Designing and Evaluating Interactive Data Visualizations
Representing the Rehabilitation Progress of Patients Recovering from a Stroke within Inpatient Rehabilitation Facilities

by

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Abstract

Stroke is a leading cause of disability worldwide, with recovery efficacy influenced by factors like adherence to rehabilitation programs. Utilizing health data visualization to increase patient involvement can enhance understanding, promote positive health behaviours, and deepen engagement in their care. In our research, we aimed to design a simple, intuitive, and accessible visualization system for stroke recovery by (1) conducting semi-structured interviews with healthcare providers with expertise in inpatient stroke recovery, (2) designing medium-fidelity visualization prototypes representing stroke recovery, and (3) refining these designs through feedback from evaluations with healthcare providers and patients recovering from stroke. The resulting designs present a comprehensive and centralized overview of patients' rehabilitation progress. The visualization system we designed aims to empower both patients and healthcare providers with a means to offer a more intuitive and interactive approach to understanding, sharing, and discussing rehabilitation results.
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Chapter 1: Introduction

1.1 Motivation

In Canada, more than 100,000 strokes occur each year, which equates to roughly one stroke every 5 minutes, and this number is predicted to increase due to population growth and aging [1]. Strokes can result in debilitating impairments that can require physical and cognitive rehabilitation for months to recover and are a significant source of stress for patients and their families [2]. The care for patients with stroke is considerable, both in terms of cost and the demand it places on the healthcare system. To meet the complex needs of these patients, an interdisciplinary team of healthcare providers often design individualized recovery programs that focus on improving motor function, postural control, and mobility. The effectiveness of these rehabilitation programs is largely dependent on the patient's adherence to the program. However, patients undergoing stroke recovery in inpatient rehabilitation centers often experience extended stays, which can be physically and emotionally exhausting [3]. The prolonged duration of rehabilitation can lead to a lack of motivation for goal-directed activities, resulting in reduced engagement and limited benefits from the rehabilitation process, ultimately impeding stroke recovery [3]. Strategies that promote patient engagement and adherence to rehabilitation programs are critical to ensuring the best possible outcomes for patients recovering from stroke [4]. One effective approach involves tracking and reviewing recovery progress and goals, which can provide tangible feedback to motivate patients and reinforce their adherence to rehabilitation programs [3].
One of the major challenges faced by patients is the complexity of the diverse recovery progress data collected over weeks or months. Patients may struggle to identify patterns, trends, and insights from their health data. Additionally, data that is verbally communicated with patients can be overwhelming and difficult to interpret or remember, especially for patients experiencing cognitive or linguistic deficits. As of now, the problem of effectively comprehending and making sense of this intricate stroke recovery data remains largely unresolved. However, there is promising potential in addressing these challenges through the application of data visualization techniques such as graphs, charts, and dashboards. Previous research highlights the benefits of visualizing health data in improving comprehension, encouraging positive health behaviours, and enhancing patient engagement [5]. Building on this foundation, the goal of this thesis is to design an accessible, intuitive, and simple visualization system for both patients and healthcare providers that presents an integrated overview of a patient’s stroke rehabilitation progress. In addition to the challenges faced by patients in navigating the complexities of their recovery progress data, healthcare providers encounter their own set of hurdles when it comes to monitoring and communicating this vital information. The healthcare landscape is constantly evolving, with providers tasked with managing large volumes of data and an increasingly diverse patient population. Keeping track of each patient's unique journey can be a daunting task, further complicated by the need to convey this information to patients in a comprehensible and meaningful manner. While patients seek clarity and empowerment through data visualization, healthcare providers require tools that facilitate efficient data interpretation, enhance communication, and ultimately contribute to more effective care delivery. This thesis not only recognizes the need to
assist patients in understanding their health data but also acknowledges the invaluable role of healthcare providers in this process. The thesis objectives are designed to address and pave the way towards empowering patients and providers with an intuitive and accessible understanding of patient health data through interactive data visualizations. In summary, this research emphasizes the prominent role of healthcare providers while also recognizing the insights and perspectives of patients. This collaboration signifies a step forward in healthcare practices, driven by the synergy between those who provide care and those who receive it.

1.2 Research questions

The objectives of this research are to answer the following questions:

1. What are the current practices and significant challenges confronted by healthcare providers when assessing patient stroke recovery and communicating recovery data to patients?

2. How can interactive data visualizations be designed to effectively portray stroke recovery in a manner that is intuitive, simple, accessible, and facilitate communication between healthcare providers and patients?

3. How do healthcare providers and patients perceive the comprehensibility of the data visualization designs?

While the immediate objectives of this research revolve around the design and evaluation of these visualizations, it is essential to acknowledge the existence of broader, long-term objectives that extend beyond the scope of this thesis. The long-term objectives
aim at fostering enhanced patient comprehension and engagement in their rehabilitation journey as well as enhance communication between patients and providers. It is important to note that this research does not encompass the evaluation of patient outcomes or levels of engagement, as such objectives are beyond the scope of this thesis. Nonetheless, the specific objectives within this thesis have been devised to address specific tasks that serve as pivotal steppingstones towards achieving the long-term objective. By accomplishing these thesis objectives, this research seeks to make progress in contributing to the overarching goal of enhancing patient comprehension and engagement with their health data through the application of interactive data visualizations.

1.3 Contributions

By analyzing a retrospective stroke rehabilitation dataset, and conducting semi-structured interviews with healthcare providers involved in stroke recovery and patients recovering from a stroke, this thesis makes several contributions:

1. We identified the content, procedure, and technological needs for effective communication of recovery progress between patients recovering from a stroke and their healthcare provider team.

2. We identified the design requirements to develop an interactive data visualization representing recovery progress and designed medium-fidelity data visualizations based on the design requirements.
3. We have provided a list of recommendations for future researchers and designers who seek to develop innovative solutions that display the stroke recovery progress for patients recovering from stroke.

1.4 Thesis outline

This thesis comprises 8 chapters. Chapters 2, and 3, set the context and background of this research. Chapter 2 provides a literature review of health data visualizations and includes relevant studies that have examined patient-facing visualizations and their impact on recovery, specifically for in-clinic and at-home rehabilitation, including stroke recovery. Chapter 3 outlines the methodology used in this thesis, which includes a review of a retrospective stroke rehabilitation dataset, interviews with healthcare providers, the development of data visualization designs, and the evaluation of the designs with healthcare providers and patients. This chapter also highlights the key target users of the visualization system.

The following chapters are structured around four principal phases of research: Discovery, Design, and two Evaluation Studies.

The Discovery phase, covered in Chapter 4 presents the results of the retrospective dataset review and findings from interviews with healthcare providers. We then provide a list of design requirements, derived from the interviews with healthcare providers, necessary for data visualization designs representing stroke recovery.

In the Design phase, Chapter 5 presents the first design iteration. Current methods for presenting patient data in the hospital are presented, followed by an overview of the initial sketches and designs of data visualizations representing stroke recovery.
Additionally, we present the interactions used within the designs and user interface features for the visualization system.

The results of the first round of Evaluation are discussed in Chapter 6.1, where the feedback from healthcare providers is used to evaluate and refine the designs, resulting in the second design iteration. Following that, in Chapter 6.2, the results of the second round of Evaluation are discussed, where the patient feedback is considered, leading to the third and final design iteration. Additionally, chapter 6 presents an overview of the user flow and navigation of the final designs of the visualization system.

Chapter 7 presents a comprehensive discussion of the findings and implications of this research. This chapter also provides a list of recommendations for future researchers and designers to design and develop interactive data visualizations representing post-stroke recovery. Finally, the limitations section examines the constraints and challenges encountered throughout the research process, offering insights into areas that warrant further investigation and improvement.

Finally, Chapter 8 serves as the conclusion of this thesis, where the key findings and contributions are summarized. Through a cohesive synthesis of the research outcomes, the conclusion sheds light on the significance and implications of the study's results. Moreover, this chapter reiterates the research objectives and discusses how they were addressed, offering a holistic perspective on the research journey. Additionally, Chapter 8 explores the future directions of the research, outlining potential avenues and considerations for further study and development in this field.

The four phases described above represent one complete iteration of the design process. However, it should be acknowledged that additional iterations are likely required
to refine and finalize the development and implementation of an effective data visualization tool for stroke recovery (Figure 1).

Figure 1: The 4 principal phases of this research (Discover, Design, Evaluate #1, and Evaluate #2) and future directions (Develop, and Implement).
Chapter 2: Literature review

In this section, we explore the pivotal role and application of health data visualizations for both healthcare providers and patients. First, we discuss the fundamentals of data visualization (Section 2.1) and discuss how it plays an instrumental role in rendering complex health data into understandable, interpretative forms. Following that, we examine the concept of interactive data visualization (Section 2.2), revealing how interactivity amplifies the benefits of data visualization and promotes active engagement. Further, we provide an overview of the importance and application of health data visualizations for healthcare providers and patients (Section 2.3). Then, we outline relevant studies on patient-facing visualizations that have assisted in recovery for both in-clinic and at-home rehabilitation, including stroke recovery (Section 2.4).

2.1 Data visualization

Visualization is a term that is frequently used and has a rich history in conveying information and facts through visual representations [7]. Visualization has been referred to a dictionary definition of the term: visualize – to form a mental model or mental image [6]. Despite the long-standing use of visual representations for communicating facts and information, visualization as a distinct field of research has only been around for about three decades. In 1987, the concept of visualization in scientific computing was first introduced by McCormick as a computational method that converts symbolic data into geometric forms, allowing researchers to visually observe their simulations and computations [7]. The objective of this emerging area of research is to combine the abilities of human visual perception with the immense processing power of computers,
aiming to assist people in analyzing, comprehending, and effectively communicating their data [8]. Visualization provides a way to see the unseen, enhancing the process of scientific discovery and leading to profound and unexpected insights [7].

In the realm of data analysis, visualization, or 'vis' as it is often abbreviated, is a powerful tool [9]. It involves the use of computer-based systems to generate visual representations of datasets. The goal of these visualization systems is to augment human capabilities, not to replace them, by providing a more effective way to carry out tasks [9]. The success of this process is critically linked to three major criteria: expressiveness, effectiveness, and appropriateness, as suggested by Schumann and Muller [8].

Expressiveness, the first criterion, emphasizes that visualization should capture precisely the information contained in the data, neither omitting nor adding irrelevant details. This principle echoes the notion of 'task abstraction' in data analysis [9], where the process of simplifying data seeks to highlight essential information and facilitate the user's tasks and goals. By using task abstraction, irrelevant details are removed or represented in a simplified manner, allowing users to focus on the essential aspects of the information and derive meaningful insights [9]. Effectiveness, the second criterion, underlines the importance of creating visual representations that are intuitively recognizable and interpretable [8]. This criterion takes into account the cognitive capabilities of the human visual system, the task at hand, the application background, and other context-related information to derive meaningful insights from data. Appropriateness, the final criterion, involves the evaluation of the cost-value ratio in order to assess the benefit of the visualization process with respect to achieving a given task [8]. This criterion necessitates an understanding of the value derived from a visualization versus the cost involved in its
creation and interpretation. Cost often relates to the computation time spent and the screen space exploited. Appropriateness thus encapsulates the principle that a good visualization not only effectively represents the data but does so in an efficient and useful manner. The application of these three criteria is centered around the two core aspects of the visualization process: the data and the task at hand. Understanding 'what' needs to be presented (the data) and 'why' it needs to be presented (the task) forms the backbone of creating effective visualizations [8].

### 2.2 Interactive visualization and role

Interactive data visualization play a crucial role in data analysis and exploration, as it enables users to actively engage with the data, gain insights, and uncover meaningful patterns [8]. When datasets are large and complex, merely presenting everything at once becomes impractical due to human limitations and display constraints [9]. Static visualizations can only show a few aspects of a dataset, whereas interactivity allows user actions to trigger changes in the view to support multiple queries. This dynamic approach empowers users to directly interact with the data, explore it more deeply, and reveal patterns and insights that might not be immediately apparent in static representations. Users can focus on specific elements, regions, or the entirety of the dataset, customizing their exploration based on their interests and questions. To support users in achieving their visualization goals effectively, interactive data visualizations offer a range of tasks that involve both visual and interactive aspects. Shneiderman's taxonomy [10] provides seven high-level tasks for information visualization: obtaining a comprehensive understanding of the entire dataset (overview), focusing on data of interest (zoom),
excluding uninteresting information (filter), selecting data of interest and retrieving details (details-on-demand), observing relationships among data items (relate), maintaining a record of actions for undo and redo (history), and enabling extraction of data and query parameters (extract). Yi et al. [11] further refined the aspect of interaction in data visualization and developed several categories of interaction tasks. These categories are centered around the user's intentions to interactively adjust visual representations to the tasks and data at hand. Consequently, a "show me" prefaces six categories: show me something else (explore), show me a different arrangement (reconfigure), show me a different representation (encode), show me more or less detail (abstract/elaborate), show me something conditionally (filter), show me related items (connect). In addition to the "show me" categories, Yi et al. [11] introduced three further interaction tasks: mark something as interesting (select), let me go to where I have already been (undo/redo), and let me adjust the interface (change configuration). These tasks allow users to switch between different subsets of the analyzed data (explore), different arrangements of visual primitives (reconfigure), and different visual representations (encode). They also address the navigation of different levels of detail (abstract/elaborate), the definition of data of interest (filter), and the exploration of relationships (connect).

As discussed, interactive data visualization plays a crucial role in gaining insights, uncovering patterns, and enabling users to actively engage with complex datasets. By allowing users to interactively manipulate visual representations and focus on specific aspects of the data, interactive data visualization offers a dynamic approach to understanding information that goes beyond static visualizations. This versatility and
user-centric nature of interactive data visualization make it a valuable tool in a wide range of applications, including health data visualization, as explored in subsection 2.3.

2.3 Health data visualization

Visualizing health data is a technique for organizing large amounts of data to extract and present valuable information [12]. Visualizing health data has gained significant attention due to its potential in assisting both healthcare providers and patients in interpreting data analytics, recognizing trends, making better decisions, and engaging and informing patients about their care [13], [14],[5],[15]. Health data is stored in many different sources, including Electronic Health Records (EHR), Electronic Medical Records (EMR), remote monitoring devices, diagnostic centers, laboratories, pharmaceutical companies, and many Internet of Things (IoT) devices within and outside the hospital. Visual overviews of clinical patient data have primarily focused on displaying large amounts of patient health data, particularly in EHR systems [16]. Data in EHR systems are typically large, diverse, and temporal, which makes them difficult to understand [17]. Visualizing health data can be a strategic way to achieve several goals. First, it aims to present health data in user-friendly and easily comprehensible formats that is intuitive to navigate and manage. Second, it aims to highlight subtle details related to diagnosis, therapy, patient management, and the healing process, which might otherwise go unnoticed. Third, visualizing health data plays a crucial role in preventing information overload, empowering clinical staff to effectively handle larger volumes of information [15]. In the following, we illustrate several examples of visualization systems that display patient health data.
The visualization of health data has been thoroughly explored and investigated [16]. For example, Lifelines [18] is an interface that provides a visual overview and facilitates the navigation and analysis of clinical patient records. Outflow [19] is an interactive visualization that summarizes temporal event data extracted from medical data and can be used to analyze health outcomes. HARVEST, offers an interactive visualization tool for longitudinal patient records [20]. HARVEST incorporates a patient record summarizer that extracts relevant information from patient notes, aggregates data from various care settings, and provides clinicians with a flexible tool to review patients’ information [20]. Visualizing health data has also been used in healthcare to advance medication safety [21], intensive care patient management [22], promote patient wellness [23], and to help patients make decisions about their healthcare management strategies [24].

Research has shown that patients often lack the resources to fully interact with their health information and treatment [25]. The inability to obtain this information affects patients’ capacity to participate in the treatment they receive [26]. Given the high number of hospitalizations for stroke occurring in Canada each year, it is necessary to harness the benefits of interactive data visualization to assist healthcare providers while informing and engaging recovering patients. Interactive data visualizations representing post stroke recovery progress could provide healthcare providers with a visual overview to facilitate communication with patients and increase stroke survivors’ engagement in their health management and understanding of their health status.
2.4 Visualizing health recovery data

Visualization of health data has been widely applied to aid in various forms of rehabilitation. This section introduces visualization tools that represent health data for patients recovering in clinics and home environments.

2.4.1 Visualizing health recovery progress at home

As outpatient treatments are becoming increasingly popular in the healthcare industry, rapid advancements in technology have played a crucial role in creating new tools that allow healthcare providers to monitor, treat, and educate patients recovering at home while providing patients with access to their health information [27]. The increased desire for better patient engagement and more efficient patient-provider communication has pushed the use of patient-facing technology and consumer e-health solutions to empower patients in their at-home rehabilitation [27]. Patient-facing tools enable patients to better control their health by allowing them to access their health information, monitor their health status, and manage and follow their treatment at home while recovering [28][27]. These patient-facing tools can visually display recovery data to enhance patient engagement and patient-provider communication. For example, a wearable sensory display called PTViz was designed to visualize knee rehabilitation for at-home physical therapy for patients recovering from surgery, providing immediate feedback on a range of motion and consequently increasing bodily awareness [29]. Visualizing at-home recovery was also found helpful in addressing the lack of patient engagement in Vestibular Rehabilitation Therapy. Salisbury et al. [30] designed a platform that provides patients with real-time guidance and feedback on therapeutic exercises and allows physical
therapists to remotely monitor exercise adherence and performance. Because of
difficulties for patients to visit rehabilitation centers for stroke treatment, at-home
technological tools have been used to promote patient participation in stroke recovery.
For example, MusT, an IoT platform device, was designed to track muscle contraction in
the upper limbs of patients recovering from a stroke and send the results to physicians or
caregivers to monitor patients’ progress and keep patients motivated during the process
[31]. Similarly, Ploderer et al. [32] developed a sensor-equipped wearable prototype
designed to track arm movements. The collected data is then represented on dashboards,
offering a clear means to monitor and visualize patient progress throughout stroke
rehabilitation. Subsequently, researchers broadened this study by developing ArmSleeve
[33], a wearable device with interactive visualizations that illustrate how the arm is
undergoing treatment, allowing the rehabilitation plan to be adjusted accordingly. The
dashboards used in this tool which demonstrate how progress was achieved via the
wearable technology, benefited both therapists and patients. Furthermore, a home-based
rehabilitation application, SMART, was developed to record the performance of daily
tasks and rehabilitation exercises for patients recovering from a stroke at home [34].
SMART allows therapists to track patients’ progress and provide guidance. The
information gathered from these rehabilitation systems is important for patients’ health
monitoring and rehabilitation at home. It can provide significant assistance to healthcare
providers and patients, such as feedback on the progress of the therapy program, decision
-making, and forecasting future treatment plans. While the advancements in wearable
technology and data visualization for stroke rehabilitation, such as the ArmSleeve and
SMART, are commendable, they do not directly address the specific research problem of
this study. Firstly, the ArmSleeve focuses predominantly on physical rehabilitation, specifically tracking arm movements. This is a narrow scope, as stroke recovery is multifaceted and requires a comprehensive overview that encompasses more than just physical rehabilitation. Secondly, the SMART wearable technology, although innovative, is primarily geared towards home-based rehabilitation, emphasizing exercises. This specificity to one aspect of stroke recovery, combined with its home-based application, diverges from the identified need for data visualizations within inpatient stroke rehabilitation facilities. There exists a gap in knowledge regarding the creation and application of such visualizations in these inpatient settings. While the aforementioned tools offer valuable insights and have their place in the broader landscape of stroke recovery, they do not provide a holistic solution to the challenges identified in this research.

2.4.2 Visualizing health recovery progress in the clinic

Prior studies have demonstrated that patients are eager to assist in managing their health while staying in clinics [35]; however, they face barriers to accessing, consuming, sharing, and managing their information [35]. Inpatient hospital settings present unique challenges for patients and caregivers attempting to access, manage, and comprehend information concerning their treatment [36]. As a result, several technological and visualization tools representing recovery progress have been designed to increase patient-provider communication and patient engagement within rehabilitation care in the clinical setting. For example, AnatOnMe [37] is a projection-based handheld device designed to
facilitate in-clinic doctor-patient medical information exchange regarding physical therapy. AnatOnMe increased patient engagement in rehabilitation and understanding of medical information. Li et al. [38] also used visualizations to represent electromyography biofeedback during physical therapy sessions for patients with acute spinal cord injury, which helped increase muscle use and engagement during therapy.

Designing and evaluating patient-facing visualizations in the case of stroke recovery progress in clinical practice has not been thoroughly studied. Unfortunately, current guidelines and knowledge bases predominantly cater to broader healthcare contexts or other specific settings, leaving a void when it comes to inpatient stroke rehabilitation. This highlights the need for dedicated research and design principles that can guide the development of effective and user-centric interactive data visualizations for this critical area of healthcare.

One factor for the scarcity of patient-facing visualizations of stroke recovery in the inpatient hospital environment might be the notion that patients are already being cared for and do not need further assistance. Although they may be physically looked after, the slow and gradual nature of stroke therapy can make it mentally difficult for stroke survivors to perceive improvement and might lead to dissatisfaction or a lack of enthusiasm toward goal-directed activities. Visualizing and presenting patients with an overview of their progress could significantly enhance their participation and motivation in their treatment. Thus, we aim to address the gap in the literature by taking the first steps to design and develop interactive data visualizations representing patients’ overall recovery progress after a stroke while staying in inpatient rehabilitation centers.
Chapter 3: Methodology

In this thesis, we focused on designing a data visualization tool that displays the recovery progress of patients recovering from stroke within the inpatient rehabilitation facility. We took an iterative user-centered design approach [39], [40], [41] with the involvement of healthcare providers and patients at Élizabeth-Bruyère Hospital located in Ottawa, Ontario.

User-centered design (also commonly referred to as human-centered design) emphasizes the importance of designing for users and their needs and involves continuous refinement based on user feedback to ensure that the final product meets users' needs and expectations [33]. It involves several phases, including discovering the context of use and requirements, designing through prototyping, reflecting on feedback, and analyzing and refining the designs. In this thesis, we considered two target user groups: healthcare providers involved in stroke recovery and patients undergoing inpatient rehabilitation after a stroke. First, healthcare providers encompass a diverse group of professionals involved in guiding and facilitating the recovery journey of stroke patients within an inpatient rehabilitation facility. These experts possess a deep understanding of the complexities inherent in stroke recovery, as well as the intricacies of patient assessments, monitoring, and communication. Healthcare providers, including physiatrists, physiotherapists, speech-language pathologists, and occupational therapists are one of the intended target users of the envisaged visualization system. With substantial expertise accumulated over a decade in their respective fields, they offer valuable insights into the multifaceted aspects of patient care, rehabilitation protocols, and the challenges inherent to the recovery process. As essential participants in the design
process, healthcare providers play a pivotal role in shaping the system's fundamental requirements, reviewing prototypes, and providing invaluable insights to ensure that the visualization tool aligns with their professional practices and goals. Particularly noteworthy is their role in utilizing the visualization system as a means of accessing patients’ rehabilitation data and conveying pertinent insights to patients themselves. Second, patients undergoing inpatient stroke rehabilitation stand as the primary beneficiaries of the designed data visualization system. Patients constitute a diverse group that includes individuals of varying backgrounds and demographics. These individuals have directly experienced strokes and are currently receiving care within an inpatient rehabilitation unit. The age range of patients typically falls between 45 to 80 years, reflecting the broader demographic profile of stroke occurrences and the prevalence of stroke-related complications in this age bracket. Their journey towards recovery encompasses navigating various challenges, including cognitive, physical, and emotional hurdles. Given the diverse range of individuals within this group, their unique insights and perspectives are invaluable to the design process. By adopting a user-centered design approach, we prioritize the needs and perspectives of both healthcare providers and patients.

The methodology used in this thesis can be broken down into 4 phases: A discovery phase, and 3 rounds of design iterations which include a design phase, and two evaluation phases (Figure 1). During the discovery phase, we conducted an in-depth analysis of a retrospective stroke rehabilitation dataset to better understand the standard course of rehabilitation outcome measures (Section 3.1). Additionally, we conducted semi-structured interviews with healthcare providers that had at least 1 year of experience
in stroke recovery to better understand how the health assessments of patients recovering from stroke are assessed, how healthcare providers review the patients’ progress over time, and how they communicate rehabilitation progress with patients (Section 3.2). For our first design iteration, we leveraged the knowledge from the dataset review and interviews to propose potential visualization designs representing the stroke recovery progress (Section 3.3). Building upon these initial designs, we proceeded to the second design iteration (Section 3.4), where we conducted a second round of interviews with healthcare providers seeking their reflections on our suggested visualization designs. Their reflections and suggestions were then incorporated into our evolving designs. In the third and final design iteration, we conducted semi-structured interviews with patients who were undergoing inpatient stroke rehabilitation, seeking their reflection on our suggested visualization designs, and subsequently integrating their insightful suggestions into our evolving prototypes (Section 3.5). It is important to note that the four stages described above represent a complete iteration of the design process. However, it should be acknowledged that additional iterations are likely required to refine and finalize the development and implementation of an effective data visualization tool for stroke recovery. This study was reviewed and approved by the Bruyère Continuing Care Research Ethics Board (Clearance #M16-22-031) and by Carleton University Research Ethics Board-B (CUREB-B Clearance #117087).

3.1 Retrospective dataset review

We reviewed a retrospective dataset derived from a longitudinal study at a local hospital involving 235 patients recovering from stroke in the inpatient unit [42]. We
examined this dataset to better understand standard assessment measures for stroke recovery and to help inform the questions for the interviews in the next section of the study. Patients with a confirmed stroke diagnosis who were hospitalized within 72 hours of experiencing a stroke were included in the dataset. Patients with subarachnoid hemorrhage, as well as cognitive or comprehension impairments were excluded. Data was collected from June 2002 to March 2005. Within three days following their stroke, patients were examined by trained healthcare providers who assessed their performance on various activities and asked them to rate their ability in executing certain tasks. Patients were reviewed three months later using the same tests, plus a series of additional tests, including assessing activities and participation in their rehabilitation.

3.2 Interviews with healthcare providers

We sought to gain insights into the nature of the stroke recovery process from the perspective of experienced healthcare providers. We conducted semi-structured user interviews with the first user group: healthcare providers who had at least one year of experience in stroke recovery. We chose to focus on healthcare providers with at least one year of experience to ensure that we were capturing insights from individuals with a deep understanding of the complexities and nuances of stroke recovery. User interviews [43] are a qualitative research method that involves open-ended questions, where the interviewer further probes to understand the user’s response fully. User interviews will ensure that the insights gathered provide a rich understanding of the healthcare providers’ perspectives, which is invaluable in designing a tool that meets their needs. Our interviews were designed to elicit detailed information about the current practices and
processes used by healthcare providers in tracking patient information and communicating with patients throughout the stroke recovery process. By conducting these interviews, we aimed to identify potential areas for improvement that our designs could address.

3.2.1 Healthcare provider recruitment

To recruit participants for our study, we used a variety of recruitment methods in collaboration with the manager and a physician lead of the stroke rehabilitation unit at Élisabeth-Bruyère Hospital. First, during a stroke departmental meeting, the physician lead presented a research summary and invited healthcare providers to participate in the study. This initial approach aimed to engage those directly involved in stroke rehabilitation. Second, the hospital's communication team placed recruitment posters around the hospital. Interested participants reached out through the e-mail provided on the posters. Through these recruitment methods, we were able to identify healthcare providers whose primary responsibility is performing the rehabilitation of stroke within the inpatient rehabilitation unit. Third, to expand our participant pool, we employed a technique known as snowball sampling. This approach involved leveraging existing participants as a source of referrals for potential participants [44]. At the end of each interview, we asked the healthcare providers if they knew of other healthcare providers that would be interested in participating in the study. By doing so, we were able to tap into their professional networks and gain access to a wider range of potential participants. Additionally, we asked the healthcare providers if they would be willing to return for a second interview to discuss the preliminary designs.
3.2.2 Participants and interview process

In total, we recruited 4 healthcare providers from Élizabeth-Bruyère Hospital experienced with stroke recovery within the inpatient stroke rehabilitation unit: a physiatrist (PH), a physiotherapist (PT), a speech-language pathologist (SLP), and an occupational therapist (OT). Each healthcare provider has over 10 years of experience in stroke recovery. Interviews were conducted over the phone or online over MS Teams or Zoom. Interviews lasted 30 minutes to 1 hour, depending on the participant's availability and willingness to share. Interviews were audio recorded and the audio recording was later transcribed verbatim. Healthcare providers were not allowed to be monetarily compensated for their time per the hospital's review board, which approved all study procedures. The duration of the data collection process was from July 2022 to October 2022. Participants agreed to complete an audio-recorded interview after providing oral informed consent. The interview questions covered 3 main topics: assessing patient health outcomes, reviewing patient progress, and communicating rehabilitation progress to patients. Some example questions include:

- Can you walk me through the steps of your treatment protocol?

- What are the main health outcomes that you assess, and what questionnaires or tests do you use for them?

- To what extent are the patients aware of their progress results, and how is it communicated to them?

*Why a mix of healthcare providers?* Patients in the stroke unit are cared for by a team of healthcare providers with different specialties. Thus, we interviewed healthcare
providers with various specialties to gain a complete picture of how each assesses stroke rehabilitation progress.

*Why the low number of healthcare providers?* Recruiting healthcare providers willing to participate in research studies is challenging since they often have a busy schedule or may be skeptical of the value of new technology research [45]. Additionally, Ottawa has only one inpatient stroke unit with 10-12 active healthcare providers offering rehabilitation care for patients after a stroke. We approached all healthcare providers in this clinic and interviewed at least one healthcare provider from each specialty. While the number of participants may initially appear low, it's important to highlight the significant experience each of these healthcare providers brought to the table. Each of them has been working in inpatient stroke rehabilitation for at least a decade, a period of time that is substantial enough to provide a deep and nuanced understanding of the topic. Their extensive experience and insights, gathered over ten years of practice, offer a rich and comprehensive perspective on stroke rehabilitation. Thus, we are confident that the number of participants, coupled with the depth of their experience, sufficiently covers the breadth and complexity required for this study.

3.2.3 Data analysis

We reviewed the interview transcripts using an inductive thematic analysis technique [46]. This method involves the systematic identification and coding of patterns and themes that emerged from the data, rather than imposing preconceived categories on the data [46]. First, the transcriptions were analyzed individually by two researchers, who then convened to discuss similarities and differences in themes. Following that, we
generated the initial codes based on the meaning of elements identified in the transcripts. The codes were then organized and evaluated to discover potential themes that captured the essence of the data. Through an iterative process of reviewing and re-analyzing the data, the themes were refined and modified until the most significant themes emerged. Researchers discussed disagreements during the coding process and reached an agreement on case-by-case instances of uncertainty in coding (Appendix A). Additionally, from the interviews with healthcare providers, we generated a list of health assessments that healthcare providers use in stroke rehabilitation (Appendix B) and a list of design requirements (Appendix C).

3.3 Designing data visualizations

For our first design iteration, we sketched various visualization design alternatives to meet the design requirements derived from our interview analysis. We then created medium-fidelity wireframes produced in Figma software version 116.5.17, which is a collaborative web application for interface design. All the visualizations were designed by one team member and were reviewed by other fellow researchers and supervisors on the team. Then, we chose one or more alternative designs that best matched those design requirements and presented a series of visualization designs to healthcare providers and patients for feedback.

3.4 Evaluating data visualization designs with healthcare providers

We presented our visualization designs to 3 healthcare providers who were part of the first round of interviews and sought feedback from them. For the evaluation of the
designs, we conducted semi-structured user interviews. Participants were encouraged to share their thoughts and impressions while reviewing the designs, providing detailed qualitative data that was valuable in pinpointing areas for improvement. Taking into account the design recommendations provided by the healthcare providers, we initiated a second iteration of our design process to ensure that our designs meet their expectations and align with their preferences.

3.4.1 Participants and interview process

The physician, physiotherapist, and speech-language pathologist who originally participated in the study returned to participate in the evaluation of the designs. Interviews were conducted over MS Teams or Zoom and lasted 30 minutes to 1 hour, depending on the participant’s availability and willingness to share. Interviews were audio recorded and later transcribed. Participants were not monetarily compensated for their time. The duration of the data collection process was from October 2022 to November 2022. During the interviews, we used screen-sharing to present the visualization designs we had developed in Figma design software, allowing healthcare providers to see the designs firsthand. Engaging in virtual interviews with healthcare providers presents its own set of considerations and challenges, particularly given their demanding schedules and responsibilities in patient care. In addition to the time constraints, another significant factor that influenced our approach was the intricate nature of the prototype itself. The prototype, while an essential tool for illustrating the envisioned system, was not a high-fidelity representation at that stage of development. Its complexity, coupled with the healthcare providers' busy routines, could have potentially
led to navigational hurdles and difficulties in comprehending the system's functionality. As a result, we chose to guide healthcare providers through the prototype during the virtual interview sessions. By facilitating their interaction with the design, we aimed to create an environment that fostered their understanding and engagement without burdening them with the complexities of navigating a developing system remotely. As we navigated the prototype, we introduced providers to the overview of the system and highlighted its various features. We took the role of facilitators, enabling providers to explore different areas of interest. This facilitated approach allowed us to adapt to the preferences of each provider, ensuring that their engagement was organic and aligned with their individual curiosities and concerns. Throughout this process, we observed their reactions and encouraged participants to share their thoughts while discussing the ideas openly. During the interviews, our primary focus was to gain healthcare providers’ perspectives on our designs. To ensure focused feedback, we prompted them at the outset to consider specific questions while reviewing the designs. Some example questions included:

- What is your general view of the designs? Would you like to see more or less detail?
- Do you understand the results by looking at the visualizations?
- What are your thoughts on the labels and language used in each visualization?
- Is there anything you think is missing or that you would change?
3.4.2 Data analysis

The same inductive thematic analysis method described in Section 3.3.1 was employed for analyzing the transcripts from the interviews conducted to evaluate the designs with healthcare providers. This method involved the systematic identification and coding of patterns and themes that emerged from the data, rather than imposing preconceived categories on the data. The transcriptions were analyzed individually by two researchers, who then convened to discuss similarities and differences in themes (Appendix D). We placed emphasis on criticisms or recurring comments by healthcare providers that might affect the overall comprehension and utility of the designs. The themes extracted from the data analysis served as a useful resource to refine the designs of the interactive data visualization tool. We then applied these considerations to our designs to ensure the tool provided meaningful and relevant information.

3.5 Evaluating data visualization designs with patients

Evaluating the effectiveness and comprehensibility of our designs with patients is crucial in ensuring that the tool meets patients’ needs [43]. To do so, we conducted user interviews with a sample of 2 inpatients at Élizabeth-Bruyère Hospital who had experienced a stroke within the past six months.

3.5.1 Patient recruitment

The physician lead and a speech-language pathologist of the stroke rehabilitation unit who previously participated in the study were asked to help facilitate the recruitment of patients recovering from stroke at the Élizabeth-Bruyère Hospital. They invited patients recovering from stroke within the inpatient rehabilitation center to participate in the study by sharing a research summary sheet with patients and providing them with the
researcher’s e-mail. Patients who expressed interest in participating, shared their contact
with healthcare providers, who then shared it with researchers. Then, researchers reached
out to participants via e-mail. Patients were asked to provide oral or written consent prior
to beginning the study.

3.5.2 Participants and interview process

In total, we recruited 2 participants that are recovering from a stroke within the
inpatient stroke rehabilitation unit. Participants were invited to take part in the semi-
structured interview to provide insights into our prototype. The patient's caretaker
provided assistance in accessing a laptop, guiding the patient through the login process,
and resolving any technical difficulties that may have arisen. The presence of a caretaker
or healthcare provider during patient interviews ensured that patients had the support they
needed to participate fully in the study and ensured that there were no technological
barriers to viewing the prototype. Interviews were conducted over MS Teams or Zoom
and lasted 30 minutes to 1 hour, depending on the participant’s availability and
willingness to share. Interviews were audio recorded and later transcribed. Participants
were not monetarily compensated for their time. The duration of the data collection
process was from May 2023 to June 2023.

In the interview sessions, we began by asking participants about their recovery
journey. Then, we used screen-sharing to present the prototype of the visualization
designs we had developed in Figma design software. Although this allowed patients to
see the designs firsthand, patients did not have remote control of the prototype.
Navigating virtual interviews with elderly individuals poses a challenge in ensuring a
seamless and meaningful interaction. Given the potential complexities that can arise from virtual technology and the consideration that some participants may be less familiar with digital interfaces, we adopted a cautious approach. Consequently, we opted to facilitate the exploration of the prototype, rather than granting patients direct access. As we navigated through the prototype together, we introduced participants to the overview of the system and highlighted its various features. We took the role of facilitators, enabling patients to explore different areas of interest. This facilitated approach allowed us to adapt to the preferences of each patient, ensuring that their engagement was organic and aligned with their individual curiosities and concerns. Throughout this process, we observed their reactions and encouraged patients to share their thoughts and reactions while discussing the designs. During the interviews, our primary focus was to gain patients’ perspectives on our designs. To ensure focused feedback, we prompted them at the outset to consider specific questions while reviewing the designs. Some example questions include:

- Could you please tell me about your condition (tell me your story)?
- What was your recovery process like?
- What is your general view of the designs? Would you like to see more or less detail in the data visualizations?

3.5.3 Data analysis

The same inductive thematic analysis method described in Section 3.3.1 was employed for analyzing the transcripts from the design evaluation interviews with patients. This method involved the systematic identification and coding of patterns and themes that emerged from the data, rather than imposing preconceived categories on the
data. The transcriptions were analyzed individually by two researchers, who then convened to discuss similarities and differences in themes (Appendix E). We placed emphasis on criticisms or recurring comments by the patients that might affect the overall comprehensibility and utility of the designs. The final themes that emerged from the analysis provided valuable insights and suggested changes that we applied to the data visualization designs. With the goal of developing an interactive and engaging data visualization that was tailored to the needs and preferences of the patients, the themes were used to help guide decisions regarding the appearance, content, and functionality of the designs. Additionally, by incorporating the identified themes into the design process, we aimed to enhance the comprehensibility and utility of the data visualizations to improve patients’ comprehension of their health data.
Chapter 4: Eliciting data requirements for health data visualizations that display recovery from stroke

During the discovery phase, our aim was to ensure that we gained a comprehensive understanding of stroke recovery. To achieve this, we examined a retrospective dataset involving patients recovering from a stroke in the inpatient unit (Section 4.1). Additionally, we conducted interviews with four healthcare providers from the stroke department at Élizabeth-Bruyère Hospital. These investigations covered various aspects, including the standard course of rehabilitation outcome measures, common areas of functioning in stroke recovery, and requirements for designing visualizations representing stroke recovery. Our analysis of the initial interviews with healthcare providers revealed 6 themes (T1-T6) that we discussed (Section 4.2). From the themes identified, we defined 5 requirements (DR1-DR5) to design data visualizations representing stroke recovery (Section 4.3).

4.1 Retrospective dataset review

The retrospective stroke recovery dataset encompasses three main categories including baseline characteristics, health assessments performed at 3 days and 3 months, and self-rating of performance index at 3 the month mark.

The baseline characteristics category includes information about patients’ initial condition and background and provides a snapshot of patients’ health status. This category includes patient ID, age at stroke onset, gender, co-morbidity, prior physical function limitations, side of lesion, type of stroke, length of stay in acute care, stroke severity, discharge destination, Barthel Index (measure of patients’ activities of daily
living and functional independence) at three days and discharge, and SIS-16 (Stroke Impact Scale) at three days. These baseline characteristics provide essential information about patients’ demographics, medical history, stroke severity, functional limitations, and initial functional status, which are important factors for analyzing and understanding their subsequent recovery progress.

We summarized the health assessments performed at 3 days and 3 months into categories that align with their associated areas of functioning. These categories include Motor Recovery, Mobility, Lower Limb Ability, Balance, Upper Limb Ability, and Cognition. By categorizing the assessment tools, we were able to gain a comprehensive understanding of the domains of stroke recovery necessary to evaluate during in-patient stroke rehabilitation and common health assessments used in each category of rehabilitation. These assessments are designed to evaluate the patients' progress and functional abilities during their recovery period. They may involve various tests, measurements, and observations performed by healthcare professionals, such as neurological examinations, functional assessments, and performance evaluations.

The self-rating of the performance index at 3 the month category involves self-assessment measures completed by patients themselves at the 3 months mark. Patients rate their own performance in various areas of functioning related to stroke recovery. These self-ratings provide valuable insights into how patients perceive their progress and functioning levels.

The review of this dataset played a role in shaping the subsequent steps of the research. The detailed baseline characteristics and categorized health assessments offered a comprehensive view of the stroke recovery journey. This, in turn, directly influenced
the formulation of our interview questions for healthcare providers. By understanding the intricacies of the dataset, we were better equipped to delve into meaningful discussions with healthcare professionals, ensuring our questions were both relevant and insightful. Furthermore, the datasets clear organization of health domains in stroke recovery served as a foundation for ideating and conceptualizing the design of preliminary sketches. With a clearer understanding of the common categories of health domains, we were able to craft preliminary sketches that resonated with the actual recovery metrics and assessments. However, it's important to note that different hospitals employ varied tests, leading to potential inconsistencies in the data. While the dataset provided a foundational understanding and some of its elements aligned with our findings, our designs were primarily guided by the insights from our interviews with healthcare providers to ensure clinical relevance to Élizabeth-Bruyère Hospital.

4.2 Healthcare provider interview results

Our analysis of the interviews with 4 healthcare providers involved in stroke recovery at Élizabeth-Bruyère Hospital revealed 6 themes (T1-T6) discussed in this section.

*T1: Mediums to communicate health progress to patients.* Healthcare providers mentioned ways in which they communicate rehabilitation results and progress to patients. Healthcare providers use verbal communication to discuss rehabilitation progress with patients. Additionally, they share notes with patients that have a handwritten explanation of their progress in certain areas of rehabilitation. Lastly, patient progress is communicated to patients through communication whiteboards installed in
every hospital room. They document patient information such as level of mobility, transfer abilities, and anticipated discharge dates on these boards.

**T2: Types of content communicated to patients.** Healthcare providers communicate various types of information with patients, including baseline tests, rehabilitation goals, health status scores, discharge summaries, and comparisons between admission and discharge health assessments. A typical example is the process the SLP follows: “I always have a folder... for all my patients, and I put all the exercises in that. So that the first page of the initial assessment is always there. So then, they (patients) can go back to it and review it. And then, at the end, when I do the assessment, I summarize all the information again for the patients. And then I put all those two pages together, and I would say, Okay, now you see and compare... so then they can see how much progress they made.”

**T3: Information in a patient's weekly progress report.** Healthcare providers mentioned that they assess patients' overall progress over time by discussing aspects of patients' recovery with other healthcare providers in a weekly meeting. This meeting discusses patients' rehabilitation goals as well as their level of function at admission and their progress over time. The PH will discuss any of the patients' medical conditions that may interfere with rehabilitation. The PT discusses the patients' physical functions like mobility, lower-limb function, upper-limb function, transfer, walking ability, and balance. The SLP discusses the patients' cognitive, communication, language, and swallowing abilities. The OT discusses the patients' level of functioning in activities of daily living, cognitive-perceptual, and visual-perceptual functions. Healthcare providers use similar categories from the Functional Independence Measure (FIM) health
assessment as a guide in the team clinical rounds using a scale from 1-7 to discuss patients' independence in each area of rehabilitation. The PH states “We do have a one-page sheet, which we use to summarize all of the activities of the patient in our rounds, which has basically, the level of function of each patient using, in particular, one weighting system for disability, called the FIM. That stands for the Functional Independence measure. It's a 1 to 7 rating system, which grades the performance of patients in various activities.” In the weekly progress meetings, healthcare providers also discuss the patients' discharge planning, including discharge date, discharge destination and family counselling, as well as follow-up plans, including referrals to outpatient services and healthcare provider follow-up sessions. Each week, the healthcare providers update the patients' functional results and discharge plans, upload them in the EMR software, and communicate the results to patients. Though it is encouraged for healthcare providers to engage patients by sharing patients' results, healthcare providers mentioned that patients do not typically see all their health assessment results due to lack of time.

*T4: Attempts to increase patient engagement.* Healthcare providers believe that patients should be involved in their rehabilitation journey. Thus, they try to engage patients in their care and focus on increasing patients' knowledge about their health status. To keep patients informed about their health progress, healthcare providers communicate patients' test scores to them. Oftentimes, they conduct assessments in front of the patient so that the patient better understands the results. Test results can be complex and use medical jargon, so providers are mindful to use simple language to increase comprehension of the results that they communicate to patients. As the PT...
articulates, “The tests you're using are complex, so I use simple language for the patients, then they understand and use it as a tool to encourage them to participate.”

Furthermore, healthcare providers adopt a motivational approach by using positive reinforcement, open communication, and referring back to patient goals to encourage patients as they progress in their rehabilitation. The OT outlines their strategy, “I always use open communication. At the end of the session, we usually provide some positive feedback, like, that was really good work today, strong work, I'm happy with the improvements that I've seen in this and this and this. And then I also refer back to the goals that we had established during admission. I would refer back to them and say, you're getting very close to being independent with your self-care, which is what is your goal.”

Interestingly, the adoption of Virtual Reality (VR) in rehabilitation has shown promising results in engaging patients, as noted by the physiotherapist, who leads a VR unit in the hospital. The VR games offer immediate feedback on patient performance and a summary at the end, sparking interest and active participation. The PT elaborates ‘‘If you have a game that is very straightforward, I've seen ladies in their 80s and 90s in love with going down a virtual ski hill. I love that. And they love it. And they want to know everything about it. And they want to know how they did it. So yeah, definitely really, really engaged.” In essence, providers utilize a blend of strategies to encourage patient engagement, ranging from clear communication and motivational reinforcement to innovative techniques like VR, all aimed at fostering a positive and participative rehabilitation experience.
T5: Issues with technology to store and access patient health data. Healthcare providers raised concerns about the current technology employed to store and access patient health data. Providers frequently struggle to retrieve patient health data, particularly when it's not properly logged or stored in unconventional locations within the system. Furthermore, patients’ health records are often stored in a fragmented state across various locations, leading to an incohesive representation of patient health data. The PH elaborates, “This stuff [patient health data] is buried in the [EMR software] and it sucks. People always complain that it's very hard to find the level of function and care.”. The current EMR software does not have an overview of patient health data, so healthcare providers do not have access to an integrated overview of patient rehabilitation progress. Additionally, healthcare providers think it would be beneficial to have a screen in every room to have all patient information readily accessible.

Healthcare providers expressed a desire for a standard template for summarizing patient health progress. Despite the acknowledgment that each patient's rehabilitation journey is unique and therefore may not fit a singular template, providers still express the need for some form of standardization to streamline their processes. The SLP states “Actually, I wish I had one [template], but it depends on the patient, you know, not all patients are the same. So then, like, there's no one template that I can use, basically.”. The uniqueness of each patient's rehabilitation journey makes it difficult to create an interchangeable template for healthcare providers to summarize patient health progress, and personalizing each report is necessary.

Finally, providers pointed out the absence of exercise-tracking devices provided by the hospital. They believe it is crucial for patients to monitor their cardiovascular
health and exercise habits, suggesting the use of devices like Fitbits. These concerns highlight the need for more refined and comprehensive tools and systems to better manage and track patient rehabilitation progress.

**T6: Inpatient treatment protocol and therapy.** Generally, the healthcare provider's protocol begins by conducting a baseline admission assessment to determine the patient's health status upon arrival to the inpatient unit. A team of healthcare providers assesses specific domains of the patient's health status, including the level of cognition, swallowing abilities, language and communication abilities, physical abilities, and medical situations. Rehabilitation goals and treatment plans are then determined based on the level of care the patient needs, the current health challenges they face, and the severity of the patient's condition. In this section, we explain each healthcare provider's treatment protocol to care for patients staying in the inpatient stroke unit of the hospital and the health assessments they use to determine the patient's health status and rehabilitation progress. From our interviews with healthcare providers, we gathered a list of health assessments they use to assess patients' health status and rehabilitation progress (Table 1).

The PH's treatment protocol includes assessing the patient's health status and comorbidities that could be interfering with the patient's rehabilitation, such as hypertension, diabetes, lipids, fever, swelling, and complex regional pain syndrome. PH typically sees patients daily and uses the SOAP (Subjective, Objective, Assessment and Plan) method, a standardized worldwide method for documenting patients' medical notes in their charts.
The PT treatment protocol includes assessing patients' ability to get in and out of bed, stand, and walk. The PT typically finishes admission assessment within the first three days of arrival, which involves inquiring about the patient’s social and home environment, mobility, occupation, hobbies, and assessing the ability to perform daily activities. A treatment plan is made depending on the severity of the patients' impairments and typically involves 5 days a week of physiotherapy to work on regaining movement and relearning everyday activities. When applicable, the PT uses assistive devices such as stationary bikes and treadmills to help improve the patient's cardiovascular health.

The SLP treatment protocol includes assessing patients' language, communication, and swallowing abilities. The SLP assesses for symptoms of aphasia which is a language disorder caused by damage in the brain after a stroke that affects the patient's language expression and comprehension. The SLP also assesses for symptoms of dysarthria, which are speech problems often resulting from weak or paralyzed speech muscles. Additionally, the SLP assesses cognitive-linguistic disorders where a patient's attention, concentration, and problem-solving may be impacted by a stroke and affects their ability to communicate. Lastly, the SLP assesses the patient's ability to swallow food and drinks. A treatment plan is made depending on the severity of the patient's impairments and typically involves 2-5 speech-language therapy sessions a week. Treatment can involve communication devices, speaking activities, exercises for developing speech muscles, and implementing coping strategies.

The OT treatment protocol includes assessing patients' capacity to perform tasks and comparing it with their pre-stroke self-reported abilities. OT focuses on improving
patients' functional capacity in their activities of daily living (personal hygiene, dressing, toileting, transferring, and eating) and instrumental activity of daily living (managing finances, medications, food preparation, housekeeping, and laundry). A treatment plan is made depending on the severity of the patient's impairment and typically involves 3-5 occupational therapy sessions per week to improve the patient's motor control and function in the stroke-affected limbs. Additionally, the OT will help the patient make strategies to manage cognitive, perceptual and behavioural changes after a stroke, and prepare the home and work environment for the patient's return.

4.3 Design requirements

Drawing upon the themes identified through the analysis of healthcare provider interviews, we derived five key design requirements (DR1-DR5) aimed at improving the navigation of a patient’s comprehensive rehabilitation progress and enhancing communication of this progress with patients.

DR1: Visualize patients' level of independence in daily activities and goals. This design requirement is drawn from healthcare providers' interview analysis results presented in theme T3. When asked about visualizing results from the weekly rounds, healthcare providers agreed that it would be beneficial since they use it frequently as a way to discuss the patient's status and rehabilitation progress. The PH states “I think that [visualizing weekly rounds] will be amazing. Because then we could show it to people and to ourselves. The rounds, they'll become faster and faster.”. Since weekly rounds are based on the FIM categories and independence scale, the FIM was used as a guide for data visualization.
DR2: Visualize and categorize patients' health assessments in their associated health domains. This design requirement is drawn from healthcare providers' interview analysis results presented in themes T2, T4, and T6. Healthcare providers believe that showing patients their health assessments and exercise results would be beneficial in engaging patients in their rehabilitation. The PT states “I think they're all [results] important because they give information on the patient on, you know, their rehab, and where they are at some point and where they can be later.”. Additionally, the PT mentioned that measuring patients' activity and cardiovascular health could have positive outcomes. To ensure that these results are presented clearly to patients, each health assessment should be placed in their associated health domain, including cognition and perception, language, swallowing, upper-body, lower-body, total motor recovery, and exercise.

DR3: Display patients' progress from admission to discharge and display an overview of their progress. This design requirement is drawn from healthcare providers' interview analysis results presented in themes T2, T4, and T5. It was noted to be beneficial to communicate patients' progress from admission to discharge for patients to observe how they've been able to progress and achieve their goals over time. The OT gives an example “Something written down that compares admission and discharge. For example, minimum assistance, moderate assistance, maximum assistance, so at admission self-care, maximum assistance, for upper body dependent for lower, and then on discharge, minimum assistance for the upper and lower body now, showering.”

Additionally, as mentioned by healthcare providers, designing the visualization to have
an integrated overview of patients' rehabilitation results is necessary to ease the burden of looking for data in a fragmented EMR system.

**DR4: Using plain language.** This design requirement is drawn from healthcare providers' interview analysis results presented in themes T2, and T4. Healthcare providers mentioned that the health assessments used can be complicated for patients to understand. To overcome the challenge of communicating the results of complex health assessments, they use plain language to ensure patients can comprehend and get engaged. The SLP gives examples “auditory comprehension, for example, I would say 'you're listening'. If it says, 'verbal expression', I would say 'finding the vocabulary' instead of, say, 'written language', I would just say 'writing', instead of saying 'executive content', I would say like 'problem solving or decision-making'.”

**DR5: Using visualization designs that are cognitively accessible.** This design requirement is drawn from healthcare providers' interview analysis results presented in theme T4. The data visualization must address the different levels of comprehension and cognition in patients by using simple-to-understand visualizations. The OT states “We were dealing with clients who cognitively and perceptually may not be able to manage the type of information we're giving them. So it [visualization] would have to be client-centered as well.”

The design requirements for this visualization system were developed through in-depth interviews with healthcare providers who possess valuable insights into the complexities of stroke recovery monitoring and patient communication. Their insights have informed the foundation of the visualization system and reflect a dedicated effort to enhance patient understanding and communication.
Chapter 5: Preliminary sketches and data visualizations

In this chapter, we present the initial iteration of our designs, showcasing preliminary sketches and visualizations of stroke recovery data that were created in response to the research findings and design requirements highlighted in Chapter 4. An additional aspect of our design approach was to ensure that the visualizations closely correspond with the current approaches practiced by healthcare providers to interact with and discuss patient data (Section 5.1). Our aim is to foster familiarity and ease of use, anticipating a seamless integration of our designs into the healthcare providers’ toolset. Building upon this foundation, we discuss our design choices and present preliminary sketches and visualizations that represent the stroke rehabilitation data of inpatients recovering from a stroke (Section 5.2). Next, we discuss an overview of the interactions chosen for our visualization system (Section 5.3). Finally, we discuss several user interface elements to provide a holistic perspective of our designs (Section 5.4).

5.1 Aligning designs with current methods for interacting with and presenting patient data

Through interviews conducted with healthcare providers, we familiarized ourselves with healthcare providers' existing methods for tracking patient rehabilitation information and communicating it to patients recovering from stroke and other healthcare providers. Our designs strive to address the identified design requirements while closely aligning with healthcare providers’ current practices and processes of tracking and communicating patient stroke rehabilitation progress. Our aim is to foster familiarity and ease of use in the prospective implementation of our designs into a visualization system.
Seamless integration could enable the system to become a natural extension of their existing systems and processes, promoting continuity of care and efficient data exchange. Furthermore, aligning with established practices enhances user acceptance and trust, as healthcare providers perceive the system as a reliable and valuable resource.

To track patients’ stroke rehabilitation progress, healthcare providers review patient health data on EMR system. This data includes progress reports, generated by the team of interdisciplinary healthcare providers in their weekly meetings, and various health assessments as part of the routine care for patients recovering from a stroke. These assessments serve as valuable tools for monitoring progress and tailoring treatment plans.

In the inpatient stroke rehabilitation unit, healthcare providers typically engage in frequent discussions with patients recovering from stroke regarding their admission and discharge assessments, weekly progress reports, and goal setting. Healthcare providers typically share the results of these health assessments with the patient. Additionally, during patients’ rehabilitation in the inpatient facility, healthcare providers often give notes to patients with handwritten updates on their rehabilitation progress. However, due to time constraints, complex information, or prioritization, not all results of a health assessment are uploaded to the EMR system or effectively communicated through verbal or written means to patients.

In response to these findings, our designs take into account the design requirements mentioned in Chapter 4 and the healthcare providers’ current practice. In our pursuit of designing a visualization system, we seek to empower healthcare providers with a means to offer a more intuitive and interactive approach to sharing and discussing results with their patients. Inspired by the process of presenting patients with their
performance on paper-based tests, we designed the visualization system to enhance this experience by providing a dynamic and engaging system to communicate results with patients. By leveraging the visualization system, healthcare providers could facilitate clearer communication and foster a deeper understanding of rehabilitation progress, thereby strengthening the patient-provider relationship. Our designs could present comprehensive patient health assessment results and offer an integrated overview of stroke rehabilitation progress data. Our designs incorporate features such as simplified health assessment results and place emphasis on providing clear and concise admission and discharge assessment results to ensure that patients depart with a comprehensive understanding of their health information.

By closely mirroring healthcare providers’ existing practices and processes and following the design requirements derived from interviews with healthcare providers, our designs aim to bridge the gap between provider communication and patient access to health assessment results.

### 5.2 Preliminary sketches and visualizations

To design the patient health progress visualizations, we considered the current practices and processes of healthcare providers, the design requirements (DR1-DR5) identified from our interviews and followed visualization design guidelines established in the literature.

Our design process followed an iterative approach, starting with low-fidelity sketches and progressing through a series of group discussions with researchers involved in the project. Initially, we created preliminary sketches displaying individual health
assessments, health domains, and a weekly progress report (Figure 2). These sketches served as a starting point for our design exploration. Through collaborative group discussions with the researchers in our team, we gathered valuable feedback and insights. These discussions allowed us to gather different perspectives, explore potential improvements, and refine our designs until we reached a point of comfort and confidence. Once we were satisfied with the designs, we transitioned to mid-fidelity visualizations. Using Figma software, we created more detailed prototypes that provided a clearer and more representative depiction of the final product. These mid-fidelity visualizations allowed the researchers to evaluate the designs more effectively and provide feedback based on a more tangible representation of the system’s functionality.

Our design process unfolded within a context that envisions the utilization of the developed visualization tool in various scenarios within the healthcare setting. This tool was designed to serve both healthcare providers and patients, aiming to facilitate effective communication and engagement during the stroke recovery process. The envisioned scenarios for utilizing the visualization system encompass several key settings within the hospital environment. Firstly, the tool was designed to be accessible on iPads, enabling healthcare providers to efficiently communicate rehabilitation progress with patients in their inpatient hospital rooms. This scenario fosters personalized interactions, as healthcare providers can engage patients in meaningful discussions while sharing visual representations of their recovery journey.

Moreover, the visualization tool was tailored for use on computers, allowing healthcare providers to view patient data within the hospital setting. This setup facilitates
comprehensive data analysis and informed decision-making by healthcare providers, ensuring that patient care is driven by accurate insights.

Simultaneously, patients are empowered to interact with the visualization tool in their hospital rooms, using either an iPad or a computer. This patient-centric approach grants patients the opportunity to engage directly with their recovery data, fostering a sense of ownership over their progress and enhancing their comprehension of the rehabilitation journey.
Figure 2: Preliminary sketches displaying rehabilitation health domains (A), rehabilitation progress for swallowing and communication (B), cognition (C), upper/lower limb/total motor recovery (D), exercise (E), and the weekly progress report: provider view (F) and patient view (G).
To meet DR1 (Visualize patients' level of independence in daily activities and goals, we created a weekly progress view that displays the patients' goals and level of function to be shared and discussed between a patient and healthcare providers (Figure 3). Each functional activity is represented by a coloured flower that grows in height from level 1 (dependent) to level 7 (independent), mirroring the FIM assessment used by healthcare providers during their weekly meetings. Within this view, the grey flowers in the background represent the goals chosen by the healthcare providers, indicating the desired level of functional activity the patients strive to achieve. By scrolling through the time bar at the top left, which represents weeks, patients can actively track their progress each week. The choice of a flower garden metaphor was deliberate, as it provides an easily understandable and visually engaging representation for patients. The metaphor of a garden with blooming flowers symbolizes growth, progress, and the gradual improvement of their functional abilities over time. Additionally, we designed a separate view for healthcare providers (Figure 4) that can be used to share during the healthcare providers’ weekly meetings. This view mimics the page that healthcare providers currently use in their weekly progress meetings and has the same categories listed in the flower view. The provider view additionally includes notes that healthcare providers can make during their meetings and decide to share with patients when the time permits.
Figure 3: Design Iteration #1 of the Weekly Progress View for patients which displays level of independence in functional activities (coloured flowers) and patient’s goals (grey flowers).
Figure 4: Design Iteration #1 of the Weekly Progress View for providers which displays the patient's level of independence in functional activities and progress notes.
To fulfill DR2 (Visualize and categorize patients' health assessments in their associated health domains), we designed an overview of all the categories of health assessments for rehabilitation which are signposted to their relevant body parts on an image of a human (Figure 5). All the patients' health assessment results can be viewed by selecting a button with the associated category of rehabilitation.

![Figure 5: Design Iteration #1 of rehabilitation health domains.](image)

To fulfill DR3 (Display patients' progress from admission to discharge and display an overview of their progress), we designed an overview of patients' progress between admission and discharge with line graphs that either display the incline or decline in their rehabilitation (Figure 6).

From the Overview, patients can select a health assessment, which will display a side-by-side comparison of admission and discharge assessment results for either cognition (Figure 7), upper body (Figure 8), swallowing (Figure 9), total motor recovery (Figure 10), lower body (Figure 11) and exercise (Figure 12).
Figure 6: Design Iteration #1 of Patients' progress overview.
Figure 7: Design Iteration #1 of patient health assessment results for cognition.
Health assessments

Figure 8: Design Iteration #1 of patient health assessment results for upper body.

Figure 9: Design Iteration #1 of patient health assessment results for swallowing.
Figure 10: Design Iteration #1 of patient health assessment results for total motor recovery.

Figure 11: Design Iteration #1 of patient health assessment results for lower body.
To fulfill DR4 (Using plain language), we used lay language to label and describe the results of each health assessment in our design for patients’ ease of understanding (See Table 1). This ensures that the information presented is better understood by the patient. Additionally, in the description of the health assessment, we provided the original name of the test in case the patient decides to share the results with other healthcare providers after discharge. Using a blend of plain language and medical terminology helps
patients with varying levels of cognition to easily comprehend their data while providing sufficient medical information for other healthcare professionals to identify the health assessment offered.

To fulfill DR5 (Using visualization designs that are cognitively accessible), we adopted the design principle of skeuomorphism, which involves replicating real-life objects within a digital context to enhance familiarity and ease of use [47]. By incorporating skeuomorphism into our designs and utilizing commonly known graphs and charts, we aimed to create a user interface that users could easily relate to and understand. An example of how we implemented skeuomorphism can be seen in Figure 8 where we employed a visualization of a dynamometer to represent the grip strength test. By mimicking the appearance and functionality of a real dynamometer, we aimed to create a visual representation that users would recognize and associate with the specific assessment being performed. Skeuomorphism is further evident in other aspects of our visualization system. For instance, in the Walking speed test in Figure 11, we incorporated a speedometer-like visual element to represent the speed of a patient's progress. This design choice allows users to intuitively gauge their progress as if they were looking at a traditional speedometer, which is a familiar and easily understood metaphor. Similarly, in the Balance scale test displayed in Figure 9, we implemented skeuomorphic elements to resemble a real-world balance scale. Lastly, in the Trail making test and Finger movement test in Figure 7, we employed skeuomorphism to design a stopwatch feature, mirroring the appearance of a physical stopwatch. This familiar representation enables users to easily grasp and interact with the time-tracking functionality. By also incorporating familiar graphical representations like bar charts and
donut charts throughout our interface, we leveraged their existing knowledge and experiences. Additionally, by recognizing the importance of minimizing cognitive overload for patients, they are presented with an overview alongside a details on-demand approach [43]. This approach allows for a progressive display of information, ensuring that patients can navigate the visualizations at their own pace and explore specific aspects as desired.

<table>
<thead>
<tr>
<th>Health Assessments</th>
<th>Lay Term</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment of Language-Related Functional Activities (ALFA) [48]</td>
<td>Language-Related Activities</td>
<td>cognitive-linguistic problems related to functional activities</td>
</tr>
<tr>
<td>Berg Balance Scale (berg) [49]</td>
<td>Balance test</td>
<td>balance levels</td>
</tr>
<tr>
<td>Boston Naming test [50]</td>
<td>Image Naming test</td>
<td>confrontational word retrieval</td>
</tr>
<tr>
<td>Box and Blocks test [51]</td>
<td>Box and Blocks test</td>
<td>manual dexterity</td>
</tr>
<tr>
<td>Chedoke McMaster Stroke Assessment [52]</td>
<td>Motor Recovery test</td>
<td>physical impairment and activity</td>
</tr>
<tr>
<td>Cognitive-Linguistic Quick test (CLQT) [32]</td>
<td>Cognitive-Linguistic test</td>
<td>cognitive-linguistic problems</td>
</tr>
<tr>
<td>Gait speed test [47]</td>
<td>Walking speed test</td>
<td>gait speed</td>
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<tr>
<td>Grip Strength test [53]</td>
<td>Grip Strength test</td>
<td>muscular strength</td>
</tr>
<tr>
<td>International Dysphagia Diet Standardisation Initiative (IDDSI) [54]</td>
<td>Swallowing test</td>
<td>swallowing ability</td>
</tr>
<tr>
<td>Montreal Cognitive Assessment (MoCA) [55]</td>
<td>Cognitive test</td>
<td>cognitive impairment</td>
</tr>
<tr>
<td>Motor Free Visual-Perceptual test [56]</td>
<td>Visual perceptual test</td>
<td>visual perception independent of motor ability</td>
</tr>
<tr>
<td>Ross Information Processing Assessment - 2 [57]</td>
<td>Information Processing test</td>
<td>cognitive-linguistic deficits</td>
</tr>
<tr>
<td>Star Cancellation test [58]</td>
<td>Star Cancellation test</td>
<td>unilateral spatial neglect</td>
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<tr>
<td>Trail Making test [59]</td>
<td>Trail Making test</td>
<td>executive function</td>
</tr>
<tr>
<td>Western Aphasia Battery (WAB) [60]</td>
<td>Language Test</td>
<td>linguistic skills affected by aphasia</td>
</tr>
<tr>
<td>2-Minute Walk test [61]</td>
<td>2-minute Walk test</td>
<td>endurance and gait speed</td>
</tr>
<tr>
<td>9 Peg Hole test [62]</td>
<td>9 Peg Hole test</td>
<td>finger dexterity</td>
</tr>
</tbody>
</table>

Table 1: Health assessments used to measure recovery after a stroke, the lay term used in our data visualization, and the function of the health assessments.
In this section we have presented the initial iteration of our designs, showcasing the preliminary sketches and visualizations that were developed in response to the design requirements outlined in Chapter 4 and aligning closely with healthcare providers’ current methods for tracking and presenting patient data. Our designs incorporate features such as personalized summaries, progress reports, and handwritten notes to enhance patient engagement and understanding. Using intuitive visualizations, we provide a comprehensive overview of patients’ progress and facilitate active tracking over time. By mirroring current practices and focusing on effective communication, our designs strive to improve stroke rehabilitation outcomes by fostering a transparent exchange of information within the healthcare setting.

5.3 Interactions designed in the data visualizations

In this section, we provide an overview of the interactions we use within our visualization system including navigate, manipulate, and select [9].

Navigate: Healthcare providers expressed concern about spending excessive amounts of time in the current software to find relevant patient information. In order to address this issue and enhance the efficiency of accessing patient information, we have included a navigation feature. The choice to incorporate navigation is a simple and effective way to explore different areas of the system, facilitating efficient access to desired information.

This navigation feature enables healthcare providers to narrow down and isolate specific pieces of patient information that are most relevant to their current needs such as
navigating and viewing data based on health assessment, results from type of healthcare providers, and timeframe. For instance, if a healthcare provider or patient needs to examine the health assessments from a specific provider, they can select the button from the drop-down menu which will, in turn, display all health assessments that the specific provider conducted (Figure 5). Finding results can be done by selecting categories of health assessments based on body function or by choosing between admission and discharge assessments. Additionally, users have the option to navigate information by using a search bar at the top of each page to look up specific terms and retrieve relevant information. This feature further streamlines the process of navigating to desired data.

The exercise page offers users the convenience of navigating their exercise data in various ways (Figure 12). By selecting a specific day within a monthly calendar, users can view their daily exercise details. Additionally, a drop-down menu allows users to choose between weekly or monthly exercise results, providing flexibility in the displayed timeframe. To further view the exercise data, users have the option to select a specific week to focus on a particular timeframe within the chosen month. This allows users to display a specific week's exercise progress.

Lastly, users can navigate through the weekly progress view based on the category of functional independence and timeframe (Figure 3). This feature can enable them to easily focus on specific parts of data, reducing cognitive load for patients and reducing the amount of time healthcare providers would need to spend manually searching through large datasets.

Manipulate: The term "manipulation" in data visualization refers to the ability of the user to alter and adjust various aspects of the displayed visualization in real-time [9].
Healthcare providers and patients can use this functionality to accommodate the user's specific vision abilities. For instance, if a patient has low vision, they may benefit from changing the visualization to night mode to reduce eye strain and improve readability (Figure 13).

**Select:** Selecting is a fundamental interaction technique that empowers users to choose one or multiple specific components within the visualization, facilitating a wide range of interactive actions [9]. This technique allows users to interact with the data in a more personalized and focused manner, enhancing their ability to explore, analyze, and comprehend the presented information. The result of a selection process often serves as the input for subsequent operations, enabling users to customize their analytical journey and obtain insights that are most relevant to their specific needs or questions [62]. In our designs, all interactions are induced by a user selecting a button or slider, providing users with a seamless and intuitive way to navigate the visualization and gain real-time feedback on their actions.

The interactions incorporated into our visualization designs were chosen based on the needs and feedback expressed by healthcare providers. By addressing their concerns regarding information accessibility and efficiency, we implemented key interactions such as filtering, manipulate, and selection.
5.4 Data visualization system layout

Our visualization design has 2 essential user interface elements that play a role in enhancing the overall user experience: the navigation bars and dashboard overview (Figure 14). The navigation bars include both a vertical panel situated on the left-hand side of the user interface and a horizontal panel positioned at the top of the user interface. The vertical navigation bar offers healthcare providers and patients a convenient and intuitive way to navigate through different sections. When selected, “Home” will display the dashboard view (Figure 14), “Health Assessments” will display a patient’s health assessment results (Figure 7, Figure 8, Figure 9, Figure 10, Figure 11), “Progress” will display the patient’s weekly progress (Figure 3) and “Exercise”, will display the patient’s
exercise results (Figure 12). By incorporating the vertical navigation panel, we ensure that users can efficiently access critical components of the visualization.

The horizontal navigation bar complements the sidebar by providing additional navigation options and quick access to essential features. The navigation bar contains navigation elements such as a search bar, back and home buttons, and a dark theme slider. The navigation bar acts as a feature that allows healthcare providers and patients to tailor their analytical journey.

The dashboard view is a central component of our visualization, offering a concise and comprehensive overview of patients' overall progress from admission to discharge, exercise overview, and weekly progress overview. It condenses critical information into an easily digestible format, empowering healthcare providers and patients to assess progress at a glance. The dashboard design aligns seamlessly with Schneiderman's Visual Information-Seeking Mantra [10], a set of principles for effective information visualization. Firstly, the dashboard adheres to the "Overview First" principle by presenting a high-level summary of patients' progress. Secondly, the "Zoom and Filter" aspect of Schneiderman's mantra is catered to through the interactive features of the dashboard. Lastly, the dashboard view fulfills the "Details-on-Demand" principle, enabling patients to explore each category of their rehabilitation results in depth.
Integrating the sidebar, navigation bar provides easy access to functionalities and critical insights. These elements align with our aim to address healthcare providers' concerns about information accessibility and efficiency.
Chapter 6: Healthcare provider and patient evaluation of designs

The contemporary healthcare landscape places increasing emphasis on the active involvement of both healthcare providers and patients in the design and evaluation of innovative solutions. In this chapter, we discuss the outcomes of our interviews conducted with both pivotal user groups: healthcare providers involved in stroke recovery (Section 6.1) and patients recovering from stroke within the inpatient rehabilitation center (Section 6.2). Each section discusses the outcomes derived from the interviews, highlighting the feedback received from each user group, and subsequent design modifications implemented as a result. Lastly, we provide a concise overview of our designs, depicted through a user flow. Overall, this chapter demonstrates the iterative nature of our design process, guided by the feedback from healthcare providers and patients. Their valuable insights have driven the evolution of our designs, resulting in enhancements that prioritize comprehensibility and personalization. By incorporating their perspectives, we aim to create designs for a visualization system that could support healthcare providers in delivering effective patient care while empowering patients to actively engage in and understand their rehabilitation progress.

6.1 Design evaluation with healthcare providers

In this section, we present the perspectives of three healthcare providers, including a physician, a speech-language pathologist, and a physiotherapist, who were interviewed to gather feedback on our visualization designs. Through a 1-hour video call conducted over Zoom or MS Teams, we shared our designs with them using screen sharing and encouraged them to think out loud, sharing their experiences and insights.
These interviews were audio recorded and we conducted a thematic analysis using NVIVO transcription software. After analyzing the data collected during the interviews, we identified 4 themes that we will discuss in this section (See Appendix D for the full codebook of interview results). In this subsection, we introduce the second iteration of our designs, which have been refined based on insights garnered from interviews with healthcare providers.

*Clear categorization and labelling of health assessments.* First, healthcare providers recommended a reorganization of health assessments into categories that accurately correspond to their respective health domains. For instance, in the healthcare provider interview, the SLP recommended that the 'Assessment of language-related functional activities (ALFA) test', previously housed under the language category, was identified as more fittingly placed within the cognition and perception test category, given its cognitive evaluation nature. As healthcare providers are familiar with these tools, ensuring that health assessments align with appropriate domains becomes crucial in facilitating their swift navigation through the visualization system.

Second, healthcare providers emphasized the significance of signposting each category to its corresponding body part within the visualization, as it shows can be highly beneficial in aiding patients' navigation and comprehension of the nature of each category. For instance, in the initial iteration of the landing page, the category 'Communication and Swallowing' was signposted to the mouth of the body (Figure 5), however, healthcare providers suggested that a more accurate representation of health domains would involve having two distinct labels: 'Language' signposted to the brain and 'Swallowing' signposted to the throat. By making this adjustment, health assessments can accurately display the
categories they encompass, allowing patients to associate each category with the relevant body part effortlessly.

Lastly, healthcare providers noted that enhancing the patient's health progress overview for easier comprehension at first glance was crucial. Additionally, there was a need to include information indicating when a patient's rehabilitation results show neither progress nor worsening. In the previous design iteration, the patient’s health progress overview utilized a line graph with increasing green lines to indicate progress and decreasing red lines for regression (Figure 15 - A). To address healthcare providers’ concerns, we integrated the following recommendations: on the health overview page, we replaced the line graphs with visually intuitive "action dots." These circular indicators are colour-coded to represent patients' rehabilitation results as either progressing, worsening, or remaining the same (Figure 15 - B). The incorporation of action dots into the visualization has proven to be highly effective in providing a simpler, faster, and more visually scannable representation of information [61]. This visual enhancement could help healthcare providers and patients to grasp the overall trajectory of each patient’s recovery journey quickly and easily.
Communicating Severity Levels, Health Assessment Subdomains, and Comprehensive Explanations. Healthcare providers mentioned a few ways in which the visualization designs could provide more valuable information to patients recovering from a stroke. The first improvement involves adding the severity levels of scales of assessment tools, which can be informative for patients, providing them with a richer and more detailed representation of their progress. For example, a specific scenario highlighted by the SLP demonstrates the significance of specifying the level of impairment. The SLP discussed an instance in which the patient’s level of impairment in an area of rehabilitation had decreased from severe to mild. In this situation, a scale that only
displays ‘impairment’ and ‘no impairment’ (Figure 16 - A) without specifying the level of impairment misses a chance to appropriately portray the patient’s progress. The SLP states “If I say you were impaired, and now you’re impaired, what’s the difference? The difference is that it was severe. Now it’s mild. So, it’s good to tell them how severe it was.” To address this feedback, we added the severity levels to each scale, avoiding generic labels and replacing them with detailed scales (Figure 16 - B). For instance, when assessing impairments, the scales might include categories such as "No deficits (26-30)," "Mild deficits (18-25)," "Moderate deficits (11-17)," and "Severe deficits (11-17)." These number ranges correspond to the extent of impairment, allowing patients to understand the severity of their condition on a quantifiable scale. As they make progress in their rehabilitation, they can observe changes in the numerical values, providing a clearer and more precise indication of their improvement. Similarly, in terms of independence, the scales can be expanded to include categories like "Complete dependence (1)," "Need for assistance (2)," and "Complete independence (3)" (Figure 17 – B), compared to a previous design iteration that only displayed “Dependent” and “Independent” categories on the independence scale (Figure 17 – A). The associated numbers provide patients with a quantifiable measure of their level of independence, facilitating a more accurate assessment of their abilities over time. By employing such detailed and quantifiable severity levels, patients can easily grasp the nuances of their results and precisely identify areas that require improvement.
**Figure 16:** Left (A), Design Iteration #1 of Cognitive Test, Right (B) Design Iteration #2 of Cognitive Test with specified severity scale.

**Figure 17:** Left (A), Design Iteration #1 of Language-Related Activities. Right (B) Design Iteration #2 of Language-Related Activities with specified independence scale.
Healthcare providers mentioned that rather than visualizing composite scores, the results should instead display subdomain categories of each health assessment in order to communicate informative results. Although visualizing a composite score of a health assessment can be useful for minimizing cognitive load, they fail to highlight specific areas of concern that the patient should focus on. For example, in the context of the total motor recovery test, the impairment inventory (Figure 18 - A) initially displayed a composite score, which represented an overall assessment of the patient's motor function. However, this composite score lacked specificity in pinpointing the exact areas of the body that showed impairment. To address this limitation and provide more precise information to patients, we incorporated subdomain results into the visualization. These subdomains include specific areas such as the leg, arm, hand, foot, postural control, and shoulder domain (Figure 18 - B). By adding these subdomains, the results now offer a detailed breakdown of the patient's motor function assessment, indicating which specific areas of the body are experiencing impairment.
Additionally, healthcare providers emphasized the importance of going beyond the patient's score and providing a deeper understanding of what the results signify. This approach aligns with how healthcare providers typically engage in face-to-face discussions with patients, offering them valuable insights into the meaning of their scores for their rehabilitation journey. The PH states “They’ll [healthcare providers] put it together in a bigger picture, they won’t just write the report as the results. The results will be so integrated to say they are independent in their self-care, they are independent in their ability to toilet”. To address these concerns, we have incorporated the healthcare providers' recommendation of presenting an explanation that encompasses the broader meaning of the patient's scores. These additional insights into the meaning of results are drawn from the information provided in the standard health assessments found online. For instance, in the Berg balance test, instead of solely providing the patient with their numerical scores (Figure 19 – A), we now also offer a
contextual interpretation such as "At admission, you scored 39/56 on the balance test. This score indicates that you may need some kind of walking assistance like a cane or walker." (Figure 19 – B). These assessments offer detailed descriptions and interpretations of the scores, providing patients with meaningful insights into the significance of their rehabilitation results.

Figure 19: Left (A), Design Iteration #1 of Berg Balance Test. Right (B), Design Iteration #2 of Berg Balance test with comprehensive explanation of results.

Personalize the display of information for patients: Healthcare providers advocate for personalized visualizations tailored to each patient's rehabilitation journey. To facilitate a more personalized experience, we implemented a design feature that allows patients to choose to display one category of functional activity at a time (Figure 20) instead of overwhelming the patient by displaying all items within each category of functional activity on one display (Figure 3). In the new design (Figure 20), each category of functional activity is presented within a cloud. The design choice of using
clouds was intentionally made to maintain consistency with the nature theme while also serving a functional purpose. When a cloud, or health domain is selected, progressive disclosure of results is provided by revealing the corresponding items within that category, displaying the patient’s level of independence for each activity and goal (Figure 21). This feature empowers patients to personalize the information they want to review, which could allow for more efficient exploration of their rehabilitation progress.

Figure 20: Design Iteration #2 of The Weekly Progress View that display results from one category of functional activity at a time. Each category of functional activities within clouds.
Additionally, it was noted that a designated place to add notes about food inclusions, exclusions, and swallowing strategies in the swallowing test could be helpful in communicating patient results and help support patients with diet planning. We implemented the suggested changes to address the need for a designated place to add notes and communicate patient results (Figure 22 - B). Figure 22 – B showcases the revised visualization that includes the added textboxes for notes for healthcare providers to elaborate on diet planning in the context of the swallowing test, compared to a previous iteration that did not include this information (Figure 22 - A).
Personalize healthcare providers’ choice of health assessments: In light of feedback from healthcare professionals, it is essential to prioritize the incorporation of commonly used assessments specific to their respective hospitals while eliminating irrelevant ones. This is particularly crucial as each rehabilitation facility may have its own unique preferences for health assessments. To address this feedback, data visualization systems should enable healthcare providers to customize and select assessments aligned with their rehabilitation center's protocols. These considerations, essential for personalizing health assessments, should be considered by those considering the adoption of such designs in rehabilitation facilities. This customization feature ensures that the data visualization platform supports healthcare providers in...
making well-informed decisions based on assessments that are most beneficial for their patients, thereby facilitating the delivery of tailored and effective care.

In summary, healthcare providers emphasized the need for clear categorization and labelling of health assessments, communicating severity levels, subdomains, and comprehensive explanations, personalized display of information for patients, and personalization of healthcare providers' choice of assessments. The design changes based on healthcare providers’ recommendations aimed to create a visualization system that improves communication, supports result comprehension, and enhances personalized rehabilitation experiences. Subsequently, we presented the revised designs based on healthcare providers’ recommendations to patients recovering from a stroke in the inpatient rehabilitation facility for their input and feedback. The results of these patient perspectives will be elaborated upon in Section 6.2.

6.2 Design evaluation with patients

In this section, we discuss the outcomes of our visualization design evaluation, conducted with two patients who were undergoing stroke recovery in the inpatient rehabilitation facility. Their perspectives and recommendations served as valuable feedback within our iterative design process. By conducting interviews and gathering feedback from both patients, we aimed to understand their perspectives on the designs and identify areas for improvement. In the interview sessions, we began by asking participants about their recovery journey. Afterward, we engaged in a screen-sharing session with the patients, thoroughly walking them through each aspect of the designs. Patients were asked to provide feedback on the comprehensibility of the designs. We
observed their reactions and encouraged participants to share their thoughts while discussing the ideas openly. These interviews were audio recorded and we conducted a thematic analysis using NVIVO transcription software. Through analyzing the data collected during the interviews with patients, we obtained valuable insights that guided our design modifications. We identified the 4 key themes derived from patient interviews that can be broken down into two sections: Patients’ current experience in recovery (Section 6.2.1), and Patients’ feedback on the interactive data visualization designs (Section 6.2.2) (See Appendix E for full codebooks). In this subsection, we introduce the third iteration of our designs, which have been refined based on insights derived from interviews with patients.

6.2.1 Patients’ current experience in recovery

Interviews with patients during the recovery process provided valuable insights into their motivations, challenges, and experiences while staying in the inpatient rehabilitation facility. It is noteworthy that both patients were in the final stages of their inpatient stay, preparing to return home. P1(M, 60) had spent 6 weeks in the inpatient rehabilitation facility and focused on increasing swallowing ability, mobility, and strengthening left-side and walking ability. P2 (F, 49) had spent 9 weeks in the inpatient rehabilitation facility and was working on recovering from severe cognitive deficits, speech intonation, and left-side mobility.

Patient’s perspectives on supportive care and memory challenges in stroke recovery: Both patients expressed feeling encouraged and supported by their healthcare providers throughout the stroke recovery journey. One patient indicated that they gauge
their recovery progress by observing the increasing ease with which they complete the tests over time. Nevertheless, this patient expressed difficulty in remembering all the tests they have participated in stating “Yeah, I guess that's one of the difficulties is there's so many different tests that you do and I'm not sure that I can remember if I was told what they were or how I did.” (P2). Based on the patient's perspectives from their stroke recovery experience, it is evident that remembering all the tests they have undergone during their rehabilitation journey poses a challenge. Our visualization designs have the potential to play a crucial role in addressing this issue by providing patients with a comprehensive overview of their health assessment results. Through this visual representation of their progress, patients can have a clearer understanding of their performance in various assessments and track their improvements over time.

Communication of instructions, recovery progress, and test results with patients:

Additionally, effective communication of instructions, progress, and results plays a vital role in stroke recovery. Patients receive exercise instructions on printouts, providing them with a tangible reference for their therapy exercises. In the context of speech therapy, patients receive instructions through an application on an iPad, enabling them to engage with the exercises interactively. Patients also report receiving verbal communication from healthcare providers regarding their stroke recovery progress and test results. This verbal communication is particularly important for discussing results that worsen, as it allows for direct explanation and discussion. Handwritten results from admission and discharge test scores are also provided to patients. Moreover, patients receive their medical results through a patient portal called Meditech, accompanied by daily medical updates through
email notifications. This multi-channel approach ensures that patients are informed about their progress and results. Despite the robust multi-channel approach employed for patient communication, one crucial aspect that currently remains unaddressed is the inclusion of all health assessments within the patient portal. Health assessments play a vital role in comprehensively understanding a patient’s well-being and progress during their recovery process. However, these valuable assessments are currently not all accessible through the patient portal, limiting patients’ ability to gain a holistic view of their health status and track their progress over time. By integrating health assessments into the patient portal and providing patients with an integrated overview of their progress, we can bridge this gap and empower patients with greater control over their health information.

6.2.2 Patients’ feedback on the interactive data visualization designs

Patients provided their comments on the design elements of the data visualization designs and provided their perspectives on the comprehensibility and impact of the data visualization designs.

Patients’ comments on design elements of the data visualization: The first set of design recommendations from the patients emphasized the importance of the readability of the texts used in the designs. Patients recommended using a larger font size for the words in the designs, surpassing the current 12 pt. font. This suggestion, especially pertinent for older individuals, aims to improve the legibility of the presented results. It is worth noting that some patients mentioned that the difficulty in viewing the visualizations may have been partially influenced by the screen share setting during the interviews,
which prevented them from zooming in for a closer look. Nonetheless, the recommendation for larger than 12 pt font size stands as a valuable consideration for improving the overall readability of the visualization designs. Additionally, patients recommend designing mobile-friendly layouts to accommodate the widespread use of smartphones.

To address the feedback regarding readability, we took several measures to enhance the legibility of the text in our designs. One crucial step was increasing the font size to adhere to the industry standard of 16 pt font for website content. By adopting this standard, we aimed to provide a comfortable reading experience for our users across different devices and screen resolutions. Furthermore, we introduced a hovering magnifying glass icon, to enhance text readability. When users select this feature, it enables a zoomed-in view of the text (Figure 23), enabling a closer examination of the content and ensuring that even individuals who may prefer larger text sizes or have low vision can access the information effortlessly.

Figure 23: Visualization of the hovering magnifying glass feature for enhanced text readability.
Patients expressed a preference for visualizations that utilize numbers or commonly used charts (i.e., line chart, donut chart, or bar chart) to help them better understand the scores, as visualizations that were more complex were found to be less helpful for understanding results. For example, a patient commented on the star cancellation test stating “The graphic of the stars doesn't really help. I would like a big number of the result in this one.” (Figure 24– A). A similar comment was also made for the box and blocks test (Figure 25– A). For both the star cancellation test and box and blocks test, we simplified the visualizations by using a bar chart and donut chart (Figure 24- B, Figure 25- B).

![Figure 24: Left (A), Design Iteration #2 of the Star Cancellation Test, Right (B), Design Iteration #3 of the Star Cancellation Test with simplified bar chart.](image)
Patients provided specific recommendations related to the swallowing test. They suggested modifications to increase comprehension, such as using larger coloured circles to highlight the results and increasing the size of food and drink subtitles for better noticeability. Additionally, patients expressed a preference for removing the greyscale from the visualization (Figure 26 - A) as it was not easily understood. Instead, they recommended using colour to fill the food and drink categories that the patient can swallow (Figure 26 - B). This change aims to enhance the clarity and comprehensibility of the visualization, making it more intuitive for patients to interpret and engage with the information regarding their swallowing abilities.
Furthermore, a patient provided specific recommendations for the exercise overview line graph and suggested displaying the numerical scores on the line graph to offer patients the ability to easily see their scores (Figure 27).
Lastly, patients believe that visualizations that display clearly defined goals can serve as a motivating factor in their recovery process. P2 stated “So it (data visualization system) could be really helpful to some patients who need that motivation to improve. I
think that helps to motivate you when you see that you are making progress and to have those goals clearly labeled out too.”. Their insights shed light on the promising role that visualization designs can play in enhancing patient motivation and fostering a more proactive approach towards recovery.

In summary, incorporating patient perspectives through evaluation and feedback sessions enabled us to design a visualization system that prioritize the needs of the patients. By considering patients' experiences and suggestions, our aim is to design an empowering system that enhance the overall experience for patients recovering from a stroke.

6.3 Visualizing stroke recovery progress: A user flow and navigation overview

In this section, we display a user flow within the visualization designs (Figure 28), demonstrating the sequential steps and interactions involved in navigating the design’s interface and features. The user flow demonstrates the logical progression of tasks, showcasing how a patient can interact with the visualization system to access vital information about their stroke recovery journey [63]. To bring this concept to life, we will be using the example of a user persona named Sally. Sally is a middle-aged woman who is in the process of recovering from a stroke at an inpatient rehabilitation facility. Her rehabilitation journey, her engagement with various healthcare interfaces, and her objectives will serve as a real-world example throughout this chapter.
Figure 28: User flow of the interactive data visualization system representing stroke recovery progress.
Start (1): Sally, a patient on the road to recovery from a stroke at an inpatient rehabilitation center, finds herself at the design’s dashboard. This is her main system for accessing information about her recovery journey, offering her a comprehensive view of her exercise results, weekly progress, and an overview of her recovery trajectory.

Selecting a Category: From the dashboard view, Sally has the option to select a category. The categories available include Overview (2), Health Assessments (3), Exercise (4), and Weekly Progress (5). These categories are designed to help her track her recovery progress and stay informed about her health status.

Overview (2): Sally can select Overview to get a summary of her health assessment progress from admission to discharge. This page provides Sally with a quick snapshot of her recovery progress, using color-coded circles to indicate whether her progress has increased, decreased, or remained unchanged.

Health Assessments (3): If Sally selects Health Assessments, she is presented with an overview of all the categories of health assessments for rehabilitation which are signposted to their relevant body parts on an image of a human. She can further choose from various health categories (4) such as Language, Cognition, Swallowing, Upper Body, Lower Body, and Motor Recovery. These assessments are crucial for Sally as they provide a comprehensive view of her health assessment results at admission and discharge. She can select the radio buttons to choose to view her admission results, discharge results, or both for a side-by-side comparison. Sally can also choose the drop-down menu to further filter the display of her results based on which healthcare provider conducted the health assessments.
Weekly progress (5): The Weekly Progress category offers Sally a dual perspective - her own (Patient View) and her provider's (Provider View). The Patient View presents each category of functional activity within a cloud, including Movement, Self-care, Communication, Sphincter Control, Cognition, and Swallowing. By selecting a category, Sally can track her weekly progress in that area, visualized through growing flowers as she scrolls through each week using the time bar (6). The Provider View (7), on the other hand, provides Sally with personalized notes written by healthcare providers during their weekly meetings.

Exercise (8): If Sally navigates to the Exercise category, she can monitor her daily, weekly, and monthly performance metrics, including the number of steps, treadmill level, and time spent on the treadmill. These metrics serve as a mirror reflecting Sally's physical recovery progress, inspiring her to stay committed to her rehabilitation exercises.

Navigation and viewing (9): At any point, Sally can choose to go back or go to the home page by selecting the back button or home button. She can also choose to use the Zoom function to gain a better view of the data. Sally has the option to use the search bar at the top of each page to search for specific information. This flexibility in navigation and viewing allows Sally to access the information she needs quickly and easily.

Dark Mode (10): Noticing that it’s getting late, and to ease her viewing in the dimmed evening, Sally decides to switch to the Dark Mode. The switch to darker colours helps reduce the strain on her eyes and makes the readability of the data more comfortable for her at night.
In this section, we displayed the user flow and navigation within the visualization system, emphasizing its role in enabling patients like Sally to efficiently access and interpret their stroke recovery information. By incorporating intuitive features and providing a seamless user experience, the visualization system could facilitate patient engagement and comprehension.

This chapter showcases the iterative design process, driven by evaluations and feedback from healthcare providers and patients, ultimately resulting in a user-centric system that prioritizes comprehensibility and personalization.
Chapter 7: Discussion, Guidelines, and Future work

In this chapter, we provide a comprehensive discussion that not only summarizes the key findings and contributions of this thesis but also explores the implications and potential applications of our research (Section 7.1). Next, we provide practical guidelines based on our research for future designers and engineers who seek to design interactive data visualizations in the healthcare setting (Section 7.2). We then discuss the limitations of this thesis (Section 7.3), providing an assessment of the challenges and potential areas for improvement. Finally, we outline future directions for further investigation, shedding light on potential avenues for continued research and development in this particular domain (Section 7.4).

7.1 Discussion

Our first round of interviews was designed to elicit detailed information about the current practices and processes used by healthcare providers in tracking patient information and communicating it with patients throughout their stroke recovery process. In our interviews with healthcare providers, we identified several challenges. One challenge was about healthcare providers experiencing frustration when attempting to locate a patient's health assessment results within the hospital's current EMR system. The disorganized placement of health assessments in the EMR system makes it difficult for providers to navigate and find patient information, as assessments from a diverse range of healthcare providers and progress notes are scattered across multiple locations. This finding is supported by literature which highlights a similar issue in medical record systems, including data fragmentation, usability issues, and the need for standardization.
These studies suggest that the challenge identified is part of broader, systemic issues in patient care information systems. Therefore, these findings contribute to a growing body of evidence highlighting the need for improvements in the design and implementation of EMR systems, particularly in terms of usability, interoperability, and standardization. Our designs offer a solution to a fragmented EMR system by providing a user-friendly system that includes a comprehensive and centralized overview of patients' rehabilitation progress. By presenting a diverse range of patient results in a single location with filtering features, our visualization system has the potential to alleviate the need for providers to search through different sections of the EMR system, saving them time and effort. Additionally, the integrated overview of patient rehabilitation progress could facilitate communication between healthcare providers as well as between healthcare providers and patients by streamlining the process of accessing and reviewing patient information. This ensures that crucial insights and assessments are easily accessible to all healthcare providers involved in the patient's care, leading to more coordinated and effective rehabilitation care. Furthermore, the visualization system we designed has the potential to enhance communication between healthcare providers and patients. By presenting a clear and concise overview of the patient's rehabilitation progress, providers can use the visualization system to effectively communicate the outcomes, goals, and recommendations to the patients. This enhanced communication allows patients to be informed and could empower patients to actively participate in their own rehabilitation journey.

In our initial interviews with healthcare providers, we learned that providers currently employ a mix of methods for communicating recovery progress to patients.
These methods include verbal communication, handwritten notes, patient portals, and applications. The use of a mix of methods for communicating health progress with patients can lead to several challenges and inefficiencies. When healthcare providers rely on various disjointed methods, patient information may be scattered across different sources, making it difficult for patients to access a comprehensive view of their health status and progress [64], [26]. This scattershot approach highlights the need for enhanced systems to support patients and caregivers in effectively monitoring health and care within the hospital setting [65]. To address this challenge, researchers suggest systems that support collaboration between provider and patient, provide visualizations, and support exploration through simplicity [66]. Our visualization system offers patients and caregivers a comprehensive and accessible visualization of the patient’s rehabilitation progress in a centralized location, allowing patients to independently monitor their data. By consolidating data from various sources into a single interface, both patients and providers can grasp the big picture without the need to navigate multiple platforms or systems.

Our interview with patients revealed a noticeable gap in patients forgetting their health assessment results. This finding aligns with existing literature that indicates patients tend to forget a substantial portion, ranging from 40% to 80%, of the information communicated during verbal encounters [67]. Reducing the cognitive load of patients is particularly important in the population of inpatient stroke recovery, where patients may experience cognitive difficulties affecting their memory retention. Providing patients with a centralized overview of their health assessments and rehabilitation progress could minimize the cognitive load on patients by reducing the burden of relying on memory
Patients' feedback on our designs also provided valuable insights into the potential benefits of visualizing recovery data on a patient's motivation and engagement during their rehabilitation journey. Patients expressed enthusiasm for the visualization system, highlighting its potential to increase motivation, track their progress, and stay focused on their recovery goals. This aligns with the core aspect highlighted in most patient engagement definitions, emphasizing patients' awareness of their health status, comprehension of their healthcare needs, and engagement in specific behaviours [3], [68]–[70]. Our visualization system has the potential to offer patients easy access to their test results, progress updates, and goals, empowering them to be actively engaged in their care. This is consistent with the principles advocated in the literature, where informed and engaged patients are more likely to have better care experiences [71] and better health outcomes [72].

Our visualization designs have been thoughtfully tailored to address the unique characteristics and abilities of patients recovering from stroke by considering the different levels of cognitive, linguistic, and visual abilities that patients may have. During our patient interviews, one patient expressed a preference for data visualizations that incorporated commonly used visualizations, as opposed to complex visualizations with intricate details. For instance, while discussing the Blocks and Boxes test results in stroke recovery, one patient recommended using a bar graph representation as it could offer a clear visual summary of their performance. This approach was favoured over a more intricate visualization that involved up to 150 coloured blocks (Figure 25) making it easier for patients to comprehend their progress. This preference aligns with the principles of "data simplification" and "cognitive load reduction" employed in data
visualization design [73]. Data simplification involves presenting information in a concise and easily digestible manner, stripping away unnecessary complexities that might overwhelm or confuse the viewer [73]. Cognitive load reduction, on the other hand, emphasizes reducing the mental effort required for data comprehension, enabling viewers to process and interpret information more effortlessly [73]. By focusing on data simplification and cognitive load reduction, the data presentation becomes more straightforward and transparent, allowing patients to quickly grasp the key information without getting lost in intricate details.

Furthermore, we have incorporated the best practices outlined in the existing literature for designing visualizations specifically tailored to individuals with cognitive deficits. For instance, we have avoided the use of pie charts, which can be challenging to interpret for individuals with cognitive impairments [74]. Instead, we have employed natural metaphors and commonly used graphs and charts to enhance comprehension and retention of information. Our designs strike a balance between conveying meaningful semantics and maintaining simplicity to optimize clarity and understanding. Additionally, we have leveraged the concept of a discrete axis-aligned encoding [74], ensuring that the visualization is accessible and easily interpretable for patients with different abilities.

Patients recovering from a stroke may face communication problems, one of which is aphasia, the inability to understand and use language [75] [76]. During our interviews with healthcare providers, we found a consensus regarding the importance of using lay language in communication with patients, a simple and easily understandable language that avoid technical jargon and complex medical terminology. Research also supports the benefits of lay language in healthcare communication, highlighting its
positive impact on patient satisfaction, adherence to treatment plans, and overall health outcomes [77]. Studies in this area highlight the significance of tailoring information to patients' comprehension levels and recommend the use of plain language as a fundamental aspect of patient engagement [77], [78]. Therefore, in the context of our visualization system by presenting information in an accessible and jargon-free manner, our designs strive to optimize patient-provider communication and contribute to improved stroke recovery outcomes.

Visualizing patient health data holds immense benefits for patients with language comprehension deficits, particularly those facing challenges like aphasia, which impairs their ability to understand and use language effectively. By presenting health assessment results through simple visualizations, our designs offer a different medium for patients to grasp their progress and outcomes, transcending the limitations posed by traditional text-based communication. To further support patients with aphasia, our designs follow a number of recommendations for developing clear information for people with communication disabilities [80], [81]. These recommendations include using straightforward language, short and simple sentences, bullet points, bolded keywords, images, headings, and signposting, which we took into consideration for our designs. By integrating these best practices into our visualization system, we aim to empower patients with communication disabilities to access, comprehend, and engage with their health assessment results effectively.
7.2 Guidelines for designing interactive data visualizations representing stroke recovery

The development of guidelines for a visualization system for stroke recovery was a dynamic process, influenced by continuous interactions with both healthcare providers and patients. The first round of interviews with healthcare providers shed light on the complexities they encounter when conveying multifaceted health data to patients, drawing from their expertise, and understanding of their patients’ needs. Their feedback emphasized the necessity for an integrated overview of patient data, clear and concise language, visual accessibility, and motivation. As the research progressed, the design evaluation with healthcare providers further supported and refined our guidelines. From the interactions, the significance of ensuring visual accessibility, minimizing cognitive load, and providing context and interpretation of data became evident. Finally, in the design evaluation with patients, the recurring themes of ensuring visual accessibility, minimal cognitive load, and motivation were reiterated. Each round of interviews validated previous insights and introduced nuanced perspectives, ensuring that the guidelines were tailored to both patients recovering from a stroke and healthcare providers. Based on this iterative and collaborative process, we have derived the following guidelines intended to guide designers and researchers in creating visualization systems within the inpatient stroke recovery facility.

- Provide an Integrated Overview of Data: Stroke recovery involves multiple aspects, including physical therapy, speech therapy, and cognitive rehabilitation. The system should include an integrated overview of all relevant information and metrics that patients recovering from stroke need to track their progress, and
provide an overview of their progress, their current physical function, and their
goals. This ensures that patients have a complete picture of their recovery journey.

- **Place Minimal Cognitive Load on the Patients:** Stroke can often result in
cognitive impairments, such as difficulties with attention, memory, and problem-
solving. Therefore, it is crucial that the system is designed to minimize cognitive
load. By providing an overview first, allowing users to zoom in and filter
information, and offering details on demand, the system can help users navigate
and understand their data without feeling overwhelmed or confused. This
framework emphasizes the importance of enabling users to quickly and easily
locate and understand the information they need, without overwhelming them
with too much information at once. Additionally, using commonly used
visualizations can help convey complex health data in a way that is easy to
understand, further reducing cognitive load.

- **Ensure visual accessibility:** Stroke can cause sensory impairments, including
visual deficits, which can significantly impact a patient’s ability to interact with
digital systems. The system should be designed to be accessible to patients with
visual impairments by using large fonts, high-contrast colour schemes to
differentiate between elements, and implementing intuitive navigation structures.

- **Use Clear and Concise Language:** A common consequence of stroke is a
language impairment known as aphasia, which can significantly impact a patient's
ability to understand and produce speech. Given the prevalence of aphasia among
stroke survivors, it is crucial to use simple, clear, and concise language in the
design of the visualization system. This approach ensures that the system is
accessible and comprehensible to patients with aphasia, allowing them to effectively engage with the visualization system despite their language impairment. Furthermore, avoiding technical jargon and medical terminology can make the system more user-friendly not only for patients with aphasia but also for their caregivers who may not have a medical background.

- **Provide Context and Interpretation**: Understanding medical data and what it means for their recovery can be challenging for stroke patients. By providing context and interpretation, the system could facilitate patients to understand the significance of their data, such as what their progress metrics mean, and identify areas for improvement.

- **Provide Motivation, Feedback, and Support**: Stroke recovery is a long and often challenging process that requires ongoing adjustments to the rehabilitation plan. By providing feedback and support, such as personalized recommendations, progress notes, or motivational visualizations, the system can help patients stay engaged in their recovery.

These guidelines provide support for the development of future information visualization systems in healthcare. By following these guidelines, engineers and designers can create systems that are effective, user-friendly, and beneficial to patients recovering from stroke.
7.3 Limitations and challenges

One limitation of this thesis was the challenge faced during patient recruitment. Our study targeted patients within the inpatient stroke rehabilitation unit, a group that constitutes a vulnerable population. Patients recovering from stroke are often in a fragile state of health, requiring specialized care and attention. Their conditions may fluctuate, and they might face communication barriers due to aphasia or other language comprehension deficits. As a result, the recruitment process needed to prioritize patient safety and well-being, which led to a more cautious approach when approaching potential participants. Additionally, it is a well-acknowledged ethical principle in clinical research that care must be taken when recruiting vulnerable individuals to avoid any form of coercion or undue influence. In accordance with this principle, the research unit at the hospital limited the involvement of healthcare providers in the recruitment process to mitigate any potential power dynamic issues that could inadvertently influence a patient's decision to participate in the study. Due to these reasons, we were only able to recruit a sample size of 2 participants. While the insights and feedback obtained from these individuals were valuable, the small sample size does limit the generalizability of our findings. Therefore, future endeavors should aim to involve a larger number of stroke recovery patients to obtain a more comprehensive understanding of their perspectives. However, despite this limitation, our research provides essential groundwork for future researchers to understand the challenges and considerations involved in recruiting patients with language comprehension deficits, particularly in stroke recovery settings. This could be helpful information for researchers planning to conduct studies in similar vulnerable populations, guiding them to design recruitment strategies that prioritize patient safety, adhere to ethical principles, and potentially expand the sample size for more robust and comprehensive findings.
Another limitation of the thesis is that the patients did not have the opportunity to directly interact with the prototype themselves. Firstly, hospital regulations prohibited our physical presence in inpatient areas, making it challenging to provide patients with direct access to the prototype and hands-on assistance. Secondly, the current state of our designed system was at the prototype stage, not yet fully ready to grant patients complete control, which could be particularly challenging for those with cognitive deficits. Patients with cognitive deficits, such as those recovering from stroke, may require additional support and guidance to effectively interact with the prototype. Providing them with full control at this early stage could lead to potential confusion and frustration, affecting the quality of their interaction and feedback. Instead, patients relied on the researcher's guidance and demonstrations of the system’s visualization designs and interactions through a screen-sharing feature. This challenge limits the evaluation of the designs’ usability and user experience. Without the opportunity for patients to independently explore the prototype, valuable insights regarding their preferences, ease of use, and potential difficulties may be overlooked. Each patient may have unique needs and specific requirements that can only be observed through firsthand interaction. To address this limitation, it would be beneficial for future research to incorporate sessions where patients can interact directly with a fully interactive prototype.

During this thesis it was unclear which health assessments were used and stored in the hospital’s EMR system, and we began to ask ourselves how to determine which health assessments to present to patients? To address this issue, we followed guidelines provided by the Heart and Stroke Foundation and took into consideration the recommendations of healthcare providers that we interviewed. These sources helped us identify the most commonly used health assessments that are generally employed in stroke recovery settings.
Despite this, our approach may not encompass the diversity of assessment practices across various healthcare settings. This brings us to an additional challenge - the customization of the visualization designs for different inpatient stroke rehabilitation facilities. Each hospital or healthcare facility may utilize different sets of health assessments based on their specific protocols, specialties, or preferences. The challenge lies in developing visualization designs that can be easily tailored and adapted to the specific assessment practices of different hospitals. Customization requires a comprehensive understanding of the unique requirements and preferences of each clinical setting, which may vary significantly. This limitation highlights the need for further research to explore methods and strategies to facilitate the customization of the visualization system, allowing it to align seamlessly with diverse clinical practices.
Chapter 8: Conclusion

8.1 Summary

Reviewing and understanding the recovery progress data, which is diverse and collected over a long period, can be overwhelming for post-stroke patients, especially those dealing with cognitive or linguistic impairments. In this thesis, we focused on designing and evaluating interactive data visualizations that represent the stroke recovery progress for patients staying within inpatient rehabilitation facilities to support patients in understanding their health progress.

The research was steered by answering three primary questions:

1. What are the current practices and significant challenges confronted by healthcare providers when assessing patient stroke recovery and communicating recovery data to patients?

2. How can interactive data visualizations be designed to effectively portray stroke recovery in a manner that is intuitive, simple, accessible, and facilitate communication between healthcare providers and patients?

3. How do healthcare providers and patients perceive the comprehensibility of the data visualization designs?

Chapter 1 set the stage by introducing the problem area, highlighting the complexities and challenges faced by stroke patients in understanding their health data. The need for a more streamlined and efficient system was identified, setting the stage for the subsequent research.
Chapter 2 provided a comprehensive literature review, laying a theoretical foundation for the research. This chapter discusses the existing body of knowledge on the application of medical data visualizations for healthcare providers and patients. It highlights the role of these visualizations in enhancing the understanding of complex health data, facilitating effective communication, and ultimately improving healthcare delivery in both at-home, and in-clinic rehabilitation. This chapter also identified a significant gap in the current body of knowledge – a lack of rehabilitation data visualizations specifically designed for inpatient stroke recovery. This gap indicates the need for further research and development in this area, setting the stage for the subsequent chapters of this thesis.

In Chapter 3, we outlined the methodology employed in this thesis. This chapter described the user-centered methods that we used to design an interactive data visualization representing recovery from stroke. This chapter provided a detailed plan for how the research was conducted, including a retrospective dataset review, and iterative design cycles with a team of healthcare providers each specializing in a certain role within stroke recovery care (a physician, an occupational therapist, a speech-language therapist, and a physiotherapist) and with patients recovering from stroke within the inpatient rehabilitation facility.

Chapter 4 of the thesis was dedicated to eliciting data requirements for health data visualizations that display recovery from stroke. This chapter was a crucial step in the research process, as it laid the groundwork for the design of the interactive data visualizations. The chapter began with a retrospective dataset review derived from a longitudinal study involving 235 patients recovering from stroke within the inpatient unit.
This dataset was examined to gain a better understanding of standard assessment measured for stroke recovery and to inform the questions for the interviews with healthcare providers conducted later in the thesis. Following the dataset review, semi-structured interviews were conducted with healthcare providers to gain insights into the nature of the stroke recovery process from the perspective of experienced healthcare providers. From the analysis of the initial interviews with healthcare providers, six themes were identified. These themes provided a comprehensive understanding of the challenges and requirements in designing visualizations representing stroke recovery. Based on these themes, five design requirements were defined. These requirements served as the guiding principles for the design of the interactive data visualizations, which would be created in the subsequent chapters of the thesis.

Chapter 5 explored current methods for presenting patient data and introduced preliminary designs for data visualization. The chapter began by assessing existing practices used by healthcare providers to communicate patient recovery data. The initial designs, introduced in this chapter, were created to align with the design requirements derived from interviews with healthcare providers and additionally to align with healthcare providers’ current practices for communicating stroke rehabilitation progress. This alignment aimed to foster familiarity and ease of use.

Chapter 6 detailed the evaluations of the visualization system designed with healthcare providers and patients and the process of refining the design based on the feedback received. We made several modifications to the designs, enhancing its comprehensibility and functionality based on patients’ and healthcare providers’ feedback.
Finally, Chapter 7 presented a comprehensive discussion of the potential benefits that a visualization system based on our designs could have for stroke recovery, emphasizing its potential to streamline communication among healthcare providers and empower patients in monitoring their progress independently. This chapter provided practical guidelines for future designers to create effective and user-friendly healthcare visualizations for patients recovering from stroke. Despite certain limitations, such as a small patient sample size and the inability for patients to directly interact with the prototype, our research offers valuable insights and groundwork for future studies.

This thesis research made the following contributions:

1. We identified the content, procedure, and technological needs for effective communication of recovery progress between patients recovering from a stroke and their healthcare provider team.

2. We identified the design requirements to develop an interactive data visualization representing recovery progress and designed medium-fidelity data visualizations based on the design requirements.

3. We designed an interactive data visualization system representing the rehabilitation progress of patients recovering from stroke in an inpatient rehabilitation facility.

4. We provided a list of recommendations for future researchers and designers who seek to develop innovative solutions that address the communication needs of healthcare providers involved in stroke recovery and patients recovering from stroke.
8.2 Conclusion

In conclusion, this thesis has made significant strides in addressing the challenge of presenting complex health data to stroke patients in a comprehensible manner. The visualizations created have the potential to provide a user-friendly, straightforward, and accessible way for patients to grasp their recovery progress. These visualizations convert health data into an easily digestible format, thereby simplifying the understanding of recovery progress and encouraging patients to actively participate in their rehabilitation journey. By enhancing patient understanding of their health data, these visualizations could promote the adoption of healthy behaviours and increase involvement in care, ultimately leading to better health outcomes.

8.3 Future directions

Our work represents the completion of one design cycle, demonstrating the feasibility and potential benefits of an interactive data visualization system for stroke recovery. While this research has made significant strides in the design of a data visualization system for stroke recovery, design is an iterative process, and further design cycles may be necessary to further develop and refine the system. This includes enhancing its functionality, user interface, and overall user experience based on feedback from healthcare professionals and stroke patients. The development phase will involve implementing new features, optimizing performance, and ensuring compatibility with existing healthcare systems. Additionally, it is crucial to address important considerations such as data security, privacy, and sustainability during the development process.
As the development of this integrative rehabilitation system continues to progress, there may be a need to expand beyond the current set of rehabilitation metrics to provide a more comprehensive and patient-centered approach. In addition to incorporating standard metrics of physical function and other rehabilitation outcomes, future systems may include additional patient-specific metrics such as pain levels, mood, medication adherence, and educational information about stroke. The inclusion of these features could potentially enhance patient engagement and communication between healthcare providers and patients, allowing for a more holistic understanding of the patient's recovery journey. Additionally, future work could explore the integration of digital rehabilitation exercise instructions into the system. The transition from a paper-based rehab exercise format to a digital could provide patients valuable resource that is centralized and accessible for their recovery, further enhancing the utility and impact of the system.

The current research has primarily focused on the conceptualization and design of the system. Future endeavors could concentrate on its practical application within healthcare systems. This would entail deploying the system in real-world environments, refining it based on user feedback, and assessing its impact on patient progress and healthcare provider efficiency. Ensuring seamless data acquisition for visualization requires synchronization with EHRs, potentially demanding technical adjustments and adherence to data privacy protocols. Furthermore, the adoption of our system within a clinical setting introduces the need for user training and acclimatization, as healthcare providers and patients may require time to familiarize themselves with its functionalities. The diverse demographic of patients, including those with varying levels of digital
literacy, could introduce usability concerns and necessitate tailored support to ensure successful user interactions. One crucial challenge that future work needs to address revolves around the potential for human error during data input. As healthcare providers input patient information into the system, ensuring accuracy and reliability becomes paramount. Measures to mitigate this challenge might include incorporating validation mechanisms, error-checking protocols, and intuitive user interfaces that minimize the risk of incorrect information being entered.

Data security and privacy emerge as a critical consideration as the system transitions toward practical application. Future research could investigate optimal strategies for data encryption, secure data transmission, and user control over data access. Given the confidential nature of health data, it's crucial to meet legal and ethical standards for patient privacy.

Sustainability is another crucial aspect to consider in future research. This includes establishing plans for maintaining and updating the system, funding strategies, and ensuring its continued relevance and value to users in the long run.

Looking forward, the visualizations created in this thesis could be incorporated into existing healthcare systems, providing a valuable resource for healthcare professionals and caregivers to convey complex health data to patients in a clear and comprehensible manner. Future research could build upon this thesis by conducting additional design cycles, further developing our visualizations into a comprehensive tool, and testing its effectiveness with a diverse group of patients post-stroke. In essence, this study marks a significant advancement in the realm of health data visualization. It
showcases the role of design in converting complex health data into a system for patient empowerment and sets the stage for future research in this area.
Appendices

Appendix A

This is Appendix A: Interviews with healthcare providers.

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<thead>
<tr>
<th>Code</th>
<th>Description</th>
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<tbody>
<tr>
<td>1 Mediums to communicate health progress to patients</td>
<td>Codes in this category relate to ways in which healthcare providers (HPs) communicate rehabilitation results and progress to patients.</td>
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<tr>
<td>1.1 Communication board</td>
<td>Communication boards in every room display patient names, discharge dates, mobility, and transfer abilities.</td>
</tr>
<tr>
<td>1.2 Verbal communication (synchronous)</td>
<td>HPs use verbal communication to discuss rehabilitation progress with patients.</td>
</tr>
<tr>
<td>1.3 Written notes (asynchronous)</td>
<td>HPs share handwritten notes with patients to show their progress.</td>
</tr>
<tr>
<td>2 Types of content communicated to patient</td>
<td>Codes in this category relate to types of content that HPs communicate to patients recovering from a stroke.</td>
</tr>
<tr>
<td>2.1 Baseline test results</td>
<td>HPs communicate baseline test results with patients.</td>
</tr>
<tr>
<td>2.2 Goals of rehabilitation</td>
<td>HPs discuss the goals of rehabilitation services with patients.</td>
</tr>
<tr>
<td>2.3 Health scores</td>
<td>HPs use objective data like health scores to remind patients of their rehabilitation status.</td>
</tr>
<tr>
<td>2.4 Discharge summaries</td>
<td>HPs provide patients with written updates of discharge summaries.</td>
</tr>
<tr>
<td>2.5 Comparisons between initial health assessment and final assessment</td>
<td>HPs provide patients with a written document that compares the initial health assessment to the final assessment to show progress.</td>
</tr>
<tr>
<td>2.6 Weekly rounds report</td>
<td>HPs discuss weekly rounds with patients.</td>
</tr>
<tr>
<td>3 Information provided in a patients’ weekly progress report</td>
<td>Codes in this category are related to information in a weekly progress report that HPs complete together.</td>
</tr>
<tr>
<td>3.1 Weekly goal setting</td>
<td>HPs discuss rehabilitation goal setting for patients.</td>
</tr>
<tr>
<td>3.2 Discuss the patients’ level of function at admission and changes in function over time</td>
<td>Healthcare providers discuss the level of function in a patient at admission and progress in the level of function over time.</td>
</tr>
<tr>
<td>3.3 Categories in weekly progress report based on the Functional Independence Measure (FIM) categories</td>
<td>Healthcare providers discuss categories of patients’ health similar to categories found in the FIM test.</td>
</tr>
<tr>
<td>3.3 Physiotherapist (PT) discusses patients’ physical function</td>
<td>PT fills out sections in weekly report related to physical function like mobility, lower limb function, upper limb function transfer, walking ability, if the patient can do stairs, bed mobility, balance</td>
</tr>
<tr>
<td>-------------</td>
<td>---------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3.4 Speech-Language Pathologist (SLP) discusses patient’s communication, language, and swallowing abilities</td>
<td>SLP fills out sections in weekly rounds report related to patient’s communication language, and swallowing abilities.</td>
</tr>
<tr>
<td>3.5 Occupational Therapists (OT) discusses patient’s activities of daily living (ADL), instrumental activities of daily living (IADL), cognition-perceptual functions and visual-spatial functions</td>
<td>OT fills out sections in weekly rounds related to patient’s ADL, IADL, cognition-perceptual and visual-spatial functions.</td>
</tr>
<tr>
<td><strong>4 Attempts to increase patient engagement</strong></td>
<td>Codes in this category relate to ways in which HPs attempt to increase patient engagement in rehabilitation process.</td>
</tr>
<tr>
<td>4.1 Giving patients handwritten summary notes</td>
<td>HPs give patients handwritten summary notes, to keep patients engaged.</td>
</tr>
<tr>
<td>4.2 Communicating test scores to patients</td>
<td>Providing patients with test scores is fundamental for engagement.</td>
</tr>
<tr>
<td>4.3 Positive reinforcement</td>
<td>HPs use positive reinforcement to motivate patients in their recovery process.</td>
</tr>
<tr>
<td>4.4 Scoring health status in front of patients</td>
<td>HPs will score and explain patient’s assessment results right in front of the patient so that the patient better understands their results.</td>
</tr>
<tr>
<td>4.5 Educating patients about stroke</td>
<td>Healthcare providers focus on increasing education and awareness about stroke to increase patient understanding and engagement.</td>
</tr>
<tr>
<td>4.6 Using simple language to describe progress to patients</td>
<td>Healthcare providers use simple language to communicate scores to patients to increase patient understanding.</td>
</tr>
<tr>
<td>4.7 Virtual Reality (VR) for engagement in physical rehabilitation</td>
<td>PT uses VR games to promote engagement in rehabilitation exercise.</td>
</tr>
<tr>
<td>4.8 Patients can see physician reports through Electronic Medical Records (EMR)</td>
<td>Patients can stay informed on reports from physicians by seeing them through an online portal.</td>
</tr>
<tr>
<td><strong>5 Issues with technology to store and access patient health data</strong></td>
<td>Codes in this category relate to challenges that HPs face regarding issues with technology storage and accessing patient health data.</td>
</tr>
<tr>
<td>5.1 Difficulty accessing patient information from other healthcare providers</td>
<td>Accessing EMR between OT, PT, SLP can sometimes be difficult if they have not uploaded documents or if they are uploaded in unfamiliar places.</td>
</tr>
<tr>
<td>5.2 EMR system is not organized cohesively making it difficult to find patient information</td>
<td>EMR are stored in different places and are sometimes fragmented.</td>
</tr>
<tr>
<td>5.3 No overview of patient data</td>
<td>There is no overview of patient health data in EMR.</td>
</tr>
<tr>
<td>5.4 No standard template for summarizing patient health progress</td>
<td>HPs do not have an automated template for patient results.</td>
</tr>
<tr>
<td>5.5 Patient information is not readily accessible</td>
<td>HPs think it would be beneficial to have a screen in every room to have information readily accessible.</td>
</tr>
<tr>
<td>5.6 Tracking exercise and cardiovascular health is limited without fitness tracker</td>
<td>PT think that every patient should have a Fitbit to track their cardiovascular health and exercise.</td>
</tr>
</tbody>
</table>

<p>| 6 Inpatient treatment protocol and therapies | Codes in this category relate to inpatient treatment protocol and types of therapy that patients receive. |
| 6.1 General protocol: Assess patient status and determine goals | First assessment starts with assessing the patient's status, then goals are created based on their rehabilitation status, health, mobility, ability to transfer, and ability to provide care for themselves. |
| 6.2 Treatment amount depends on the severity of problem | The number of therapy sessions depends on the severity of the patients’ problem. |
| 6.3 Physiatrist's protocol | Physiatrist’s treatment protocol for caring for patients after a stroke. |
| 6.3.1 Assessment of patient’s health status | Physiatrists assess patients' individual medical situations that could interfere with rehabilitation like a painful shoulder, a painful neck, or a painful back swelling. |
| 6.3.2 Assessment of the comorbidities of patients | Physiatrists assess comorbidities like blood pressure, diabetes and lipids, fever, swelling, and complex regional pain syndrome. |
| 6.3.3 Using SOAP (Subjective, Objective, Assessment, and Plan) method to document a medical situation | Physiatrists use the SOAP method as a standardized worldwide method for documenting a medical situation. |
| 6.3.4 Monitoring patients daily | Physiatrists see patients daily to assess their health status. |
| 6.4 PT protocol | PT treatment protocol for caring for patients after a stroke. |
| 6.4.1 Assessment of patient's ability to transfer, stand and walk | PT assesses patients’ ability to transfer in and out of bed, patients’ ability to stand and walk. |
| 6.4.2 Timeline of patient assessment after admission | Within the first 3 days of admission, PTs assess the patients’ social and home environment, their mobility, occupation, what activities they enjoy, and muscular strength. |
| 6.4.3 Using Virtual Reality (VR) to promote physical rehabilitation | PT leads a program in the VR therapy unit for patients recovering from stroke to promote exercise and engagement. |
| 6.4.4 Giving patients exercise programs | PT gives patients exercise programs to increase cardiovascular health. |
| 6.4.5 Assessments of patient’s muscular strength | PT assesses a patient’s muscular strength. |</p>
<table>
<thead>
<tr>
<th>6.4.6 Asking patients to use fitness equipment</th>
<th>PT asks patients to use fitness equipment like a bike and treadmill for exercise.</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4.7 Duration of treatment</td>
<td>Patients receive 5 therapy sessions a week with a PT.</td>
</tr>
<tr>
<td>6.5 SLP protocol</td>
<td>SLP treatment protocol for caring for patients after a stroke.</td>
</tr>
<tr>
<td>6.5.1 Assessing of difficulty with speech, language, and swallowing</td>
<td>Patients get access to a SLP if they have problems with language, speech or swallowing.</td>
</tr>
<tr>
<td>6.5.2 Duration of treatment</td>
<td>Patients receive 2-5 therapy sessions a week with a SLP.</td>
</tr>
<tr>
<td>6.6 OT Protocol</td>
<td>Occupational therapy treatment protocol for caring for patients after a stroke.</td>
</tr>
<tr>
<td>6.6.1 Assessing patient’s capacity to perform everyday tasks</td>
<td>OT assesses patients’ capacity to perform tasks (ADL and IADL) and compare it with their pre-stroke self-reported abilities.</td>
</tr>
<tr>
<td>6.6.2. Improving patient’s functional capacity, ADL and IADL</td>
<td>OT focuses on improving patient’s functional capacity in their ADL (personal hygiene or grooming, dressing, toileting, transferring, eating) and IADL (managing finances, medications, food preparation, housekeeping, and laundry).</td>
</tr>
<tr>
<td>6.6.3 Assessing cognitive functioning</td>
<td>OT assesses a patient’s cognitive-perceptual functioning.</td>
</tr>
<tr>
<td>6.6.4 Helping patients learn strategies to manage cognitive, perceptual, and behavioural changes after a stroke</td>
<td>OT helps patients learn strategies to manage behavioural, cognitive, and perceptual changes associated with stroke.</td>
</tr>
<tr>
<td>6.6.5 Preparing the home and work environment for patient’s return</td>
<td>OT prepares the home and work environment for patient’s return after a stroke.</td>
</tr>
<tr>
<td>6.6.6 Improving patient’s motor control and hand function</td>
<td>OT focuses on improving the patient’s motor control and hand function in the stroke-affected upper limb.</td>
</tr>
<tr>
<td>6.6.7 Duration of treatment</td>
<td>Patients receive 3-5 therapy sessions a week with an OT.</td>
</tr>
<tr>
<td>6.7 Nurse’s protocol</td>
<td>Nurse’s treatment protocol caring for patients after a stroke.</td>
</tr>
<tr>
<td>6.7.1 Helping pain management, assistance with mobilization, assistance with medication administration, and ADL</td>
<td>Nurses help with a range of rehabilitation services including pain management, assistance with mobilization, assistance with medication administration, and ADL.</td>
</tr>
<tr>
<td>6.7.2 Role of Nurse</td>
<td>Nursing is a fundamental component. Inpatients get cared for by nurses every day.</td>
</tr>
</tbody>
</table>
Appendix B
This is Appendix B: Types of questionnaires used by healthcare providers.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of questionnaires</td>
<td>Codes in this category relate to questionnaires that HPs use to assess function and rehabilitation progress in patients.</td>
</tr>
<tr>
<td>6- and 10-Minute Walk Test</td>
<td>6- and 10-minute walk tests are used to test endurance and gait speed.</td>
</tr>
<tr>
<td>Assessment of Language related Functional Activities (ALFA)</td>
<td>ALFA test is used to test cognitive linguistic problems related to functional activities.</td>
</tr>
<tr>
<td>Bells Test</td>
<td>Bells test is used to test visual neglect.</td>
</tr>
<tr>
<td>Berg Balance Test</td>
<td>Berg balance test is used to test balance.</td>
</tr>
<tr>
<td>Boston Naming test</td>
<td>Boston Naming test measures confrontational word retrieval.</td>
</tr>
<tr>
<td>Chedoke McMaster Stroke Assessment Tool</td>
<td>Chedoke McMaster Stroke Assessment tool is used to measure physical impairment and activity of an individual after stroke.</td>
</tr>
<tr>
<td>Cognitive Linguistic Quick Test (CLQT)</td>
<td>CLQT is used to test cognitive-linguistic problems.</td>
</tr>
<tr>
<td>Western Aphasia Battery (WAB)</td>
<td>WAB is used to test the linguistic skill and main non-linguistic skill in adults with aphasia.</td>
</tr>
<tr>
<td>Functional Independence Measure (FIM)</td>
<td>FIM is used to test the functional status of a patient based on the level of assistance they require.</td>
</tr>
<tr>
<td>Montreal Cognitive Assessment test (MoCA)</td>
<td>MoCA test is used to assess cognitive impairment.</td>
</tr>
</tbody>
</table>
Appendix C
This is Appendix C: Design requirements for data visualization.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Requirements for data visualization</td>
<td>Codes in this category relate to design requirements of the data visualization representing patient health progress mentioned by HPs.</td>
</tr>
<tr>
<td>Visualize weekly report</td>
<td>Visualizing weekly progress report would be useful since healthcare providers use it frequently.</td>
</tr>
<tr>
<td>Visualizing patient results</td>
<td>Healthcare providers believe that visualizing assessment results and showing patients would be beneficial.</td>
</tr>
<tr>
<td>User-Interface should have two views: patient and provider</td>
<td>Display weekly report visualization with two views, one for the healthcare workers and the second for the patient.</td>
</tr>
<tr>
<td>Compare levels of assistance in patients at intake and discharge</td>
<td>Display patients' level of assistance required at intake and discharge (minimum assistance, moderate assistance, maximum assistance).</td>
</tr>
<tr>
<td>Display section for patient goals, admission test results, discharge test results and check-in points in between</td>
<td>Display section for patient goals, admission test results, discharge test results and check-in points in between.</td>
</tr>
<tr>
<td>Simple to understand patient-centered results</td>
<td>Display results that are simple to understand are necessary for patients that may have lower levels of comprehension and cognition.</td>
</tr>
</tbody>
</table>
Appendix D

This is Appendix D: Healthcare provider evaluation.

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Clear categorization and labelling of health assessments</strong></td>
<td>Codes in this category relate to the theme of clear categorization and labelling of health assessments in the visualization designs.</td>
</tr>
<tr>
<td>1.1 Categorize health assessments into their corresponding health domains</td>
<td>Health assessments should be placed in their corresponding health domains.</td>
</tr>
<tr>
<td>1.2 Add signposts to categories of health assessment in the overview</td>
<td>Health assessments should be signposted to their related categories.</td>
</tr>
<tr>
<td><strong>2 Display informative scales and results</strong></td>
<td>Codes in these categories relate to the theme of displaying informative scales and results in the visualization designs.</td>
</tr>
<tr>
<td>2.1 Display severity levels of scales</td>
<td>When applicable, tests should demonstrate severity levels in the scales to inform patients about the meaning of their results.</td>
</tr>
<tr>
<td>2.2 Display health sub-domains that are relevant to the patient's rehabilitation</td>
<td>The results should demonstrate sub-domains relevant to the patient rehabilitation so that results are more informative and meaningful to them.</td>
</tr>
<tr>
<td>2.3 Record and display additional text for results of tests as applicable</td>
<td>To support patients with diet planning, additional information about diet should be included in a comment box.</td>
</tr>
<tr>
<td>2.4 Display meaningful context of patients results</td>
<td>The progress findings from each health assessment tool should give meaningful context about the areas of rehabilitation that have improved or worsened.</td>
</tr>
<tr>
<td><strong>3 Personalize the display of information for patients</strong></td>
<td>Codes in this category relate to the theme of visualizing results that are personalized to the patient.</td>
</tr>
<tr>
<td>3.1 Display functional independence goals</td>
<td>Visualization of goals should demonstrate all levels of functional independence to patients to support them in reaching specific goals.</td>
</tr>
<tr>
<td>3.2 Enable patients to personalize their data view</td>
<td>Allow patients to select which elements display in the visualization to reduce cognitive burden.</td>
</tr>
<tr>
<td><strong>4 Personalize healthcare providers choice of health assessments</strong></td>
<td>Codes in this category relate to the theme of personalizing the healthcare providers choice of health assessments in the visualization designs.</td>
</tr>
<tr>
<td>4.1 Visualization should demonstrate the most common tests that are used by healthcare providers</td>
<td>Visualization should take out tests that are not used by the healthcare providers at the hospital and add tests that are most used.</td>
</tr>
</tbody>
</table>
Appendix E

E.1 Sub-Appendix

This is Appendix E, Sub-Appendix: Patients’ current experience in recovery.

<table>
<thead>
<tr>
<th>Codes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1 Patient’s experience in recovery</strong></td>
<td>Codes in this category describe the patient’s experience during recovery</td>
</tr>
<tr>
<td>1.1 Patient expresses feeling encouraged by healthcare providers</td>
<td>Patients report feeling motivated and supported by their healthcare providers throughout the stroke recovery process.</td>
</tr>
<tr>
<td>1.2 Patient gauges their recovery progress based on the increasing ease of performing a test over time</td>
<td>Patients perceive their recovery progress by measuring the relative ease with which they can complete tests as time progresses.</td>
</tr>
<tr>
<td>1.3 Patient expresses difficulty remembering all the tests they completed</td>
<td>Patients discuss that they participated in many tests and could not remember exactly which ones they did</td>
</tr>
<tr>
<td><strong>2 Communication of progress and results with patients</strong></td>
<td>Codes in this category describe ways in which patients receive information regarding their progress and results in stroke recovery</td>
</tr>
<tr>
<td>2.1 Verbal communication from healthcare providers</td>
<td>Patients receive verbal communication from healthcare providers on their stroke recovery progress and test results</td>
</tr>
<tr>
<td>2.3 Handwritten results from admission and discharge test scores</td>
<td>Patients receive handwritten health results from admission and discharge test scores</td>
</tr>
<tr>
<td>2.4 Patient portal and email notification</td>
<td>Patients receive their medical results through a patient portal called Meditech. A medical update is sent to patients daily via e-mail notification</td>
</tr>
<tr>
<td><strong>3 Communication of Instructions with patients</strong></td>
<td>Codes in this category describe ways in which patients receive instructions for therapy exercises</td>
</tr>
<tr>
<td>3.1 Recovery instructions on printouts</td>
<td>Patients receive recovery instructions, such as exercises on printed materials</td>
</tr>
<tr>
<td>3.2 Recovery instructions on iPad</td>
<td>Patients receive recovery instructions, such as speech therapy exercises through a speech-language therapy application on an iPad</td>
</tr>
</tbody>
</table>
E.2 Sub-Appendix

This is Appendix E, Sub-Appendix 2: Patients’ feedback on the interactive data visualization designs.

<table>
<thead>
<tr>
<th>Codes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Patients’ comments on design elements of the data visualization designs</td>
<td>Codes in this category describe patient’s comments including their feedback and perspectives on the data visualization designs</td>
</tr>
<tr>
<td>1.1 Accommodate for a mobile layout</td>
<td>It is recommended to design a mobile-friendly layout since most patients will have access to the data visualizations on their phones.</td>
</tr>
<tr>
<td>1.2 Preference for numerical results over complex visualization designs</td>
<td>Patients suggested that results presented as numbers or percentages are easier to understand than some of the more complex skeuomorphic data visualization designs</td>
</tr>
<tr>
<td>1.3 Clearly labeled legends are valuable for understanding results</td>
<td>Patients believe that showing clearly defined labels help them understand more complex visualizations</td>
</tr>
<tr>
<td>1.4 Preference for numerical results over complex visualization designs</td>
<td>Patients indicated a preference for numerical results that are displayed in a visually apparent and prominent matter when complemented with complex data visualizations.</td>
</tr>
<tr>
<td>1.5 Greyscale was not intuitive or easy to understand</td>
<td>Patients did not understand the use of greyscale within the swallowing test and recommended removing it.</td>
</tr>
<tr>
<td>1.6 Clearly defined goals could help direct patients in their recovery</td>
<td>Patients believe that showing clearly defined goals could help direct patients in their recovery</td>
</tr>
</tbody>
</table>
References


[38] G. Li, C. Doman, and N. L. Suresh, “Increase in muscle activation during physiotherapy with electromyography biofeedback for patients with acute cervical spinal cord injuries,” presented at


[79] M. Benham-Hutchins, N. Staggers, M. Mackert, A. H. Johnson, and D. DeBronkart, “‘I want to know everything’: a qualitative study of perspectives from patients with chronic diseases on
