapy should be configured based on the number of repetitions. It was ultimately decided that two options should be available: one allowing the specification of repetitions and another permitting time-based exercises. The repetition-based option is particularly suitable for competitive children, while the time-based approach offers greater adaptability to accommodate fluctuations in a child's mood or physical condition. For instance, shorter time intervals can be programmed to prevent frustration or discomfort. No modifications or additional observations were made regarding the game itself. The proposed enhancements aim to improve patient engagement, facilitate individualized therapy adjustments, and optimize rehabilitation outcomes.

3.6.2 Focus Group 2: Enhancing Data Visualization and Clinical Utility

One participant commented on the adjustment of the therapy's starting and ending points, noting that while a patient's achievable angle is determined experimentally, it is not a precise quantitative measurement. While right angles, such as 90 degrees, are easy for therapists to visualize, less conventional angles, such as 36 degrees, can be more challenging. To address this, one proposed solution was to visually display the inputted angle on the configuration screen. Another suggestion was to externally illustrate the angles to facilitate a clearer understanding of the physical positioning and the corresponding angle inputted into the system. In traditional therapy, objective data could be highly valuable, yet they are often not systematically recorded due to time constraints and limited communication between physical therapists and physicians. This can result in missing essential data, such as time and number of repetitions, needed for comparisons.

When asked whether objective parameters had ever been considered for measurement, clinicians affirmed that such data would be beneficial for prognosis. However, many current assessments remain subjective, including range of motion, which is typically based on the child's capabilities on the day of therapy. While therapists record observations such as signs of fatigue or pain, even time-related data are often noted subjectively. In practice, therapy is often guided by real-time patient observations rather than predefined measurements. Given these inconsistencies, the focus group emphasized the importance of objective data collection, particularly regarding working angles.

Regarding time measurements, it was considered essential to assess the patient's synchronization with the target ball, which sets the movement speed. To enhance precision, it was proposed that the working range be divided into ten equal segments, allowing for a corresponding set of ten-time measurements. If the patient maintained a consistent speed, the recorded times would be similar across all segments. However, deviations in specific segments could indicate areas of impaired mobility. In parallel with these technical considerations, participants also commented on the game's visual design. Feedback was positive, with participants noting that environmental elements such as clouds and mountains were present but not overly distracting. Specifically, the slow movement of the clouds was regarded as beneficial, as it did not interfere with the patient's focus. The workflow depicted in Figure 1 illustrates the comprehensive process from initial game design to the evaluation of therapy outcomes, highlighting the key themes involved in the focus groups' methodology.

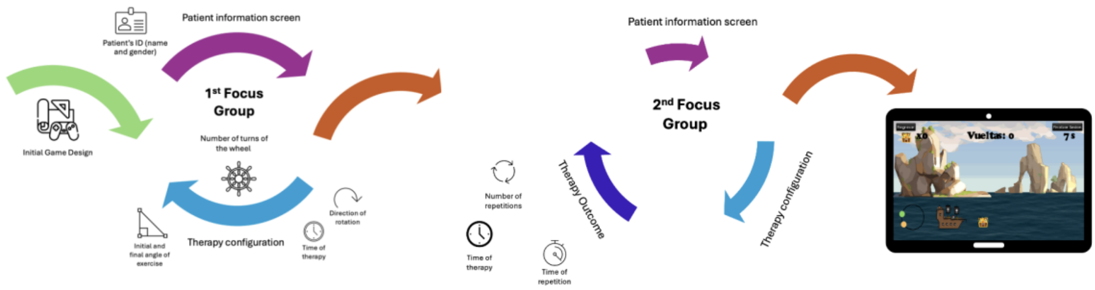

Figure 1. Focus Groups Workflow: From Initial Game Design to Therapy Outcomes

3.6.3 Final Validation and Clinician Training

No additional changes were requested by the participants, and a final training session was scheduled. The placement of the measurement system on the wheel is shown in Figure 2. The tablet's height can be adjusted to accommodate individual patient needs using a Velcro strap. A brief training session was conducted with clinicians to familiarize them with attaching the system to the shoulder wheel and configuring the game parameters.

Figure 2. Picture of the system on shoulder wheel

Pictures of the tablet running the game and the electronic enclosure containing the microcontroller and gyroscope are shown in Figure 3. An orange reference ball moves at a preprogrammed speed, and the patient must match its direction and velocity. The gyroscope measures the position of the shoulder wheel and transmits this data to the tablet, where the actual wheel position is represented by a green ball. When the patient's movement closely follows the reference ball, the ship successfully collects treasures, which are displayed as a score in the upper-left corner of the screen. The system also records the number of rotations and the total session duration. In addition, the application includes configuration screens to record patient information, set initial and final angles or full rotations, choose rotation direction, and adjust speed according to the patient's physical capacity.

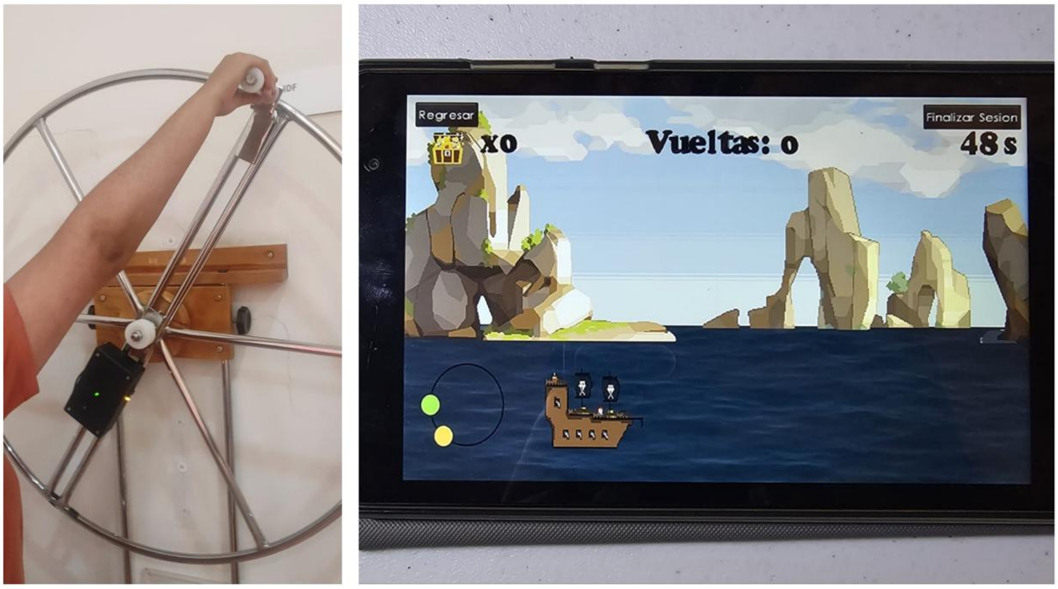

Figure 3. Tablet running the game and the shoulder wheel

4. Results

The study evaluated the "Rhythm Ship Adventure" game in an exploratory feasibility trial rather than a controlled clinical study. The objective was to explore its potential to support engagement, motivation, and rehabilitation adherence, while also gathering feedback from children and clinicians to identify clinically relevant metrics for future research. This was conducted as a single-session feasibility trial integrated into the participants' scheduled rehabilitation programs at CRIT. All participants were pediatric patients already undergoing shoulder rehabilitation to improve range of motion, strength, or pain control. Each child was familiar with the conventional, non-gamified shoulder wheel from their ongoing therapy and was asked to perform at least a few cycles with it immediately before the gamified trial, enabling a direct comparison. The duration and intensity of each session were not fixed but depended on clinical realities, as pediatric rehabilitation is highly influenced by the child's daily predisposition, including factors such as fatigue, pain, medication, and behavioral state.

Data were collected through structured questionnaires completed by eight child participants, providing quantitative insights into user experience, game usability, and perceived therapeutic benefits. Additionally, feedback from two clinicians provided a professional perspective on the game's integration into pediatric rehabilitation. Due to strict confidentiality policies enforced by CRIT, demographic data of the participants were not permitted to be collected or analyzed. As a result, this study focuses solely on the reported experiences and feedback without demographic segmentation.

4.1 Quantitative Analysis: Participant Feedback

Standardized usability questionnaires were not suitable for pediatric users due to the complexity of the questions, given their age and cognitive ability. Instead, with input from the main clinical collaborator, a structured survey incorporating emojis and simple language was developed to ensure accessibility and comprehension. The survey employed a five-point Likert scale, where emojis visually represented different levels of enjoyment and ease, making the questionnaire more intuitive and engaging for children. The results indicated a consistently high level of engagement, with most responses clustering around values of 4 and 5 across all evaluated parameters. These findings provide preliminary support for RQ1, suggesting that, within this single-session feasibility context, participants expressed greater enjoyment, motivation, and preference for the gamified shoulder wheel compared with the conventional exercise.

For the Rhythm Ship Adventure game, participants rated their overall experience positively (mean = 4.0, SD = 0.45), indicating that the game successfully maintained engagement throughout the exercise. The usability of the system was also rated favorably, with a majority of participants finding it intuitive to navigate (Q2: mean = 4.1, SD = 0.64). Furthermore, rhythmic synchronization in gameplay was rated highly for motivation (Q6: mean = 4.3, SD = 0.52), aligning with prior research on the impact of rhythm-based engagement in rehabilitation.

Participants found the ship's movements in sync with rhythm to be an engaging feature (Q2: mean = 4.5, SD = 0.54), and the control mechanism was considered easy to use (Q3: mean = 4.2, SD = 0.63). The reward system, which involved collecting treasures, was well-received (Q5: mean = 4.3, SD = 0.48), further supporting the idea that positive reinforcement enhances engagement in rehabilitation activities.

One notable finding was the strong participant preference for the gamified exercise condition, which indicates potential to support willingness to participate in therapy. Willingness to integrate the game into regular therapy sessions was consistently rated highly (Q10: mean = 4.4, SD = 0.57). Additionally, when comparing participant experiences with and without gamification, the preference for game-enhanced rehabilitation was evident, suggesting a strong potential for long-term engagement. The difference in ratings between exercise without the game (Q11a: mean = 2.8) and exercise with the game (Q11b: mean = 4.5) suggests a clear participant preference for the gamified condition, which indicates potential to support engagement and willingness to participate in therapy.

Figure 4 illustrates the average ratings given by participants across all survey questions, highlighting their engagement with the Rhythm Ship Adventure game. Error bars represent standard deviations, showcasing variability in responses. The figure emphasizes the notably higher scores for engagement, enjoyment, and motivation when compared to traditional rehabilitation exercises. Question Q11(a) (exercise without the game) received a substantially lower mean rating (M = 2.8, SD = 0.65) compared to Q11(b) (exercise with the game; M = 4.5, SD = 0.48). Participants consistently rated the gamified condition higher than the non-gamified condition across engagement-related questions, as reflected in higher mean ratings for exercise with the game compared to exercise without the game. These findings suggest that participants perceived the gamified condition as more engaging and expressed greater willingness to participate in the activity. Below is a reference list of the questions corresponding to each label on the x-axis of the figure:

- Q1 What did you think of the "Rhythm Ship Adventure" game?
- Q2 Did you understand how the ship moves with the rhythm?
- Q3 How easy was it for you to control the ship's movements using the rhythm keys?
- Q4 How would you rate the: a) The colors used, b) The graphics of the game, c) The ship, d) The Mountains, e) The oceans, f) The treasure, g) Receive a reward.
- Q5 Did you enjoy moving the ship to get treasures?
- Q6 Did you enjoy following the rhythm?
- Q7 Would you want to play "Rhythm Ship Adventure" again?
- Q8 How likely are you to recommend this game to your friends?
- Q9 How did you feel after playing the game?
- Q10 Would you like playing this game regularly as part of your rehabilitation routine?
- Q11 How would you rate the exercise with and without game? a) Without game b) With game.

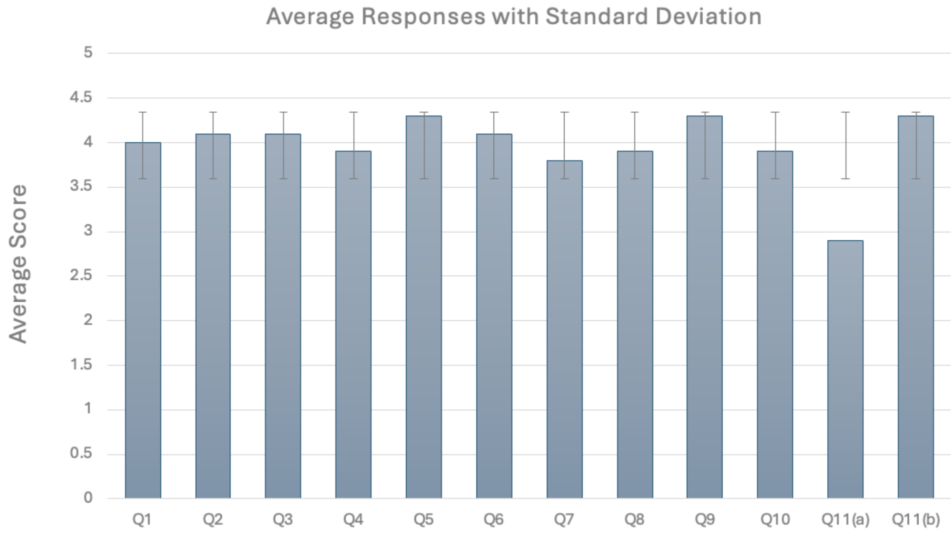

Figure 4. Average participant responses to survey questions assessing engagement, usability, and motivation in the Rhythm Ship Adventure game

In addition to subjective engagement ratings, the system's motion-tracking capability enabled analysis of motor performance. Figures 5 and 6 illustrate angle–time trajectories captured during therapy. There are data from different patients with only one turn, as well as from the same patient performing multiple turns. In the first case (Figure 5), the trajectories illustrate how different patients exhibited variations in movement timing across distinct angular ranges, as reflected by slower progression times at specific intervals. In the second case (Figure 6), repeated rotations from the same patient consistently showed delays within the same angular interval, suggesting a localized area of increased motor challenge. These findings directly address RQ2 by demonstrating that the system can capture clinically relevant objective measurements, such as angle-specific delays and rhythm consistency, which are not obtainable through traditional shoulder wheel therapy.

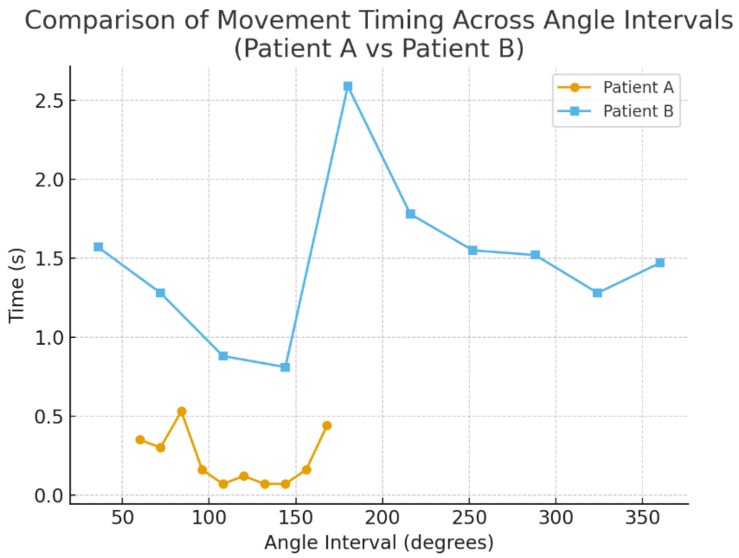

Figure 5. Angle–time trajectories from single rotations of two different patients

In the context of this single-session feasibility study, however, these kinematic traces are intended as illustrative examples of the type of movement data the system can capture, rather than as standalone indicators of clinical difficulty. The plots display wheel angle (degrees) as a function of time (seconds), derived from continuous gyroscope measurements during gameplay. Clinicians indicated that the potential clinical value of such data lies in comparative interpretation across repeated sessions, where consistent timing variations or increased variability within specific angular ranges could inform assessments of motor control, fatigue, or rehabilitation progress.

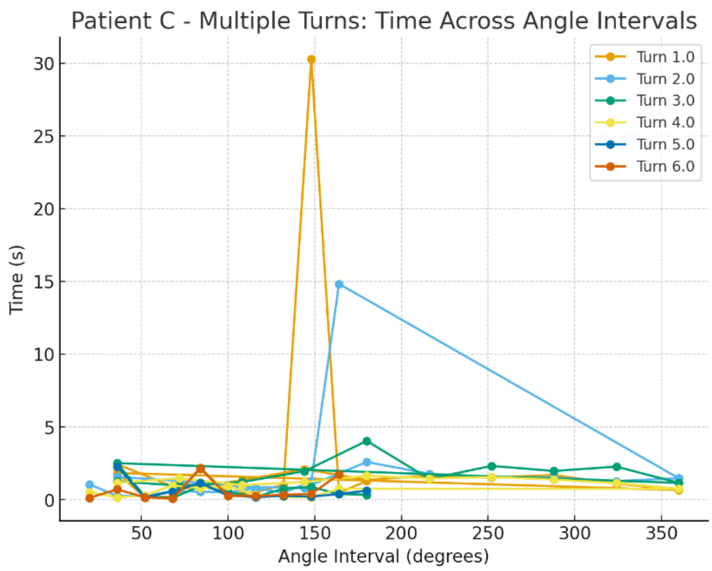

Figure 6. Angle–time trajectories from multiple rotations of the same patient

4.2 Mixed-Methods Analysis: Clinician Feedback

Beyond numerical evaluations, therapist and nurse feedback provided additional insights into the game's effectiveness in clinical settings. Clinicians rated the integration of the game into rehabilitation highly, with scores of 9 and 8 out of 10, emphasizing its perceived ability to support motivation and focus. This clinician feedback further supports RQ1 by indicating higher perceived motivation and engagement compared to conventional therapy. Clinicians also noted that the game helped divert attention from pain and discomfort, making therapy more enjoyable and interactive. However, age-related differences in engagement were observed. Clinicians indicated, based on their professional experience and observations during the study, that the game may be most suitable for children between 8 and 12 years old; younger children often struggled to fully understand it, and older children found it less engaging. This suggests the need for age-specific adaptations or additional customization options to sustain engagement across broader age groups.

In terms of usability and guidance, therapists found the game easy to administer (scores of 10 and 7), though they noted that younger patients struggled to follow instructions. Customization received mixed responses, with one clinician rating it 9 out of 10 and another 7 out of 10, indicating that while the game offers flexibility, additional adaptation features could enhance its clinical utility. Regarding therapeutic value, clinicians indicated that Rhythm Ship Adventure was perceived as having potential to support rehabilitation sessions, particularly by increasing motivation and participation during therapy. They highlighted that children were more motivated to participate when therapy was gamified, aligning with patient-reported findings. However, they also emphasized that not all children had the cognitive level to fully engage with the game, suggesting the need for simplified modes for younger or neurodivergent patients.

4.3 Implications

The findings of this feasibility study suggest that gamification may represent a viable and clinically relevant approach within pediatric rehabilitation settings. Clinician feedback highlighted the importance of customization and adaptive difficulty scaling, suggesting that future iterations could benefit from more flexible adjustment of challenge levels. The study also underscores the practical value of integrating objective performance metrics, supporting the potential for enhanced clinical monitoring and individualized rehabilitation planning in future developments.

5. Discussion

Gamifying an established rehabilitation device such as the shoulder wheel represents an alternative approach to integrating engagement-oriented design and objective data capture without disrupting existing therapy workflows. This study explored how such integration can be achieved while maintaining clinical relevance and usability.

RQ1: What are the benefits of integrating gamification into shoulder wheel therapy?

Surprisingly, research on gamified applications for the shoulder wheel is limited. Existing studies primarily examine patient perceptions and evaluations, often without incorporating clinical input [4]. The findings related to RQ1 suggest that gamification can influence engagement and motivation during shoulder wheel therapy, as reflected in participant preferences and clinician observations. Participants consistently rated the gamified exercises higher than traditional rehabilitation, with strong preferences for game-based therapy (Q11a vs. Q11b). Clinicians corroborated these findings, noting that children displayed greater enthusiasm and fewer signs of boredom or fatigue when using the gamified system. However, they also highlighted the need for age-specific customization, as younger children sometimes struggled with the mechanics, while older children required more challenging tasks to maintain engagement.

Many studies suggest that reward systems should be contingent on goal achievement, while others propose continuous reinforcement to maintain engagement [37]. In practice, pediatric patients can be broadly categorized into two groups: those who are highly competitive and those who become easily frustrated by goal-oriented tasks. To accommodate both, the system allows competitive children to pursue repetition-based goals while offering time-based exercises for children who prefer a less demanding structure. Clinicians also emphasized the importance of adaptive difficulty to account for individual differences and day-to-day variability in engagement, highlighting key design considerations relevant to RQ1 and the application of gamification in pediatric therapy. However, although the system was originally conceived as age-independent, our findings indicate that tailored adaptations will be necessary to maintain engagement for both younger and older children.

In addition to showing potential to enhance engagement and willingness to participate, the system provides clinicians with objective parameters that are difficult to obtain using conventional shoulder wheel therapy. These include the time required for a full rotation, the total number of rotations, and the duration of specific trajectory segments, all of which may support more consistent tracking and comparison of patient performance over time. While other studies have developed entirely new rehabilitation devices with functionalities similar to the shoulder wheel [38], our approach focused on gamifying an existing device determining what, how, and when to measure in a clinically relevant way, rather than on designing new equipment and retraining medical staff. An initial proposal to measure wheel position with an encoder, a mechanical optical sensor on the wheel's axis, was not adopted, as the medical team emphasized the importance of avoiding modifications that might alter normal operation or require additional procedures in therapy.

RQ2: What clinically relevant objective measurements can be recorded during therapy?

Existing studies primarily measure the initial and final positions of shoulder wheel exercises, with less emphasis on movement timing and synchronization [38]. One of the participating clinicians suggested that, in addition to measuring position, movement timing and synchronicity should also be recorded. This would provide valuable insight into the progression of movement quality rather than simply determining whether a target was reached. Analyzing intermediate movement data would reveal underlying motor control difficulties, enabling a more nuanced assessment of patient improvement.

The results from clinician evaluations align with these observations. Therapists found that the ability to track real-time movement patterns, velocity, and rhythm provided meaningful insights into patient progress, which directly addresses RQ2 by showing that the gamified system can capture clinically relevant objective data often missing from conventional therapy. They highlighted that the system's real-time performance tracking capabilities were particularly useful for monitoring rehabilitation adherence. Clinicians rated these features highly, emphasizing their potential for standardizing therapy assessments.

The development team played a crucial role in expanding the range of possible measurements, identifying new assessment parameters that were not initially considered by the medical team. One of the most significant contributions was the introduction of constant speed control as a therapeutic objective. Interestingly, a physician involved in the study anticipated that this feature could provide additional fine motor training benefits, an area traditionally more challenging to address through shoulder wheel therapy. While conventional therapy focuses primarily on range of motion, the requirement to maintain a steady speed introduces an element of motor precision and control.

Clinicians noted that movement variability could indicate underlying motor impairments and suggested additional visualization tools to track patient performance over time. The incorporation of angle-based and temporal data enables comparative analyses that provide insights into both short-term fatigue and long-term patient progress. For example, inter-repetition time can indicate increasing fatigue, while comparisons across multiple sessions can reveal overall improvements. By enabling the objective measurement of movement continuity, rhythm, and synchronicity, this system provides clinicians with a deeper understanding of a patient's motor function. These findings address RQ2 by illustrating how gamified shoulder wheel therapy can support clinically relevant objective measurement beyond conventional approaches. This is particularly beneficial for identifying specific ranges of motion where spasticity or stiffness may be limiting movement, offering potential diagnostic and therapeutic advantages. These observations highlight how integrating quantitative tracking into gamified shoulder wheel therapy can complement existing rehabilitation practice and inform clinical assessment. Moreover, identifying stable “ranges of difficulty” would require longitudinal data and clinical judgment across repeated sessions, which was beyond the scope of this single-session feasibility study.

This study has a few limitations. First, it was limited to a single-session feasibility evaluation rather than a longitudinal intervention. While the results provide preliminary evidence of engagement benefits, further controlled studies with repeated sessions and standardized protocols are needed to assess long-term rehabilitation outcomes. Second, the evaluation did not include a control group, which restricts comparison with traditional therapy. Third, statistical testing was not performed. The small sample size and exploratory nature of the study were intended to generate preliminary insights rather than definitive evidence. In addition, while engagement and motivation were positively perceived, these measures were based on subjective reports and a smiley-based questionnaire rather than standardized, validated instruments, which limits the strength of conclusions regarding usability or clinical effectiveness.

Due to strict CRIT privacy protocols, demographic data of the pediatric participants (e.g., age, sex, diagnosis) could not be collected or analyzed. While this ensured compliance with institutional privacy requirements, it limits the interpretability and generalizability of the findings in relation to participant characteristics. Clinician involvement in the study design and evaluation may have introduced bias, as both children and therapists could have been positively predisposed toward the system's novelty. Technical constraints present further limitations. Although short-term tests confirmed stable data transmission and responsive control, long-term validation of system reliability has not yet been performed. Potential risks such as sensor drift, Bluetooth interference, calibration shifts, and hardware durability may affect accuracy over extended use. Finally, clinical integration may also be influenced by children's daily variability (e.g., fatigue, pain, medication, behavioral state), which was observed informally but not systematically measured in this study. Future work should address these limitations by incorporating control groups, larger sample sizes, standardized usability frameworks, multi-session reliability testing, and statistical analyses to assess efficacy more rigorously.

6. Conclusions & Future Work

This mixed-methods feasibility study suggests that gamifying a shoulder wheel can support engagement and enable objective performance tracking in pediatric rehabilitation. Specifically, our work examined the benefits of gamification for patient motivation and adherence (RQ1), as well as the clinically relevant parameters that can be captured during therapy (RQ2). The study highlights the promise of repurposing widely used rehabilitation devices into engaging, data-aware therapeutic tools without requiring costly or complex new systems. While the results are preliminary, they indicate the potential value of this approach and lay the groundwork for controlled trials to establish efficacy.

Future research should build on these findings through controlled and longitudinal studies to assess therapeutic efficacy and generalizability. Further work may explore extending gamification to other commonly used rehabilitation devices, refining adaptive game mechanics that adjust difficulty based on real-time performance, and enhancing the capture and visualization of continuous movement data. These directions could support more personalized rehabilitation planning and strengthen the clinical value of engagement-driven, data-aware therapy systems.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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