DTU Health Tech
Department of Health Technology

ALL RISE

A mHealth Tool for Sit-to-Stand Rehabilitation in Patients with Acquired Brain Injury

Bachelor Thesis



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A mHealth Tool for Sit-to-Stand Rehabilitation in Patients with Acquired Brain Injury

Bachelor Thesis
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By
Rasmus Harbo

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Rasmus Harbo - s224519

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Signature

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Date

Abstract

Acquired Brain Injury (ABI) often leads to cognitive and motor impairments that hinder rehabilitation efforts, particularly in exercises such as Sit-to-Stand (STS) training. This thesis presents All Rise, a mobile health (mHealth) application designed to support STS rehabilitation for ABI patients by providing real-time feedback and enhancing motivation through gamification. The system was developed using a user-centered design approach in collaboration with clinicians, and implemented using Flutter with a sensor-based repetition detection algorithm.

The application was evaluated with 21 clinicians from Rigshospitalet Glostrup through a demonstration and questionnaire based on the User Engagement Scale. Results showed high usability (4.3/5), strong clinical relevance (4.4/5), and positive feedback on the motivational design. While patient testing was not feasible within the project scope, the findings indicate that All Rise is a promising tool for ABI rehabilitation. Future work should focus on patient trials, long-term motivation tracking, and broader device testing.

During the preparation of this work the author used ChatGPT 4o in order to improve writing and punctuation throughout the thesis. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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1 Introduction

Acquired Brain Injury (ABI) is a life-altering condition that impacts millions of individuals globally, often resulting in long-term cognitive, emotional, and motor impairments [1]. In Denmark alone, over 230,000 individuals live with ABI, representing a significant portion of the population with varying degrees of disability [2]. For these individuals, regaining basic motor function is essential for reclaiming independence and quality of life. One of the most fundamental of these motor functions is the ability to transition from a seated to a standing position, an activity formally known as the Sit-to-Stand (STS) movement.

STS rehabilitation exercise is widely recognized as an important intervention for improving mobility, balance, and lower body strength among ABI patients. However, patients with ABI face multiple barriers to rehabilitation, including reduced motivation, impaired cognitive function, and physical fatigue [3]. These challenges not only hinder progress but also make it difficult for clinicians to maintain patient engagement in repetitive exercises like STS training.

The increasing availability of sensor-equipped smartphones and advances in Mobile Health (mHealth) technologies present a promising avenue for enhancing rehabilitation practices. When designed thoughtfully, mHealth systems can provide real-time feedback, track progress, and offer motivational elements through gamification. Yet, despite the potential, few systems currently address the unique needs of ABI patients in a clinical context.

The field of neurological rehabilitation has seen growing interest in incorporating digital tools into therapeutic practices. Rehabilitation is frequently carried out in-room, where patients can practice exercises in a familiar and accessible environment. Multiple studies have demonstrated the effectiveness of STS training for enhancing motor function in ABI patients [4, 5, 6]. Technologies such as Microsoft Kinect, wearable sensors, and smartphone-based video analysis have been explored to assess and monitor STS performance [7, 8, 9]. However, these systems often lack portability, real-time feedback, or are not designed with ABI-specific cognitive limitations in mind.

Gamification has emerged as a particularly promising strategy to address motivational decline in patients with neurological impairments. By integrating game elements such as progress tracking, visual rewards, and goal setting, systems can significantly improve engagement and therapy adherence [10, 11, 12]. Still, very few applications provide an ABI-specific experience that integrates STS monitoring with real-time feedback and gamified progress visualization in a portable format.

This thesis builds upon this body of work by targeting the intersection of STS rehabilitation, ABI patient needs, and mobile sensor based feedback systems enhanced by gamification.

1.1 Research Question

Due to the significant cognitive and physical challenges often faced by patients with ABI, adherence to STS rehabilitation can be difficult and highly demanding for both patients and clinicians. Research indicates that STS rehabilitation can enhance patient outcomes and quality of life; however, sustaining motivation and engagement for cognitively impaired patients remains a persistent challenge [5, 4, 6]. While evidence suggests that real-time visual feedback can enhance patient engagement and improve rehabilitation outcomes,

there is a noticeable lack of systems specifically designed to integrate these benefits into STS rehabilitation.

To bridge this gap, this thesis explores how to design and implement a mobile health (mHealth) application that motivates and engages ABI patients to increase STS repetitions and thereby improve mobility.

1.2 Goals and Methods

To address this challenge, the primary goal of this thesis is to design and implement a prototype for a mHealth application that supports and enhances STS rehabilitation for ABI patients. The system is designed to fulfill the following goals:

- **Provide Real-Time Feedback:** Implement a sensor-based system that uses the smartphone's built-in accelerometer to detect valid STS repetitions and offer immediate, visual feedback during training.
- **Enhance Motivation through Gamification:** Integrate game elements, such as progress visualization and long-term goal tracking, to promote patient engagement.
- **Support Clinical Usability:** Design the system using User-Centered Design (UCD) methods, ensuring that clinicians can easily integrate the tool into their rehabilitation sessions and tailor it to individual patient needs.
- **Ensure Portability and Accessibility:** Build the system on existing mobile technology to reduce equipment costs, increase portability, and facilitate in-room rehabilitation.

The research employs a UCD approach [13], and includes fieldwork at the Department of Brain and Spinal Cord Injury at Rigshospitalet Glostrup, stakeholder interviews, iterative prototyping, and evaluation in collaboration with clinical professionals. The application is developed using Flutter and structured using the Model-View-ViewModel (MVVM) architecture to ensure modularity, scalability, and maintainability.

2 Background and Related Work

This chapter provides an in-depth examination of the medical and technological context surrounding rehabilitation practices for ABI patients, with an emphasis on STS training. By reviewing related research, evaluating existing technologies, and identifying their limitations, this chapter sets the foundation for the rationale behind developing the mHealth application specifically tailored for this patient group.

2.1 Acquired Brain Injury: Symptoms and Rehabilitation Challenges

Acquired Brain Injury is a broad term describing any damage to the brain occurring after birth, typically resulting from traumatic events such as accidents or medical conditions, including strokes, tumors, or infections. ABI significantly disrupts normal brain function, profoundly affecting physical, cognitive, emotional, and social abilities. This disruption often leads to severe impairment in patients' daily functioning and quality of life [14].

Recent data compiled by the Danish Health Data Authority in 2020, based on records from 2017, provides valuable insight into the scale of ABI within Denmark's adult population. As of 2017, approximately 230,000 individuals in Denmark were living with an ABI. This population is primarily divided into two broad groups: around 169,000 individuals (roughly 74%) have sustained ABI due to cerebrovascular events, such as stroke or Transient Ischemic Attack (TIA), while approximately 60,000 individuals (26%) are affected by Traumatic Brain Injury (TBI) or related conditions. The classification of ABI in the Danish context encompasses 13 diagnostic groups, including spontaneous brain hemorrhage, brain infarctions, TBI, encephalopathy, infections, and tumors within the central nervous system, among others [2].



Figure 2.1: Distribution of adult patients in Denmark admitted with ABI in 2017 [2]

In terms of hospitalization data, 26,204 adults were admitted to Danish hospitals with ABI in 2017, averaging 72 new admissions per day. Notably, 72% of stroke-related admissions involved individuals aged 65 or older, with a higher incidence among men (56%) compared to women (44%). Similarly, for TBI cases, men comprised 64% of hospitalizations, with 60% of patients aged 65 and above, while 18% were under the age of 45. In Figure 2.1, the distribution of adults admitted with ABI can be seen. This data shows a high prevalence of ABI among older adults, though significant cases also exist among younger populations, particularly in TBI cases. Data from 2010 indicates that between 1,006 and 1,154 new cases of ABI in individuals aged between 28 days and 17 years occur annually. Traumatic brain injuries, encephalopathy, infections, tumors, and cerebrovascular incidents account for the majority of these cases [2].

This highlights the diverse nature of ABI across age groups and genders, which emphasizes the necessity for targeted rehabilitation solutions that accommodate the needs and challenges faced by the patient group. In particular, the high incidence of ABI among older adults makes functional mobility interventions, such as STS training, a key area of focus in rehabilitation strategies, while the notably high amount of children and young adults calls for a solution that is engaging for all ages.

Physically, ABI patients often suffer from impaired motor function, reduced muscle strength, balance problems, and coordination deficits, all severely limiting their ability to perform basic tasks, such as standing from a seated position. Cognitive challenges include impaired memory, attention difficulties, confusion, and slowed information processing, creating significant barriers to patient engagement with complex or repetitive rehabilitation activities. Emotional and psychological issues such as depression, anxiety, and decreased motivation further reduce adherence to rehabilitation programs, significantly hindering progress [3].

For the design of rehabilitation solutions, these multifaceted symptoms must be carefully considered. Systems aimed at ABI rehabilitation need to minimize cognitive load, ensure ease of use, and provide personalized, immediate feedback. Furthermore, these systems must allow therapists to adjust exercise complexity easily, reflecting the highly individualized rehabilitation needs typical of ABI patients.

2.2 Sit-to-Stand Training: Importance and Benefits

STS training has become a core exercise within ABI rehabilitation protocols, recognized for its ability to significantly enhance patients' lower limb strength, balance, and overall functional mobility. The STS exercise is critical because it directly correlates with an individual's ability to perform daily tasks independently, such as getting out of bed, transitioning from wheelchairs, and performing basic self-care routines [15].

STS training is a repetitive, functional movement exercise that involves rising from a seated position to a full standing posture and returning to sitting again. This seemingly simple action requires coordinated effort across multiple muscle groups, particularly in the lower extremities, as well as adequate balance and postural control. For ABI patients, regaining this fundamental motor skill is essential for achieving greater independence in everyday activities.

A standard STS repetition, as illustrated in Figure 2.2, consists of four key phases. First, the patient initiates the movement from a seated position, typically with feet flat on the floor and knees bent at approximately 90 degrees. The second phase involves leaning the upper body forward to shift the center of gravity over the feet, which is necessary to generate forward momentum. In the third phase, the patient activates the quadriceps



Figure 2.2: A correct STS repetition performed by a physiotherapist from the Department of Brain and Spinal Cord Injury at Glostrup Hospital.

and gluteal muscles to lift the body into an upright, standing position. Finally, the patient carefully reverses the movement to return to the seated position in a controlled manner. A detailed description can be found in Appendix C.

Proper execution of the STS movement demands both strength and coordination, and therapists often assist or cue patients to ensure correct technique. Common adaptations include adjusting the height of the seat (or plinth), providing verbal prompts, or using assistive devices to support balance. In clinical settings, therapists also monitor posture, asymmetry, and weight distribution during the motion to assess motor function and guide rehabilitation.

Several studies emphasize the substantial benefits of targeted STS exercises for ABI rehabilitation. Hyun et al. (2021) investigated the effectiveness of STS training combined with real-time visual feedback for stroke patients, concluding this approach significantly improved muscle strength, balance, and walking performance compared to traditional therapy [16]. Similarly, Canning et al. (2003) demonstrated that intensive STS exercises significantly improved motor performance in TBI patients, highlighting the necessity of repetitive, task-specific training to enhance early rehabilitation outcomes [4].

Additional research by Tung et al. (2010) reinforces the value of targeted STS exercises, revealing supplementary training significantly improved weight-bearing ability, balance, and overall mobility in stroke patients [5]. Furthermore, de Sousa et al. (2019) showed that even short-term, intensive STS interventions markedly improved functional outcomes in severely impaired stroke patients previously unable to perform independent standing movements, suggesting high-intensity training's critical role in ABI rehabilitation [6].

These findings collectively show STS training's potential for substantially improving functional mobility, balance, and overall quality of life for ABI patients, validating the need for user-centered technologies specifically targeting this rehabilitation approach.

2.3 Technological Innovations in STS Rehabilitation

Recent technological advancements have enabled new ways to monitor and enhance STS exercise. Depth sensor technology, as investigated by Leightley and Yap (2018), allows precise, markerless motion capture, capable of detecting subtle differences in STS performance across various participants. They used a Microsoft Kinect One to record the movements of the participants during five STS repetitions, which provided usable data for extracting features to assess the STS motion sequence [7]. However, its practicality in

clinical or home settings remains limited due to it being a stationary setup, and requiring potentially expensive new equipment. Having a non-portable system might create unwanted problems, due to the patient group usually performing their STS rehabilitation in their own rooms.

Boswell et al. (2023) researched the use of smartphone-based video analysis systems, which demonstrated significant potential due to their scalability and ease of use [8]. Similarly, wearable accelerometer-based systems, described by Adamowicz et al. (2020), effectively monitor STS in real-world environments and can be used to effectively detect and assess STS motion [9]. Ruiz-Cárdenas et al. (2018) validated a smartphone application that accurately measures key STS performance metrics, which shows how smartphones can be integrated in clinical settings. The application uses the smartphone camera to record a STS repetition and provide feedback on velocity and leg power [17]. These systems effectively predict health outcomes through simple, self-recorded, or home-based STS assessments but generally offer only post-session feedback without real-time intervention capabilities and would therefore not be suitable for rehabilitation purposes.

Adusumilli et al. (2017) created an application to record STS tests by using the built-in accelerometer and gyroscope in the smartphone. The data recorded by the application was validated against gold-standard manual measurements and showed high correlation. The study concluded that the app-based performance testing was both valid and reliable [18]. This approach of using the built-in sensors of the smartphone could provide a reliable portable system, which doesn't require any new equipment.

Despite these advancements, current technological approaches often lack integrated real-time feedback, simplicity, and customization capabilities specifically required for the ABI patient group, highlighting a significant gap for targeted technology development.

2.4 Motivational Factors and Gamification in Rehabilitation

Sustained motivation significantly influences rehabilitation adherence among ABI patients. Gamification, integrating game-design elements such as rewards, badges, immediate feedback, and achievable goal-setting, has emerged as an effective strategy to enhance patient engagement, adherence, and motivation.

Gamification has shown potential in improving rehabilitation for people with neurological conditions. Studies have found that using game-like elements in therapy can boost motivation, engagement, and overall satisfaction during the recovery process. For example, a review by Adlakha et al. (2020) looked at different types of gamified rehabilitation tools like virtual reality, active video games, and serious games. They found that the tools helped patients not only physically, but also emotionally and socially. These tools were often more effective than traditional rehabilitation methods [10]. Another large review by Sánchez-Gil et al. (2025), which included 169 studies and over 6,000 stroke patients, showed that a wide range of gamified technologies, such as robotic devices, VR setups, and neuromuscular electrical stimulation, helped improve both motor and cognitive function, while also supporting emotional and social aspects of recovery [11]. A well known example outside of clinical settings is the Ubifit Garden developed by Consolvo et al. (2008), where users grew a digital garden by staying physically active. This simple visual feedback made users more motivated to exercise and has since influenced many health-related apps [12].

Overall, existing literature and technological assessments indicate the need for specialized solutions explicitly tailored for ABI rehabilitation. Current systems lack integration of

real-time feedback, portability between patient rooms, and motivational elements critical for ABI patients' rehabilitative success.

3 Research Methods

Developing an engaging mHealth application for clinical use presents unique challenges, particularly when designing for individuals with cognitive and motor impairments resulting from ABI. To address these challenges, the mHealth application All Rise was developed following a UCD approach, structured according to the User Experience (UX) lifecycle as defined in *The UX Book* by Hartson and Pyla [13]. This approach ensured that the needs, limitations, and context of use for both patients and clinicians remained central throughout the design and development process.

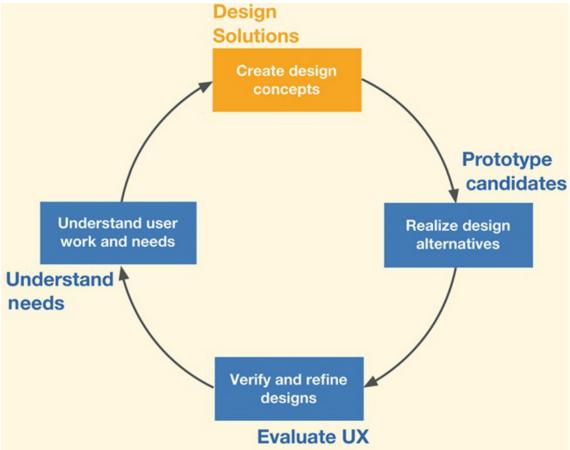


Figure 3.1: The UX lifecycle as described in *The UX Book* by Hartson and Pyla [13]. Image from the book.

The UX lifecycle, seen on figure 3.1, emphasizes an iterative and user-focused process divided into four main phases: (1) Understand Needs, (2) Design Solutions, (3) Prototype Candidates, and (4) Evaluate UX. These stages were applied cyclically throughout the project to continuously refine the solution based on stakeholder feedback and usability evaluations. The overall timeline of the project is shown on figure 3.2, which covers the main iterations of designs and prototypes.

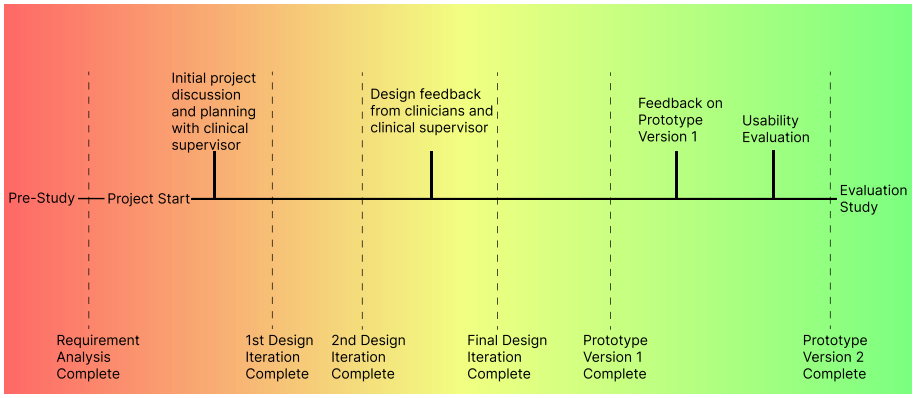


Figure 3.2: Timeline of the iterations of the project.

3.1 Understanding User Work and Needs

The first phase of the UX lifecycle, understanding user work and needs, focuses on gathering and interpreting data about users, their tasks, and the context in which the system will be used. For this project, the methods followed the structure outlined in *The UX Book* [13], which divides this phase into four key steps: data elicitation, data analysis, data modeling, and the formulation of user needs and requirements. The overall goal was not to ask users what they wanted, but to observe and infer the actual work practices that a well designed system should support.

To elicit relevant data, a combination of qualitative methods was employed. In addition to the literature, a field study was required to earn a deeper understanding of the patient group and current practices at the Department of Brain and Spinal Cord Injury at Rigshopitalet Glostrup. This was performed and described in a special course report, which also outlined the functional requirements for the mHealth application [19]. Special focus was placed on sessions involving STS training, during which interactions between therapists and patients were documented, along with environmental factors, equipment used, and motivational strategies applied. Shadowing allowed for unobtrusive, contextual insights into workflows and patient engagement.



Figure 3.3: Feedback session on the requirement analysis with Subject Matter Expert (SME)s at Glostrup Hospital.

Additionally, interviews were conducted with SMEs in two distinct categories. The first group consisted of research-oriented physiotherapists with backgrounds in rehabilitation science. Their input helped establish the theoretical foundations of the STS exercise and informed the understanding of what measurable improvements could be expected from patients. The second group included ward-based physiotherapists with hands-on experience. Their insights were practical and offered a detailed picture of the challenges and routines of daily rehabilitation sessions.

Although the intention was to include patients as informants, cognitive limitations made direct interviews largely ineffective. Simple, informal questions such as “Do you use your phone?” or “What do you like to do while you exercise?” were attempted but failed to

yield meaningful data. Instead, all information about patient needs and behaviors had to be inferred from observations and from interviews with therapists.

During these field visits, existing artifacts used in the rehabilitation process were also documented. These included hand-held tally counters used to track repetitions, measuring tapes to measure leg length and chair height, and a standard operating procedure (SOP) defining what constitutes a valid STS repetition. All visits were carefully documented as notes shortly after they took place to preserve context, and important details were photographed. Photographed artifacts can be found in Appendix C. The raw notes formed the basis for the following analysis.

Data analysis involved reviewing observation notes and interview transcripts to identify patterns and meaningful themes. From this, system requirements were developed, including functional and non-functional requirements. Feedback sessions and SME meetings were carried out at Glostrup Hospital as seen on figure 3.3. The full process resulted in a detailed set of requirements that would guide the rest of the design process. These are presented in Appendix B.

3.2 Creating Design Concepts

Design activities began by constructing personas that represented typical users of the application. These personas were grounded in the collected field data and depicted patients as well as clinicians. Each persona included motivation, relevant symptoms, and patient personality. These personas served as an anchor point to design around throughout the development process.

A Lean UX Canvas was used to document core assumptions about the problem space, such as user pain points and value propositions. The canvas helped align the design focus with stakeholder expectations and ensured that the system was grounded in practical needs.

To structure and prioritize functionality based on the users' goals and tasks, a User Story Map was created. This method provided a clear visual overview of the tasks and the sequential steps they follow when interacting with the system. The User Story Map was constructed using insights from field observations and interview data, and it served to align the development process with real-world rehabilitation workflows. The mapping process began by identifying overarching user activities, such as recording a session and setting a long-term goal. This approach ensured that user needs were kept central throughout design and development, while also providing a practical framework for determining which features to implement first. By focusing initially on the most critical tasks for supporting STS rehabilitation, the User Story Map helped define a Minimum Viable Product (MVP) and guided the iteration cycles that followed.

Finally, design ideas were visualized through sketching and wireframing. Sketches were used to explore alternative layouts, interaction flows, and feedback mechanisms, with an emphasis on clarity and accessibility.

3.3 Design Prototyping

During prototyping, multiple versions were developed and improved using Figma. The 2nd design iteration was finished just before a large feedback session with the clinical supervisor and physiotherapists, which included a discussion on key missing elements and how they should be prioritized. This feedback session lead to the final design iteration, which was used for the implementation. This can be viewed on the timeline on figure 3.2.

Smaller tests were also conducted by letting friends use the prototype and asking them to find specific parts in the application i.e. ”Please start a session.” or ”Please find the settings page.”. This gave quick insights into how people unfamiliar with the design would expect it to behave, and lead to updating the design accordingly.

3.4 Evaluating UX



Figure 3.4: The design feedback session held with clinicians at Rigshospitalet Glostrup.

Prototyping candidate designs and evaluating the resulting user experience were closely interwoven and conducted through several iterative cycles. The timeline on figure 3.2 shows the main feedback sessions held with clinicians. Feedback was also received during meetings with the main supervisor of the project, which helped shape the design and functional prototype over time. The feedback sessions with clinicians usually including an update on the project and a demonstration of the design/prototype followed by feedback from the clinicians. On figure 3.4 the large feedback meeting on the design can be seen.

4 The All Rise Application

Since the main goal of this project is to design and implement a prototype that motivates and engages ABI patients, a continuous focus on the needs of the patient group and physiotherapists is required. Given the complicated symptoms of ABI discussed in Chapter 2, the design must rely on physiotherapists being the main users of the application and guiding the patients during sessions.

4.1 Design Models

To promote this focus a set of personas were created to identify characteristics among patients and physiotherapists. The personas were originally created for the requirement analysis [19], but continue to be useful in the design phase. The personas can be seen on figure 4.1.

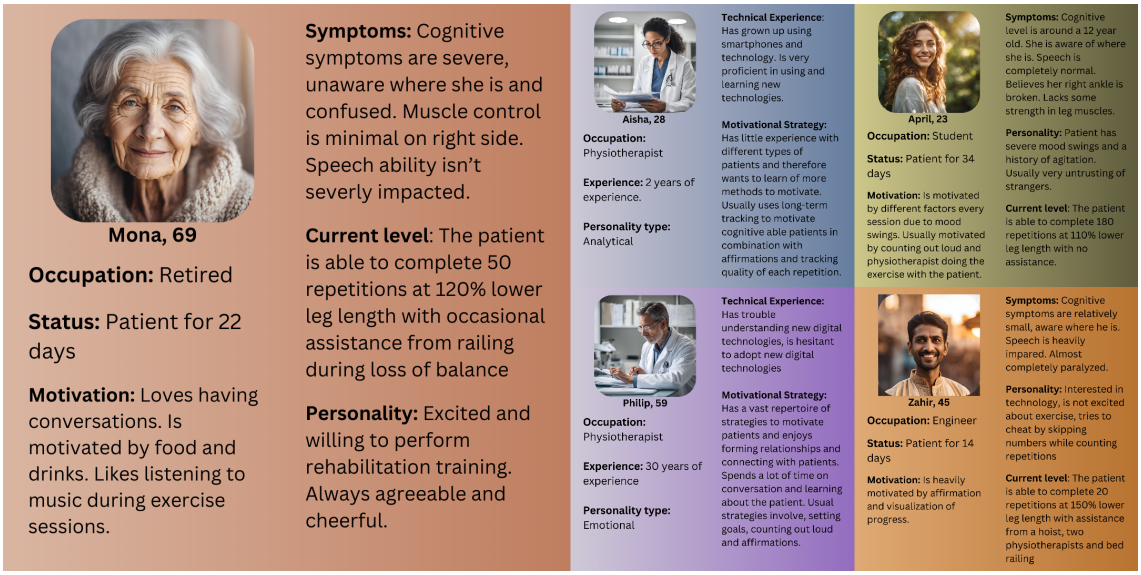


Figure 4.1: Personas of ABI patients and physiotherapists.

To frame the development process, a Lean Canvas was completed to outline key user problems, value propositions, and target users. Only some fields were filled out, since this project does not seek to sell itself, but a Lean Canvas can provide a focus on the core functionalities that should be included in the design and prototype. The application addresses three core problems: providing real-time feedback during a STS session, visualizing long-term patient goals, and increasing patient motivation with gamification elements. The Lean Canvas can be seen in Appendix D.

A User Story Map was developed to further explore important tasks that the application should include. The User Story Map can be viewed on Figure 4.2. This map breaks down the primary user goal of motivating patients to engage in STS rehabilitation. These include registering a patient, setting short- and long-term goals, connecting to an external screen, initiating and monitoring a session, and visualizing patient progress. This structure dictated the layout of the application's main screens and ensured the MVP covered the most important functionalities.

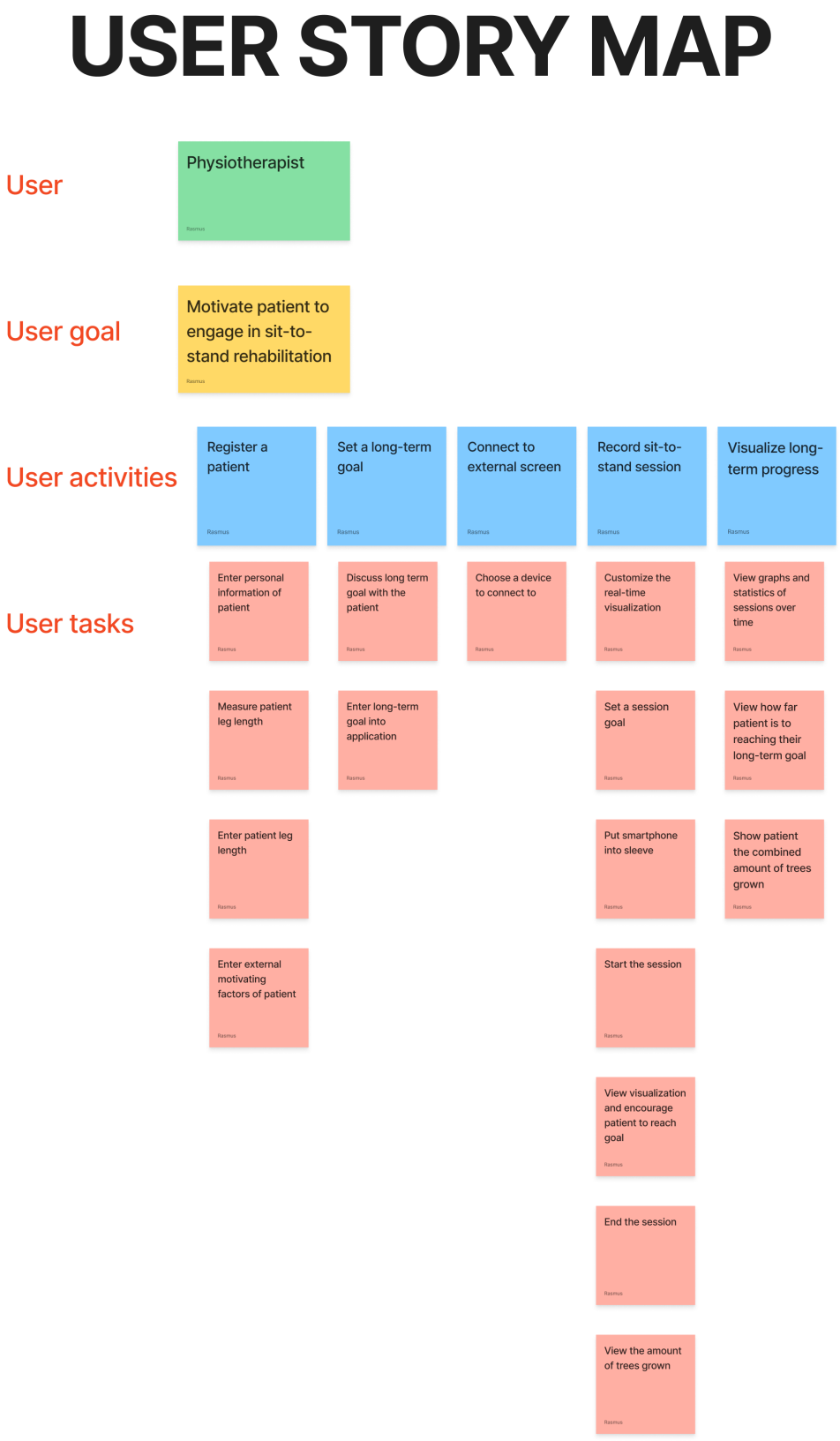


Figure 4.2: User Story Map for All Rise, which gives an overview of user goals and tasks.

4.2 Design Iterations

While following the *The UX Book* by Hartson and Pyla [13] an early conceptual design was created to begin forming the idea of the system. It outlined some core screens and functionalities, but ultimately most ideas were scrapped. The main ideas that survived were the use of a bottom navigation bar and circular progress indicator for the session progress.

The conceptual design was translated into Figma, which sparked the foundation for the first design iteration. The first iteration included few functionalities but did include new widgets and a colorscheme.

The second design iteration expanded greatly on the functionalities and the usability of the application. Gestalt principle of common region was used by choosing cards as a common widget to suggest which elements should be grouped together. To uphold the usability heuristics, choices were made to keep a simple and standardized design, to ensure that users wouldn't become frustrated with the application. The new design also included a gamification element, providing visual feedback in the form of an animated tree growing with each repetition completed. The conceptual design and early design iterations are shown in Appendix E.

A feedback session with clinicians was held after the completion of the second design. The feedback was generally positive and changes suggested were included in the third and final iteration. The main ideas from the feedback session included tracking long-term progress by counting the numbers of trees grown and displaying a forest as a visualization for the patient of their long term progress. Another addition was the option of making the application grayscale, since some ABI patients develop colorblindness as a result of their condition [20]. The final design iteration showing the smartphone and TV screen design can be seen on Figure 4.3 and 4.4.

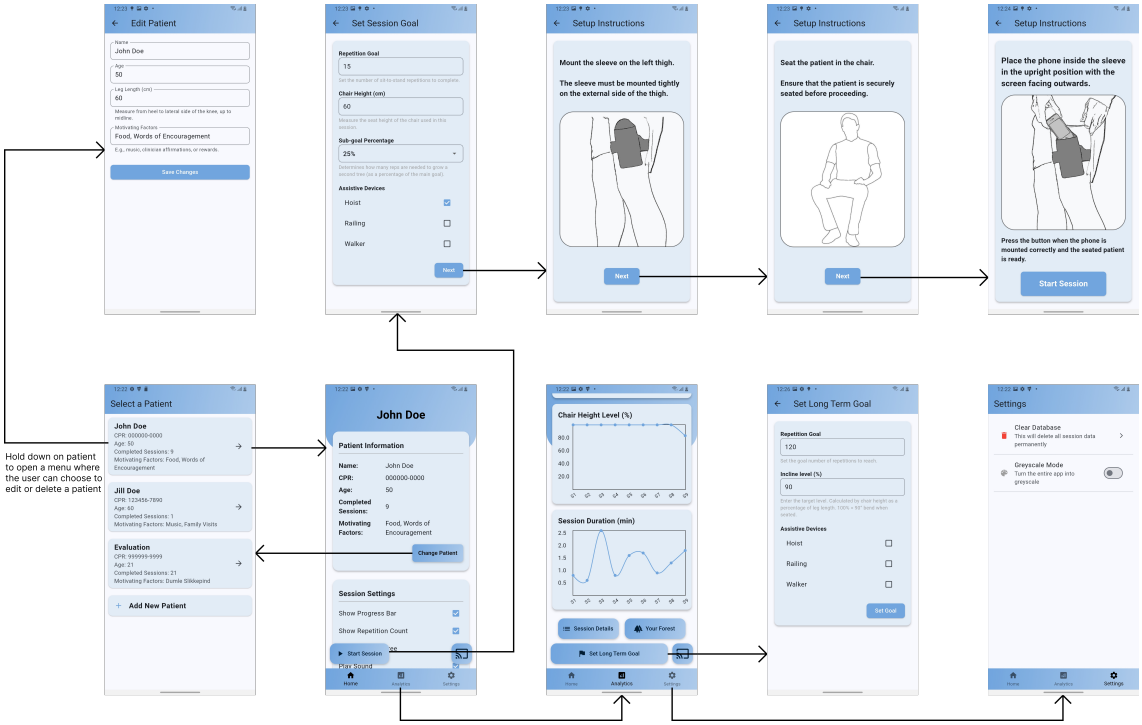


Figure 4.3: Wireframes of the final design for the smartphone screens.

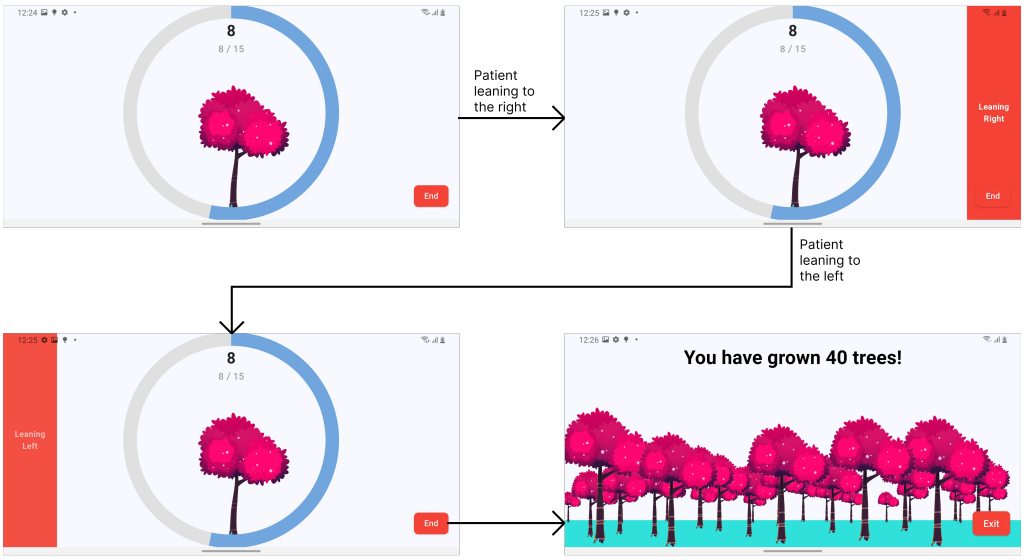


Figure 4.4: The final design for the TV screens.

4.3 Implementation

The All Rise application was developed using Flutter, chosen for its ability to create mobile interfaces across platforms and for its support for sensor integration. The app architecture follows the MVVM pattern, which promotes modular design, testability, and separation of concerns. The ViewModel acts as a mediator between the user interface and application logic, updating the UI in real time based on user actions and sensor input.

The modularity of the MVVM structure allows easy expansion in future iterations, which would provide more functionality for clinicians. This could be including cloud storage, data export, or more gamification elements. The repetition detection algorithm is encapsulated in the recorder class in the model, which makes it possible to test independently from the UI and easily substitute with improved models if needed. An overall diagram of the code can be seen on Figure 4.8. The source code can be found on Github.

A central aspect of the implementation is the use of the smartphone's built-in accelerometer to detect STS repetitions. The phone is placed inside a soft armband that has been extended with a 3D-printed clip and elastic band to securely attach the phone to the patient's left thigh. The strap can be seen on figure 4.5. The full strap development process can be seen in Appendix F. This placement ensures a consistent and stable orientation of the device relative to the body.



Figure 4.5: The strap made for ensuring correct placement of the smartphone on the patient's left thigh.

As illustrated in Figure 4.6, the accelerometer measures motion along three axes: X (left-right), Y (up-down), and Z (forward-backward). In this setup, the phone is positioned with the screen facing outward and the top edge pointing toward the patient's hip. When the patient is seated, gravity is primarily aligned with the phone's $+x$ axis. As the patient transitions to a standing position, gravity shifts toward the $-y$ axis. This predictable change in gravity's direction is used to detect a valid STS repetition.

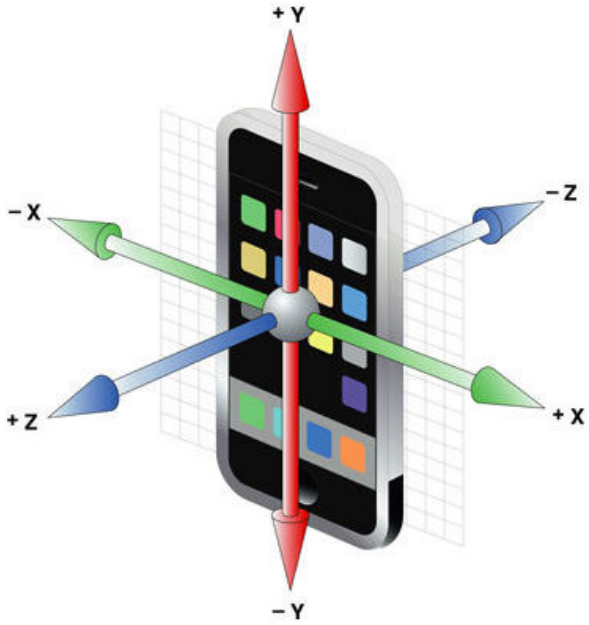


Figure 4.6: 3D depiction of the triaxial coordinate system of a smartphone using the built-in accelerometer [18].

The app continuously reads accelerometer data and calculates the direction of the gravity vector using the algorithm found in the Recorder class. By tracking changes in the dominant axis and calculating which state the patient is in (Sitting, Moving up, Standing or Moving down), the system is able to identify the initiation and completion of each STS repetition. A repetition is registered when the gravity vector shifts from predominantly $+x$ (sitting) to $-y$ (standing). The algorithm also contains a calibration phase, which calculates the seated position of the patient, such that the session can be carried out from different chair heights. While the patient carries out a repetition a lean value is calculated based on the Z axis, which indicates how much the patient is leaning to each side. During the session a red bar appears if the Recorder detects that the patient is leaning too much to one side.

The application provides real-time feedback on the external screen during each repetition. It uses visual indicators such as an animated progress bar, a repetition counter, and an incrementally growing tree to provide multiple visualizations to both the patient and therapist. After the session, a summary screen presents the total number of trees grown during all sessions performed by the patient. The summary is designed to support patient reflection and acts as a gamification element. The smartphone uses the built-in screen-mirror function of android devices to display the screen on the external screen (usually a chromecast connected to a TV). The setup can be seen on figure 4.7.

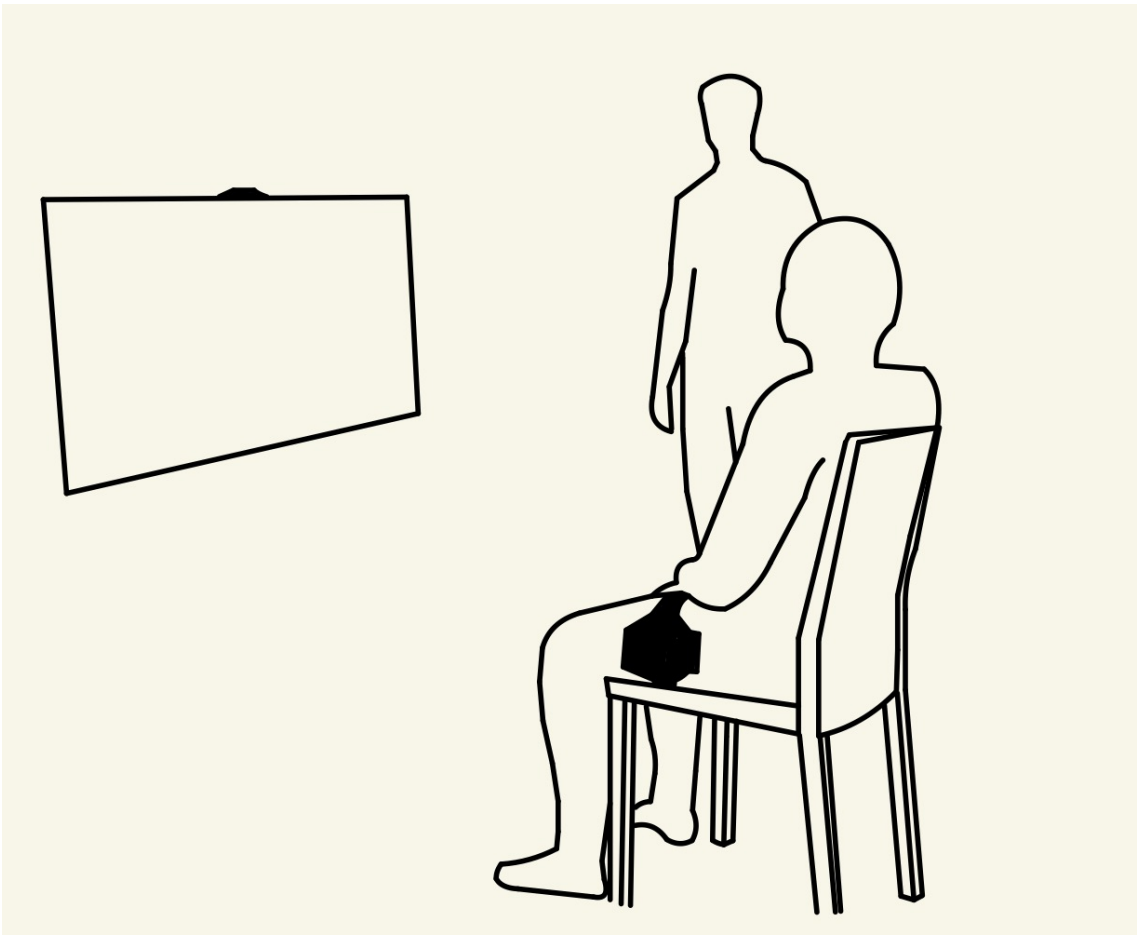


Figure 4.7: The overall setup of the system. The smartphone is placed in the strap on the left thigh of the patient. The smartphone connects to the TV and visualizes the repetition count for the patient. A physiotherapist guides and assists the patient.

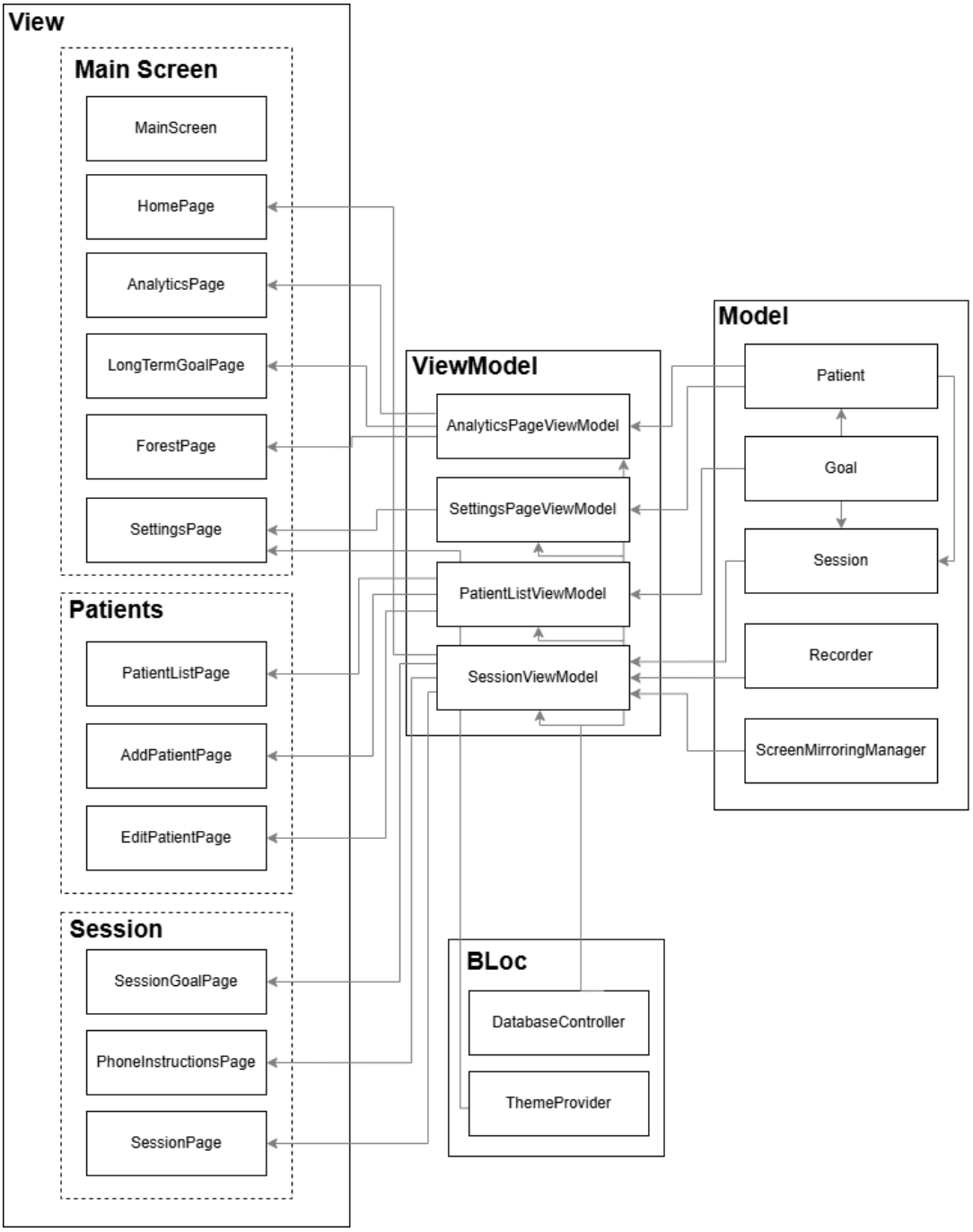


Figure 4.8: Code architecture for the All Rise application.

5 Evaluation

The evaluation of the All Rise application served to assess how well the prototype functions in a realistic clinical context. Although the design was based on established practices and input from experts, testing was needed to determine how users interact with the system and how they perceive its usability and relevance. The evaluation also provided feedback that can guide further development and help identify any issues before future testing with patients.

5.1 Method

Evaluating the All Rise application with the intended target group of ABI patients was not possible within the timeframe of this project. Due to the cognitive impairments associated with ABI, patients are often unable to provide informed consent for research participation. In such cases, consent must be obtained from a legal guardian, which significantly complicates the recruitment process. Furthermore, research involving vulnerable populations such as ABI patients requires formal approval from a regional ethics committee. Submitting a detailed proposal, undergoing the review process, and receiving approval would have exceeded the duration of the projects timeframe.

Given these constraints, the evaluation was instead conducted with healthy participants from the Department of Brain and Spinal Cord Injury at Rigshospitalet Glostrup. These participants were all clinicians with experience working with ABI patients in clinical settings. Although not a direct substitute for evaluating with the target patient group, involving domain experts ensured that the feedback was informed by extensive knowledge of patient needs and rehabilitation practices.

The evaluation consisted of a structured demonstration session followed by a questionnaire. During the demonstration, the participant assumed the role of a patient. Participants were instructed to perform a STS training session with the application, engage with the real-time feedback visualizations, and complete a number of repetitions to experience the interaction flow fully.

Following the demonstration, participants were asked to complete a questionnaire designed to assess their user experience, level of engagement, and the perceived clinical potential of the All Rise application. Prior to participating, each individual provided informed consent by signing a consent form that explained the purpose of the evaluation, how the data would be used, and their rights as participants. The full questionnaire can be viewed in Appendix G.

The questionnaire consisted of 15 statements, each rated on a five-point Likert scale ranging from Strongly Disagree to Strongly Agree. Twelve of these items were adapted from the User Engagement Scale – Short Form (UES-SF), a validated instrument developed to assess user engagement in digital systems. The UES-SF captures four key dimensions of engagement: focused attention (such as feelings of immersion and absorption), perceived usability (including experiences of frustration or cognitive effort), aesthetic appeal (evaluating the visual and sensory design), and the reward factor (capturing the user's sense of interest and value in the experience) [21].

In addition to these standard items, three custom questions were included to assess the perceived clinical relevance of the prototype. These additions focused on whether participants could see potential in the system, whether they believed it could help increase

patient repetitions, and whether it would be a useful tool in a clinical setting. These questions proved particularly valuable, as they provided insight into the system's practical applicability in a clinical setting. Since the participants were all clinicians working with this patient group, they all had significant insight into whether or not the prototype could be useful in their daily work.

5.2 Recruitment

A total of 21 participants took part in the evaluation study. The group consisted of 8 males (38%) and 13 females (62%), with ages ranging from 26 to 65 years. All participants were professionals affiliated with the Department of Brain and Spinal Cord Injury at Rigshospitalet Glostrup and had relevant clinical experience with patients with ABI. Their involvement in daily rehabilitation work made them well suited to evaluate the All Rise application from a clinical perspective.

This diverse group of clinicians and researchers ensured a multifaceted evaluation, incorporating perspectives from both direct clinical practice and academic insight. Figure 5.1 provides a visual breakdown of the participants' occupational distribution.

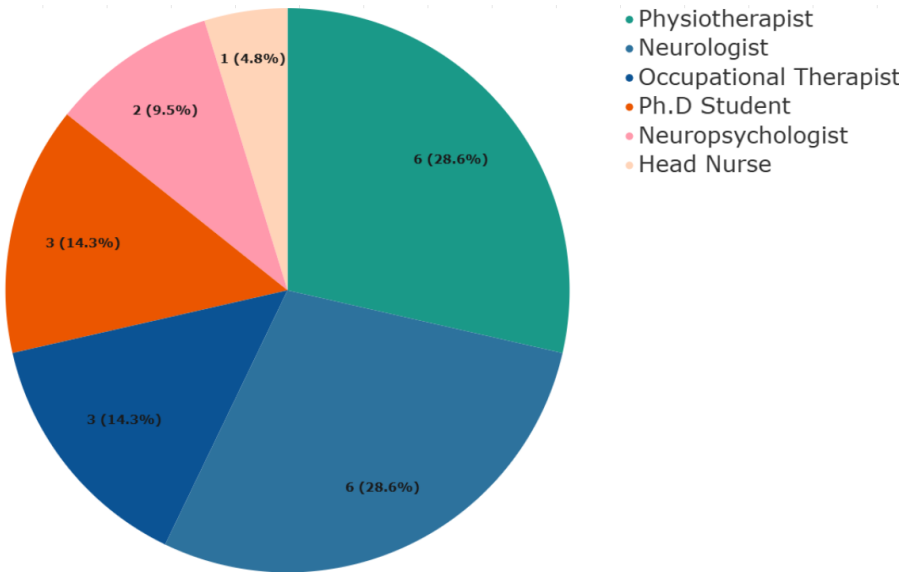


Figure 5.1: The distribution of occupations between the participants.

5.3 Results

Participants completed a questionnaire consisting of 15 items, including 12 items from the UES-SF and 3 custom items focused on clinical relevance.

Average scores across the four UES-SF subscales are summarized in Figure 5.2, with the lowest score being 3.4 for Focused Attention, and the highest being 4.3 for Perceived Usability.

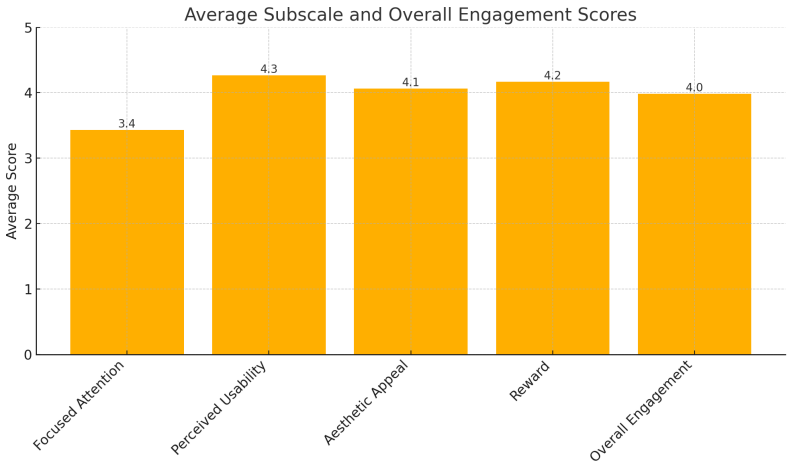


Figure 5.2: Scores across the four subscales of the User Engagement Scale questionnaire.

The overall average engagement score across all UES-SF items was 4.0 out of 5.

For the three custom questions assessing the clinical value of the prototype, the average score was 4.4. All participants either agreed or strongly agreed with the first two items, while one participant selected “Neither agree nor disagree” for the final item. These results are illustrated in Figure 5.3.

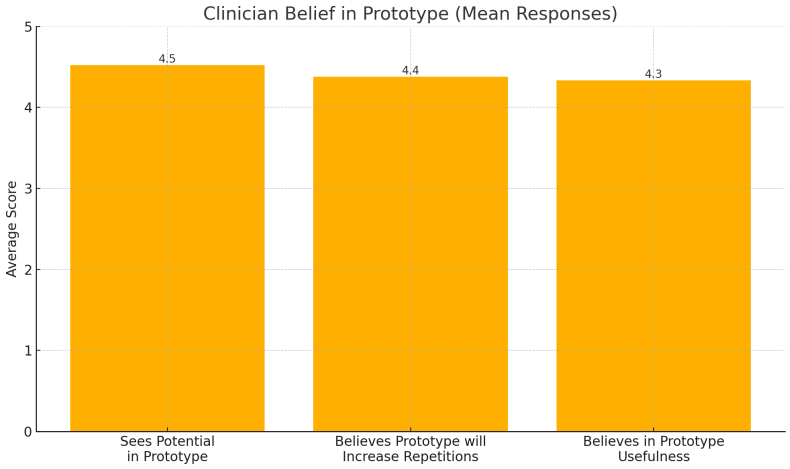


Figure 5.3: Scores on the clinicians’ belief in the clinical potential of the prototype

Qualitative feedback from open-ended comments highlighted the real-time feedback visualization (the growing tree) and the long-term progress visualization (the forest) as notable features. Participants also mentioned the simplicity of the interface and the availability of a grayscale mode. Suggested areas for improvement included adding more customizable feedback options during sessions and incorporating additional small reward mechanisms.

6 Discussion

The evaluation showed that participants generally found the All Rise application engaging, aesthetically appealing, and clinically promising. Average scores across the four subscales of the UES-SF were consistently high, with Perceived Usability scoring the highest at 4.3, followed by Reward Factor at 4.2, Aesthetic Appeal at 4.1, and Focused Attention slightly lower at 3.4, as seen in Figure 5.2. These results suggest that while the prototype was well received in terms of usability, visual appeal, and motivational impact, the degree of immersive engagement measured by responses to statements such as “I lost myself in this experience” was comparatively lower.

One possible explanation for this drop is the short and artificial nature of the test session, which may not have allowed participants to become fully absorbed. However, another likely factor is language ambiguity. All participants were native Danish speakers, and several asked for clarification on specific questionnaire items, particularly phrases like “I lost myself in this experience” and “Using the All Rise application was taxing.” These expressions do not translate intuitively into Danish and were perceived as vague or confusing by some respondents. A validated Danish translation of the UES-SF does not currently exist, and as such, the original English version was used.

Despite this, the overall engagement score still averaged 4.0 out of 5, and the application’s usability and motivational design were consistently recognized as strengths. The results support that while some specific items in the questionnaire may have been linguistically unclear, the general perception of the application was strongly positive.

In the three additional questions assessing the perceived clinical value of the prototype, responses were overwhelmingly positive. As shown in Figure 5.3, all but one participant agreed or strongly agreed that the system had clinical potential. Only one participant selected ‘Neither agree nor disagree’ on the last of the three statements. The average score across these three questions was 4.4, demonstrating a high level of belief among clinicians that the prototype could be a useful tool for increasing patient repetitions and supporting rehabilitation efforts in clinical practice.

These findings reflect a successful realization of the original research goals outlined in Chapter 1. Each of the four main objectives defined was addressed during the development and confirmed in the evaluation:

The application provides real-time feedback by detecting STS repetitions using the smartphone’s built-in accelerometer. Real-time feedback is delivered via visual elements on an external screen, including a circular progress indicator, animated tree growth, and a repetition counter. Participants confirmed that these visualizations were intuitive and motivating.

Gamification was integrated by visualizing each successful repetition with a growing tree and representing cumulative progress with a forest. This metaphor was well received by participants, who noted it as both engaging and suitable for supporting long-term reflection, aligning well with motivational needs in ABI rehabilitation.

Clinical usability was ensured through continuous involvement of clinicians in both the design and evaluation phases. Their feedback directly shaped the design iterations, interface structure, and functional priorities. Evaluation results confirmed that the application

fit well into existing clinical workflows and was considered practical and relevant by all participants.

The application was implemented using only a standard Android smartphone and a TV with screen mirroring capabilities, avoiding the need for additional hardware. This allowed the prototype to function within patient rooms, supporting accessible and in-room rehabilitation.

These results confirm that the application was not only usable and engaging but also perceived by professionals as relevant and potentially impactful in real-world rehabilitation settings. Qualitative comments from participants further highlighted that the real-time feedback provided by the growing tree visualization was considered motivating and intuitive. The long-term forest visualization was seen as a good strategy to support patient reflection and maintain engagement over multiple sessions. The simplicity of the user interface was praised, especially given the cognitive challenges faced by ABI patients. Participants also appreciated the option to switch to a grayscale mode, acknowledging that it addressed potential color vision deficiencies in the target group.

However, participants also suggested that further improvements could be made, including allowing for real-time customization during sessions if the original goal proved to be too ambitious and expanding the real-time feedback with more types of small rewards to further increase engagement.

6.1 Limitations

While the project followed a UCD methodology and incorporated valuable feedback from domain experts, certain limitations should be acknowledged. Most notably, the tight timeframe of the project constrained the scope and depth of user involvement, particularly during the latter stages of development. Although multiple feedback sessions were held with clinicians, these were relatively short and spaced out, limiting the ability to conduct more extensive co-design workshops or repeated usability evaluations.

Additionally, the feedback collected during the design and early prototyping phases was primarily qualitative and based on a small group of clinicians. While this provided critical insight into clinical workflows and user expectations, it does not fully substitute for empirical, quantitative evaluation with actual patients. The perspectives gathered reflect expert opinion rather than direct patient interaction, which, due to ethical and logistical challenges, could not be included within the project timeline.

A single usability test was conducted with clinicians acting as both users and proxies for patients. While this approach offered useful insight into system usability and clinical relevance, it falls short of a comprehensive evaluation strategy. A follow-up usability test, ideally incorporating design changes based on the first, would have strengthened the reliability and generalizability of the findings, especially from a quantitative standpoint. Conducting such testing would be a key next step in future iterations of the project.

It should also be noted that the development and testing of the All Rise application was carried out exclusively on a single Android smartphone model. While the application was designed using Flutter, differences in hardware specifications, such as sensor calibration or screen resolution, may affect performance on other devices. This lack of multi-device testing introduces a potential limitation to the system's robustness and reliability across the broader range of Android hardware. Future work should include testing on multiple devices to ensure consistent functionality and user experience.

6.1.1 Evaluation

While the evaluation yielded valuable insights, several limitations must be acknowledged. Although the participants were experienced clinicians, they cannot fully replicate the cognitive, physical, and motivational challenges faced by ABI patients. As such, actual patient testing will be essential before clinical deployment. Additionally, the artificial setting of the demonstration may not capture real-world variables such as varying patient abilities, environmental distractions, or emotional responses.

The small sample size and restriction to clinicians limit the generalizability of the findings. Broader testing, including patient trials under ethically approved conditions, is needed to confirm clinical efficacy. Finally, the study did not assess long-term motivation due to time constraints, which is an important factor for ensuring sustained patient engagement and improved outcomes.

7 Conclusion

This thesis set out to investigate how to design and implement an mHealth application that motivates and engages ABI patients to increase STS repetitions and thereby improve mobility. To answer this, the project defined four primary goals: to provide real-time feedback using mobile sensors, to enhance motivation through gamification, to support clinical usability by involving clinicians in the design process, and to ensure portability by relying on accessible hardware such as smartphones and TVs.

These goals were addressed through the iterative design and development of the All Rise application. Real-time feedback was implemented by using the smartphone's built-in accelerometer to detect valid STS repetitions, allowing the application to provide immediate visual cues to both patients and clinicians. The feedback was displayed on an external screen and was designed to be easily understood and motivating. To support long-term engagement, the application incorporated gamification features on an external screen, including an animated growing tree for each completed repetition and a forest visualization that symbolized cumulative progress over time. These elements were designed to reflect progress in a way that could be easily grasped by users with cognitive impairments and were positively received during the evaluation.

Clinical usability was ensured by involving domain experts from the Department of Brain and Spinal Cord Injury at Rigshospitalet Glostrup throughout the process. Feedback from clinicians shaped the system's functionality, interface, and design, ensuring that the system fits within clinical workflows and was usable in clinical conditions. In terms of accessibility and portability, the decision to use standard Android smartphones and wireless screen mirroring ensured that the system could be easily deployed in the patient rooms without requiring specialized or expensive equipment. This makes the solution practical and scalable within typical rehabilitation settings.

Participants highlighted several strengths of the application, including the intuitive real-time feedback, the engaging visualizations of patient progress, and the simplicity of the interface. They also made suggestions for future improvements, such as the ability to adjust feedback during sessions and expanding the range of motivational elements.

The evaluation of the system, although constrained by time and ethics-related limitations, produced encouraging results. Clinicians (N=21) with relevant experience participated in structured evaluation sessions and completed a questionnaire based on the UES-SF. The prototype received strong scores across all subscales, with perceived usability rated the highest and aesthetic appeal and reward factor also scoring well. Focused attention received a slightly lower score, likely influenced by the short duration of the test and potential ambiguity in the questionnaire language, as many participants were non-native English speakers. Despite this, the overall engagement score averaged 4.0 out of 5, and the average score across three custom questions assessing clinical value was 4.4. These results indicate a high level of confidence among clinicians that the application could be a useful and effective tool for supporting ABI rehabilitation.

In conclusion, this project demonstrates that it is both technically and clinically feasible to create a portable, sensor-based rehabilitation tool that supports STS training in patients with ABI. By combining real-time feedback, gamification, and user-centered design methods, the All Rise application addresses key barriers to patient engagement and offers a

promising approach to increasing repetition and improving mobility. Although the current evaluation is based on input from clinicians rather than patients, the results provide a strong foundation for future work. Further studies involving patients, extended usability testing, and long-term motivation tracking will be necessary to validate the full clinical usefulness and usability of the system.

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A Acronyms

ABI	Acquired Brain Injury
mHealth	Mobile Health
MVP	Minimum Viable Product
MVVM	Model-View-ViewModel
SME	Subject Matter Expert
STS	Sit-to-Stand
UCD	User-Centered Design
TBI	Traumatic Brain Injury
TIA	Transient Ischemic Attack
UES-SF	User Engagement Scale – Short Form
UX	User Experience

B Requirements

B.1 Functional Requirements

- **Requirement 1:** *The system should count the repetitions of sit-to-stand movements.*

  This is required to track the exercise progression in real time. Counting repetitions ensures that both patients and physiotherapists can measure performance during and after a session. For example, a patient completing 10 repetitions can compare this number to previous sessions to track improvements. A repetition of a STS movement is defined in appendix C.

- **Requirement 2:** *The system should provide real-time visual feedback of repetition count and a progress indicator.*

  Real-time visual feedback will motivate patients and provide a target to work towards, encouraging them to complete more repetitions. For example, a progress bar that fills with each repetition could visually engage the patient to reach their goal.

  Real-time visual feedback is defined as a visualization of the progress made during the STS session. This visualization must be current and with so little delay, that the patient has time to make adjustments on their next repetition.

- **Requirement 3:** *The system should visualize and display information about multiple training sessions, including the number of repetitions and the use of assistive devices from each.*

  This feature allows for tracking the patient's progress over time and enables the system to suggest appropriate difficulty levels for future training sessions. For example, storing data on assistive device usage can show whether the patient is gradually becoming more independent.

  The displayed information should be visualized such that relatives, the patient and the physiotherapist can get an overview over progress made by the patient. Assistive devices are defined by what the patient uses as support during a STS session. This can include a hoist, a wheelchair, the physiotherapists or none.

- **Requirement 4:** *On first launch, the system should prompt the physiotherapist to measure the patient's leg length from the bottom of the heel to the lateral side of the knee at the midline.*

  This measurement is necessary to determine the patient's initial difficulty level and calculate future progression levels for sit-to-stand training sessions. For example, patients with shorter leg lengths may require adjusted difficulty settings to ensure a manageable exercise routine.

- **Requirement 5:** *The system should provide options for long-term goal-setting by the patient or physiotherapist.*

  This feature ensures that the physiotherapist and patient can align expectations and stay motivated to reach goals while tracking long-term progress. For instance, a long-term goal might be to achieve 30 repetitions in one session, with no use of assistive devices at a chair height of 120% leglength.

A goal is defined by three parameters. Number of repetitions to reach, what assistive devices to use and the height of the chair.

- **Requirement 6:** *The system should provide options for setting per-session goals immediately before starting a session.*

  This feature ensures that the patient can stay motivated to reach goals for each session. A per-session goal might be to reach 15 repetitions today with the help of a hoist at 150% leglength.

- **Requirement 7:** *The system should measure the quality of repetitions and provide real-time feedback on each one.*

  This will help both the physiotherapist and patient make adjustments during the exercise session, improving the overall quality of repetitions. For instance, the system could alert the user if their posture is incorrect or if the motion is incomplete.

  The quality of the repetition is defined as how much a repetition differs from the standard repetition in appendix C. A small difference between an actual repetition and the standard repetition equals a better overall quality.

- **Requirement 8:** *The system should incorporate gamification elements that can be displayed during training sessions.*

  Gamification elements have the potential to increase patient motivation and encourage consistency with their sessions over longer periods of time. For example, the system could award points, badges, or virtual rewards based on the number or quality of repetitions completed. Gamification elements should be creatively designed and iteratively improved during testing.

- **Requirement 9:** *The system should have options to customize the exercise session for each patient.*

  Patients with brain injuries often exhibit diverse symptoms and disabilities, which can impact their ability to exercise. Additionally, patients are motivated by different factors. Customization options, such as adjusting difficulty levels or personalizing gamification elements, will make the system more flexible and effective for individual patients.

- **Requirement 10:** *Provide additional tips and tricks for increasing patient motivation during exercise sessions.*

  This requirement intends to account for motivational factors outside the scope of the system. These tips could include playing the patient's favorite music, counting repetitions aloud, or offering words of encouragement.

B.2 Non-Functional Requirements

B.2.1 Usability

The system must be straightforward and quick to set up to be valuable for both physiotherapists and patients. For it to be effective, it should be user-friendly and convenient to operate. If the aim is to motivate patients, the system needs to be either as easy to use as current motivational methods, or it must deliver superior results. Clinicians often work under tight schedules and may face understaffing, which means that even a highly effective system could go unused if it is too time-consuming or complex to set up.

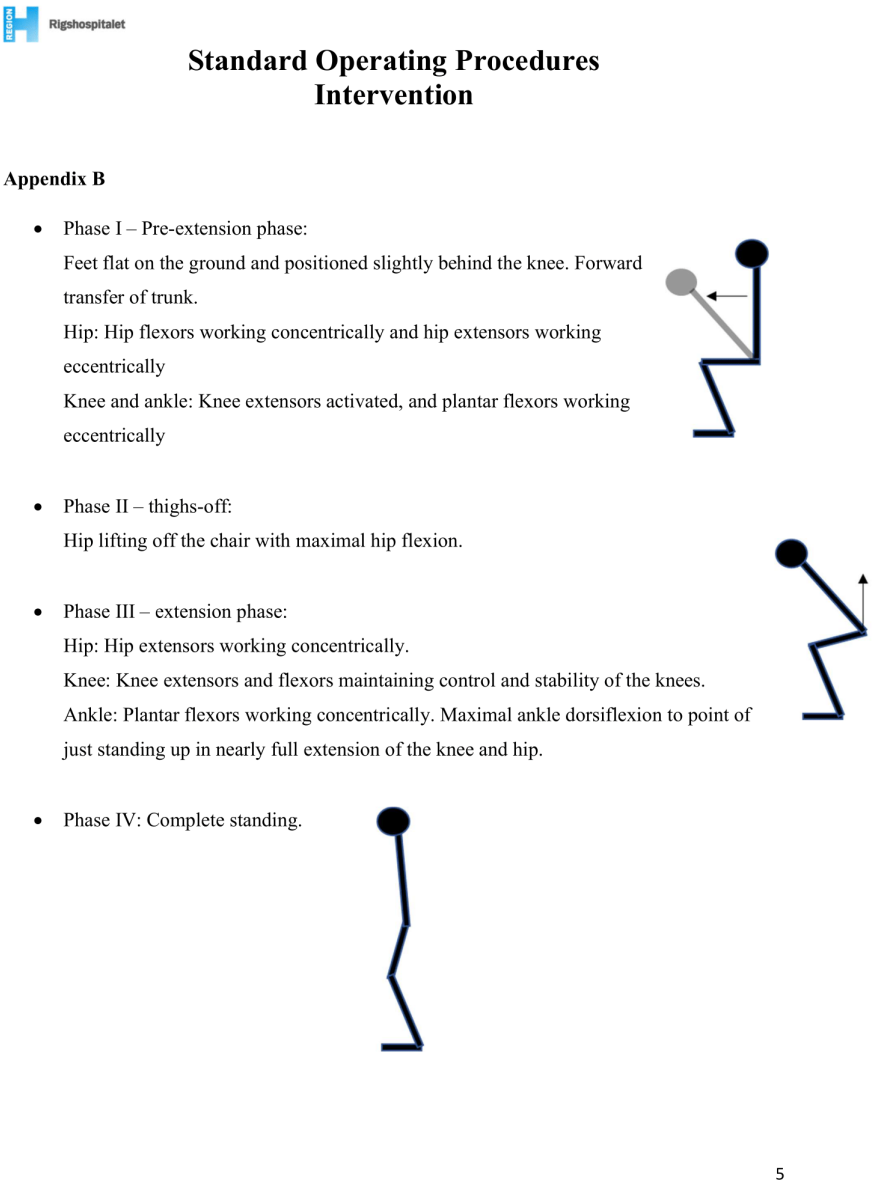
B.2.2 Reliability

For the system to be effective and practical, it must be reliable enough for physiotherapists to want to use it. The app should maintain a stable connection and avoid crashes during sessions to prevent inconvenience and interruptions. If a crash occurs, the patient should be informed swiftly, allowing the physiotherapist to make decisions based on the error. The system should be robust enough to handle exceptions and reliable enough that the saved data can be trusted to be accurate.

B.2.3 Performance

The system should be highly responsive during the sit-to-stand exercise session, since it should provide real time feedback to the patient. Exercise repetition counting should be accurate, with minimal or no miscounts, and be visualized for the patient before a new repetition is initiated. Faster feedback will allow earlier corrections and adjustments from the patient and physiotherapist.

C Artifacts



Rigshospitalet

Standard Operating Procedures
Intervention

Appendix B

- Phase I – Pre-extension phase:
  Feet flat on the ground and positioned slightly behind the knee. Forward transfer of trunk.
  Hip: Hip flexors working concentrically and hip extensors working eccentrically
  Knee and ankle: Knee extensors activated, and plantar flexors working eccentrically

- Phase II – thighs-off:
  Hip lifting off the chair with maximal hip flexion.

- Phase III – extension phase:
  Hip: Hip extensors working concentrically.
  Knee: Knee extensors and flexors maintaining control and stability of the knees.
  Ankle: Plantar flexors working concentrically. Maximal ankle dorsiflexion to point of just standing up in nearly full extension of the knee and hip.

- Phase IV: Complete standing.

5

Figure C.1: Definition of a STS repetition.

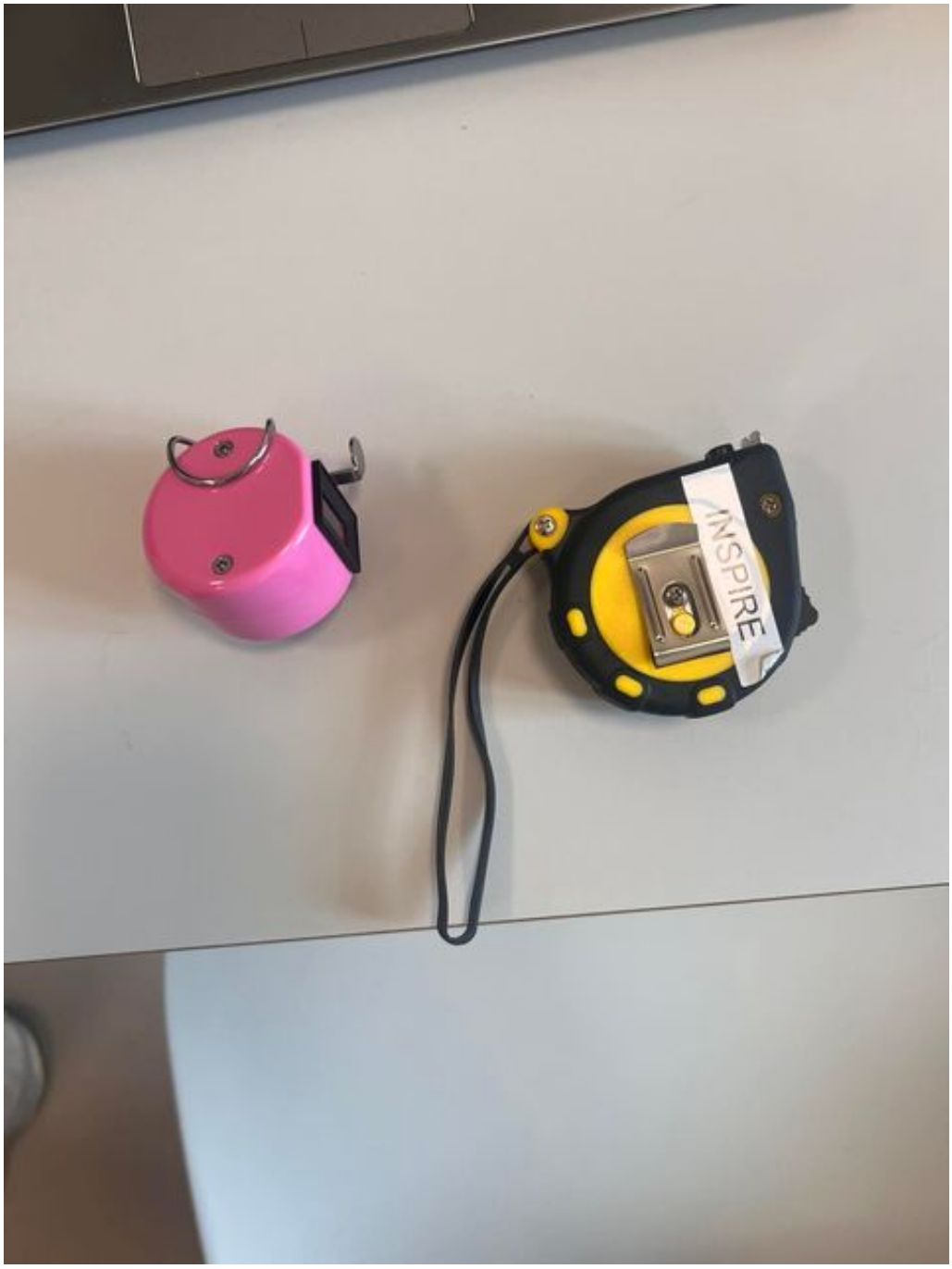


Figure C.2: Hand-held tally and measuring tape used for STS.

D Lean Canvas

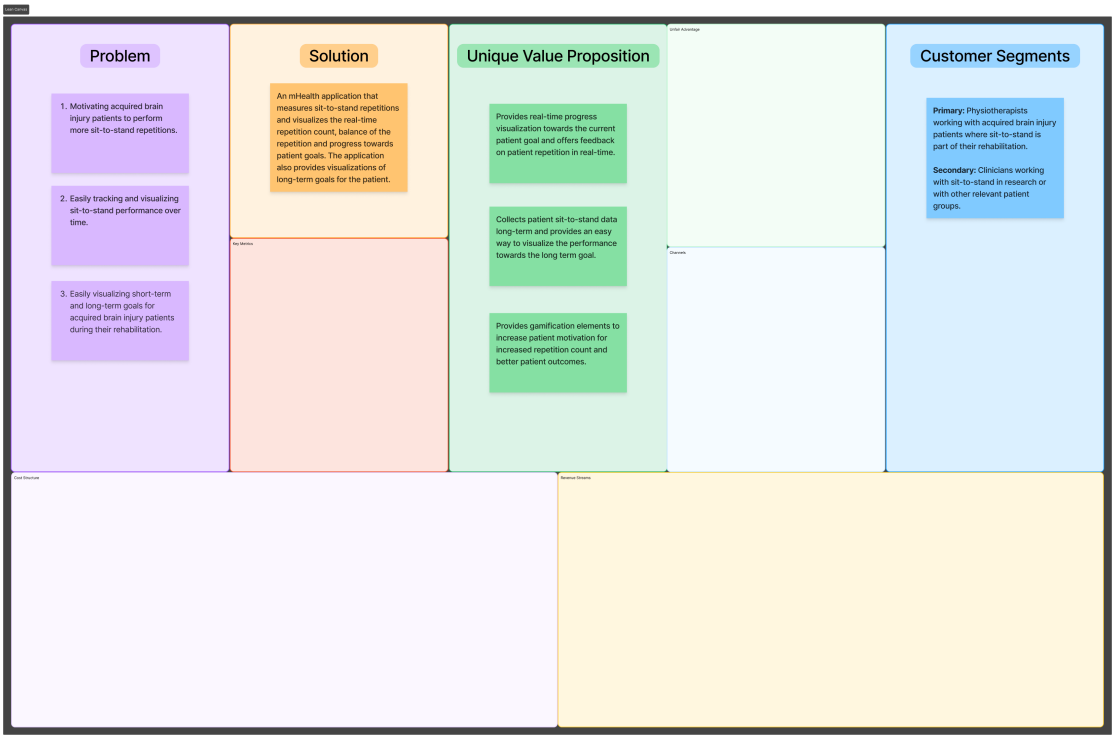


Figure D.1: Lean Canvas of All Rise, describing the key problems that the application attempts to solve.

E Design Iterations

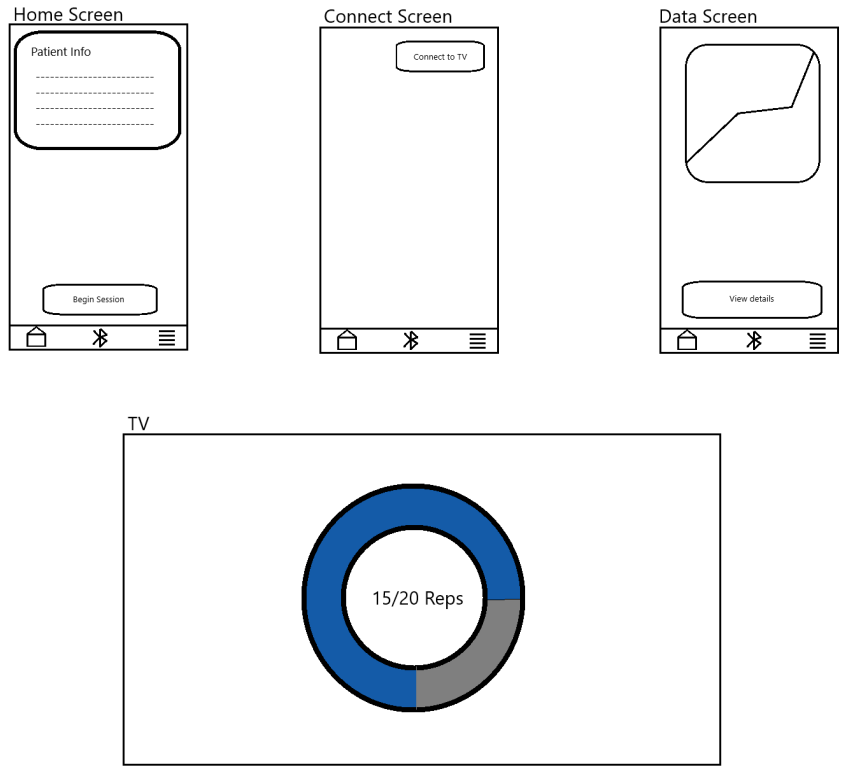


Figure E.1: The early conceptual design of the system

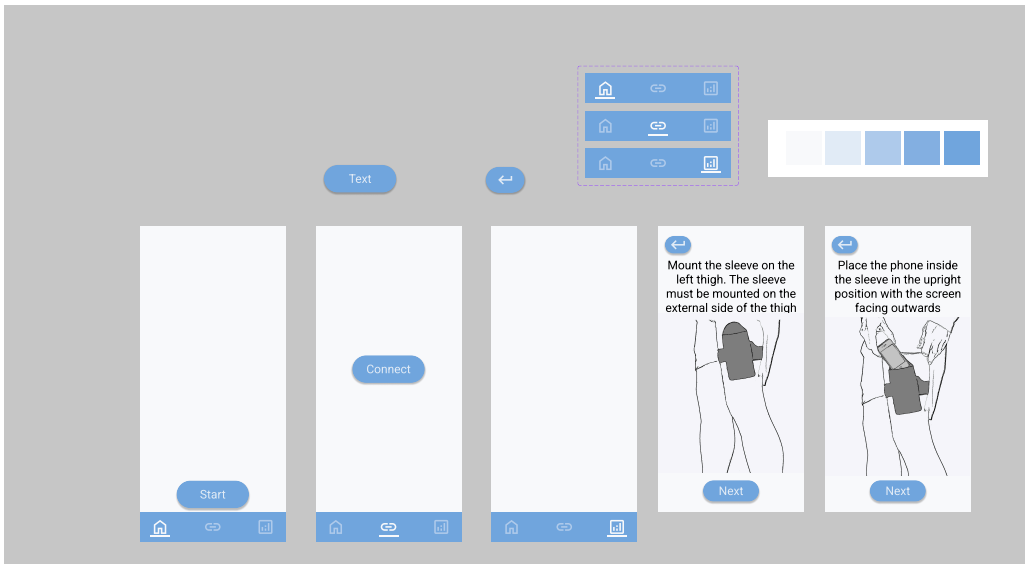


Figure E.2: The first iteration of the design

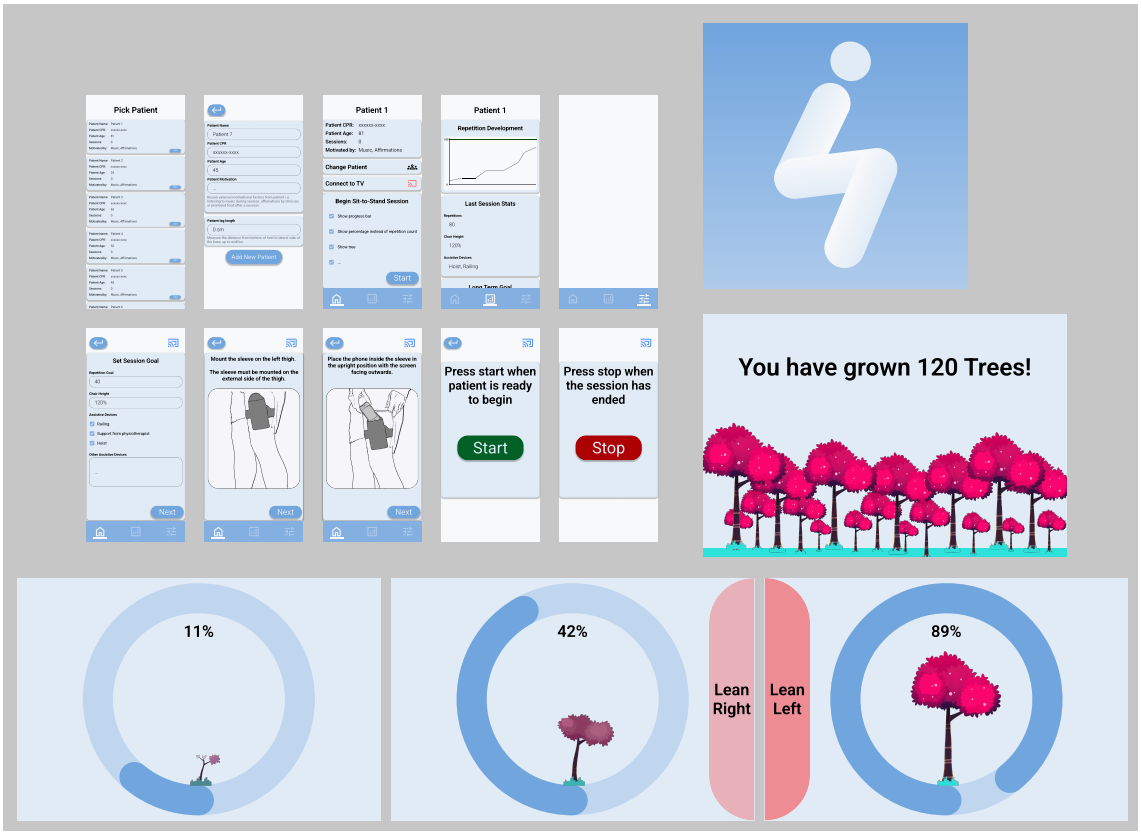


Figure E.3: The second iteration of the design

F Strap Design

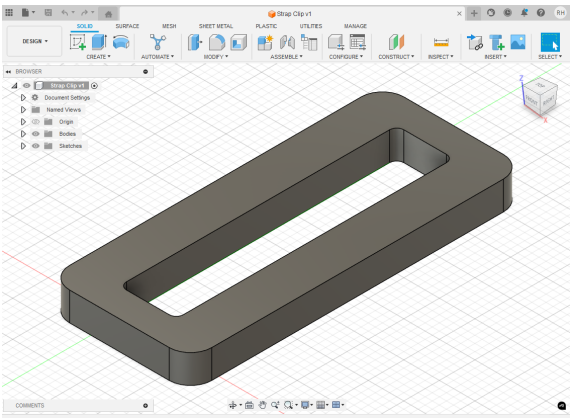


Figure F.1: Creating clip in Fusion 360.



Figure F.2: Printing the clip.



Figure F.3: The final strap used for the evaluation.

G Questionnaire

To evaluate the All Rise prototype, a questionnaire was administered consisting of 15 statements rated on a 5-point Likert scale ranging from Strongly Disagree to Strongly Agree. The questionnaire included 12 items from the validated UES-SF and 3 custom items focusing on clinical relevance.

User Engagement (UES-SF)

The UES-SF items are grouped into four subscales:

- **Focused Attention**
  - I lost myself in this experience.
  - The time I spent using the All Rise application just slipped away.
  - I was absorbed in this experience.
- **Perceived Usability**
  - I felt frustrated while using the All Rise application.
  - I found the All Rise application confusing to use.
  - Using the All Rise application was taxing.
- **Aesthetic Appeal**
  - The All Rise application was attractive.
  - The All Rise application was aesthetically appealing.
  - The All Rise application appealed to the visual senses.
- **Reward Factor**
  - Using the All Rise application was worthwhile.
  - My experience was rewarding.
  - I felt interested in this experience.

Custom Items on Clinical Relevance

Three custom questions were added to assess the perceived clinical value of the system:

- I can see the potential in this prototype.
- I believe that once finished, this prototype has the potential to increase patient repetitions.
- I believe that once finished, this prototype would be a useful tool in the clinic.

Technical
University of
Denmark

Ørsteds Plads, Building 345C
2800 Kgs. Lyngby
Tlf. 4525 1700

www.healthtech.dtu.dk