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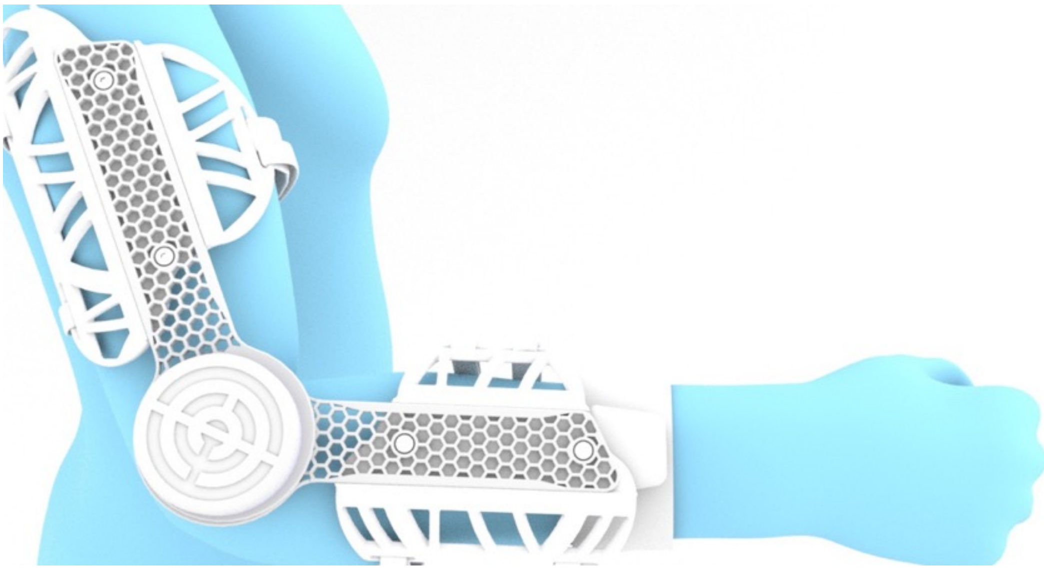

The Human Digital Twin Revolutionising Stroke Therapy Management through Data Visualization

Master's thesis in Interaction design and technology

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Department of Computer Science and Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023

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A dashboard that helps therapists to manage their patients.
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Cover: The upper-limb exoskeleton that uses its own sensing and novel actuation capabilities for generating the digital twin of the user.

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Abstract

This study delves into the innovative paradigm of the Human Digital Twin within the domain of stroke therapy management. Its primary focus lies in the design and implementation of a dedicated dashboard, specifically tailored for therapists, to facilitate patient management and interaction through data visualisation. Employing data sourced from exoskeleton devices, the project generates a virtual representation, or avatar, of patients within the dashboard interface. This avatar serves as a dynamic conduit through which patient progress can be effectively monitored and evaluated during the course of stroke therapy.

Throughout the project's trajectory, an array of diverse design methodologies has been strategically employed, with the overarching aim of achieving a human-centred design framework. By infusing various design principles, user-centric perspectives, and iterative feedback loops, the project endeavours to ensure that the resulting dashboard is intuitive, user-friendly, and effective in addressing therapists' and patients' needs.

Leveraging the inherent capabilities of data visualisation, contribute to a paradigm shift in the domain of stroke therapy management, thereby optimising patient outcomes and catalysing a transformative evolution in the manner in which rehabilitation strategies are conceptualised and executed.

Keywords: Interaction design, Dashboard design, Data visualization, User experience, Design methodology, Stroke rehabilitation.

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Introduction

The GBD 2019 Stroke Collaborators report that globally, stroke is the second most common cause of death and the third most common cause of death and disability combined (Feigin, et al., 2021). Millions of people are affected each year according to Eurostat Database (Eurostat, 2020). Stroke has devastating consequences on individuals, leading to a wide range of physical, cognitive, and emotional impairments. The aftermath of a stroke can include paralysis or weakness on one side of the body, difficulties with speech and language, memory loss, and challenges with everyday activities such as walking, dressing, and eating (Wolfe, 2000). These impairments significantly impact the quality of life for stroke survivors and often require long-term rehabilitation and support (Bronstein, 1991). Luengo-Fernandez and colleagues (2020) conducted a study to estimate the healthcare costs associated with stroke and assess the economic burden on healthcare systems and society. The findings revealed that stroke incurs an approximate annual cost of €45 billion in Europe. Given the immense impact of stroke on individuals, families, and healthcare systems, it is crucial to enhance the management of stroke therapy for better patient outcomes and to alleviate the burden on healthcare resources.

In recent years, advancements in technology have presented novel opportunities to transform stroke therapy management. One tool that has the potential to revolutionize stroke therapy management is the Human Digital Twin (HDTs) (Lauer-Schmaltz et al., 2022). A HDTs is a cutting-edge technology that provides a virtual representation of a patient's physiology and health status (Barricelli et al., 2020). In the case of stroke therapy management, visualizing patient data from the Human Digital Twin can be a powerful tool for therapists to monitor state and progress, as well as make informed therapy decisions.

Funded by the Horizon 2020 Framework Programme of the European Union, The ReHyb project (ReHyb, 2021), short for "Rehabilitation Hybrid: Robotics, Cognitive, and Virtual Reality for Stroke Rehabilitation" aims to develop a hybrid upper-limb exoskeleton for stroke rehabilitation that generates a digital twin of the user, enabling personalized interaction strategies based on the user's neuromechanical and psychological status. Central to the ReHyb project is the development of a sophisticated Human Digital Twin platform that captures and visualizes patient-specific data. This platform utilizes advanced computational algorithms and artificial intelligence to process and interpret data from various sources, including wearable devices, serious games, and electronic health records. By generating a virtual representation of the patient's physiology, the Human Digital Twin offers therapists a comprehensive and dynamic overview of the patient's health status, enabling them to make data-driven decisions and design tailored therapy plans (Şimşek, 2023).

In the realm of stroke rehabilitation, interaction design plays a vital role in optimizing the usability and effectiveness of these emerging technologies (Balaam et al., 2010). Interaction design focuses on creating intuitive and user-friendly interfaces that facilitate meaningful interactions between users and technology. In the context of stroke rehabilitation, effective interaction design ensures that the technology is accessible to individuals with a wide range of impairments, promotes engagement and motivation, and supports seamless integration into the therapy workflow.

Interaction design principles such as simplicity, visual clarity, and feedback mechanisms are essential in designing user interfaces for stroke rehabilitation technologies. Clear and intuitive interfaces help stroke survivors navigate the technology independently, minimizing frustration and facilitating engagement. Visual feedback, such as progress tracking or performance indicators, provides stroke survivors with a sense of accomplishment and encourages them to persist with their rehabilitation efforts. Furthermore, customization options and adaptability in interaction design allow therapists to tailor the technology to individual needs and progression, optimizing therapy outcomes (Balaam et al., 2010).

The aim of this thesis is to use data visualisation tools to effectively communicate patient data collected through digital twin technology to support therapists in making informed decisions about stroke therapy. By leveraging the power of data visualisation and digital twin technology, the project seeks to improve the efficiency and effectiveness of stroke therapy management.

1.1 Research questions

The foundation of this project is built upon a comprehensive exploration of the opportunities and challenges posed by Human Digital Patient Twins in the context of stroke rehabilitation, with a specific emphasis on data visualisation and the creation of a user-friendly dashboard for therapists. Given the inherent diversity in patients' health conditions, it often becomes a challenging task for therapists to monitor their progress and customize rehabilitation plans accordingly. Human Digital Twins provide a crucial means of visualizing patient data and displaying their therapy journey, assisting therapists in making informed decisions for personalized care. The role of Interaction Design is vital in ensuring the dashboard aligns seamlessly with therapists' workflow.

To navigate this complex landscape effectively, we have formulated a set of pivotal research questions. These questions, outlined below, will be the guiding framework for our project:

Main Research Question:

> What are the opportunities and challenges of using Human Digital Patient Twins for stroke rehabilitation in terms of data visualisation, interaction and communication?

Sub-Research Questions:

1. How to visualise the data of the digital twin in an understandable way?
2. What are the most important features and functionality desired by therapists in a solution for visualising patient data for stroke therapy management?
3. What are design elements, features, and functionalities that could support the communicated data regarding understandability and human-computer interaction?

By answering these questions, the project can gain a deeper understanding of the needs and expectations of therapists, as well as the best practices in data visualisation, communication, and interface design, which can inform the design of the solution and ensure that it meets the user's needs and achieves its goals.

By answering these research questions, the project aims to contribute significantly to the field of stroke rehabilitation and healthcare technology. It seeks to bridge the gap between technological innovation and practical usability by unravelling the intricacies of data visualisation, communication, and interface design in the context of Human Digital Patient Twins. Through a nuanced exploration of the challenges and opportunities, the project endeavours to align the solution closely with the needs and expectations of therapists, ultimately enhancing the quality of care provided to stroke patients. Moreover, it aspires to set new standards and best practices in the realms of data visualisation and human-computer interaction, laying the foundation for more efficient, user-centric, and impactful solutions in the domain of healthcare technology.

1.2 Added values

This master thesis project, conducted in collaboration with Rehyb, focuses on analysing the needs of various stakeholders involved in stroke rehabilitation, including stroke patients, therapists, and third-party individuals. Through thorough user research, this project aims to identify and address these multifaceted needs by harmonising them with user experience (UX) design principles. The ultimate goal is the creation of interactive dashboards that elevate the user experience to new heights.

With a central focus on the therapist's dashboard, this project endeavours to simplify the complex landscape of patient monitoring and rehabilitation training. This dashboard serves as an accessible and user-friendly interface, streamlining therapists' daily tasks and enabling effective patient profile management. By refining the interaction design, therapists gain easy access to critical data, making informed decisions and delivering tailored care a seamless process. In essence, this project aims to empower therapists, enrich the patient experience, and foster efficient and compassionate stroke rehabilitation through thoughtful design and technology integration.

2

Background

2.1 Stroke rehabilitation and new technology

Stroke is a widespread and severe medical condition, often resulting in substantial physical and cognitive challenges for affected individuals (Norlander et al., 2018). Successful therapy management is paramount in the journey to enhance patient outcomes and quality of life. However, managing stroke therapy is a multifaceted undertaking fraught with complexities. It necessitates a comprehensive comprehension of each patient's specific condition, medical background, and therapy objectives. Moreover, it demands the capability to sift through and make sense of extensive volumes of patient data. This intricate process involves not only providing the right interventions but also understanding the dynamic nature of stroke recovery, which can vary greatly among individuals. In essence, effective stroke therapy management is a crucial factor in the recovery equation, demanding both expertise and advanced tools to navigate the intricate path toward improved patient well-being.

2.2 Traditional rehabilitation ways

Historically, stroke rehabilitation has adhered to a well-established paradigm, primarily conducted within the controlled environment of clinical settings. This traditional approach to stroke rehabilitation has been marked by a rigorous regimen of in-clinic sessions encompassing physical, occupational, and speech therapies (Wolfe, 2000). These sessions are thoughtfully designed to address a spectrum of post-stroke challenges, including mobility limitations, muscular weakness, coordination deficits, and difficulties in performing daily activities. The overarching aim has always been to facilitate the recovery process, helping stroke survivors regain functional independence and enhance their overall quality of life. While this traditional approach has its merits, it comes hand in hand with several noteworthy limitations. The financial burden associated with clinic-based rehabilitation can be formidable, potentially restricting access for individuals with limited resources. Additionally, the commitment of substantial time and effort, often requiring frequent clinic visits, poses a significant challenge. Furthermore, there is a notable lack of real-time feedback mechanisms for patients to gauge their progress during the rehabilitation journey (Janice et al. 2010).

In response to these challenges and with a steadfast commitment to improving rehabilitation outcomes, alternative approaches have steadily gained traction. One such approach involves the shift toward home-based therapy, which empowers stroke survivors to engage in rehabilitation exercises from the comfort of their own homes. This transition not only addresses accessibility and financial concerns but also enhances patient autonomy and convenience. Furthermore, the integration of novel technologies into stroke rehabilitation, such as wearable devices and digital platforms, has opened up new avenues for therapy delivery and monitoring. These technological innovations hold the potential to revolutionise stroke rehabilitation by providing personalised, data-driven interventions and real-time progress tracking (Tageldeen et al. 2017).

2.3 Trending technology in stroke rehabilitation

In the ever-evolving landscape of healthcare, we're witnessing a significant shift in how we approach stroke rehabilitation. The reason behind this transformation is the rapid development and adoption of cutting-edge technologies. These trending technologies have the potential to make rehabilitation more accessible, tailor therapies to individual needs, and provide immediate feedback. There are now several new ways that stroke rehabilitation can be approached.

2.3.1 Serious games

Virtual reality and serious games are used to help patients with stroke rehabilitation. These technologies provide patients with a fun and engaging way to practise their motor skills, cognitive skills, and daily living skills (Rocha et al. 2016). For example, virtual reality can be used to simulate real-life environments, such as a grocery store or a park, where patients can practise navigating and performing tasks. Knackfuß and Lawo introduced a project developed by Rehab@Home (figure 2.1), which is a Reference Rehabilitation Platform (RRP) called REHABILITY for Serious Games (2018). This innovative platform provides patients with a hardware kit that connects their TV, tablet, or PC screen, enabling automatic data exchange with their clinic. By using gamified tele-rehabilitation technology, patients can engage in therapy remotely and stay in constant communication with their therapists.

Figure 2.1: REHABILITY program

2.3.2 Virtual reality

Mateus and colleagues developed a VR-based serious game for post-stroke rehabilitation (2017) and found it to be effective in motivating patients during rehabilitation sessions. Studies have demonstrated that using VR and interactive video gaming can enhance patient adherence and motivation during rehabilitation programs (Alamri et al., 2010). Although the use of VR and AR was not found to be more beneficial than conventional therapy in improving upper limb function, it may be beneficial as an adjunct to usual care by increasing overall therapy time and potentially improving limb functions in stroke patients (Laver et al., 2017). This technology offers the potential for more engaging and personalised rehabilitation experiences, which could ultimately lead to improved patient outcomes.

2.3.3 Robotic devices

Robotic devices can be used to assist patients in their rehabilitation also. Feingold-Polak and colleagues (2021) have described a robot-based gamified exercise platform in their paper that provides automated motor assistance during stroke rehabilitation. This device is designed to help patients improve their arm or leg strength and range of motion by guiding them through exercises, particularly when using an exoskeleton to help move the arm, wrist, and hands more freely. Research has shown that incorporating robotic devices into rehabilitation can improve patients' activities of daily living, arm function, and muscle strength (Mehrholz et al., 2018) and increase their motivation, particularly for repetitive tasks (Feingold-Polak et al., 2021). However, it is important to interpret studies of electromechanical and robot-assisted arm training with caution, as the intensity, duration, and amount of training, as well as the type of treatment, participant characteristics, and measurements used, may vary (Mehrholz et al., 2018).

While in-clinic rehabilitation has traditionally been the go-to for stroke patients, the use of new technologies is becoming increasingly prevalent. Robotic devices offer exercise assistance and can provide real-time tracking of user data, which allows for tailored exercise regimes and allows for immediate feedback to be given to both the patient and therapist. VR and serious games offer an engaging and immersive experience that can motivate users to continue exercising, potentially improving adherence to therapy and overall outcomes. These technologies also offer the potential for remote rehabilitation, which can help overcome limitations such as high costs and limited access to in-clinic rehabilitation. Overall, the use of these new technologies alongside traditional rehabilitation methods may provide a more comprehensive and effective approach to stroke rehabilitation.

3

Theory

3.1 Project element

This section Serves as a foundational exploration of key concepts and components that lay the groundwork for the project. It delves into the intricate world of Human Digital Twins, Avatars, Dashboards, and Data Visualization, offering an in-depth understanding of these critical elements that underpin the project's theoretical framework. Examining these facets establishes a strong foundation for the subsequent chapters, where I will delve deeper into their respective roles and significance within the context of the dissertation's research and analysis.

3.1.1 Human digital twins

Recent research has explored the potential of Human Digital Twins (HDTs) in stroke rehabilitation applications. For example, a study examined the applicability of digital twins for home remote motor rehabilitation (Falkowski et al., 2023), demonstrating the potential of HDTs to enable remote rehabilitation and improve therapy outcomes. Another study surveyed the use of digital twin coaching for physical activities (Gámez Díaz et al., 2020), highlighting the potential of HDTs to provide personalised feedback and guidance during rehabilitation exercises. Hussain and his colleagues (2021) developed a healthcare digital twin for the diagnosis of stroke, which leveraged machine learning techniques to identify stroke cases and predict patient outcomes. Finally, a systematic review explored the use of HDTs for behaviour-changing therapy and rehabilitation (Lauer-Schmaltz et al., 2022), highlighting their potential in providing personalised treatment and support for stroke rehabilitation. These studies demonstrate the broad range of applications for HDTs in stroke rehabilitation, from remote rehabilitation to personalised coaching and diagnosis, highlighting the potential of this technology to improve therapy outcomes and patient care.

3.1.2 Avatar

Avatars are digital representations of human beings that can be used to simulate the patient's body movements and provide real-time feedback on their performance. Recent research has investigated the potential of avatars for stroke rehabilitation applications. The study conducted by Aljaroodi and colleagues (2017) has shown promising results for the use of avatars in stroke rehabilitation, as they can provide a more engaging and immersive rehabilitation experience for patients, leading to improved motivation and adherence to therapy. Another study explored the use of Avatar-Facilitated Therapy and Virtual Reality as a next-generation approach to functional rehabilitation (Benrachou et al., 2020), demonstrating the potential of avatars to enhance patient motivation and engagement in therapy. A third study investigated the use of a virtual avatar to facilitate gait rehabilitation post-stroke (Thikey et al., 2014), showing that the avatar-based approach was effective in improving gait symmetry and patient confidence. Sangani and the colleagues (2020) examined the use of real-time avatar-based feedback to enhance the symmetry of spatiotemporal parameters after stroke, showing that real-time avatar-based feedback can be used as an intervention and improve patient gait parameters. Overall, these studies demonstrate the potential of avatars in stroke rehabilitation to enhance patient engagement and motivation, improve gait symmetry and confidence, and provide real-time feedback to support therapy. The use of avatars for stroke rehabilitation holds promise for the development of innovative, patient-centred approaches to therapy that can improve patient outcomes and quality of life.

3.1.3 Dashboard and Data visualisation

Stroke rehabilitation typically involves both cognitive and physical therapy, and in traditional clinical settings, treatment plans are often developed based on clinical assessments using tools such as the Fugl-Meyer Assessment (FMA) and the Wolf Motor Function Test (WMFT) (Tamayo, Garbaya & Blazevic, 2018). These tools, which are often paper-based, rely on therapists' observations and measurements of patients' motor behaviour during predefined motor tasks within the clinic. However, data visualisation provides clinicians with a more comprehensive view of patients' rehabilitation progress, enabling them to identify areas for improvement and adjust therapy accordingly (Liakopoulou et al., 2021).

Visualising upper limb movement information from stroke patients can be a powerful tool for therapists. There is a study that explores the use of visualisations in therapy sessions and found that they can help therapists better understand their patients' abilities and progress (Ploderer et al., 2016). Similarly, Liakopoulou and colleagues explore the use of data visualisation techniques to display information about patients' progress during robotic rehabilitation exercises. These studies demonstrate the potential of dashboards and data visualisation techniques to improve the effectiveness of stroke rehabilitation. Finally, a paper describes a system that uses a clinician dashboard to provide therapists with real-time information about their patients' progress during game-based rehabilitation exercises (Rahman et al., 2016). By providing therapists with informative and intuitive information about their patients' progress and creating personalised rehabilitation exercises, these technologies can improve the effectiveness of stroke rehabilitation and help individuals make a full recovery from a stroke.

By using advanced visualisation techniques, clinicians can visualise the data produced by exoskeletons and use avatars to display patients' body movements, including arm function and muscle strength. Additionally, a dashboard can be utilised to monitor the therapy management process, allowing healthcare professionals to track patients' progress over time and provide more targeted support.

Now, regarding the use of Human Digital Twins and Avatars, these technologies have the potential to revolutionise how therapists and patients approach stroke rehabilitation. By creating digital representations of patients' movements and abilities, therapists can gain a much deeper understanding of their patients' progress and tailor rehabilitation exercises to their specific needs.

One of the main advantages of using Human Digital Twins and Avatars is that they can provide enhanced visualisation techniques that go beyond simple graphs or observation. For example, 3D models of patients' movements can be used to show the range of motion in a joint or the angle of a limb during an exercise. These models can also be used to simulate different scenarios and show how patients would perform in different situations.

Another advantage of using Human Digital Twins and Avatars is that they can be used to create personalised rehabilitation exercises that are tailored to the patient's specific needs. By analysing data from sensors and other sources, therapists can create exercises that are designed to target specific areas of weakness or to challenge the patient in new and innovative ways.

Overall, I believe that using Human Digital Twins and Avatars can significantly enhance the effectiveness of stroke rehabilitation and provide therapists with the intuitive and informative information they need to help their patients make a full recovery.

3.2 UX/UI design

Within the realm of emerging healthcare technology, the synergy between User Experience (UX) and User Interface (UI) design becomes increasingly paramount, encompassing the interactions between users and the evolving landscape of healthcare products and services. In this section, we will embark on a comprehensive journey, unraveling the multifaceted dimensions of Healthcare UX/UI, Dashboard Design, Telemedicine Integration and the Role of Colors in shaping the user experience within healthcare technology.

3.2.1 Healthcare UX/UI

The goal of UX design is to create seamless and meaningful experiences by understanding user needs, conducting market research, and incorporating design strategies (Schmidt et al., 2017). To design effective healthcare products and services, it is essential for designers to identify the target users, the environment in which the device will be used, and other relevant characteristics. Understanding these factors allows medical devices to be developed as safe and efficient products that are accepted by users (Anastasia Rezhepp, 2022). The European Union (EU) Commission's eHealth Action Plan (2012 - 2020) acknowledges the need for user-friendly healthcare technology, particularly considering the challenges faced by older users. Cognitive barriers, such as difficulty reading minimal text, pose significant challenges.

Several general requirements have been identified through research to guide the design of helpful healthcare services or products, including easy access for patients and healthcare providers, synchronisation with existing systems, the use of light and calm colours and symbols, adjustable layout settings, provision of audio and text suitable for speech-disabled patients, limiting options and information overload, inclusion of instructional videos, help, and support features, consideration of communication preferences of patients and health professionals, provision of both general and complex information, information about training plans and agreements, and feedback on goals (Matt Sharritt, 2021; Anastasia Rezhepp, 2022; Tremosa, 2022).

3.2.2 Dashboard design

In the realm of healthcare, especially in the context of stroke therapy management, the design of digital dashboards plays a pivotal role in transforming complex data into actionable insights. Dashboards serve as the central hub where patient information is visualised, analysed, and communicated.

At the heart of dashboard design is the objective of making intricate data understandable at a glance. In the context of stroke rehabilitation, this means that therapists can swiftly grasp a patient's progress, identify trends, and make informed decisions regarding their therapy regimens.

To achieve this, dashboard design principles prioritise user-centricity. The user experience (UX) and user interface (UI) are meticulously crafted to ensure that therapists can easily navigate through the dashboard, access relevant information, and interpret data effectively.

Key elements of effective dashboard design include:

1. Data Visualization: Complex patient data, including mobility scores, exercise routines, and progress trends, are presented visually. Graphs, charts, and interactive visual elements simplify the comprehension of data.
2. Real-time Updates: Dashboards provide real-time updates, ensuring that therapists have access to the most current information about their patients' conditions and therapy sessions.
3. Customization: Therapists often have specific preferences and priorities when it comes to data. Effective dashboard design allows for customization, enabling therapists to tailor the display to their needs.
4. Accessibility: Accessibility features ensure that the dashboard is usable by therapists with varying levels of technical expertise or those with disabilities.
5. Security: Given the sensitive nature of patient data, robust security measures are in place to protect patient privacy and maintain compliance with healthcare regulations.

In summary, dashboard design in stroke therapy management aims to empower therapists with a tool that simplifies the interpretation of complex patient data.

By adhering to UX/UI design principles and prioritising user-centricity, these dashboards enhance the overall quality of care, support data-driven decision-making, and contribute to improved patient outcomes.

3.2.3 Data visualisation

Data visualisation plays a critical role in healthcare technology. Gotz and Borland (2016) emphasises the need for interactive visualisation techniques to effectively analyse and interpret complex healthcare data. The authors highlight the potential of interactive visualisations in enabling healthcare professionals to gain insights, identify patterns, and make informed decisions for patient care. Effective data visualisation techniques enable the representation of complex patient data in a visually intuitive manner, allowing therapists and healthcare professionals to gain meaningful insights. Khan and his colleagues (2017) present a case study that demonstrates the use of various visualisation techniques, such as scatter plots and heatmaps, to facilitate data exploration and analysis, can enhance user understanding, support decision-making, and improve overall usability of healthcare systems. The study of Stadler (Stadler et al., 2016) discusses the design considerations for effective dashboard development, including data integration, visualisation techniques, and user interface design. They showcase the potential of dashboards in enabling quick and efficient analysis, leading to more informed decision-making and improved healthcare outcomes.

Through well-designed data visualisations, healthcare professionals can gain valuable insights from complex data sets, facilitating informed decision-making and personalised treatment plans.

3.2.4 Telemedicine

Telemedicine, enabled by UX/UI design, has ushered in a transformative era in healthcare. It has effectively dismantled geographical barriers, granting individuals access to medical care like never before (Wootton, 2001; Grigsby & Sanders, 1998). With telemedicine, people can engage in remote monitoring, consultations, and therapy sessions, all from the comfort of their homes. This approach prioritises convenience and accessibility.

At the heart of telemedicine's success lies the role of UX/UI design. These design principles ensure that telemedicine applications provide seamless user experiences. Whether it's a virtual consultation with a doctor or a therapy session, the design focuses on making the interaction between patients and healthcare providers as smooth as possible (Perednia & Allen, 1995). This involves creating intuitive interfaces, enabling real-time data sharing, and guaranteeing the security of patient information. In essence, telemedicine applications are designed to facilitate effective and efficient healthcare interactions, ultimately benefiting patients, including those recovering from strokes.

3.2.5 Colours

Colours play a significant role in UX/UI design, influencing user perceptions, emotions, and engagement (Kondratova & Goldfarb. 2007). In healthcare technology, including the Human Digital Twin for stroke therapy management, colour choices should be carefully considered. Colours can be utilised to convey information, highlight key data points, or evoke specific emotions (Ismail et al., 2021), as demonstrated in Table 3.1.

Colour	Emotion
Red	Anger and excitement
Green	Peaceful and calm
Yellow	Happy and cheerful
Blue	Calm and comfort
Black and gray	Sad, despondence and depression

Table 3.1: Colours and their corresponding emotions

For instance, selecting a calming colour palette may induce feelings of relaxation and comfort during therapy sessions. However, it's crucial to note that the interpretation of colours can vary across cultures. In some cultures, red may symbolise luck and happiness, while in others, it may signify danger or anger(Singer & Graciela, 2016). Similarly, the colour white can represent purity in some cultures and mourning in others(Yu, 2014). Therefore, when designing UX/UI elements for a global audience, it's essential to consider these cultural differences to ensure that the chosen colours convey the intended message and emotion accurately.

Furthermore, when contemplating colour choices, designers must also account for contrast and colour accessibility. Ensuring that interfaces are inclusive and usable by individuals with visual impairments is paramount. High contrast between text and background colours aids readability, while providing alternative colour schemes for individuals with colour blindness can enhance accessibility.

In summary, thoughtful colour selection in UX/UI design contributes significantly to creating a visually pleasing and user-friendly experience. However, it's vital to recognize that cultural nuances in colour interpretations exist and should be considered in a global context to ensure that the design effectively communicates and resonates with users from diverse cultural backgrounds, ultimately enhancing the overall effectiveness of stroke therapy management through the Human Digital Twin.

4

Methodology

The methodology employed in this thesis project embodies a strategic fusion of Interaction Design (IXD), User Experience (UX) research, and Visualization principles. The selected methods were thoughtfully chosen to collectively address the research questions and construct a design that seamlessly harmonises user needs, functionality, and data visualisation, ensuring the design's efficacy and user-friendliness.

4.1 Discover and define

In the initial stages of this project, we employ a set of essential methodologies to lay the groundwork for a user-centred and effective solution in stroke rehabilitation. To understand the multifaceted landscape of stroke therapy management comprehensively, we turn to a trio of research methods: Literature reviews, Persona creation, and User journey mapping. Each of these methods plays a pivotal role in gaining insights into the needs, preferences, and challenges faced by therapists, stroke patients, and other stakeholders. By leveraging these techniques, we aim to build a solid foundation of knowledge that will inform and guide the subsequent phases of the project, ensuring that the final solution is thoughtfully designed and tailored to the unique requirements of those it serves.

4.1.1 Literature reviews

Literature reviews are used to collect and synthesise research on the topic(Hanington et al., 2019). This methodology serves as a cornerstone for informed decision-making in the design of the dashboard By analysing existing research, this approach offers a comprehensive understanding of established design patterns, existing technology in rehabilitation and similar products, and effective data presentation techniques in Visualization. This method aligns with the project's goals by guiding design choices based on industry best practices and academic rigour, while also identifying opportunities for innovation. Ultimately, literature reviews provide a robust foundation that unifies these domains, enabling the project to advance creatively in the realm of dashboard design for stroke rehabilitation.

4.1.2 Persona

Persona is a methodology that builds a model to illustrate user behaviour patterns into representative profiles, and to humanise design focus, test scenarios, and aid design communication (Gothelf, 2013). It serves as a human-centred tool that encapsulates user behaviour, needs, and aspirations. Persona facilitate empathetic design by grounding the process in therapists' roles, challenges, and preferences, ensuring the creation of user interfaces that intuitively resonate with their expectations. This methodology bridges the gap between abstract data and tangible design elements, aiding UX decisions and addressing real-world pain points, while also providing insights into therapists' data perception and interpretation patterns, which align with their cognitive processes and decision-making, thereby enhancing the effectiveness of data visualisation in the project's scope.

4.1.3 User Journey map

The user journey map methodology serves as a potent instrument that visually portrays therapists' comprehensive engagement with the dashboard. This approach systematically traces therapists' interactions, emotional states, pain points, and pivotal decisions throughout their dashboard experience, illuminating their workflow and expectations. This methodology aids in designing interfaces that align with therapists' cognitive models, fostering user-friendly interactions, and elevating usability. Furthermore, by highlighting emotional states and pain points, user journey maps ensure a design that empathetically addresses therapists' needs and cultivates a positive user experience. Collectively, the user journey map methodology empowers the user-centred approach by offering a nuanced narrative of therapists' interactions, fostering interfaces that seamlessly resonate with their expectations, emotions, and workflow intricacies, and consequently, bolstering operational efficiency, user satisfaction, and effective data visualisation.

4.2 Ideation

The ideation phase is where the project starts taking shape. We're transitioning from understanding the problem to designing solutions. In this phase, we employ two crucial methods: Card sorting for information architecture and creating a Requirement list. These methods help us structure our ideas and decide what the final product should include. Card sorting helps us organise information logically, and the Requirement list ensures we don't miss any important features. These methods guide us in creating a solution that meets the specific needs of therapists and stroke patients. So, in this phase, we're moving from ideas to concrete plans, and these methods are our tools for doing that effectively.

4.2.1 Card sorting(information architecture)

Incorporating card sorting within the ideation phase strategically refines the dashboard's information architecture. This method involves organising content elements into meaningful categories, revealing insights into users' mental categorization patterns. By deciphering users' preferences and information categories, card sorting empowers the project to structure information in a manner that resonates with therapists, optimising navigational efficiency and overall usability. It contributes to coherent information grouping, facilitates intuitive navigation, reduces cognitive load, and enhances therapists' ability to interpret data through tailored visualisations.

4.2.2 Requirement list

The integration of a requirement list methodology during the ideation phase embodies a structured approach to distil and prioritise essential dashboard features and functionalities. This collaborative method gathers, organises, and evaluates stakeholders' needs, creating a clear development roadmap. By delineating specific requirements, it ensures that the design resonates with stakeholders' objectives, guiding decision-making and fostering a comprehensive design outcome. It forms a solid foundation for creative design solutions that meet stakeholder needs, resulting in an intuitive interface, user satisfaction, and tailored data visualisation.

4.3 Design

During the Design phase, the project enters a hands-on stage, where the conceptual ideas are translated into tangible solutions for stroke rehabilitation. This phase employs two primary methods: Prototyping and Data Visualization. Prototyping enables the creation of interactive models, allowing for a practical examination of how the solution will operate. On the other hand, Data Visualization serves to represent intricate datasets in a comprehensible manner, aligning with principles of human-computer interaction and enhancing user understanding. These methodologies facilitate the crafting of a solution that not only functions effectively but also prioritises user-friendliness.

4.3.1 Prototyping

The design method of prototyping is to To build a creation for development and testing of ideas within design teams and with clients and users (Polaine, 2013). It includes both low fidelity prototyping and high fidelity prototyping. Embedded within the Design phase, the prototyping design methodology offers a pragmatic and iterative approach to translate conceptual ideas into tangible dashboard interfaces. By creating interactive prototypes that simulate user interactions and functionalities, prototyping facilitates early validation and refinement. It empowers designers to showcase user interactions, enhance usability, and fine-tune data visualisation techniques. Prototyping's dynamic exploration and user-centric engagement foster a comprehensive interface that effectively bridges stakeholder needs and design aspirations, shaping an interface that resonates with usability principles, user expectations, and data communication requirements.

4.3.2 Data visualisation

The use of data visualisation is to aid the discovery of important relationships among content and inform meaningful narratives that move people through information(Hanington et al., 2019). By visualising patients data, it enhances therapists' comprehension of patient progress and therapy responses, enabling informed decision-making, facilitating effective communication among stakeholders, supporting predictive analysis, and empowering a comprehensive approach to stroke therapy management. Data visualisation not only simplifies intricate data but also fosters collaborative and evidence-based strategies, underlining its pivotal role in revolutionising stroke therapy management.

4.4 Testing

The Testing phase assumes a pivotal role in the project, as it involves a comprehensive evaluation of the dashboard for stroke rehabilitation we have designed. In this phase, three distinct yet interconnected methodologies come to the fore: Focus Group sessions, Think-Aloud Protocols, and Questionnaires. These methods collectively serve the purpose of gathering extensive feedback and insights from therapists, ensuring their perspectives and experiences are thoroughly considered in the assessment process. Through the implementation of Focus Groups, we facilitate group discussions to gain an understanding of broader perceptions and opinions. Think-Aloud Protocols provide valuable insight into the thought processes of therapists as they engage with our solution. Finally, Questionnaires offer a structured avenue for assessing satisfaction and gathering specific feedback. The Testing phase is the critical moment for assessing the viability and functionality of the dashboard, and these methodologies serve as the instruments for rigorous evaluation and refinement.

4.4.1 Focus group

Focus group is a design method that is used to gather qualitative data and insights by conducting a group discussion with therapists (Hanington et al., 2019). This method was chosen for testing the first prototype due to its inherent ability to capture nuanced feedback and foster dynamic interactions. Focus groups facilitate open dialogues among therapists, enabling the exploration of diverse perspectives, potential pain points, and valuable suggestions. By conducting group discussions, this method taps into collective expertise, highlighting both individual experiences and shared concerns. The choice of focus groups aligns with the goal of holistically evaluating the prototype's user-friendliness, functionality, and data visualisation effectiveness. Moreover, this method encourages a collaborative atmosphere that allows therapists to brainstorm potential improvements, further enriching the iterative design process and ensuring the interface resonates harmoniously with their needs and expectations.

4.4.2 Think-aloud protocol

Think-aloud protocol is used to gain insight into a therapist's thought process and decision-making while performing a task or interacting with the dashboard (Hanington et al., 2019). This method was selected to assess the final prototype due to its unique ability to uncover the intricacies of therapists' experiences in real-time. As therapists navigate the interface and engage with data visualisations, verbalising their thoughts provides direct insights into what catches their attention, how they interpret visualisations, and any challenges encountered. This method facilitates a comprehensive assessment of the dashboard's usability, data interpretation, and user-friendliness. By capturing unfiltered insights into therapists' interactions, the think-aloud protocol guides refinements that align the final prototype with their expectations and cognitive processes. This approach ensures that the dashboard not only meets functional requirements but also resonates intuitively with therapists' mental models, ultimately culminating in an interface that empowers effective stroke therapy management.

4.4.3 Questionnaire

The incorporation of a questionnaire in prototype evaluation involves administering structured surveys to therapists, gathering quantitative and qualitative feedback on their experience with the final prototype. This method was chosen to comprehensively assess the prototype's usability, effectiveness, and data visualisation impact. Questionnaires provide a systematic approach to collect feedback from a larger sample of therapists, ensuring a diverse range of perspectives are considered. By utilising both Likert-scale ratings and asking open-ended questions at the discuss session, this method allows for nuanced insights into various aspects of the prototype. It facilitates the measurement of user satisfaction, ease of use, and perceived value of data visualisation. Moreover, questionnaires offer a standardised approach to gather feedback, making it possible to compare responses and identify patterns. The method's scalability and structured nature align well with the objective of assessing the final prototype's impact across a broader therapist audience, contributing to the validation of design decisions and refinement of the interface based on aggregated insights.

5 Planning

The study plan will be implemented in several stages, including user research, interface design, and testing and evaluation.

1. Define the user requirements and goals for the interface, including user needs and priorities, desired functionality, and performance expectations.
2. Conduct user research or through literature reviews to gain a deeper understanding of the needs and expectations of therapists using the solution.
3. Create wireframes and prototypes to explore and test different interface design options and interactions.
4. Refine the interface design based on feedback and testing, ensuring that it meets the needs of the user and achieves the goals of the solution.
5. Develop and implement a comprehensive visual design system, including typography, colour, and iconography, to create a cohesive and attractive interface.
6. Test and iterate the design to ensure that it is accessible, user-friendly, and functional, and makes the most effective use of the visualised patient data.

As shown in table 5.1 The plan is scheduled as below:

Data	Plan	More information
Week 8 - 10	thesis Proposal	
Week 10 - 11	Define user requirements and goals for the interface Planning report	
Week 11 - 12	Literature review, Planning report, Prototyping	Conduct user research or literature review; Begin creating wireframes and prototypes.
Week 12 - 13	Prototyping, Visual design system, Final report writing	Continue refining wireframes and prototypes; Start developing visual design systems; Start writing a paper report.
Week 14 - 17	Prototyping, Visual design system, Final report writing	Finalise wireframes and prototypes; Complete visual design system.
Week 18 - 21	Testing, Evaluation, Final report writing	Begin testing and iterating the design; Refine interface based on feedback and testing.
Week 22 - 24	Final report writing, Presentation	Finalise testing and iteration of the design; Prepare final deliverables for thesis submission.

Table 5.1: Study plan

This timeline provides a more detailed breakdown of the steps and timeline involved in the implementation plan based on academic weeks. Again, it may need to be adjusted based on the specific needs and requirements of the project.

6

Execution and Process

The ReHyb project has been underway for several years, and previous students have already designed existing dashboards. However, as the exoskeleton keeps developing and evaluation from usability testing, there is a continuous demand for improvement and evaluation of these dashboards. The purpose of my master's thesis mainly focuses on redesigning the patient management system for the therapist's dashboard, and creating more comprehensive data visualisations to effectively communicate patient data collected through digital twin technology to support therapists in making informed decisions about stroke therapy.

To guide the design process, I will adopt a user-centred design approach. User-centred design focuses on understanding the needs and preferences of the end-users of a product or service (Chammas et al., 2015; ISO & STANDARD, 2010). This approach actively involves users throughout the design process, ensuring that the final product meets their needs and is easy to use (See figure 6.1).

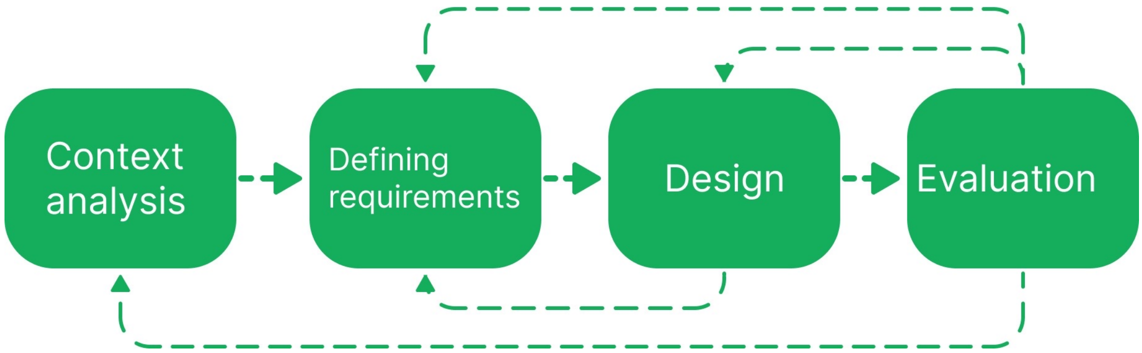

Figure 6.1: User-centred design approach

In the context of stroke rehabilitation, user-centred design approaches can be applied to develop tailored rehabilitation interventions that address the unique requirements of stroke survivors and their caregivers. By incorporating the preferences and goals of the users, interventions based on user-centred design have the potential to enhance motor behaviour and facilitate the achievement of life goals for stroke survivors (Mawson et al., 2014).

6.1 Discover and Understanding

6.1.1 Persona

In the design process of the ReHyb project, the persona (Gothelf, 2013) and scenarios (Hanington & Martin, 2019) design methods are utilised to ensure a user-centred approach. Figure 6.2 shows one persona that was created for this project that shows a general picture of a therapist, and the goals and challenges they faced in the therapy process.

Creating the therapist's persona involves gathering key information to construct a representative profile. Initially, we collect general information, including age, education, and position. In Sweden, physiotherapists typically hold a bachelor's degree as a prerequisite for their profession (Physiopedia, 2017). Additionally, we assume other demographic details based on this foundation.

In terms of technology, therapists often rely on devices like laptops and PCs in clinical settings. They also utilise mobile phones or telephones for remote communication with patients and caregivers.

Next, we delve into the therapist's goals, encompassing both professional and personal aspirations. These objectives shape their actions and decisions within and outside of the workplace.

Challenges, on the other hand, are derived from a combination of literature research and an understanding of the current landscape. For instance, Piselli and colleagues (2011) have highlighted the difficulties therapists face in effectively communicating with patients and managing unexpected session terminations. These challenges serve as valuable insights when crafting the therapist's persona.

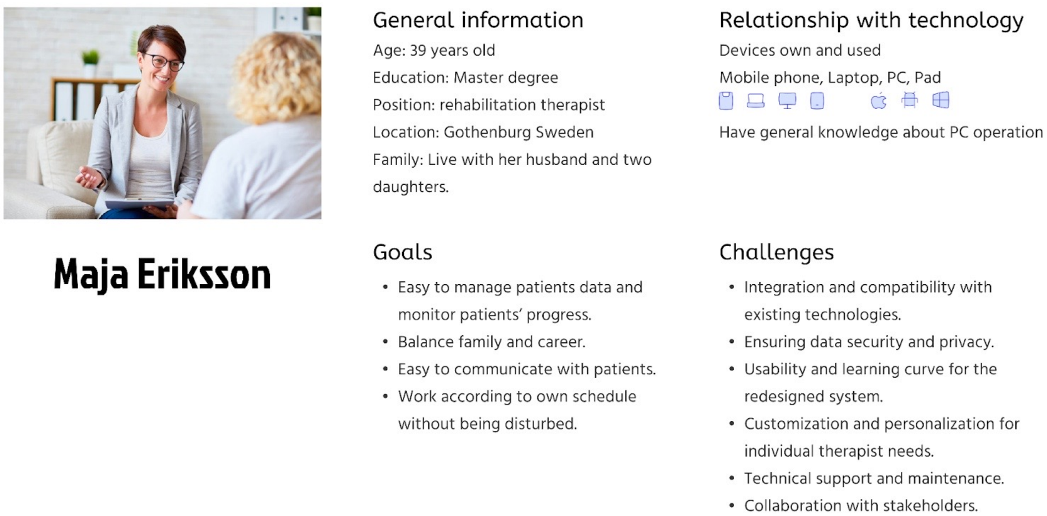

Figure 6.2: Therapists Persona

The utilisation of personas, such as the one representing Maja, a therapist, plays a pivotal role in addressing these research questions. By embodying the characteristics, goals, and challenges of a typical therapist, personas humanise the design process, ensuring that design decisions directly cater to the needs and expectations of end-users—therapists in this case. The persona Maja provides a relatable face to the challenges therapists encounter in stroke rehabilitation and visualises the context in which data visualisation and communication matter most. This methodology prioritises user-centricity by continually referencing Maja's persona throughout the project, enabling the design process to consistently align with the specific needs identified in the RQs. Consequently, the ReHyb project can ensure that features and functionalities are prioritised based on Maja's requirements, thereby enhancing the user experience and addressing the core research questions concerning data visualisation, functionality, and human-computer interaction in stroke therapy management.

6.1.2 User journey map

The customer journey map outlines the stages that a user will go through when using the stroke rehabilitation system as shown in figure 6.3.

The first stage is Awareness and Consideration, where potential users learn about the system and consider whether to use it. The next stage is Initial Onboarding, where users sign up and are introduced to the system. Using the Service is the third stage, where users start using the system and engage with the various features, including exoskeletons, serious games, and patient dashboards. The fourth stage, Progress Tracking and Adjustments, is where users can track their progress over time and make adjustments to their rehabilitation plan based on the data that is collected by exoskeleton with the help of their therapist. Finally, the Advocacy stage is where users who have had a positive experience with the system become advocates and share their experience with others. Throughout the customer journey, This system will enhance the user experience by providing personalised exercise plans, tracking progress, and providing insights and recommendations to therapists for more effective rehabilitation.

The customer journey map outlines a seamless experience for patients, their families, and healthcare providers. Patients are able to track their progress, receive guidance, and communicate with their therapists and caregivers. The use of data visualisation enhances the value of the service by providing personalised exercise plans and progress tracking. This project shed light on the opportunities and challenges of using Human digital twins for stroke rehabilitation, particularly in terms of data visualisation and communication. It aligns with the sub-research question regarding how data from the digital twin is visualised in an understandable way. The map illustrates how patients track their progress and receive personalised exercise plans, emphasising the importance of comprehensible data presentation. The project also has potential ethical implications, such as privacy concerns, misuse of data, and disparities in access to the technology. However, with careful consideration and implementation, the Rehyb project has the potential to positively impact stroke patients' rehabilitation outcomes and improve their quality of life.

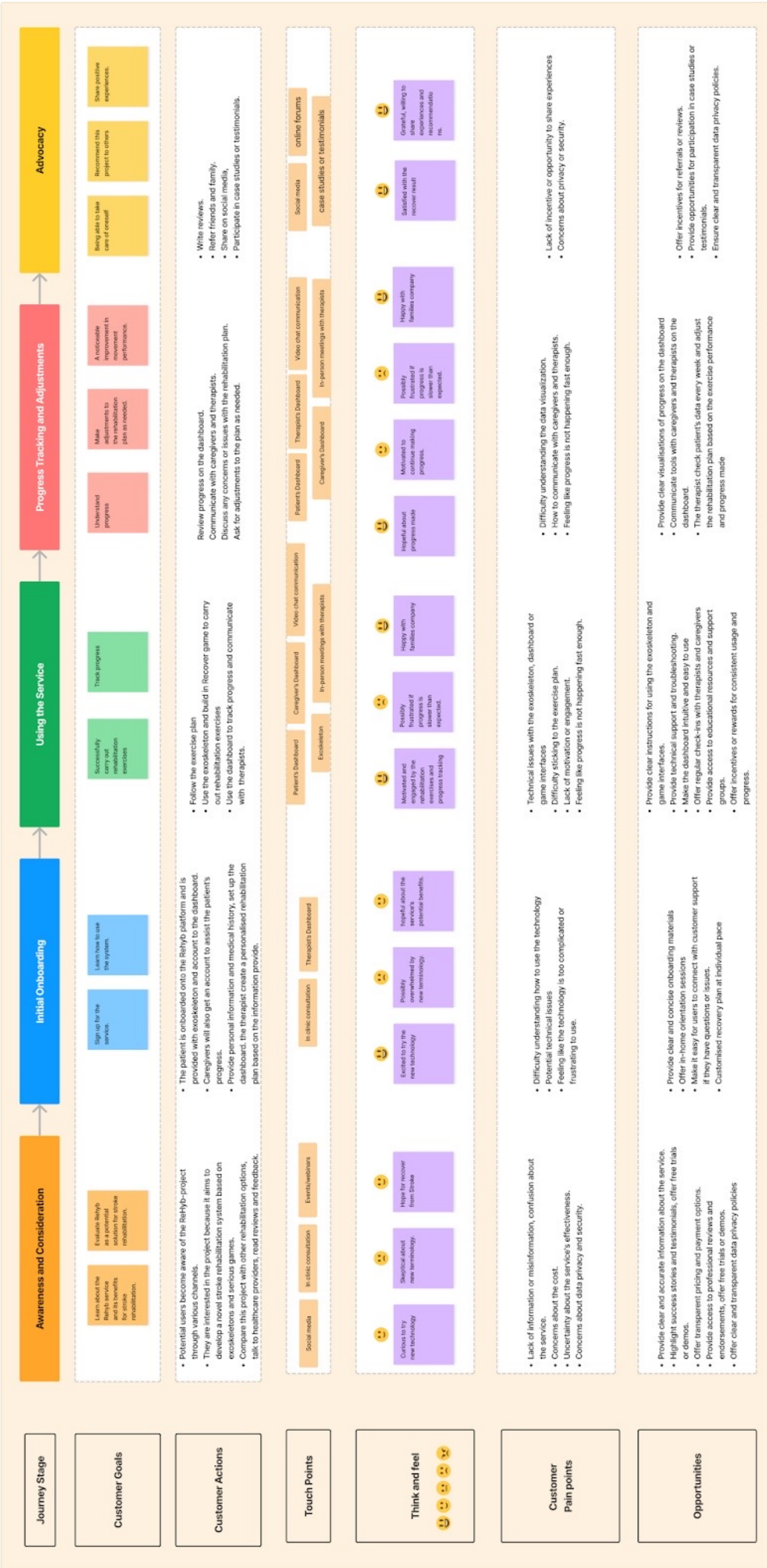

Figure 6.3: Customer journey map of a Stroke ReHyb project

6.2 Ideation and Define requirements

6.2.1 List of redesign requirements

For the redesign of ReHyb therapist's dashboard, a requirements list was collected based on literature review and the understanding of persona and scenarios of therapists. It serves as a comprehensive document that identifies and articulates the specific needs and expectations of the project stakeholders, including rehabilitation therapists, patients, and third-party caregivers.

The requirements list was divided into three parts as the architecture shows (see Appendix 1). This requirements list is regularly reviewed with the progress of this project, to maintain a focus on user-centred design and ensure the successful realisation of the ReHyb project's goals.

The requirements list plays a vital role in addressing sub-RQ 3 by specifying the necessary design elements, features, and functionalities that should be integrated into the dashboard to enhance its understandability and facilitate effective human-computer interaction. By systematically collecting and articulating the needs and expectations of various project stakeholders, including rehabilitation therapists, the list serves as a roadmap for ensuring that the redesigned dashboard aligns with user-centred design principles.

In essence, the requirements list becomes a crucial tool for translating the insights gained from user research and personas into actionable design elements and functionalities that support the communicated data, ultimately contributing to improved understandability and more seamless interactions within the dashboard. It ensures that the design choices are driven by the specific needs and expectations of the users, which is essential for achieving success in terms of human-computer interaction and the overall user experience.

6.2.2 Card Sorting - Information architecture

For the purpose of organising and arranging information in a logical and coherent manner, ensuring easy navigation and comprehension for the end-users, the card sorting method was used. Card sorting is a participatory design technique that involves having participants group and categorise concepts or terms to explore relationships and potential misunderstandings in digital interface design or content organisation (Hanington & Martin, 2019). By this method an information architecture of the patient management system was created. It serves as the backbone of the design, determining how functions, informations are categorised, grouped, and presented to the users.

Figure 6.4 depicts three main components of patient management: Patient Overview, Visualization, and Exercise Plan. Each part encompasses detailed information and functions related to its respective topic, which are organised based on their importance and the relationships between the items, facilitating a cohesive and connected system. The cards utilised in this approach are derived from the requirements list, which encompasses all the functionalities to be included in the initial prototype of the patient management system.

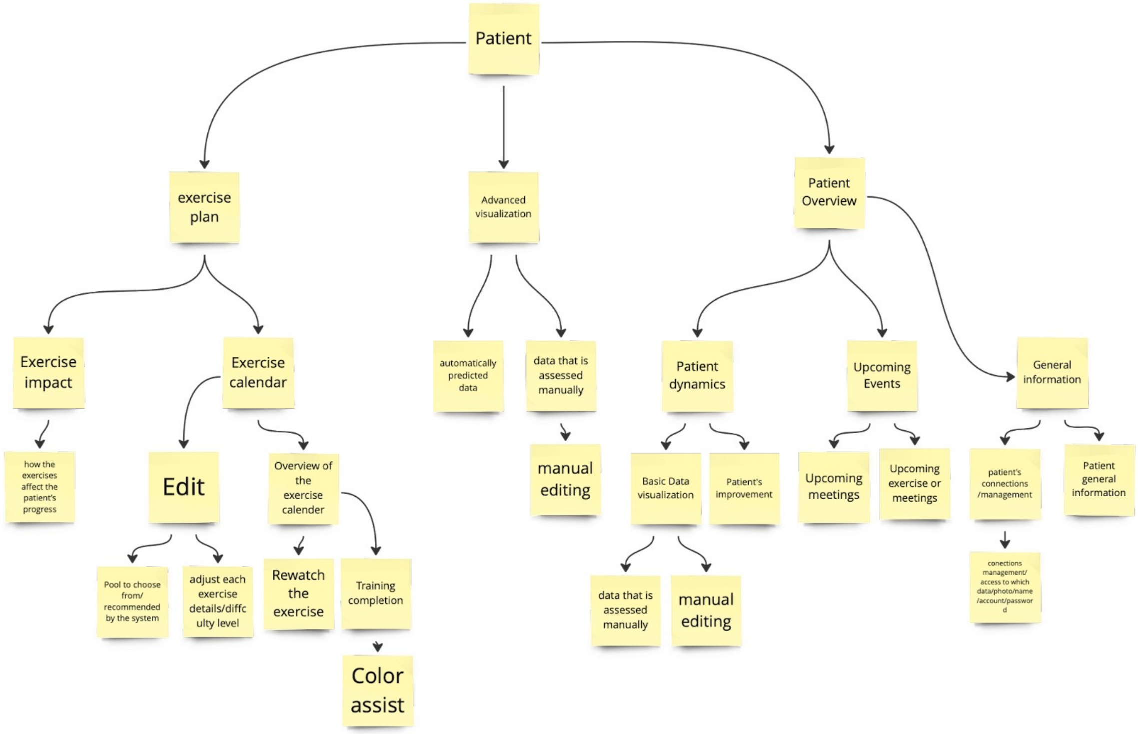

Figure 6.4: Information architecture of patient management

In the context of sub-research question 2, which seeks to identify the most important features and functionality desired by therapists in a solution for visualising patient data for stroke therapy management, card sorting aids in the organisation and categorization of these features. By involving participants in grouping and categorising concepts or terms, the method helps uncover how therapists perceive the importance and relationships of different features, contributing to the prioritisation and design of the patient management system.

Moreover, with regard to sub-research question 3, which focuses on design elements, features, and functionalities that support the communicated data regarding understandability and human-computer interaction, card sorting directly informs the information architecture of the system. It dictates how functions and information are categorised and grouped, which is crucial for enhancing understandability and usability. Card sorting ensures that the resulting design elements and functionalities are structured in a coherent and logical manner, ultimately supporting effective human-computer interaction.

6.3 Design

6.3.1 Lo-fi prototyping-paper sketch

To efficiently convey the design concepts, we utilised paper wireframe sketches for testing, idea validation, and feedback gathering. The Lo-fi prototypes served as tangible representations of the proposed system, facilitating stakeholder discussions, promoting collaboration, and aiding in the early identification of potential usability concerns. Leveraging the iterative nature of Lo-fi prototyping, we conducted swift design iterations, guaranteeing that the final product met the requirements and expectations of rehabilitation therapists and other end-users involved in the ReHyb project. The basic idea of the therapist's dashboard can be visualised in Figure 6.5.

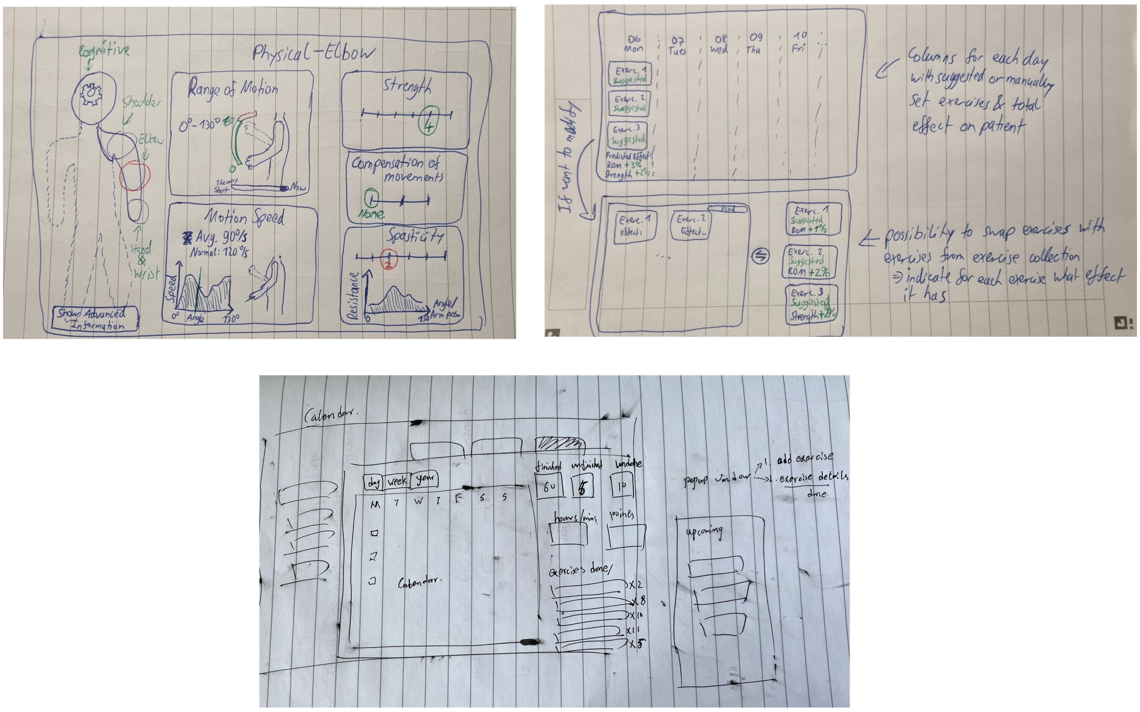

Figure 6.5: Lo-Fi prototyping

6.3.2 Visual system

Once a conceptual design was selected, each channel of the concept was further developed through a meticulous visual design phase. This encompassed refining elements such as text style, colour scheme, and UI components. A cohesive visual system was employed throughout the design process to ensure consistency and harmonious aesthetics across the various components of the ReHyb project. The visual system encompassed principles of typography, colour theory, and UI design guidelines to create a visually appealing and user-friendly interface.

6.3.2.1 Typography

The choice of using "Helvetica" as the typography for the ReHyb therapist's dashboard was driven by several factors. Firstly, Helvetica is a highly versatile and widely recognized typeface known for its clean and legible design. Its neutral and modern aesthetic makes it suitable for various applications, including digital interfaces. Secondly, the use of Helvetica helps ensure readability and clarity of the displayed information. The clean and balanced letterforms contribute to a visually pleasing and professional appearance, enhancing therapists could focus on the content without distraction. Additionally, Since the therapists will work in different environments with different devices, helvetica's flexible nature allows for easy scaling and adaptation across different screen sizes and resolutions, ensuring consistency and legibility across various devices and a responsive design approach. Figure 6.6 shows different levels of text with its font, weight and size that are applied in the dashboard design process.

Font

Level	Font	Weight	Size
Special words	Helvetica	Bold	20
Headline 1	Helvetica	Bold	20
Headline 2	Helvetica	Bold	18
Title	Helvetica	Regular	18
Body	Helvetica	Regular	14
Button	Helvetica	Regular	14

Figure 6.6: Typography

6.3.2.2 Colour theory

In the dashboard design process, colour theory was employed strategically to enhance user experience and convey meaning effectively. Various colours were assigned specific roles and functions based on their psychological associations and visual hierarchy.

As shown in figure 6.7, Blue was selected as the main colour for the dashboard and clickable elements. Blue is commonly associated with trust, stability, and reliability. By using blue, the design aimed to instill a sense of calm in users and a clean, tidy interface. Two shades of light blue were chosen as sub-colors to complement the main blue. These lighter shades were used to visually support and complement the main colour, mainly for the background of the dashboard, buttons, block elements, data, etc., creating a harmonious and visually pleasing colour palette. Dark grey was employed for the main text, providing optimal legibility and readability. Its neutral and subdued nature made it suitable for presenting essential content and maintaining a visually balanced composition. Light grey was used for the sub-text. This distinction helped differentiate secondary information and create a visual hierarchy within the text elements, making it easier for users to scan and comprehend the content. Orange was utilised to draw attention to messages, news, and important information, as it is often associated with urgency and alerts. This colour choice helped ensure that such critical elements stood out prominently within the dashboard interface. Additionally, green, yellow, and red were employed to help identify and signify different process stages or statuses. These colours are commonly associated with positive, cautionary, and critical indicators, respectively, allowing users to quickly grasp the state or progress of a particular process.

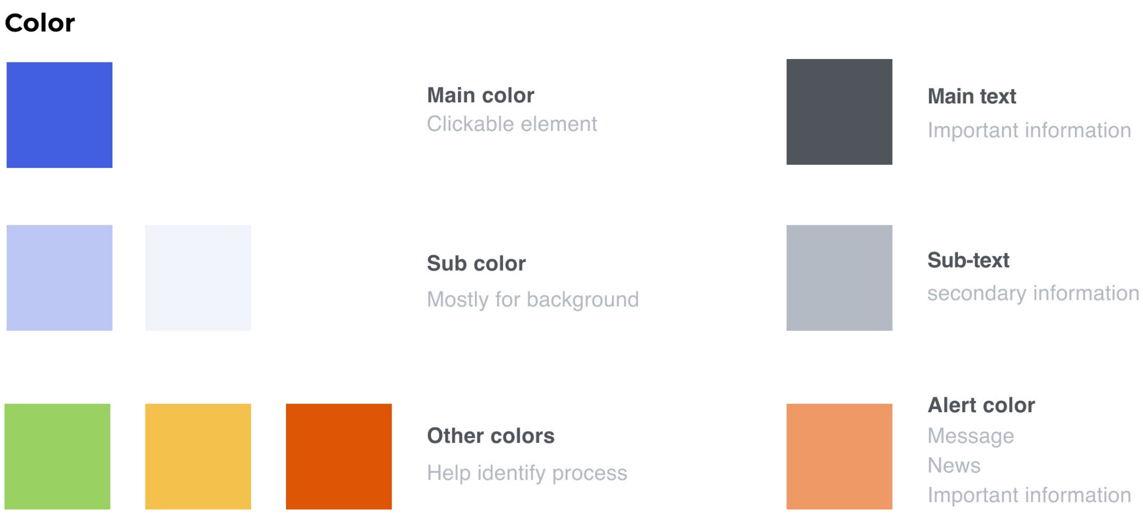

Figure 6.7: Colour theory

6.3.2.3 UI elements

The UI components served as building blocks for the overall design, providing a unified look and feel across different screens and functionalities. Components such as buttons, input fields, drop-down menus, and cards were designed with attention to detail, following established design patterns and best practices.

The interface is designed to fit a size of 1920 × 1080 pixels, providing an optimal visual experience. Detailed design specifications for the UI elements of the therapist's dashboard can be observed in Figure 6.8.

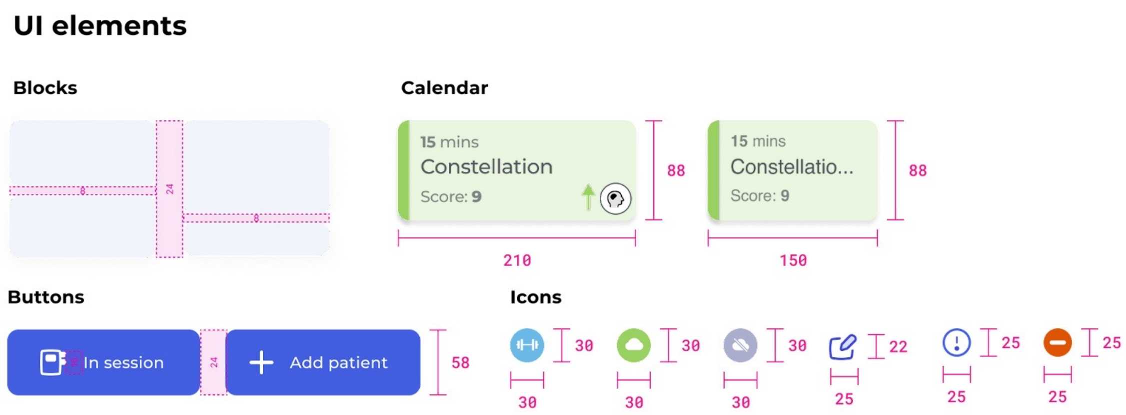

Figure 6.8: UI elements

6.3.3 Hi-fi prototyping

The general design concept of the therapist's dashboard in the first version of Hi-fi prototypes prioritised current design trends and UX design principles while focusing on meeting the specific needs of therapists. A “F” structure was adopted to support users in quickly and efficiently finding the information they need. The "F" structure is a design concept that refers to the pattern in which users typically scan and navigate a webpage or dashboard. It is based on the eye-tracking behaviour of users, where the scanning pattern often follows an "F" shape (Shrestha & Lenz, 2007). The dashboard design concept emphasised simplicity, user-friendliness, and efficient navigation, with further detailed design descriptions provided on separate parts below.

6.3.3.1 Home

The home page serves as the initial landing page for therapists after they log in, offering them a comprehensive overview of their own activities and the activities of their patients. The home page acts as a central hub, providing therapists with at-a-glance insights into their schedules, patient progress, and important notifications. It serves as a starting point for therapists to efficiently navigate and manage their daily tasks, promoting productivity and streamlined workflow within the ReHyb project.

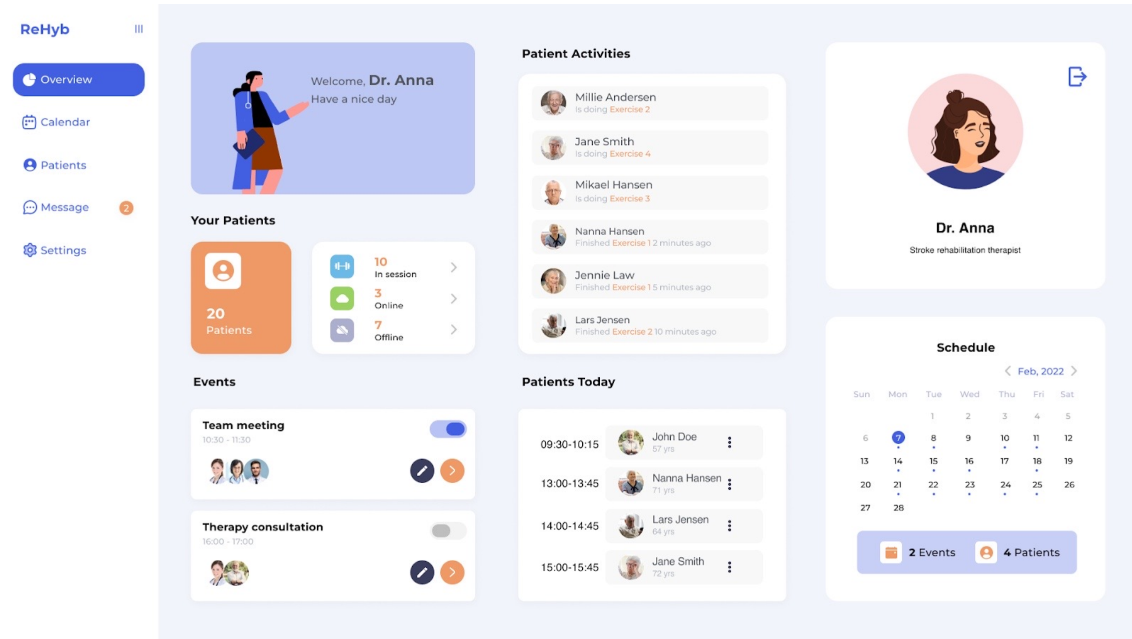

Figure 6.9: Home page

The home page's design is a critical aspect of addressing the sub-RQ 3 because it represents a key interface element that therapists will interact with regularly. By providing therapists with a comprehensive overview of their schedules, patient progress, and notifications, the home page facilitates efficient navigation and management of daily tasks for therapists. This directly contributes to improved human-computer interaction by reducing cognitive load, making important information easily accessible, and promoting a streamlined workflow.

6.3.3.2 Patient management system

The patient management system serves as the central focus of this thesis, aiming to provide therapists with a comprehensive platform for managing their patients in a unified location. All aspects and activities related to patients are consolidated within this system, offering therapists a convenient and efficient means of overseeing their patients' progress, treatment plans, and relevant information. By centralising patient management, therapists can access and update patient records, monitor therapy sessions, track outcomes, and communicate with patients more effectively.

1. **Patients list**

In Figure 6.10, a patient list is presented, displaying crucial information such as the patient's name, relevant ID number, and therapy status in a clear and organised manner. To locate a specific patient, therapists can easily utilise the conveniently positioned search box at the top of the interface. Additionally, therapists have the flexibility to refine their patient search criteria by employing filters. The filter button undergoes a transition from light blue to light blue with a dark blue stroke upon selection, offering visual feedback and adhering to the familiar filter design pattern found in many digital products. Each patient entry is accompanied by a "more" icon, providing therapists with options to manage the patient, including actions like deleting, editing, or archiving (refer to Figure 6.10). Adjacent to the filters, there are buttons for archiving patients who have completed their therapy sessions and an "add patient" button for conveniently adding new patients. The dashboard incorporates visual cues at corners of each patient's profile image, to represent the patient's current training status and therapy progress, enabling therapists to promptly assess and comprehend the patient's overall development and progress.

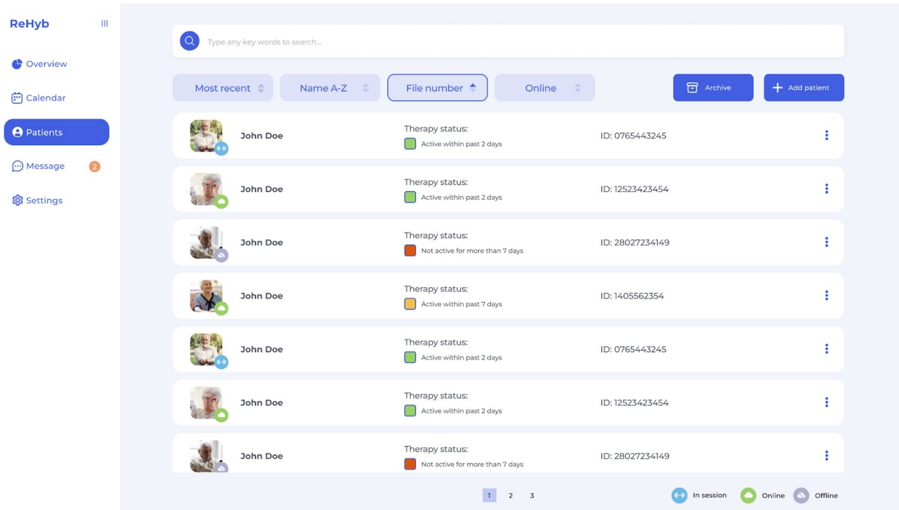

Figure 6.10: Patient list page

2. Archived patient

When a patient completes their therapy session, the therapist can simply click the "more" icon to access additional options, including the ability to archive the patient. Clicking the "more" icon triggers a pop-up window below, as illustrated in the left of Figure 6.11, where therapists can conveniently select the desired function or action they wish to perform. This intuitive interface allows therapists to efficiently manage patient records and choose the appropriate actions based on their specific needs.

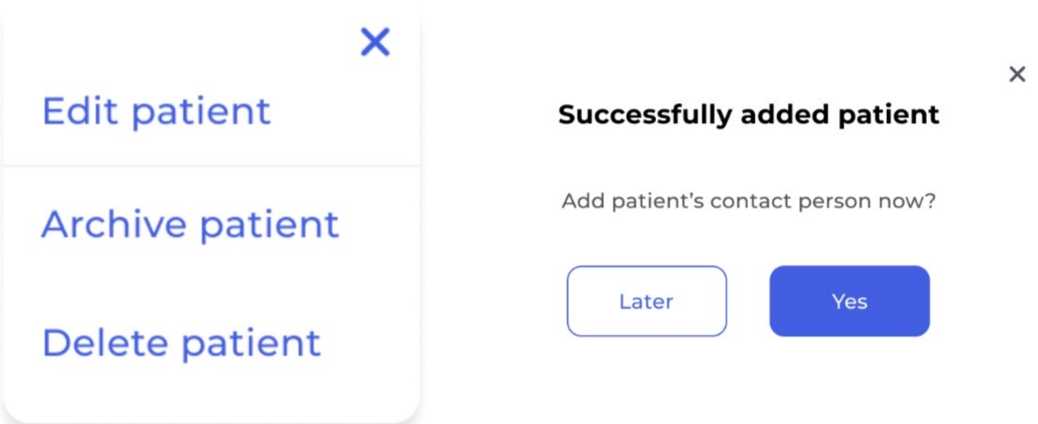

Figure 6.11: More settings of patients list (left), Successfully add a patient (right)

If therapists need to check archived patients, they can simply click the "archive" button located at the right of the search filter. Upon clicking, a list of archived patients will be displayed, providing therapists with organised patient information.

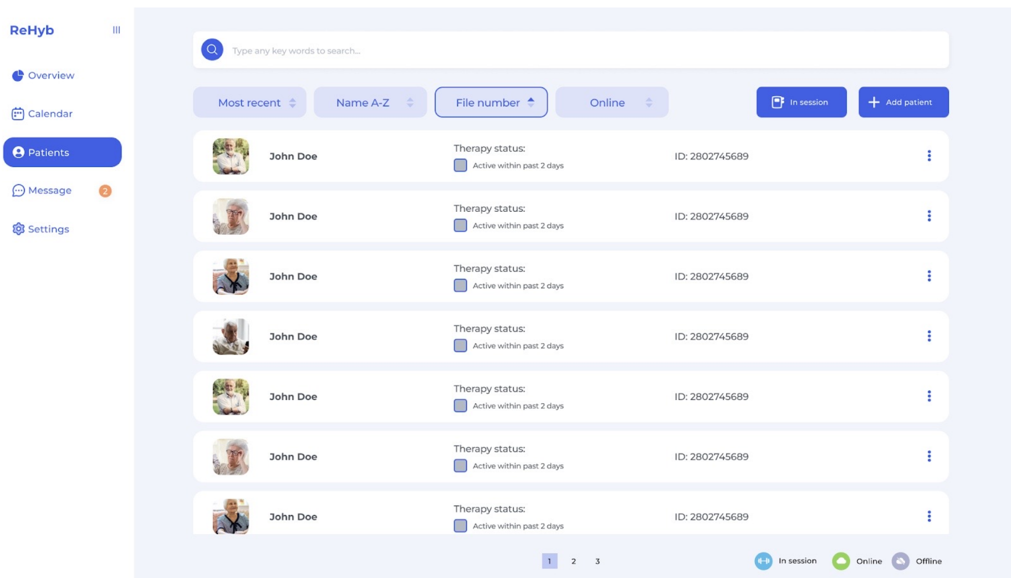

Figure 6.12: Archived patients list

3. Add a patient

Clicking the "add patient" button triggers the appearance of a pop-up window on the right side of the dashboard, as figure 6.13 shows. This window is designed in a way that prevents accidental closure when clicking outside, ensuring a seamless user experience. Therapists can conveniently fill in the patient's personal information and stroke condition within this window. Once the necessary details are completed, therapists can proceed by clicking the "next" button to successfully add the new patient to their list.

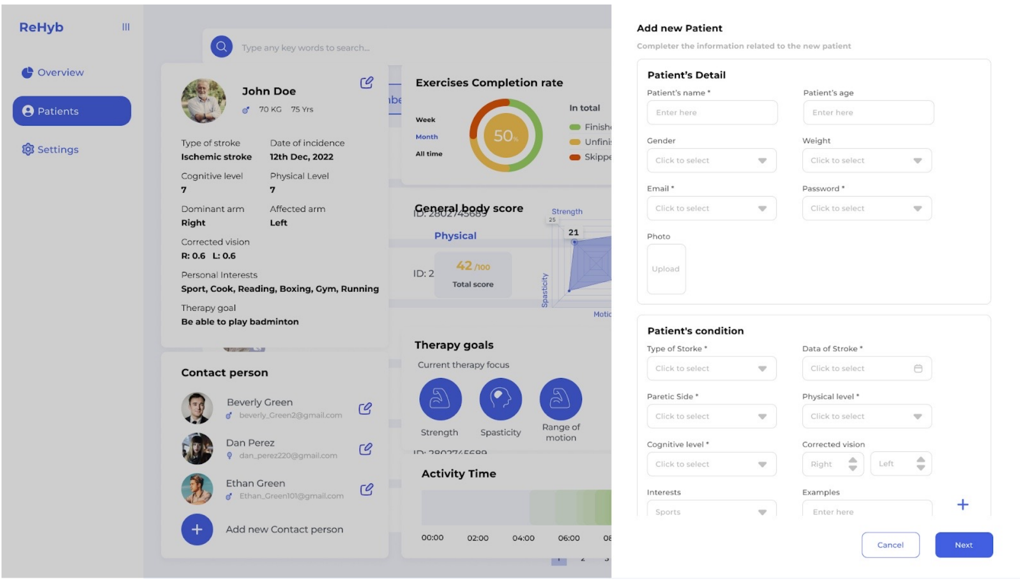

Figure 6.13: Add a new patients

4. Add a contact person

After successfully adding a patient, the system will redirect the therapist to the patient overview page, while simultaneously displaying a pop-up window to confirm the successful addition as shown on the right image of figure 6.11. Additionally, the pop-up window prompts the therapist if they wish to add a contact person for the patient. Upon clicking the "yes" button, another pop-up window will emerge from the right side of the dashboard, as depicted in Figure 6.14. Therapists can then input the contact person's information and specify the data accessibility permissions based on the patient's preferences. The design decision to set data permissions for the contact person is based on insights from previous studies conducted by the ReHyb project, which identified that patients have diverse preferences when it comes to granting access to their data by their designated contact person. By clicking the "save" button, the contact person's details are saved, and their account is created for accessing the third-party dashboard. Subsequently, the user is redirected back to the patient overview page.

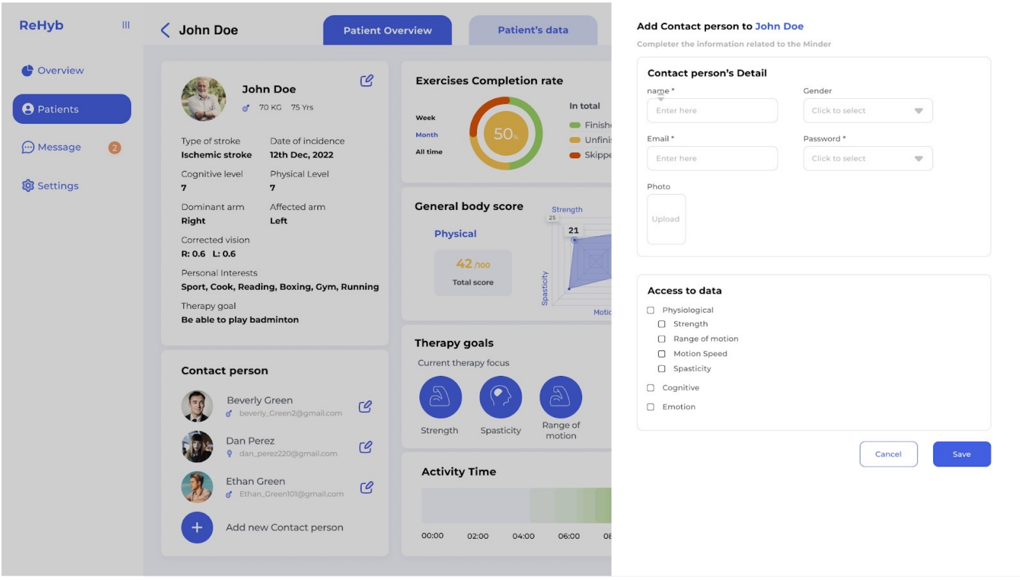

Figure 6.14: Add a new contact

5. Patient's overview

The design of the patient overview page is for therapists to gain a general idea of the patient's condition shown on figure 6.15. Including their general information, the current overall health condition on both physical and cognitive, and patient's exercise activities.

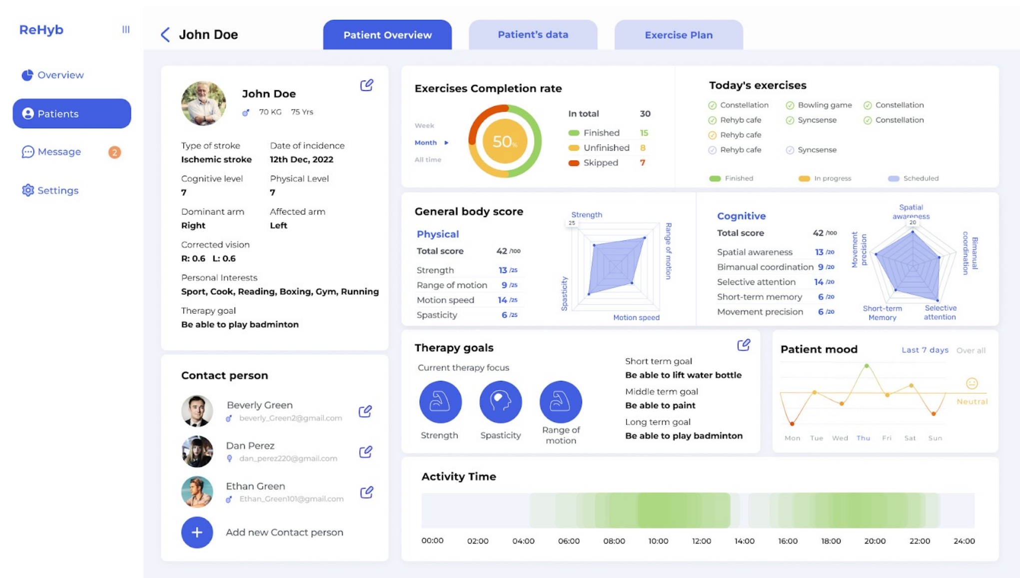

Figure 6.15: Patient overview page

The page layout follows the principle of the Gutenberg diagram. This principle helps designers understand and optimise the visual hierarchy and flow of information within a layout (Eldesouky, 2013). It is based on the principle that users' eyes naturally follow a pattern of movement when viewing content, known as the "reading gravity.", As seen at figure 6.16. By strategically placing the patient's basic information within the primary optical area and directing the user's attention towards key areas of the exercise activities and data visualisation, thus to enhance readability and guide users' attention to critical information.

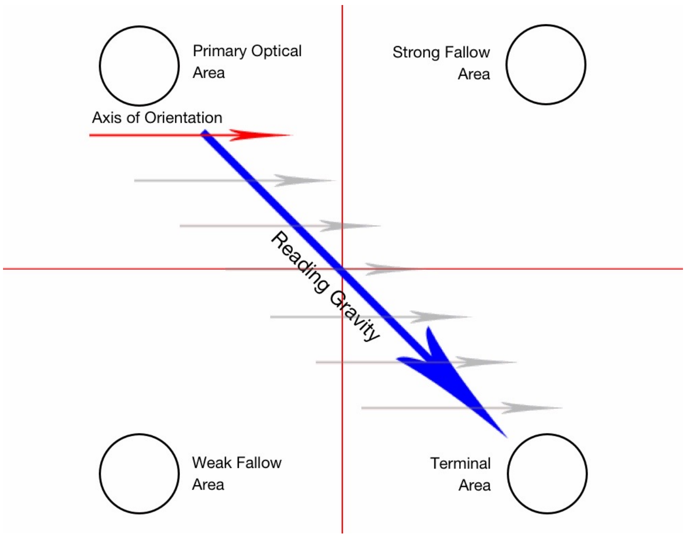

Figure 6.16: Gutenberg diagram

6. **Patient's data**

For more detailed information about the patient's data tab, please refer to Chapter 6.3.4 on data visualisation.

7. **Patient's exercise calendar**

The third tab is dedicated to the patient's exercise plan. As shown in Figure 6.17, therapists can access the patient's exercise schedule and an overview of their exercise summaries. By clicking on individual sessions, therapists can review the execution details and replay exercise videos. Therapists can also edit the exercise calendar if needed.

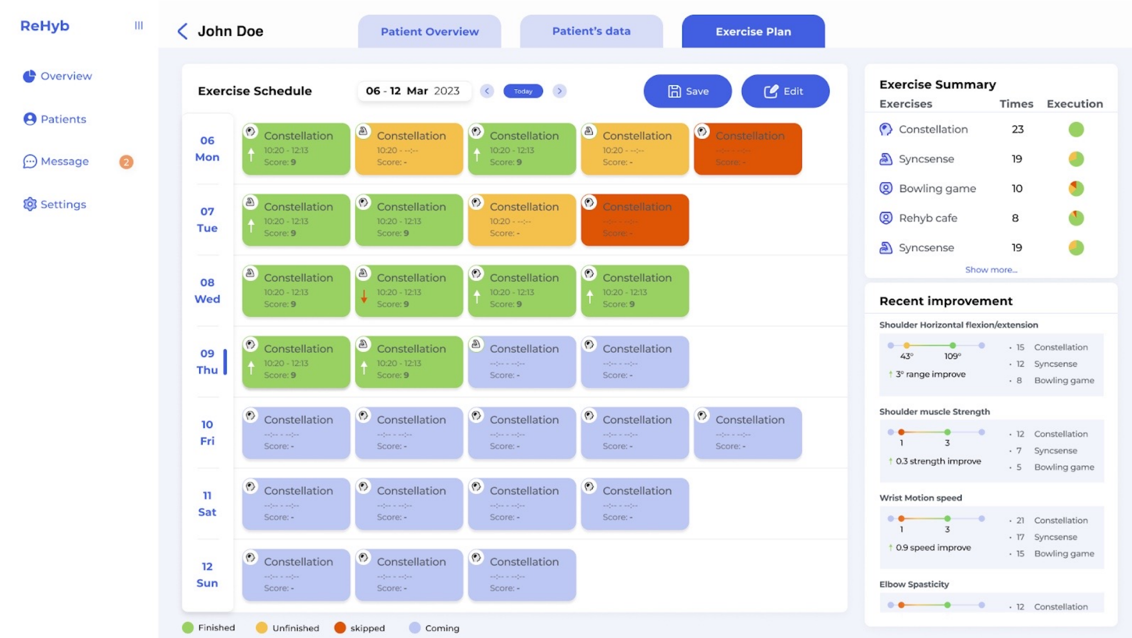

Figure 6.17: "Exercise plan" page

The page adheres to the user's visual pattern by placing the exercise calendar, which is the primary and important component, on the left side, while positioning the exercise summary on the right side. The calendar incorporates the use of four colours, Green, Yellow, Red, and Blue, strategically chosen to represent different exercise statuses: Green for Finished, Yellow for Unfinished, Red for Skipped, and Blue as the main colour of the visual system represent "Upcoming" in this calendar, as shown in Figure 6.18. The selection of these colours aligns with colour theory principles, where green signifies completion and success, yellow indicates work in progress, red denotes warnings or errors, and blue serves as a visually dominant and attention-grabbing colour, drawing users' focus to the key elements on the interface.

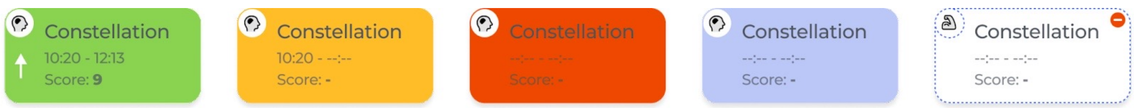

Figure 6.18: Different exercise statuses

Each session includes the session's name, exercise duration, and final score. Arrows indicate any improvement or regression following each session, and therapists can click on each exercise to view detailed session information. The exercise summary provides a list of the most frequently performed exercises throughout the therapy session, along with a pie chart showcasing execution results. This data offers therapists an overall view of the patient's preferences for specific exercises. Additionally, below the exercise summary, therapists can find recent improvements in various health dimensions, displaying the growth, exercises involved, and the frequency of each exercise performed.

8. Edit exercise schedule

By clicking the "edit" button located in the top-right corner of the exercise calendar, therapists can easily modify the patient's plan based on their recovery progress (as shown in figure 6.19). To facilitate editing, exercises scheduled after the current date are visually differentiated with a white background and black dashed line, which not only provides a clear differentiation but also adheres to the principle of gestalt theory (Graham, 2018), specifically the principle of contrast. Additionally, each exercise session within the calendar is accompanied by a remove icon in the top-right corner, allowing therapists to remove sessions as needed. On the right column of the interface, therapists have access to the recommended exercises and can utilise the search functionality to locate and drag desired exercise onto specific dates, seamlessly adding them to the calendar. This intuitive design empowers therapists to adapt and customise the exercise plan according to the individual needs and progress of each patient.

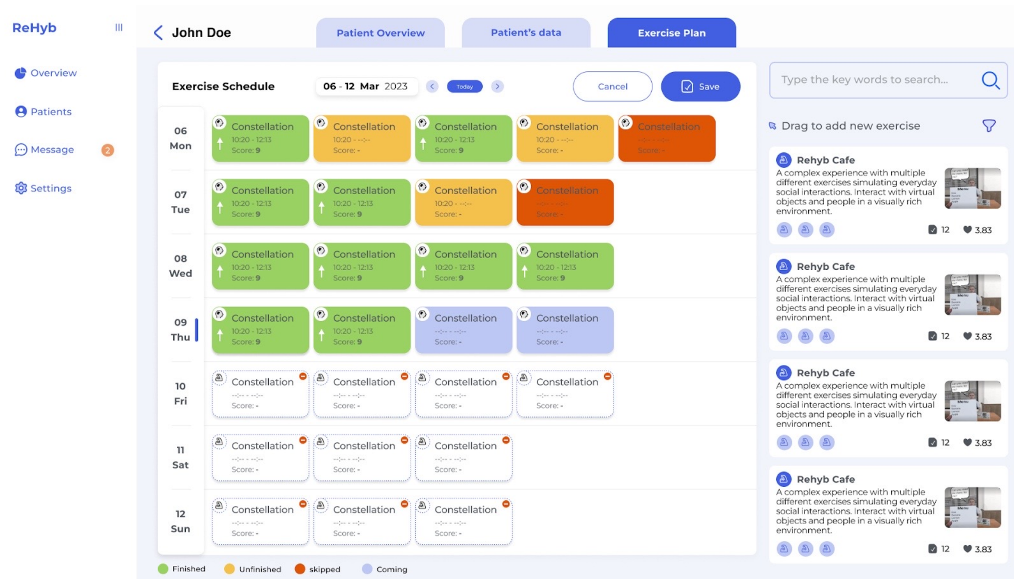

Figure 6.19: Edit exercise plan

Additionally, each exercise is presented with its name, accompanying photos, a brief introduction, and an indication of the health dimension it targets. Additionally, therapists can view the number of times the patient has performed the exercise and the corresponding ratings provided by the patient. This comprehensive display enables therapists to gain valuable insights into the patient's preferences and satisfaction level with each exercise, allowing for informed decision-making and tailored adjustments to the therapy plan.

9. Check details of each exercise execution

Clicking on each session triggers a pop-up window that provides detailed information about the session's progress. The top-left section of the window displays exercise general information, while the bottom-left section presents the patient's performance upon completing the session. Through visualisations of the data, therapists can easily identify improvements or changes in various dimensions following the session. On the right side of the window, an automatically generated video mimics the patient's movements during training, based on the exoskeleton data. Complementing the video, a set of line charts dynamically illustrate the data captured from the exoskeleton throughout the session, providing additional insights into the patient's performance.

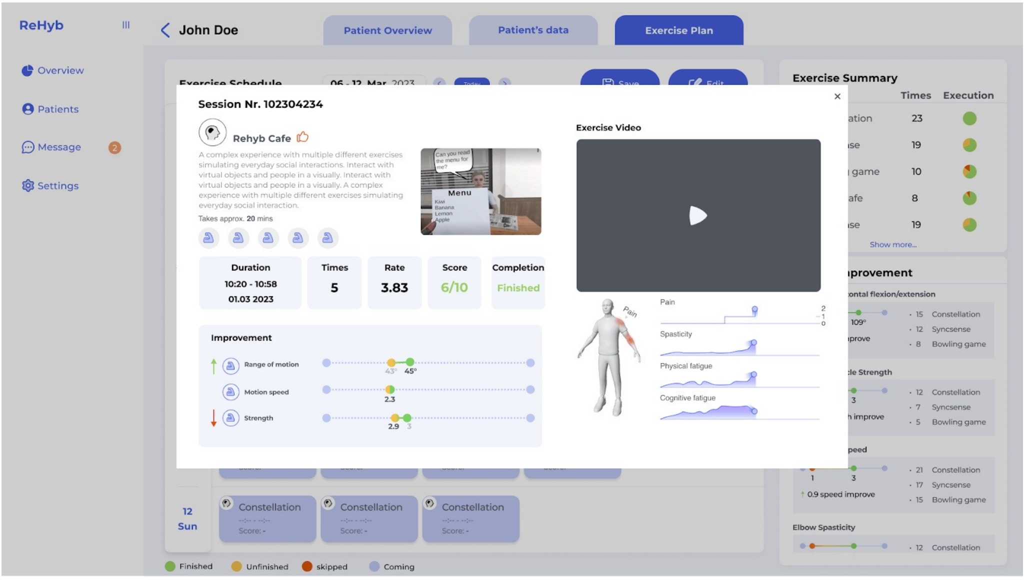

Figure 6.20: Details of therapy session

6.3.3.3 Message

The messaging feature serves as a communication tool among therapists, patients, and their designated contact persons. While this tool provides convenience for patients and their contacts, it takes into account the busy schedule of therapists. Instead of allowing direct calls, users are prompted to make a request within the chat window, as depicted in Figure 6.21. Therapists can then address the requests when they have free time and follow up with the necessary assistance. To distinguish between patients and their contact persons, the patient's profile image is differentiated by a miniature photo in the bottom right corner. This visual cue helps identify the contact person associated with the patient. Additionally, each chat window features an icon in the top-right corner, allowing therapists to easily navigate to the patient's information page for efficient management.

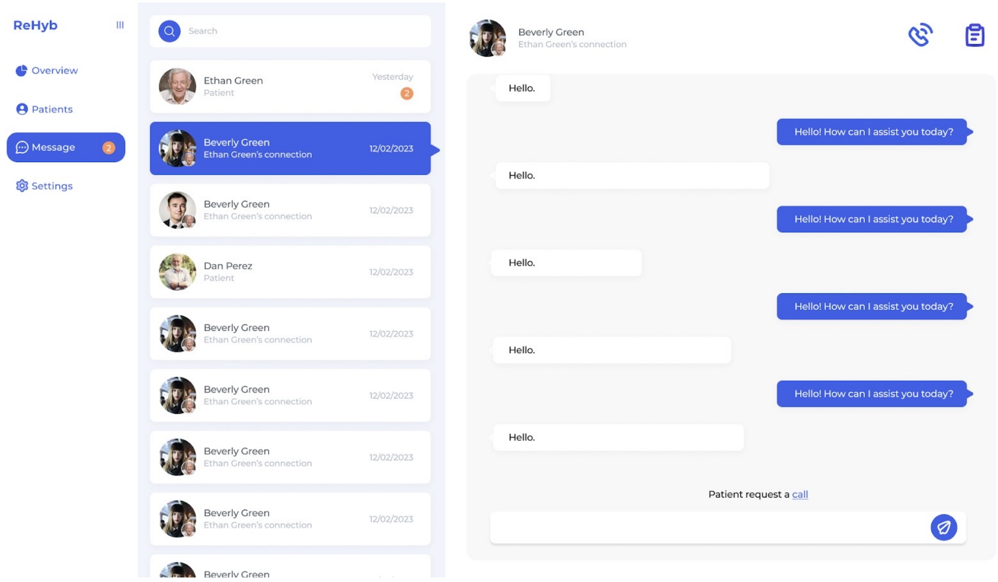

Figure 6.21: Message page

6.3.4 Data visualisation

By navigating to the "Patient's Data" tab on a patient's profile page, therapists gain access to a range of data pertinent to the patient's rehabilitation journey.
The data is presented across five distinct categories: General, Cognitive, Shoulder, Elbow, and Wrist-Hand. As shown in figure 6.22, a drop-down menu facilitates user navigation among these categories, while also providing a visual representation of the current page layout to aid users in maintaining their orientation. Additionally, users can effortlessly traverse between different data categories by simply clicking the arrows located on the avatar, enhancing the visual and intuitive navigation experience.

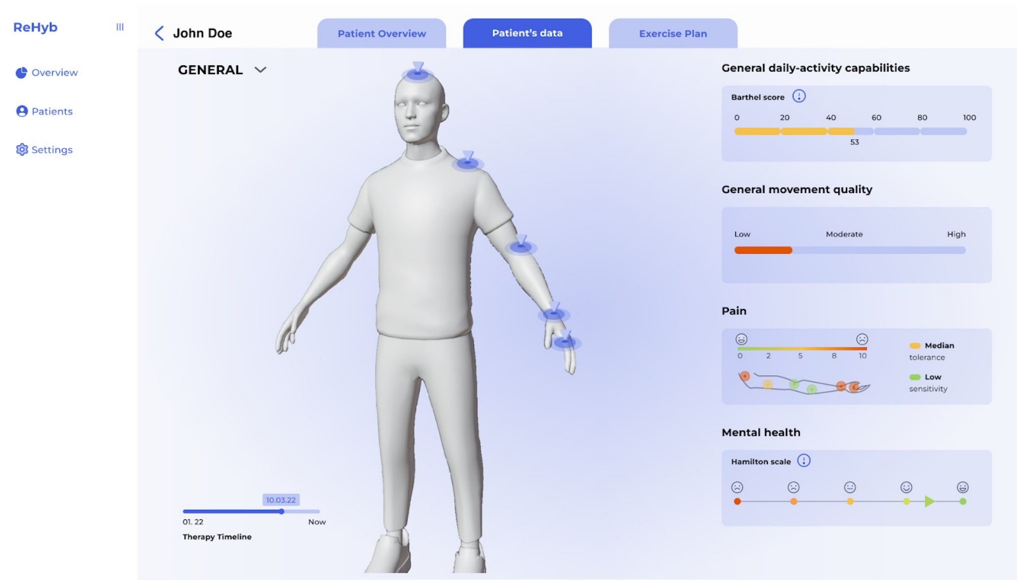

Figure 6.22: General page of patient's data

6.3.4.1 General data

The general data overview aims to provide a comprehensive initial assessment of the patient's overall condition, encompassing daily activity capabilities, movement quality, pain assessment, mental health evaluation, and therapy progress.

As depicted in Figure 6.22, the data presentation encompasses four key aspects.

1. The individual's general daily-activity capabilities are depicted through the utilisation of the Barthel score. This score encompasses various activities, including bathing, dressing, and mobility tasks, which collectively illuminate a person's self-reliance level. By aggregating these scores to a maximum of 100, healthcare professionals swiftly evaluate functional independence, thereby assisting in formulating comprehensive care plans and rehabilitation strategies. The Barthel score is meticulously categorised into five sections within a bar chart, with colour-coded segments (red, yellow, green) denoting the severity of the patient's condition. This visual representation offers therapists a lucid comprehension of the patient's abilities pertaining to daily activities.
2. The overall movement quality is categorised into three levels: low, moderate, and high.
3. Pain assessment involves evaluating patient discomfort during arm exercises across different regions. A colour gradient ranging from red, yellow to green visually represents pain levels in these areas, offering therapists an immediate understanding of the patient's condition. Additionally, on the right, it illustrates the patient's pain tolerance and sensitivity, providing valuable insights into their pain perception.
4. Mental health evaluation employs the Hamilton Scale, a standardised psychiatry tool for quantifying symptom severity in mood disorders such as depression and anxiety. With five levels, this assessment assists in diagnosis, monitoring advancement, and gauging treatment efficacy, thereby offering valuable insights into a patient's mental well-being.

Positioned in the lower left corner is a time progress bar spanning from the commencement of the therapy session to the present moment. This interactive bar allows users to drag and navigate through different time points, enabling a comparative analysis of data across various intervals. This feature greatly assists therapists in gaining a comprehensive understanding of the therapy's impact on the patient's recovery journey.

6.3.4.2 Arm data

Displayed in Figure 6.23 are the shoulder-related data assessments.

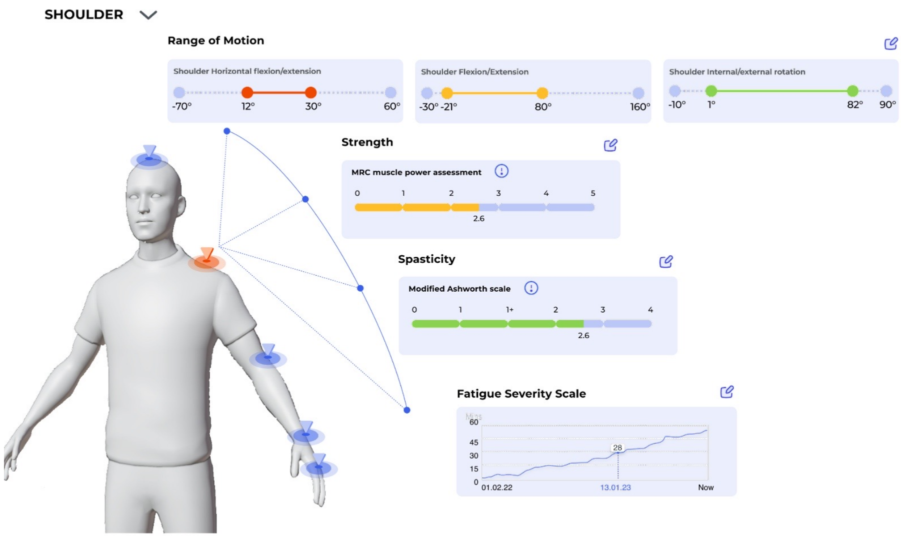

Figure 6.23: Data for shoulder

1. Range of motion: This visualisation illustrates three ranges for shoulder motion: horizontal flexion/extension, flexion/extension, and internal/external rotation. Using bars, the chart depicts the extent of motion achievable by normal individuals alongside the patient's reach. This visual aid assists therapists in gauging the progress required for effective therapy and enables them to tailor exercises, particularly for the arm segment.
2. Shoulder strength: The strength of the shoulder muscles is evaluated using the MRC (Medical Research Council) muscle power assessment. This standardised technique assigns a numeric grade, usually ranging from 0 to 5, based on the patient's ability to perform specific movements against resistance. This method tracks rehabilitation progress and evaluates the impact of interventions, providing an objective measurement of muscle strength. This empowers healthcare professionals to make well-informed decisions regarding patient care.
3. Spasticity is shown in Modified Ashworth scale, The Modified Ashworth Scale (MAS) is employed to assess spasticity in patients with neurological conditions. The scale, ranging from 0 to 4 with an additional level of 1+, quantifies resistance encountered during passive muscle stretching, thus revealing the level of muscle tone or spasticity. This standardised assessment aids in conveying the severity of spasticity's effect on motor function, facilitating comprehensive care planning.
4. Fatigue severity scale Fatigue severity is evaluated based on the time a patient experiences fatigue during a one-hour exercise session. As patients progressively extend their exercise duration, this measurement underscores their advancement over time.

These assessments collectively contribute crucial insights into patients' shoulder functionality, aiding therapists in tailoring interventions, monitoring progress, and enhancing the quality of care.

The identical data chart structure employed for shoulder assessment was also extended to evaluate the elbow, wrist, and hand, due to the resemblance of their data.

Figure 6.24 illustrates the utilisation of two distinct layouts to present those data. The first layout entails arranging charts around specific points, each corresponding to a data source, interconnected by lines leading to the central point. The second layout positions the charts on both sides of the avatar, mimicking the conventional layout of a web page. With both of these layouts incorporated into the design, our intention is to present them during the evaluation workshop. This workshop will serve to gather user feedback, allowing us to discern which layout aligns better with their preferences and requirements.

Figure 6.24: Data for different body parts

6.4 Evaluation

Following the completion of the prototyping phase, the focus shifted towards testing the user-friendliness and alignment of the prototype with therapist requirements. This section outlines the two evaluations undertaken to assess the efficacy of the dashboard. Given that the dashboard is exclusively tailored for therapist use, the evaluation phase solely involved the participation of therapists.

6.4.1 First evaluation - workshop

The first evaluation took place during the DTU ReHyb plenary meeting at Denmark Technology University in April 2023, as shown in figure 6.25.

Figure 6.25: First evaluation workshop

This pivotal phase of assessment held multiple objectives, each designed to elicit insightful feedback and refine our project's direction:

1. Clarifying User Requirements: The evaluation sought to address any ambiguities arising from user requirements and elucidate the users' genuine needs, ensuring alignment between design and user expectations.
2. Gathering Data Visualization Opinions: Participants were encouraged to express their opinions on data visualisation, opening avenues for constructive suggestions and potential improvements.
3. Assessing Management System Functionality: Aimed to determine the effectiveness of the management system and gather suggestions for enhancement.

The workshop involved six therapists from different clinics. One hour was scheduled for the session, including the patient dashboard and the third-party dashboard. The Moderator introduced each part of the dashboard, stopping in between to ask questions that were prepared beforehand.

The questions we asked helped bridge the gap between what we thought users wanted and what they actually needed. Getting therapists' thoughts on how data was shown ensured the final product would make sense to users. By testing the management system and dashboard early on, we could catch problems and improve them before going further. This approach helped us identify what's good, what's lacking, and how we can enhance the whole project, making it more valuable and practical. See the workshop guide in appendix 4.

6.4.2 Second evaluation

The second evaluation was carried out using an enhanced iteration of the dashboard following the insights gained from the initial evaluation. The study involved the participation of four therapists hailing from two different clinics. Employing an online approach, two distinct testing methods were employed: the first one think-aloud Protocol, involved participants vocalising their thoughts while interacting with the dashboard, and the second centred around administering a questionnaire to gather valuable feedback.

6.4.2.1 Think-aloud protocol

This method allows us to gain valuable insights into participants' cognitive processes and decision-making while they engage with the designated tasks. Throughout this phase, Evaluators will introduce each task to participants and guide them to 'think aloud' as they navigate through the tasks. The primary aim is to capture an unfiltered stream of consciousness from participants, which will help us uncover potential pain points, areas of confusion, and effective strategies they employ during task execution.

The overarching objective of this evaluation phase is to deepen our understanding of participants' interactions with the interactive prototyping and to identify any latent usability issues or challenges that may arise during task performance. A detailed study plan outlining our approach can be found in Appendix 2. The evaluation encompasses two tasks that have been carefully designed for all participants to complete. The first task involves planning a One-Day Exercise Plan for Patient John. The second task centres around evaluating the Strength Improvement of the Patient's Shoulder.

Given the virtual nature of the workshop, We realise that task visibility could inadvertently influence subsequent participants, and due to a regulation from one participating clinic that prevents screen sharing, we have devised an alternative method to address this constraint. Participants are asked to use their personal computers or laptops to complete the task within 3 minutes. Once all participants have concluded the task, we will inquire about their completion status and ask if they encountered any confusions or difficulties during the task. This innovative approach allows us to mitigate the potential bias introduced by task sequencing and adhere to the clinic's screen-sharing regulation, while still obtaining comprehensive insights into participants' experiences and interactions.

6.4.2.2 Questionnaire

After the Think-aloud session, introducing the prototype, participants will be prompted to complete a structured questionnaire. Subsequently, they will be encouraged to elaborate on the reasons behind their specific questionnaire ratings.

The questionnaire has been meticulously curated to encompass various dimensions of participants' impressions pertaining to the dashboard.

The questions are listed below with 1-5 scales from strongly disagree and strongly agree. Table 6.1 outlines each question in the questionnaire along with its intended purpose.

Question	**Intention of the Question**
What is your overall first impression of the dashboard's overall design?	Assess participants' initial impression of the dashboard's aesthetics and overall look.
The dashboard's structure is clear and intuitive.	Evaluate the clarity and intuitiveness of the dashboard's layout and organization.
The information visualized is highly relevant. (In-clinic version)	Determine if participants find the information presented in the in-clinic version of the dashboard highly relevant to their needs.
The information visualized is highly relevant. (Home-based version)	Determine if participants find the information presented in the home-based version of the dashboard highly relevant to their needs.
The information is visualized in an understandable and intuitive way.	Assess the ease with which participants can understand and interpret the data visualizations.
The presented scales are reasonable and useful.	Evaluate the appropriateness and usefulness of the scales used in the dashboard.
The dashboard will help to manage the patients.	Determine if participants believe that the dashboard will aid in patient management.

Table 6.1: Questionnaire for Dashboard Evaluation

These questions aim to elicit specific feedback on various aspects of the dashboard's usability, relevance, and overall effectiveness in supporting therapists in stroke therapy management.

The employment of this mixed-method approach stems from the intention to holistically capture participants' evaluations and opinions. By combining quantitative responses from the questionnaire with the rich qualitative feedback obtained through verbal explanations, we aim to achieve a more comprehensive and nuanced understanding of participant perspectives. This approach not only furnishes us with statistical insights for analysis but also enables us to delve deeper into the thought processes and motivations that underpin their quantitative responses. Consequently, this dual approach enhances the rigour and richness of our evaluation, leading to more robust conclusions and recommendations for the project. The questionnaire is accessible in Appendix 3.

7
Results

This chapter presents the findings of our research and analysis. It is divided into three sections, each focusing on a different aspect of our study. The first phase, Evaluation 1 - the Workshop, saw us engage with stakeholders, experts, and end-users, we sought to align our project objectives with real-world needs. The second phase represented a significant step forward as we integrated the feedback gathered during the workshop with our initial design, bringing our vision to life through the Final Prototyping stage. Finally, the third phase, Evaluation 2 - the Think-Aloud Protocol and Questionnaire, provided invaluable insights into user experiences and satisfaction, lending a critical dimension to our research. Together, these sections provide a comprehensive overview of our research journey and the results we have obtained.

7.1 First evaluation result

In the initial phase of project evaluation, a focus group of six experienced therapists played a pivotal role in providing valuable insights and feedback. This diverse group, encompassing a range of clinical backgrounds and expertise, engaged in a comprehensive evaluation process aimed at assessing the effectiveness and user-friendliness of the proposed dashboard solution.

7.1.1 Dashboard overall feedback

As our designed dashboard focuses on patients performing exercises at home, one of the participants' initial queries centred around whether the dashboard was intended for clinic or home use. This distinction is significant due to the differing ways exercises are scheduled. In clinics, exercises might stem from both *"what the patient wishes to do"* and *"the physicians who say the patient needs this specific therapy."* Notably, they expressed that patient attendance might not be a concern, as they treat patients based on scheduled sessions. Thus, tracking patient activity might hold limited relevance for them. Moreover, the exoskeleton that is needed for this technology is quite expensive for patients to own. In light of these concerns, we intend to evaluate the dashboard in both clinic and home versions in subsequent assessments.

Another idea surfaced during the discussion, revealing how therapists collaborate with one another. One participant indicated that patients are usually under supervision by several therapists. This often happens during various clinic visits and therapy phases.

“They(therapists) sometimes take over the responsibility of other doctors,... you can have my patients and you can have the others that come in.”

This insight highlights the need to accommodate such cooperative scenarios in the forthcoming prototype evaluation. This observation aligns with sub-research question 2, which pertains to the functionalities therapists desire, particularly the ability to collaborate with their colleagues and seamlessly share patient information among themselves.

When addressing how therapy goals could be quantified, participants introduced the SMART formula. They asked, *"Have you heard of the SMART formula to define a goal?"* SMART stands for Specific, Measurable, Achievable, Relevant, and Time-Bound. Participants suggested that therapy goals could align with the SMART framework, offering a standardised approach to quantifying patient objectives.

7.1.2 Patient overview page

Similar sentiments are echoed concerning the exercise completion rate, as therapists view it as not pertinent to clinical therapy.

"It’s not so optical, because it would be quite strange that the patients skip the therapies in clinical"

These insights highlight the need to attentively discern the disparities between clinic-based and home-based rehabilitation scenarios. The guidance provided underscores the necessity of taking into account the divergent circumstances that arise within clinical rehabilitation and home-based rehabilitation.

7.1.3 Exercise schedule

When we were working on designing an exercise schedule, we encountered a challenge in fitting a substantial number of exercises on a single screen. To address this, we sought to understand the typical number of exercises therapists usually allocate for patients. Their responses offered valuable insights:

"I usually plan for around 30 minutes to an hour, based on my experience."

"It’s not so much about the total number of exercises, but more about the duration of each exercise."

Surprisingly, therapists tend to plan sessions based on time rather than a fixed exercise count. This realisation highlighted the significance of displaying the duration of each exercise. This feature would assist therapists in accurately estimating the overall time they allocate for the session.

7.1.4 Data visualisation

When we inquired about the effectiveness of data visualisation, participants expressed that employing graphs could greatly aid in illustrating the specific angles patients' body parts are capable of reaching. One participant proposed:

"For motion speed, could we possibly replace a standard scale with a graph that depicts the motion pattern? This way, users might gain insights at particular angles."

Furthermore, as we delved into cognitive data, our initial strategy involved utilising data from serious games connected to cognitive rehabilitation. However, a concern emerged: just because these games are currently focused on those aspects doesn't necessarily indicate their relevance to our project. To address this, we engaged the participants in a discussion about the aspects they envision on this page. They specifically mentioned *"neglect aphasia"* and *"cognitive fatigue."* This feedback underlines the necessity of tailoring our data visualisation approach to align closely with the pertinent aspects of our project.

7.1.5 Key findings from the workshop

In conclusion, the findings from this workshop have provided valuable insights for the project.

1. Home-based version and clinic-based version.
2. Patients may be under supervision by several therapists.
3. Quantifying the therapy goals follows the SMART formula.
4. Exercise completion rate and activity time is unnecessary for clinic therapy
5. Display the duration of each exercise.

Overall, the therapists' collective expertise and active engagement played an integral role in shaping the project's direction. Their contributions, spanning strengths recognition and the identification of areas needing refinement, hold considerable value for subsequent developmental phases. This evaluation phase, marked by their dedicated participation and insightful feedback, is pivotal in propelling the project toward its enhanced iterations.

7.2 Final prototyping

Presented here is the ultimate prototype derived from this thesis project. The culmination of iterative development has resulted in several notable refinements, with the primary modifications centering around the following key aspects.

7.2.1 Two versions created: home-based and clinic based

As mentioned in the initial iteration, the device's cost renders it more suitable for clinic usage, potentially limiting patient sessions to clinical settings. Moreover, within clinical environments, therapists may possess distinct requirements pertaining to the dashboard's functionalities. In response to these factors, an additional iteration tailored specifically for clinic-based usage has been meticulously designed.

7.2.1.1 Homepage

Within the clinical setting, therapists possess a comprehensive understanding of patients' dynamics, rendering the omission of this element from the homepage justified. Instead, emphasis is placed on facilitating therapist scheduling and patient appointment reminders for the current day as shown in figure 7.1. Moreover, a switch button is conveniently positioned adjacent to the therapist's name, enabling seamless toggling between the clinic and home versions of the interface.

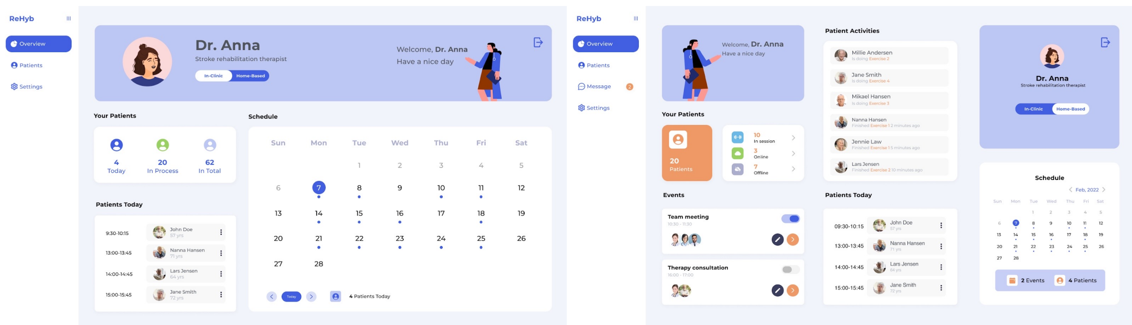

Figure 7.1: Clinic-based homepage (left) and home-based homepage (right)

7.2.1.2 Patient list

The patient list also eliminates the need for displaying active patient engagement as shown in figure 7.2, considering therapists are already informed about this aspect offline.

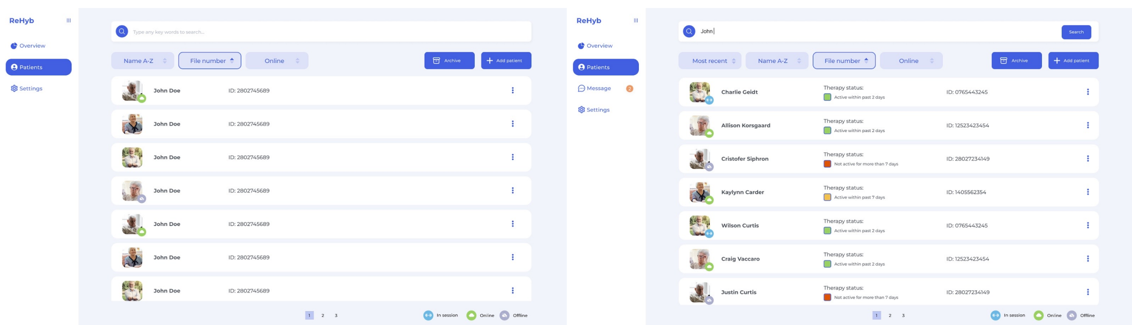

Figure 7.2: Clinic-based patient list (left) and home-based patient list (right)

7.2.1.3 Patient's general information

In the patient's general information page, as shown in figure 7.3, the exercise completion rate has been omitted, as therapists can monitor it offline. Similarly, the activity time is no longer displayed, given that in the clinic version, patient activity aligns with appointment times, rendering its presence redundant and inconsequential for therapists. Conversely, a note feature has been incorporated. This addition proves more convenient for recording the patient's condition and pertinent considerations, particularly as different therapists may oversee distinct sessions. This note-taking function streamlines communication and ensures crucial information is efficiently documented.

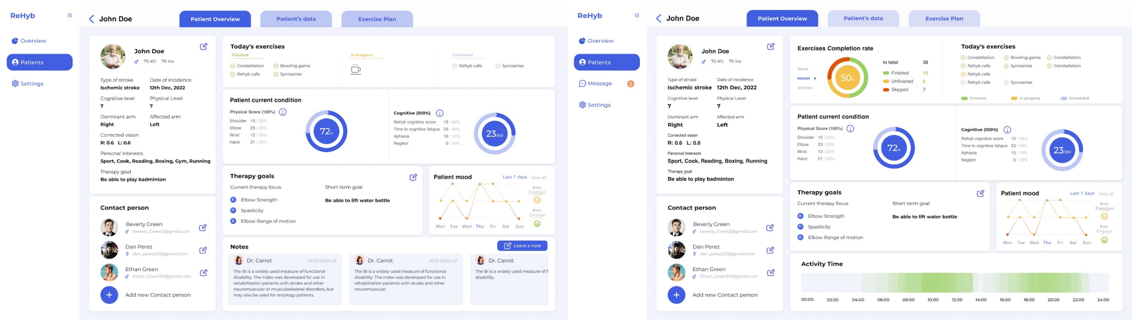

Figure 7.3: Clinic-based (left) and home-based (right) patient's general information

7.2.1.4 Patient's exercise schedule

The primary distinction between the clinic and home versions lies in the calendar display. In the clinic version, the calendar is organised chronologically to enable therapists to more effectively monitor ongoing activities.

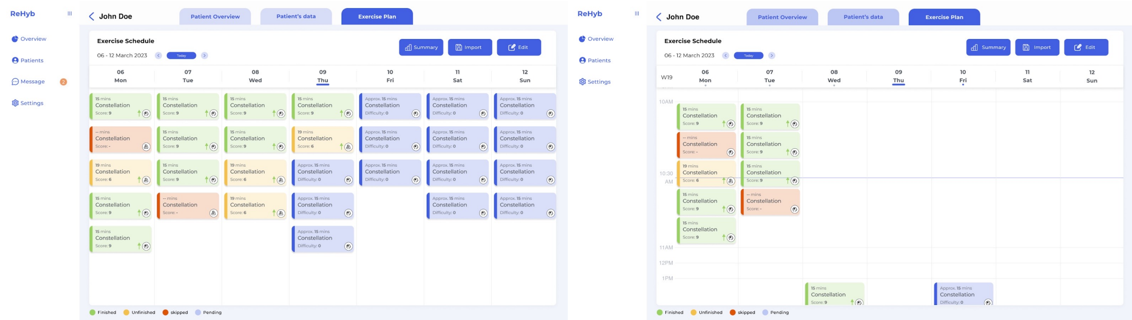

Figure 7.4: Clinic-based Patients-Calendar (left) and home-based Patients-Calendar (right)

7.2.2 Data visualisation

The data visualisation segment has undergone significant evolution since the initial evaluation. Instead of depending on assessment scales, this section now employs data directly acquired from the exoskeleton, ensuring the precision of the information.

7.2.2.1 General data

The general data layout incorporates two charts along with an advanced data visualisation, all illustrated in Figure 7.5.

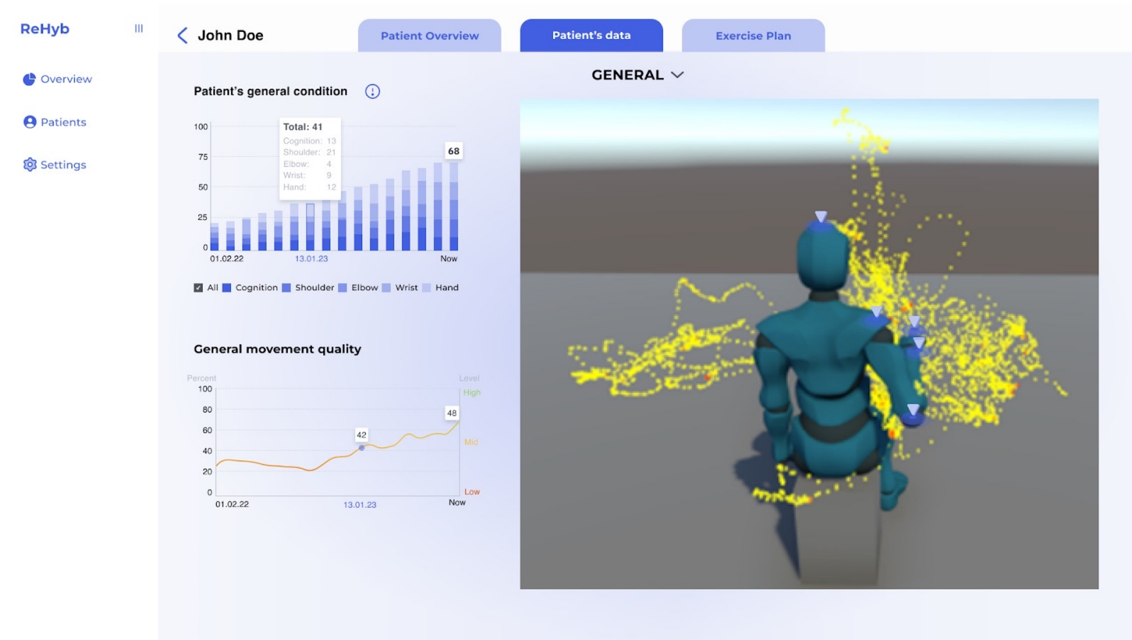

Figure 7.5: Patient's general data

1. The patient's general condition is visually depicted through a composite chart that amalgamates the scores from various assessment aspects encompassing both arm functionality and cognition. This information is presented in the form of a stacked Column Chart, where each column encapsulates the cumulative score of distinct elements, including cognition, shoulder, elbow, wrist, and hand evaluations. The temporal progression from the inception of therapy to the present moment is represented along the X-axis, while the cumulative score up to a maximum of 100 is delineated along the Y-axis. To enhance interactivity and insights, hovering the mouse pointer over each column triggers a floating window displaying intricate scores corresponding to the specific column. Furthermore, users have the option to click on individual parts—such as Shoulder—to access a focused assessment of that particular dimension's progress during the course of therapy. This interactive visualisation facilitates therapists in gaining a comprehensive initial impression of the patient's overall journey and the advancements achieved throughout the therapeutic process.
2. The metric of general movement quality quantifies the reversed compensatory movements, the higher the movement quality, the less patients get compensated during the movements. the movement quality on a scale from 0 to 100 percent, capturing its progression from the commencement of therapy up to the present moment.
3. Incorporating an advanced visualisation technique, we employ cloud points to depict the patient's movement throughout the exercise routine. Each point

corresponds to a position the patient reaches during the activity, creating a dynamic 3D representation. Users have the ability to manipulate this visualisation by rotating it for a comprehensive view. Moreover, a supplementary grey cloud of points delineates the movement range attainable by healthy individuals performing the same type of exercise. A time bar positioned at the bottom of the visualisation allows users to navigate backward in time, revealing the specific evaluation points recorded during the patient's exercise regimen. The convergence of these two sets of cloud points provides therapists with a lucid perspective on the patient's progress, pinpointing areas where additional exercise is required. This comprehensive insight aids therapists in customising exercise plans to address specific patient needs effectively.

7.2.2.2 Arm data

Displayed in Figure 7.6 is the evaluated data visualisation of shoulder-related data assessments.

Figure 7.6: Patient's shoulder data

1. Range of motion: In contrast to the previous chart, the enhanced version maintains the comparison of shoulder range of motion between normal individuals and patients. It introduces a timeline element, effectively illustrating the patient's progression over the course of rehabilitation. Furthermore, on the chart's right side, data selected using the mouse is presented alongside a corresponding diagram. This diagram delineates the angles at which the shoulder can be extended, both for normal individuals and for patients in the given condition. This feature significantly enhances data interpretation, providing a clearer understanding of the information presented.
2. Muscle strength: In lieu of relying on the MRC muscle power scales, the updated chart directly incorporates data gathered from the exoskeleton. This

chart visually represents the torque exerted by the exoskeleton at various angles during patient exercises involving Abduction/Adduction, Flexion/Extension, and Intra/Extra Rotation movements.

3. Spasticity is portrayed using a 3D matrix, where the X-axis signifies the Angle, the Y-axis represents Motion Speed, and the Z-axis denotes Torque. These three dimensions collectively form a dynamic surface that rises and falls, effectively depicting the variations in patient conditions during specific movements.
4. Fatigue is assessed by measuring the duration a patient can sustain an exercise session until reaching the point of exhaustion.

The evaluation predominantly centres on the transition of data representation, shifting from commonly used scales to data collected via the exoskeleton. Additionally, each chart is integrated with an individual timeline, allowing for the discrete examination of historical data points.

7.2.2.3 Cognition data

Given that the exoskeleton is still in the developmental phase, the data pertinent to cognitive aspects remains unavailable for direct implementation. Consequently, the ReHyb cognitive score, sourced from the ReHyb game, has been utilised as a substitute. The concept of time to cognitive fatigue mirrors the chart structure applied to arm evaluations, albeit focused on cognitive attributes. Furthermore, the presence of Neglect and Aphasia is indicated via a simple switch button that offers therapists a broad overview of the patient's condition.

Figure 7.7: Patient's cognitive data

7.3 Second evaluation results

The second evaluation mainly tests the usability of the dashboard and user satisfaction, and gathers ideas or advice for future work.

7.3.1 Think-aloud protocol

During this part, participants were given a task to create a one-day exercise plan for a patient named John within a 3-minute timeframe using their own laptops. After the time was up, they were encouraged to share their thoughts and any issues they faced while completing the task.

Overall, the task went quite well. Every participant managed to smoothly navigate from the home page to the calendar page and clicked on the "edit schedule" button, just like one participant described their process:

"I went to the patients page, selected John, and then I wanted to add an exercise. So, I thought I'd go to the exercise plan, because I expected all the exercises to be there."

This aligned perfectly with our intended user flow, showing that our design matched their expectations and the way they typically work.

However, a challenge emerged when participants tried to add an exercise to the schedule. Due to limitations in the Figma Software, certain interactions couldn't be carried out. For instance, dragging and dropping an exercise into a calendar column to schedule it wasn't possible. As anticipated, participants couldn't complete this final step, which was expected.

What participants expected to do next was to click on an exercise instead of drag and drop it onto the calendar column where they wanted it. This part needs clearer design so that new users can understand how to use it without too much effort. Some participants shared their thoughts:

"I selected one of the exercises on the right and clicked on it."

"But now I see it says 'drag to add new exercise,' so maybe I need to drag and drop it."

Interestingly, one participant encountered an unexpected situation. They couldn't initially find patient John because they couldn't scroll down to search for him. In an attempt to proceed, they tried adding a new patient but got stuck on that page. Suddenly, John's profile appeared. While we're not entirely sure why this happened, it suggests there might be a potential glitch in the interactive prototype. This is something to consider for future scenarios.

In general, participants had a positive impression of the dashboard's user flow:

"I think the process is quite clear and easy to follow. All the information I needed was there, and I don't have any specific comments. It's useful."

This session's insights helped us identify strengths in the user flow and highlighted areas that require further refinement to ensure a seamless and intuitive experience for users.

7.3.2 Questionnaire

The questionnaire carries out after the think-aloud session, it offers illuminating insights into participants' perceptions of the dashboard's design and functionality. The questions and responses provide a comprehensive snapshot of their opinions. Here's an overview of the findings:

Questions	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Participate 1	4/5	4/5	3/5	4/5	4/5	2/5	4/5
Participate 2	4/5	5/5	4/5	4/5	5/5	3/5	3/5
Participate 3	5/5	5/5	5/5	4/5	5/5	4/5	5/5
Participate 4	4/5	4/5	4/5	4/5	4/5	4/5	5/5
Average rating	4.25/5	4.5/5	4/5	4/5	4.5/5	3.25/5	4.25/5
Standard Deviation	0.5	0.577	0.816	0	0.577	0.957	0.957

Table 7.1: Questionnaire result

The average ratings provide a consolidated overview of participants' sentiments across various aspects of the dashboard. These ratings collectively inform us that the design and functionalities of the dashboard have largely met the participants' expectations.

1. **Overall First Impression:** Participants' responses to the first question, "What is your overall first impression of the dashboard's overall design?" yielded an average rating of 4.25 out of 5, with a standard deviation of 0.5. This high rating, coupled with a relatively low standard deviation, indicates that participants had a positive initial impression of the dashboard's design with relatively consistent responses.
2. **Clarity and Intuitiveness:** Question two, "The dashboard's structure is clear and intuitive," received an average rating of 4.5 out of 5, with a standard deviation of 0.577. This suggests that participants found the structure of the dashboard to be well-organized and user-friendly, with responses varying slightly more compared to the first question.
3. **Relevance of Visualized Information (In-Clinic Version):** Question three pertains to the in-clinic version of the dashboard, specifically focusing on the relevance of visualized information. Participants rated this aspect at an average of 4 out of 5, with a standard deviation of 0.816. This indicates

that responses varied somewhat more on the relevance of the in-clinic version, but the average rating remained positive.

4. **Relevance of Visualised Information (Home-Based Version):** Similar to question three, question four assesses the relevance of visualised information, but for the home-based version of the dashboard. Participants also rated this aspect at an average of 4 out of 5, with a standard deviation of 0. This indicates that there was less variability in responses for the home-based version, with participants generally agreeing on its relevance.
5. **Understanding Information Visualization:** In question five, participants were asked to evaluate how understandable and intuitive the information visualisation was. The average rating for this question was approximately 4.5 out of 5, with a standard deviation of 0.577. This implies that participants found the visualisations to be comprehensible and intuitive, with responses varying moderately.
6. **Usefulness of Presented Scales:** Ratings for question six, which concerns the usefulness of the presented scales, were varied, with an average rating of about 3.25 out of 5. The standard deviation for this question was 0.957, indicating that responses had higher variability, and opinions on the usefulness of scales varied more significantly among participants.
7. **Dashboard's Contribution to Patient Management:** In the final question, participants were asked to assess the dashboard's potential to aid in patient management. The average rating for this question was approximately 4.25 out of 5, with a standard deviation of 0.957. This suggests that participants generally saw value in the dashboard's role in efficiently managing patients. However, the higher standard deviation indicates that opinions on this aspect varied more widely among participants.

In summary, the average ratings provide a consolidated overview of participants' sentiments across various aspects of the dashboard. These ratings collectively inform us that the design and functionalities of the dashboard have largely met the participants' expectations, while also revealing specific dimensions that could be further enhanced. While participants generally had positive perceptions of the dashboard's design and functionality, the standard deviations indicate varying degrees of agreement among participants, particularly in questions related to the usefulness of presented scales and the dashboard's contribution to patient management. These deviations highlight areas where user opinions and experiences differed.

7.3.2.1 Interview after the questionnaire

After participants completed the questionnaire, they were asked to share their overall thoughts about the dashboard and whether they had any suggestions for making it better. In their words:

"We generally liked it. There's a lot of information, and the design looks nice. It also seems easy for therapists to use, both in terms of navigating and understanding

the information."

This feedback brought out positive sentiments about the dashboard, indicating that its structure is effective and the design is appealing. However, even with this positive feedback, there are some issues worth noting.

"About the scores i prefer standard scores because this is also how it's documented in our clinic... and with an MRC scale they would already know about the state of the patient"

"Clinician preferred on this to work with what they understand, and add a new case could not be a good idea, because they have to understand how this score what this score means and how this is related with the scores that they mainly use during the daily work"

Some participants highlighted that they prefer using standard scores, like the MRC scale, because that's what they are used to in their clinic's documentation. They mentioned that using a new scale we introduced, might involve a steep learning curve. They emphasised that clinicians prefer working with what they already understand, and introducing a new approach might complicate matters. They raised concerns about understanding the new score's meaning and its relation to the scores they commonly use.

On our end, we've found that existing scales aren't as reliable as expected, and converting exoskeleton data to those standard scales can be challenging and imprecise. This tension between familiarity and reliability means we need more discussions in the future to find a balance.

Additionally, some participants pointed out that the scheduling function might not fit smoothly into their clinic's workflow. They mentioned that their clinic has a dedicated department responsible for therapy scheduling, which differs from the current platform's setup.

"We have our own department of two or three people who do the therapy scheduling for all the patients,... so it does not make it works as shown on the platform"

This insight stems from our limited understanding of therapists' daily routines and responsibilities. Adjusting to this setup might require careful thought and consideration moving forward.

A noteworthy idea emerged during the discussion:

"I want a global view of my patients on all my schedules, because I want to follow some of my patients during the therapy I will need. "

Interestingly, a version of this feature already exists on the home page's calendar, showing dots to remind therapists of their agenda for the day. There's also a detailed list of patient appointments and meetings. Building on this, a comprehensive calendar that integrates all these details could be a valuable addition in future development.

The present evaluation provides valuable insights into the opportunities and challenges inherent in the utilisation of Human Digital Patient Twins for stroke rehabilitation, focusing on the aspects of data visualisation and communication. Addressing the first research question (RQ1), it is evident that the data visualisation within the dashboard garnered positive reception among participants. The clarity and intuitiveness of the presented data were acknowledged, reflecting a successful alignment with their accustomed workflow. However, it was notable that a preference for conventional metrics such as the MRC scale, Barthel Index, and MoCA emerged from participants due to their familiarity and integration with existing clinical documentation practices.

With regards to the second and third research questions (RQ2 and RQ3), the feedback underscored several critical features desired by therapists. The effectiveness of the dashboard's structure and information presentation was highlighted as a strength, facilitating its comprehensibility. The integration of standardised scales, patient scheduling, collaboration capabilities with clinic staff, and a comprehensive calendar view emerged as essential components for therapists. Nevertheless, the assessment also brought to the fore certain challenges, particularly in interactive aspects such as the "drag to add a new exercise schedule," signalling the necessity for enhanced design cues to alleviate usability issues.

The participants' perspectives strongly echoed the importance of achieving a harmonious equilibrium between established practices and innovative approaches. This sentiment emphasised the significance of ensuring usability, transparency, and relevance in the design and functionalities of the dashboard for effective stroke therapy management.

In summation, the evaluation phase has not only illuminated the strengths of the dashboard but has also identified areas warranting further refinement. The overall feedback conveyed a positive outlook, accentuating the dashboard's design and usability merits. Nevertheless, the feedback also underscored the requisite equilibrium between convention and innovation. These insights will serve as a compass for guiding future developmental endeavours, aimed at aligning the dashboard seamlessly with users' expectations and necessities.

8
Discussion

The primary focus of this research has been the exploration of the vast potential and the intricate challenges that surround the utilisation of Human Digital Patient Twins (HDTs) in the domain of stroke rehabilitation, with a particular emphasis on data visualisation, interaction, and communication. Leveraging the real-time monitoring capabilities inherent in HDTs, the overarching objective of this project was to empower medical professionals with the ability to predict patient conditions, thereby facilitating well-informed and timely medical decisions. At its core, this endeavour involved the strategic design of a dashboard tailored for stroke therapy management. The pivotal challenges faced during the course of this project included the delicate task of harmonising innovative data visualisation techniques with the well-established conventions of therapists' reliance on conventional scales, the quantification of therapy objectives, and the nuanced differentiation between home-based and clinic-based rehabilitation settings.

Subsequently, the pursuit of this main research question led to the formulation and exploration of three distinctive sub-research questions, each unravelling vital dimensions of the project. Sub-RQ1 delved into the art and science of effective data visualisation within the context of HDTs, propelled by user-centred design decisions. This exploration resulted in the implementation of a multifaceted approach, including the development of separate data presentation pages for distinct body areas and the incorporation of advanced visualisation methodologies.

Sub-RQ2 sought to unravel the critical features and functionalities highly coveted by therapists in the context of stroke therapy management. The outcomes were enlightening, revealing a pressing need for standardised scales, efficient patient scheduling tools, adaptable support for diverse therapy environments, and the integration of a comprehensive calendar view. These provisions, aligning seamlessly with therapists' established practices, ushered in heightened operational efficiency.

Lastly, Sub-RQ3 cast a spotlight on the paramount principles of user-centric design. This endeavor culminated in an interface carefully crafted to prioritise comprehensibility and user-friendliness. Key components included a task management calendar, the use of general avatars for intuitive patient progress tracking, and data visualisation mechanisms that provide valuable insights.

Despite significant progress, it's imperative to acknowledge that the journey towards crafting a fully optimised solution remains ongoing. Challenges persist, particularly in refining the interactive elements of the interface, the combining of standard scales to real-time data, highlighting the continuous need for enhancements to ensure a seamless and satisfying user experience.

8.1 limitations

While this research endeavour has yielded valuable insights into the potential of leveraging the Human Digital Twin concept for enhancing stroke therapy management, certain limitations must be acknowledged. These limitations arise from the complexity of the field and the intricacies involved in technological implementation within a sensitive healthcare context.

1. Sample Size, Diversity, and Generalization

The research's scope was characterised by a limited sample size of therapists engaged in dashboard evaluation—comprising six therapists during the initial workshop and four during the subsequent session. While this sample imparted valuable insights, the potential for broader diversity remains untapped. Expanding participation to encompass a more diverse array of characteristics, including age, gender, clinic regulations, work responsibilities, and daily routines, would have enriched the analysis. Moreover, the developed dashboard's effectiveness was scrutinised within a specific context, which potentially limits its immediate applicability to diverse healthcare settings or therapeutic methodologies. Variables such as institutional norms, therapist preferences, and patient demographics are envisaged to influence the transferability of findings to a wider stroke therapy landscape. Thus, augmenting sample diversity and exploring applicability across varied contexts would collectively enhance the dashboard's potential impact and relevance.

2. Common used assessment scales VS real-time data collected from exoskeleton

Assessment scales, such as the MRC muscle power scale, constitute a commonplace tool within the daily practice of stroke rehabilitation therapy, widely recognized by therapists. Initially, at the project's inception, the majority of data was presented in these familiar scales to facilitate therapists' comprehension of patients' conditions. However, as the interface underwent evaluation, a shift was observed: the data collected through the exoskeleton predominantly manifested as numerical values—angles, times, positions, and the like. To maintain data authenticity, a decision was made to present the actual collected data instead of converting it into commonly used scales, thus ensuring data precision. This approach possesses both merits and demerits. On one hand, it affords a more precise representation of data, upholding its integrity. On the other hand, this adjustment necessitates therapists to grapple with understanding raw data, potentially steepening the learning curve associated with utilising the dashboard. This dynamic was evident in the second evaluation's outcomes, where therapists expressed resistance to this departure from familiar assessment scales. While this alteration undoubtedly contributes to future research opportunities, the immediate implications underscore the challenge of navigating this transition and its impact on therapists' acceptance and ease of utilisation.

This findings also highlights a common dilemma in stroke rehabilitation: therapists tend to prefer traditional qualitative assessment scales due to familiarity and trust, even though newer quantitative approaches can offer more precise insights.

This tension between the comfort of tradition and the potential of innovation underscores the need for a balanced approach. Therapists' expertise in traditional scales is essential but should be complemented by training and support to harness the benefits of quantitative data. This dilemma reflects a broader challenge in healthcare: integrating new, data-driven methods while respecting established practices.

3. Technological Constraints and Affordability Considerations

The successful realisation of the Human Digital Twin concept hinged on the deployment of specialised technological infrastructure and hardware, with a particular emphasis on the robust data collection capabilities of exoskeletons, essential for thorough user progress analysis. Diligent efforts were directed towards optimising compatibility, yet it is imperative to acknowledge that the dashboard's efficacy could be influenced by divergent availability and quality of hardware and software resources across distinct healthcare facilities. The viability of implementation thus becomes interlinked with the degree to which these facilities can furnish the necessary technological support, potentially shaping the dashboard's effectiveness within varied healthcare settings.

Moreover, during the course of the study, a notable consideration emerged regarding the financial accessibility of the exoskeletons and associated devices employed. While the dashboard's design was intended to accommodate clinic usage, it requires a substantial investment. The expense associated with the exoskeletons and related equipment could render individual affordability a challenge, thus presenting an obstacle to wider adoption. To enhance the viability and democratise access to this therapy. This facet of affordability thus stands as a crucial consideration for the scalability and long-term impact of the Human Digital Twin concept in the realm of stroke therapy management.

In conclusion, while this research project has made significant strides in revolutionising stroke therapy management through data visualisation and the Human Digital Twin concept, the aforementioned limitations underscore the need for continued research and refinement. By addressing these limitations, future endeavours can build upon this foundation to create a more robust, universally applicable, and ethically sound technological solution for stroke rehabilitation.

8.2 Ethical issues

This research has the potential to revolutionise stroke therapy management. However, the pursuit of such innovation, particularly when it involves human subjects and sensitive data, necessitates a profound consideration of ethical implications.

First and foremost, an ethical concern of utmost importance revolves around patient privacy and data security. It is imperative to ensure the secure storage of patient data, safeguarding it from unauthorised access. In the context of this project, patient data is accessible not only on therapists' dashboards but also on care-givers' dashboards, raising pertinent questions about data privacy and security. To uphold data security, care-giver accounts will be established by therapists within the patients' explicit permission. Furthermore, during the account creation process, carefully designed settings will govern the information shared on the third-party dashboard, contingent upon patients' preferences regarding which aspects are disclosed to caregivers. This approach underscores a conscientious handling of data sharing and security concerns in line with ethical principles.

Secondly, it's important to acknowledge that while avatars have advantages in visually representing patients' movements for enhancing the comprehensibility of patient information, an avatar bearing too much similarity to the patient's appearance may raise concerns about the anonymity of patients and the potential for stigmatisation. Prior research (Lauer-Schmaltz et al., 2023) has emphasised that therapists do not necessarily require an exact replica of each patient's appearance; avatars that closely resemble but do not precisely replicate the patient might elicit an unsettling sensation known as the "Uncanny Valley" effect (Mori et al., 2012). Consequently, the therapists' dashboard adopts a pair of generic avatars – one male and one female – to symbolise patients, as depicted in Figure 8.1. This approach underscores the need to balance patient representation with considerations of data safety and minimising any potential sense of unease.

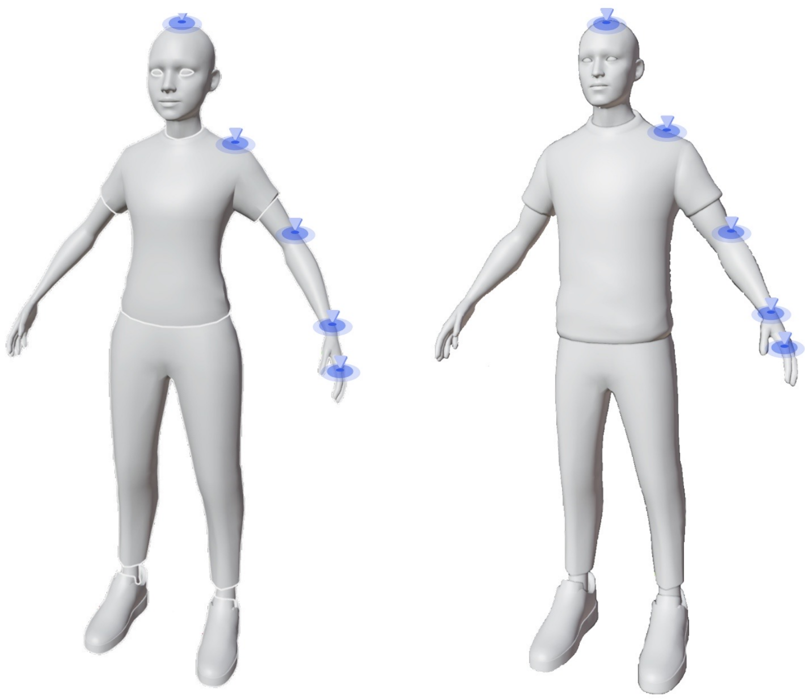

Figure 8.1: Generic avatars

Thirdly, ethical considerations encompass the intricate dynamics involving patients, caregivers, and therapists. To foster consistent interaction between patients and therapists, patient and caregiver dashboards have been developed, equipped with text and call functionalities for direct communication with therapists. This design, however, introduces a pivotal challenge, as it amplifies therapists' already demanding schedules, potentially impinging on their routine tasks. To address this ethical dilemma, a messaging system that empowers therapists to manage communication has been devised. Instead of incoming calls, notifications appear within dialogues, prompting therapists to return calls at their convenience, effectively striking a balance between immediate responsiveness and therapist engagement. This approach strives to harmonise the imperative of timely patient-therapist interaction with the ethical responsibility of upholding therapists' professional commitments, as depicted in Figure 8.2.

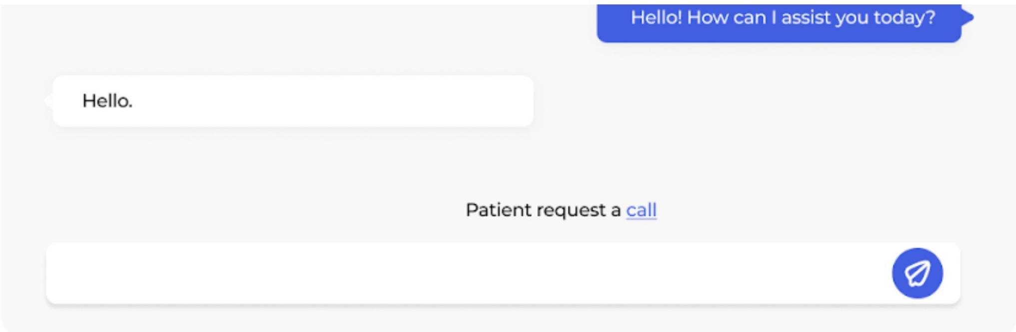

Figure 8.2: Patient requests a call floating at the bottom of a conversation.

In summation, while advancing stroke therapy management through technological innovation holds immense promise, a steadfast commitment to ethical considerations remains paramount. By ardently addressing concerns of patient privacy, data security, and potential biases, this project navigates the ethical landscape, ensuring that innovation and ethical integrity stand hand in hand.

8.3 Future work

8.3.1 Versatile Application Potential

The design of the patient management system's dashboard holds promise as a versatile tool that could extend its utility beyond the realm of stroke rehabilitation. While the primary focus of this project was to enhance stroke therapy management, several elements of the dashboard's design possess attributes that could benefit a more extensive group of patients undergoing various forms of medical treatment or rehabilitation.

Firstly, the calendar feature, which provides therapists with an organised view of their daily activities and patient therapy schedules, could be valuable in a broader healthcare context. The ability to efficiently manage appointments, track patient progress, and coordinate care activities is essential not only in stroke therapy but also in managing patients with different medical conditions.

Secondly, the use of general avatars to represent patients, combined with data visualisation, effectively portrays patients' progress across sessions. This visual representation could be adapted for different patient populations, aiding therapists in tracking patient improvements in various rehabilitation or treatment scenarios.

Additionally, the collaborative mechanisms within the dashboard that facilitate communication among healthcare professionals could be leveraged in multidisciplinary healthcare settings. Collaborative care is increasingly recognized as a valuable approach in managing complex medical cases, and the dashboard's features for teamwork align well with this concept.

Furthermore, the inclusion of patient exercise scheduling, and support for both home-based and clinic-based care can be valuable across different patient groups. These functionalities cater to the diverse needs of patients undergoing various forms of rehabilitation and therapy.

While these aspects of the dashboard design offer promise for broader application, it's crucial to consider customization and adaptation for different medical contexts. Each patient group may have specific requirements and data visualisation needs that warrant adjustments.

8.3.2 Future Directions for Research

Building upon the foundation established by this research, several promising directions emerge for future investigations in the realm of stroke therapy management and the Human Digital Twin concept.

1. Tailoring Dashboard Functionalities

To enhance the collaborative dimension, future studies could focus on aligning the dashboard functionalities with therapists' varied work duties, acknowledging that different therapists might oversee distinct segments of the therapy process. This tailored integration would cater to individual therapeutic approaches and streamline the interface's utility.

2. Enriching Data Collection Scope

Expanding the data collection scope beyond arm movements to include leg movements, possibly through improved exoskeleton developments, holds the potential to enrich the dashboard's efficacy for comprehensive rehabilitation. By combining this diverse dataset, the dashboard's visualisations could be refined into more intuitive scales, such as the MRC muscle power scale, which therapists commonly use.

3. Iterative Design Enhancements

Collaborative endeavours between human-computer interaction experts, therapists, and patients could yield iterative design enhancements, ensuring the dashboard remains user-friendly, accessible, and adaptive to the evolving demands of stroke rehabilitation.

Collectively, these avenues of exploration promise to amplify the transformative impact of the Human Digital Twin on stroke therapy management, cultivating more refined patient care and rehabilitation outcomes.

9

Conclusion

In summary, this project was centred on the development of an intuitive dashboard interface tailored to therapists, with a primary focus on harnessing data visualisation and patient management to enhance stroke rehabilitation processes. The central objective was to provide therapists with a lucid and insightful representation of patients' therapy session performances, thereby facilitating streamlined patient management. Rooted in user-centric principles, a sequence of iterative design iterations was meticulously executed to design the user interface, which was fundamentally informed by the daily work routines and operational context of therapists.

The main research question was:

What are the opportunities and challenges of using Human Digital Patient Twins for stroke rehabilitation in terms of data visualisation, interaction, and communication?

It delved into exploring the opportunities and challenges associated with the use of Human Digital Patient Twins (HDTs) for stroke rehabilitation, particularly focusing on data visualisation, interaction, and communication. Leveraging the intrinsic capabilities of HDTs for real-time monitoring and simulation, this project aimed to predict patients' conditions and requirements, providing critical insights for medical decision-making in stroke rehabilitation.

The project's design of the dashboard, coupled with adept data visualisation of exoskeleton-derived data, sought to tailor therapy regimens for stroke patients effectively. Notably, the dashboard's user interface successfully enhances therapy management by offering therapists an insightful and understandable view of patients' session performances. However, distinct challenges emerged during the project:

Reconciling Innovative Data Visualisation: The project faced the challenge of reconciling innovative data visualisation techniques with therapists' well-established reliance on conventional scales and documentation procedures.

Quantifying Patients' Therapy Goals: Addressing the quantification of patients' therapy goals was another significant challenge.

Differentiating Home-based and Clinic-based Rehabilitation: Managing the differentiation between home-based and clinic-based rehabilitation presented its own set of challenges.

Sub-Research Question 1 (Sub-RQ 1) was:

How to visualise the data of the digital twin in an understandable way?

It explored the effective visualisation of HDT data, which was achieved through user-centred design decisions. Separate pages were employed to present data from different body areas, accessible through interactive anatomical markers. This approach offered a logical and coherent structure to therapists. Data aggregation into overarching figures provided therapists with a holistic overview of patient progress, while advanced visualisation methods further enhanced their ability to monitor patient trajectories.

Sub-Research Question 2 (Sub-RQ 2) was:

What are the most important features and functionality desired by therapists in a solution for visualising patient data for stroke therapy management?

It uncovered the paramount features and functionalities desired by therapists. Standardised scales, patient exercise scheduling, support for varying use conditions (home-based and clinic-based), collaborative mechanisms with clinical personnel, and a comprehensive calendar view were underscored as pivotal requisites for enhancing patient management. These provisions aligned with therapists' accustomed practices, ultimately enhancing operational efficiency.

The Sub-Research Question 3 (Sub-RQ 3) was:

What are design elements, features, and functionalities that could support the communicated data regarding understandability and human-computer interaction?

It underscored the importance of user-centric design principles, resulting in an interface prioritising comprehensibility and user-friendliness. The inclusion of a calendar facilitated therapists in managing their daily activities and patient therapy schedules. General avatars, combined with data visualisation, effectively portrayed patients' progress across sessions, simplifying tracking and enabling tailored exercise plans. While the dashboard demonstrated efficacy in these aspects, some challenges persist, particularly in optimising interactive design elements. This highlights the ongoing need for refinement to ensure a seamless and satisfying user experience.

In conclusion, this project's innovative dashboard user interface signifies a significant advancement in stroke therapy management. By effectively leveraging data visualisation and interaction design, therapists now have a user-friendly tool that seamlessly integrates with their workflow and fosters improved patient outcomes. The dashboard serves as a bridge, enhancing communication between therapists and patients, ultimately leading to more effective therapy. Notably, the evaluation results, with an average questionnaire score of 4.1 out of 5, demonstrate a high level of satisfaction with the interaction design and data visualisation of the dashboard functionality. This project not only addresses the research questions but also paves the way for the ongoing refinement and enhancement of stroke rehabilitation practices.

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A

Appendix

A.1 Appendix 1:Therapist's dashboard Requirements list

Patient page:

1. General patient information:

Name, Age, Gender, Type of Stroke, Date of Stroke, Paretic Side, Special condition, notes, Caregivers (list of names of family members etc.)

2. Add a new patient:

Set patient information, stroke history and assign access accounts for family members.

3. Authorization for third-party dashboard:

Set which information of the third-party dashboard are shown to which third-party caregivers after discussing that with the patient

Data visualisation:

1. Physiological

Range of motion (automatic)
Strength (automatic or manual – both using the MRC 0-5 scale)
Motion speed (automatic detection – not sure if we actually have to visualise that)
Spasticity (automatic or manual – both using Modified Ashworth Scale; automatic eventually additionally with avatar visualisation?)
Muscular fatigue (automatic or manual – both using fatigue severity scale)
Pain during physical motion (automatic)
Capability to perform Activity of Daily Living (manual via Barthel index 0-100)

2. Cognitive

Short-term memory (automatic)
Reaction time (automatic)
Spatial awareness (automatic)
Coordination (automatic)
Selective attention (automatic)
Cognitive impairment assessment MoCA 0-30
Pain Tolerance (manual)
Neglect (manual)
Aphasia (manual)

3. Behavioural

Over the day, when does the patient usually do their exercises? (automatic)
How long does the patient usually exercise before taking a break? (automatic; differentiate between physical exercises and cognitive exercises)
Mood & Mental health (e.g., Depression using Hamilton Scale, Engagement/Motivation, how do certain exercises affect the mood etc. – automatic)

Messages page a little mailbox button in the main menu indicating that there are new messages, these messages could be from both patients and informal caregivers (family members). If a message comes from a caregiver, under the caregiver's name there should also be indicated to which patient they belong.
The therapist dashboard needs to come in 2 versions – one for the ReHyb system's minimal architecture where most data is assessed manually by the therapist and one for the extended architecture where most data is predicted automatically by the system. All automatically predicted information needs to be visualised in the patient-condition-overview tab (need to name this better) and all data that is assessed manually needs to be put in the manual assessment-tab.
IDEA:Theoretically, we could also merge them into one, where we visualise the data for the patient and enable manual editing for each of them by clicking on them.

Exercises page Possibility to rewatch exercises using the avatar (and indicating real-time variables such as pain etc.)
Redesign how therapists can schedule exercises (minimal architecture could stay as it is but should refer to RGS exercises (the exercises from the RGS system developed by our project partners; Therapists need to select exercise and set RGS Dosage per week); extended architecture should show the therapist more information about how the exercises would affect the patient's progress, meaning which variables does the exercise target and how much percentage, for example, would this variable increase due to the exercise).

A.2 Appendix 2: Think-aloud protocol

Who do we need:
Participants
Moderator
Technical supporters (who can also take notes)
What do we need:
A camera setup behind the participant to record their screen and the entire process. The recording should capture both the visual display and the participant's voice.
What do we need to do:
Technical supporters will set up the prototyping for each task.
Evaluators will explain the task to participants and ask them to "think aloud" by verbalising their thoughts, feelings, actions, and observations while performing the tasks.
Evaluators should refrain from providing any assistance during the task unless the participant is stuck for a while that much longer than we expected.
Tasks:
Task 1: Plan a one-day exercise plan for patient John.
Task 2: Check the strength improvement of the patient's shoulder.

A.3 Appendix 3: Questionnaire of second evaluation

Google sheet: https://forms.gle/HVQkxjTpL8c7xh5o7

A.4 Appendix 4: workshop guide for the first evaluation

1. Therapist page (Open Discussion - 1 minutes)
2. Patient list page
   (a) Describe patient list (1 minute)
   (b) Show „Add patient“-menu (Open Discussion - 5 minutes)
      i. Patient details, condition, contact persons, access to data: Anything else to add?
      ii. What do you think of adding the patient interests (drop-down list of general interests that are covered by the protocols & text-field for more detailed informations)
      iii. Therapy goals: How could we define short, medium, long-term goals? How can we quantify them?
3. Patient overview page (Open Discussion - 10 minutes):

(a) What would be the most important information that you would like to see on the overview page? Is anything critical missing? Overall first impression? (2 minute)

(b) Current patient condition (3 minutes):

i. Which visualisation technique would you prefer?

ii. What do you think of the scores? Or should that rather be more general scores (like the overall physical condition in percent?)

(c) What visualisation would you prefer for the patient mood overview? Is the information important at all? (3 minutes)

(d) Do you understand the patient exercise behaviour overview? Do you like visualisation? Is it useful?(2 minute)

4. Exercise plan (10 minutes)

(a) Vertical vs Horizontal layout?

(b) How many exercises per day?

(c) Is the additional information useful? (patient improvement)

(d) Should we show Exercise summary -> Are the information useful or do they miss further information?

5. atient condition overview (open discussion - 15 minutes):

(a) Do you like how the data is presented (Scales)?

(b) What do you think of the way progress is shown? Do you think this should entail more graphs/other visualisation techniques?

(c) How do you like the visualisation of pain?

(d) Should the page entail more visual guidance? (E.g. picture of what shoulder rotation, extension/flexion etc. is?)

6. Advanced visualisations (10 minutes):

(a) Everyone gets 5 minutes to brainstorm ideas of what advanced visualisations they could imagine/would be useful to be. For example, total range of motion and how easy each area is accessible)

(b) Then 5 minutes of discussion

7. ReHyb component parameterization integration (5 minutes)

(a) What parameters need to be set manually for each of the ReHyb components?