GoalTrack: Supporting Personalized Goal-Setting in Stroke Rehabilitation with Multimodal Activity Journaling

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Stroke is the leading cause of disability among adults, with motor impairments being the most significant complication. Stroke rehabilitation is critical for stroke survivors to regain independence in their daily activities. Central to this rehabilitation process is patient-centered goal-setting, a crucial philosophy underpinning personalized programs. However, mismatched expectations between stroke survivors and clinicians often lead to limited engagement from patients, which detracts from patient-centeredness. We envision that stroke survivors who engage in journaling activities can empower themselves to be more proactive, thereby enhancing the goal-setting process. To this end, we iteratively designed and developed *GoalTrack*, an activity journaling app utilizing voice and touch to support stroke survivors in articulating their rehabilitation goals. Using *GoalTrack* as a probe, we conducted an in-lab user study with thirteen stroke survivor participants. We present findings on how stroke survivors utilize multimodal input for different data formats, and their perspectives on its accessibility. We also report on how stroke survivors envision activity journaling in the goal-setting process, where our findings suggest that journaling supports articulating personalized rehabilitation goals and fosters enhanced engagement with therapists. We also discuss future avenues of research for designing multimodal interfaces for stroke survivors, and share lessons learned from conducting in-lab studies.

CCS Concepts: • **Human-centered computing** → **Human computer interaction (HCI)**; *Accessibility*.

Additional Key Words and Phrases: multimodal input, stroke rehabilitation, accessibility, self-tracking, activity journaling

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1 Introduction

Stroke is the leading cause of disability in the United States, with more than 795,000 people experiencing it every year [18]. Stroke occurs from blockages or hemorrhages in blood vessels leading to the brain, which leads to brain injury and various disabilities. Common disabilities due to stroke include motor impairments from hemiparesis [1],

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[1]Weakness or loss of ability to move one side of the body caused by brain injury. A common complication resulting from stroke, where the left side of the body is affected when the right hemisphere is injured and vice versa [3].

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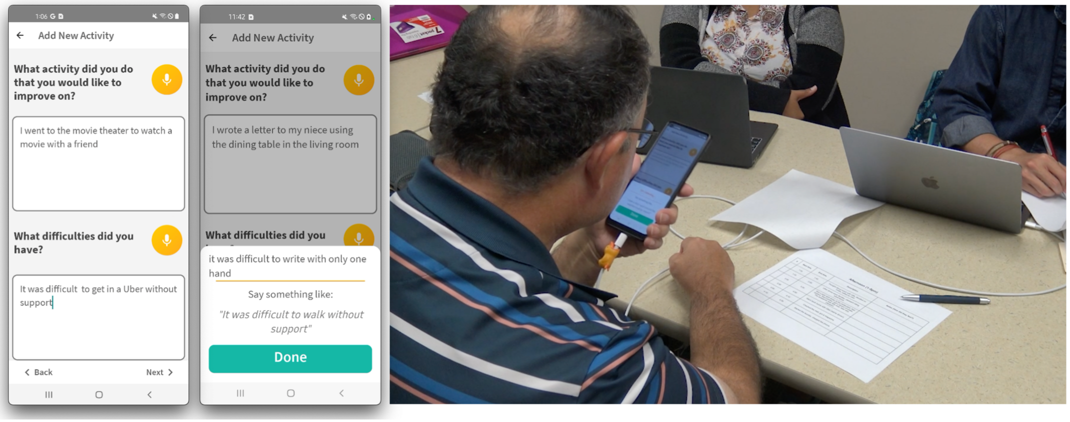

Fig. 1. *GoalTrack* utilizes voice and touch input to support stroke survivors in logging the contextual details of activities they would like to articulate as rehabilitation goals. *GoalTrack* allows capture of four contextual information of an activity: specific details of the activity, challenges associated with the activity, label of the activity, and the time and duration of the activity.

memory issues, and aphasia [2]. For many, stroke is a major event in their lives with profound effects on their abilities to perform daily tasks. Thus, engaging in rehabilitation services, such as physical and occupational therapy, is important for stroke survivors to relearn daily activities and regain independence after a stroke.

Setting clear and personalized goals is important in enhancing the efficacy of stroke rehabilitation [21, 44, 45]. Patient-centered goal-setting is a core philosophy for identifying such goals, supported by frameworks like the Canadian Occupational Performance Measure (COPM) and the Activity Card Sort (ACS) [9, 45]. During the goal-setting process, rehabilitation professionals have dialogues with their patients on how they perform Activities of Daily Living (ADL [24]). Some rehabilitation professionals use the COPM framework to probe their patients' perspectives on the importance of various daily activities (e.g., "*walking to work*") and ask them to rate their satisfaction with those activities [45]. Based on the conversations, rehabilitation professionals identify personalized goals that focus on what stroke survivors would like to achieve.

Despite the importance of patient-centeredness for stroke rehabilitation, challenges exist within patient-centered processes when it comes to identifying personalized goals. Broadly, there are two main challenges: (1) difficulties in identifying rehabilitation goals that are personally meaningful for stroke survivors, and (2) discrepancies between clinicians' expectations of achievable goals versus stroke survivors' personalized goals. Rehabilitation professionals probe for what patients want to achieve during their intervention (e.g., "*return to bowling*") and break down the goal into functional components for the patient to work on (e.g., "*standing up without parallel bars*") [51]. However, prior work in stroke rehabilitation research reveals a mismatch between clinicians' and patients' perspectives in goal-setting [68, 74]. Despite recognizing the importance of a patient-centered process in setting effective rehabilitation goals, the mismatch in perspectives has led to situations where patients were excluded from the process and the goals being overly prescriptive [23, 74, 81]. Clinicians may perceive patient's goals as overly broad and long-term aspirations, and opt to prescribe short-term "realistic" goals [68, 69, 74]. The discourse in patient-centered goal-setting highlights a need for an approach where stroke survivors can articulate rehabilitation goals that are personally meaningful and grounded in their daily lives

[2]Disorder of language comprehension and expression caused by damage to the brain. Common types of aphasia include Broca's aphasia ('non-fluent' aphasia, where producing speech with grammatical structure is impaired, but language comprehension is relatively intact) and Wernicke's aphasia ('fluent aphasia', where speech comprehension is impaired, but producing speech is relatively unaffected) [4].

while being perceived as achievable by clinicians. In this work, we focus on the first aforementioned problem by addressing difficulties in identifying personally meaningful goals for stroke survivors.

To address this problem, we draw inspiration from how journaling daily activities can help people reflect on what is meaningful in their day-to-day lives [5, 42, 58]. Journaling activities in-situ enables the capture of information that may otherwise be overlooked during goal-setting meetings between stroke survivors and clinicians. Guiding stroke survivors through a structured prompt when journaling activities, which are inspired by existing patient-centered goal-setting frameworks, can help derive functional goals from the journaled activities and help resolve some of the discrepancies between patients and clinicians. Thus, we examine how activity journaling can help stroke survivors reflect on what activities are meaningful and articulate personalized rehabilitation goals. To investigate this approach, while being mindful of stroke survivors' motor impairment, we developed a study prototype named *GoalTrack* that leverages voice and touch to support stroke survivors in activity journaling. Smartphones have increasingly become integral to our daily lives, with many using them to track various aspects of their health and well-being [80]. Furthermore, modern smartphones support multiple input modalities (e.g., voice and touch), which can improve accessibility for stroke survivors [52]. In addition to examining how activity journaling can support personalized goal-setting, we also investigate the opportunity of utilizing voice and touch to make activity journaling accessible for stroke survivors in the context of stroke rehabilitation goal-setting. To guide our research, we examine the following research questions (RQ).

(1) RQ1: How do stroke survivors use smartphone's touch and voice input for activity journaling?
(2) RQ2: How can activity journaling support stroke survivors in articulating personalized rehabilitation goals?

To achieve our research objectives, we designed and implemented *GoalTrack*, an activity journaling smartphone app that captures information to support stroke survivors in articulating their personal rehabilitation goals (Fig. 1). *GoalTrack* enables stroke survivors to log activities that they would like to improve and their contextual information. In this paper, we describe the design process for *GoalTrack* and offer design rationales for its implementation. We then present findings from in-person user studies involving thirteen stroke survivor participants and discuss implications for future research. Our contributions include:

- An understanding of how stroke survivors use voice and touch interfaces for personal data capture in the context of stroke rehabilitation goal-setting. After identifying design goals for *GoalTrack* based on prior research and comments from rehabilitation professionals, we report stroke survivors' views on using *GoalTrack*'s multimodal input and recommend design considerations when designing accessible multimodal systems.
- A detailed examination of how stroke survivors use activity journaling via a multimodal smartphone app to articulate personally meaningful rehabilitation goals. Participants viewed self-reflection through journaling activities as an effective catalyst for articulating rehabilitation goals, which can potentially address the mismatch between clinicians' and patients' perspectives in goal-setting.
- A discussion on designing an accessible multimodal input mechanism for capturing personal data, where we discuss the implications of our findings in the broader discussion on addressing accessibility issues for stroke survivors. We also reflect on lessons learned from conducting in-person user studies with stroke survivors, and add to a growing discussion on planning accessible research methods.

2 Background and Related Work

In this section, we first provide background on the stroke rehabilitation process and discuss current issues in stroke rehabilitation goal-setting. We then discuss prior work in stroke rehabilitation technology, where we cover research in HCI and related technical fields. Then, we discuss relevant work in goal-setting with self-tracking technology and provide context on accessible technology for stroke survivors.

2.1 Stroke Rehabilitation and Goal-Setting

Stroke rehabilitation is a broad term that encompasses various interventions involving multidisciplinary teams. The main aim is to reduce the effects of disability obtained after stroke and is usually a cyclical process that starts with assessment, goal-setting, intervention, and reassessment [44]. Various therapeutic practices exist to help stroke survivors regain independence and improve their quality of life. Physical therapy focuses on addressing problems in relearning motor functions to help with daily activities, where they use exercises and training routines to help stroke survivors improve motor function after stroke [66]. While physical therapy is focused on recovering motor function, occupational therapy teaches stroke survivors the skills needed to perform fundamental activities for independent self-care, or ADL [50]. Both physical and occupational therapy are goal-oriented, developed with the therapist and patient working together [38, 45]. Additional therapy programs are available for stroke survivors, such as speech therapy for recovering language and communication skills, and psychiatric therapy for assisting mental and emotional effects of stroke [66].

Patient-centered goal-setting is an important philosophy during stroke rehabilitation, and there are several frameworks that implement the idea. The COPM framework allows occupational therapists to identify and measure goals in three areas: self-care, productivity, and leisure [45]. An example application of the COPM will have the occupational therapist (OT) probe problem areas in the aforementioned three areas from the patient, where the patient will respond with certain occupations (e.g., "*I'm having trouble bathing*"). Then, OT will explore strategies to improve the problem areas with the patient (e.g., assigning exercises to address balance). The OT reassesses the problem areas after 4–6 weeks of working with the client. Similarly, the Activity Card Sort (ACS) probes the patient's levels of participation for various ADLs by using pictorial cards. For example, the OT will ask the patient to sort a card depicting an activity (e.g., "*Eating at a restaurant*") under labels "doing less after injury", "given up after injury", "continued to do after injury". The OT then can use the sorted cards to identify ADLs that the patient would like to set as goals according to their personal importance [9]. A common thread in existing goal-setting processes is identifying goals from activities that a stroke survivor considers important in their daily lives.

Despite the importance of goal setting in stroke rehabilitation, there are challenges inherent in the process. A systematic review conducted by Rosewilliam et al. reported that prescriptive goal setting by therapists may inadvertently exclude patients from active participation, posing a barrier to patient-centered goal setting [74]. Kim et al. also reported that occupational therapists tend to focus on clinical "functional measures" as rehabilitation goals, while stroke survivors prioritize personal "aspirational goals" related to their daily activities and life aspirations [41]. Similar discourse is found in stroke rehabilitation research, where researchers found that discrepancies between stroke survivors' and rehabilitation specialists' perspectives can be a barrier to patient-centered goal setting [68, 69, 74, 81]. Dekker et al. explains that while patients wanted to set goals that are broad and highly aspirational (e.g., "*be back to normal*"), clinicians considered such goals as "unrealistic" and preferred short-term goals [23, 68] that can be described as SMART goals (specific, measurable, attainable, relevant, and timely [12]). The act of 'SMART'ening goals, or transforming the patients' aspirational goals to attainable measures, were not always appreciated by stroke survivor participants and can diminish the patient-centered process. These discrepancies between patient and clinician perspectives can limit patient participation and detract from patient-centeredness. Additional barriers such as limited participation from patients [51] and patients being unclear of their roles [81] can also be a result of this discrepancy.

Based on the aforementioned research, it is clear that empowering stroke survivors with the tools necessary to articulate personalized rehabilitation goals that can help resolve the discrepancies between patients and clinicians is important. Journaling activities in-situ (i.e., logging data right-in-the-moment) can capture rich data that are better situated in stroke survivors' daily lives, which can surface personally meaningful activities. Thus, we propose a novel approach using multimodal activity journaling to enable stroke survivors to reflect on what aspects of their daily lives are personally meaningful, and to better support patient-centered goal-setting in rehabilitation.

2.2 Stroke Rehabilitation and Data-Driven Technology

Previous work in technical fields investigated how data-driven technology can support the stroke rehabilitation process. A significant body of research has focused on the use of quantitative movement data from stroke survivors' limbs for developing treatment plans and interventions [35, 41, 70, 71]. Ploderer et al. [71] prototyped an arm sleeve with embedded sensors to capture movement data and provide visual feedback to patients and therapists. Their work demonstrated the potential of wearable technology in rehabilitation, where therapists found it useful in understanding how much patients use their upper limbs in their daily lives. A follow-up study [70] further investigated how therapists use quantitative movement data generated from patients' daily activities. However, both studies fall short in accounting for contextual information, which therapists require to examine how movement data relate to patients' daily activities.

A large body of work is devoted to examining how sensor data, such as accelerometry data, can be utilized to assess limb movements in stroke survivors [6, 7, 43, 82, 84, 86]. Based on the movement data, various measurements have been developed to understand stroke survivors' limb activities in the context of rehabilitation. Lee et al. [47] proposed methods for estimating the quality of reaching movements, while another study [48] explored predicting rehabilitation outcomes. Wrist-worn devices were common in this research [67, 85], but other devices such as ring devices worn on fingers [41, 49] were also explored, which provided more targeted data on hand function but with limitations in battery life and user comfort.

Beyond the aforementioned research centered on quantitative measures, other studies highlight the importance of qualitative information in the stroke rehabilitation process. Caldeira et al. emphasized the importance of subjective preferences in stroke telerehabilitation [17]. They found that understanding patients' daily routines and preferences played a crucial role in providing physical therapy to meet their needs. Furthermore, experiential information, such as stroke survivors' motivation, stress, and frustration levels, was as important as quantitative movement data for rehabilitation specialists [2]. Despite extensive research investigating various information needs for stroke rehabilitation, relatively few works discuss how to capture these subjective, experiential data from stroke survivors and utilize them in current goal-setting practices. Furthermore, stroke survivor perspectives are relatively underrepresented in existing works, which is crucial in developing patient-centered technology for stroke rehabilitation.

2.3 Self-Tracking Technology and Goal-Setting for Personal Health

Relevant to our research is the maturing field of personal informatics (PI), which examines self-tracking technology and how people collect, reflect, and act upon their personal data [53]. Personal health is an important topic in PI research, where researchers investigated how people used self-tracking to manage their individual health [26]. More relevant to our study includes research work focusing on how people set personal health goals using self-tracking systems [25]. Ekhtiar et al. found that PI literature on health goal-setting focused mostly on physical activity and exercise [65], with the next popular domains being nutrition [8], sleep [22], and weight [8]. Prior literature in PI goal-setting also examined how to manage chronic symptoms such as migraine [77]. Related work in manual journaling of one's daily activities also examined how journaling can help promote self-reflection [1, 5]. Prior work also examined manual journaling in clinical contexts, such as irritable bowel syndrome [95] and Parkinson's Disease [88], and found that journals can be useful data collection tools.

Despite research in self-tracking and journaling, the population of study skews towards non-disabled people. Motahar and Wiese explored this issue for people with motor impairments in their literature review [61], where they found that PI research with people with motor impairments focused entirely on health, and recommended design guidelines for making PI systems more inclusive. Furthermore, contemporary research in goal-setting with PI systems exhibits an over-representation of non-disabled people [25, 61], which creates knowledge gaps in how goal-setting and self-tracking can be designed with people with disabilities in mind. To address this gap in knowledge, our work provides a first-hand examination of how stroke survivors can identify rehabilitation goals using journaling.

2.4 Multimodal Interfaces and Accessibility

Although in-situ journaling holds promise for capturing necessary information for patient-centered goal setting, such logging activities might be burdensome and not feasible for stroke survivors with hemiparesis when technology is designed without considering their specific needs, abilities, and challenges. Bridging this accessibility gap, recent HCI research examined multimodal interfaces, which can provide people with disabilities with alternatives to traditional input methods typically designed for non-disabled users. A large body of work investigated how multimodal interfaces can address accessibility issues for people with motor impairments [11, 32, 89, 90]. Most relevant to our research is a recent study by Li et al., where they investigated how people with upper-limb motor impairments used multimodal interfaces to address challenges while performing ADLs [52]. They found that multimodal input supported reliability, reachability, and efficiency for people with upper-limb impairments. Furthermore, a recent work by Wentzel et al. found that people with limited mobility utilized additional modalities, such as gaze tracking and voice input, to augment traditional input techniques (e.g., keyboard and mouse) when playing video games [91]. Other work examined how gesture input can address accessibility issues for people with disabilities [40, 75, 87]. Voice-based interfaces were also explored, where researchers found that it can improve accessibility for people with disabilities [10, 31, 72, 73]. Voice input can be especially helpful for people with motor impairments, where Li et al. reported that voice input can help people with motor impairments in performing ADLs due to their intuitiveness [52]. One of the barriers to using voice-based systems was its accuracy, where speech recognition can be affected by various factors such as noisy environments [39].

Despite a large body of work that examines how voice input can support accessibility for people with disabilities, there exist opportunities to enhance our understanding of how combining voice and touch can further improve accessibility for data input. Prior research in personal informatics investigated how voice input can be utilized to help personal data collection [57, 94]. Voice input also encouraged people to reflect more on their thoughts during self-tracking [56, 94]. Most relevantly, Luo et al. discovered that using multimodal input such as a combination of speech and touch promoted rich data entry, where each modality complemented shortcomings of the other (e.g., touch input to preserve user privacy, where using the voice input can allow information to be overheard) [58]. However, the aforementioned work in multimodal input falls short in providing insights from people with disabilities. Thus, we investigate how multimodal input, specifically a combination of voice and touch input, can support stroke survivors journal activities in the context of stroke rehabilitation goal-setting.

3 GoalTrack Design

We consulted with five stroke rehabilitation professionals to iterate the design of *GoalTrack* for use with stroke survivors. Four are faculty members in U.S.-based universities, and one is an occupational therapist. Among the four faculty members, two specialized in physical medicine and rehabilitation, and the other two specialized in speech-language pathology. We intentionally included prior literature and rehabilitation professionals to inform the design of *GoalTrack*, as its purpose is to introduce how activity journaling can support setting personal rehabilitation goals, and work as a tangible probe to explore stroke survivors' perspectives on the concept. Ultimately, consulting with rehabilitation professionals can help set initial design goals for *GoalTrack* due to their wider perspectives on working with multiple stroke survivor clients.

Table 1. Description of design goals and rationale based on existing literature and expert opinions.

Design Goal	Described In	Expert Opinions
Empower Stroke Survivors to Articulate Personalized Goals	[23, 55, 68, 69, 74]	*During occupational therapy, clients are often put on the spot when asked what they want to set as goals.*
Contextual Information Surrounding Activities is Important	[2, 17, 35, 41]	*It's helpful for occupational therapists to understand what challenges clients face when they perform activities. Also, knowing what time of day clients do certain activities can be helpful.*
Addressing Accessibility Issues for Stroke Survivors	[31, 52, 72, 73, 91]	*Stroke survivors with motor impairments in upper-limb extremities often have difficulties manipulating small buttons and text input. Using alternative ways to interact with smartphones such as voice can be helpful. For people with aphasia, pictures and icons alongside text are helpful for understanding.*

The *GoalTrack* design probe evolved through iterative online meetings with rehabilitation professionals. We demonstrated the prototype during these sessions, seeking feedback on enhancing GoalTrack to serve the goal-setting needs of stroke survivors. Professionals provided insights on the accessibility of *GoalTrack* for stroke survivors while providing anecdotes on how stroke survivors used technology and the goal-setting process. Each meeting informed prototype refinements, culminating in a version that aligned with the information needs essential for stroke rehabilitation goal setting. In this section, we outline design goals drawn from both our iterative design process and related literature Table 1, followed by rationales and explanations of how *GoalTrack*'s user interface embodies these rationales.

3.1 Design Goal 1: Empower Stroke Survivors to Articulate Their Goals Effectively

3.1.1 Rationale. The first design goal of *GoalTrack* is to enable stroke survivors to log activities right-in-the-moment, which can help prepare them before goal-setting with clinicians and enhance participation. Despite a consensus in related literature that patient-centered processes are important for setting effective rehabilitation goals [23, 55, 68], the extent of patient-centeredness being applied in practice is mixed [69, 74]. As explained in Section 2.1, discrepancies between patients and clinician perspectives can lead to prescribed goal-setting and limited patient participation. Furthermore, anecdotal accounts from our discussions with rehabilitation professionals also report that stroke survivors are often "put on the spot" during goal-setting without preparation, which can limit patient participation. Thus, there is a clear need for an approach where stroke survivors can be better prepared to articulate rehabilitation goals that are centered on their daily needs, whilst being able to translate easily to functional goals for clinicians.

3.1.2 Manifestation in Design. *GoalTrack* is designed for use in daily settings before meeting with a therapist, where the user can journal activities as they arise at the moment. When journaling an activity, *GoalTrack* guides the user in a series of prompts as shown in Fig. 2. *GoalTrack*'s prompts are specifically designed to collect details of an activity that are grounded in the stroke survivor's daily life, while being specific to be translatable into functional goals (i.e., "What activity did you do that you would like to improve on?" in Fig. 2, screenshot B).

3.2 Design Goal 2: Contextual Information Surrounding Activities is Important

3.2.1 Rationale. Design goal 2 surfaces the need for rich contextual information that articulates stroke survivors' goals from their perspectives. As we highlighted in Section 2.2, goal-setting requires experiential information surrounding activities in patient-centered perspectives. Rehabilitation professionals using goal-setting measures

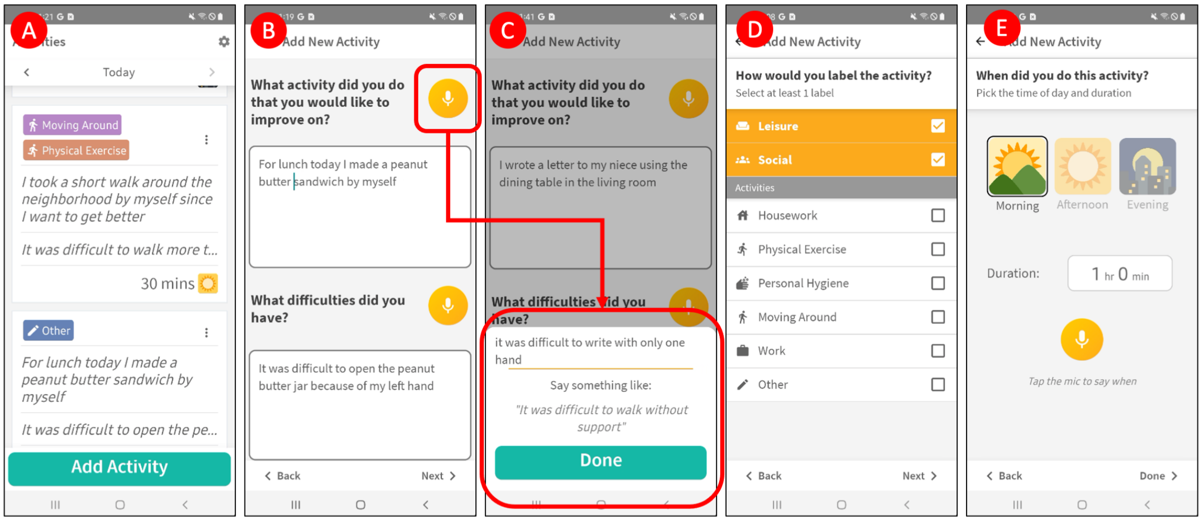

Fig. 2. *GoalTrack* app interface, with each screen labeled A–E. The user logs an activity in the left-to-right order shown in the figure. Screenshot A depicts the start screen, which displays a list of previously logged activities. After pressing the 'Add Activity' button, the user then adds the details of an activity with its difficulties (screenshot B). In addition to touch input, the user can touch the orange microphone button to enable voice input (screenshots B, C). Then, the user can label the activity (screenshot D), and log the time and duration (screenshot E). Similarly to logging text entries for activity details and difficulties, the user can use the voice interface for time and duration.

such as COPM [45] and ACS [9] elicit rich information that can help develop a personalized plan. This need for contextual information was also reflected during our discussions with rehabilitation professionals. An occupational therapist suggested adding a field to log challenges faced by stroke survivors when performing activities to improve. This added context would enrich goal setting by offering insights into the needs of stroke survivors during daily activities. Furthermore, knowing the time of day and approximate duration of each activity can help occupational therapists anticipate which activities require assistance, and better fit exercise programs in stroke survivors' daily lives.

3.2.2 Manifestation in Design. To address contextual information needs, *GoalTrack* supports capturing four different types of data for each activity information: (1) details of an activity that the user would like to improve (activity details), (2) difficulties associated with performing that activity (activity difficulties), (3) labels that categorize the activity (activity labels), (4) the time of day the activity is performed and its duration (time and duration). Drawing inspiration from prior work in self-tracking systems [56, 58], activity details and activity difficulties are captured as free-form text or **unstructured data** (Fig. 2, screenshot B) to capture rich information. The activity labels and time and duration data are captured as **structured data**, where users can use buttons to select and log data (Fig. 2, screenshots D, E).

3.3 Design Goal 3: Addressing Accessibility Issues for Stroke Survivors

3.3.1 Rationale. Manually logging personalized activity goals can be burdensome, where prior research finds that manual tracking can impose a significant data capture burden on the users [20]. This data capture burden is further increased for stroke survivors with hemiparesis. Stroke survivors with hemiparesis often use one hand to interact with their smartphones, which provides significant challenges to data entry using touch input. The data capture burden is further increased when hemiparesis affects a stroke survivor's dominant hand, where data entry that requires fine motor coordination can be burdensome. Discussions with rehabilitation professionals emphasized the need for strategies to account for this, such as large buttons in smartphone interfaces. Discussions also highlighted the need to lower data capture burden for stroke survivors with aphasia. Two rehabilitation professionals, who were speech-language pathologists (SLP), commented that icon- and picture-based interactions are helpful, and nouns instead of verbose sentences are easier to understand for people with aphasia. For data entry, the rehabilitation professionals also commented that text predictions accommodated people with expressive aphasia.

3.3.2 Manifestation in Design. Drawing inspiration from prior research in multimodal interaction [58], *GoalTrack* utilizes flexible multimodal input using a combination of voice and touch. Related literature showed that multimodal input helps address accessibility issues for people with motor impairments [52, 91], which *GoalTrack* implements by providing multimodal input for free-form text, time, and activity duration data entries. Furthermore, voice input can benefit stroke survivors with hemiparesis by providing them with a hands-free option to capture data. *GoalTrack* also enabled icon-based entries for activity label and time data entry (screenshot D, E in Fig. 2) for people with mild to moderate aphasia. To further ease the data capture burden, *GoalTrack* enabled word prediction based on keyboard strokes in the default Android keyboard.

3.4 GoalTrack Implementation

GoalTrack was implemented with Typescript using the React Native framework [79], supplemented by Java using the official Android SDK [29] for Android-specific features. *GoalTrack* was built for the Android smartphone, with room for cross-platform support due to using React Native [79]. To implement the voice interface, *GoalTrack* used Microsoft Speech Services [60] to transcribe speech into text. The voice interface uses an off-the-shelf API for voice-to-text transcriptions, where individual differences were not accounted for. For logging structured data from voice, *GoalTrack* recognizes keywords from transcribed speech (e.g. when the user says "in the afternoon for 20 minutes," *GoalTrack* extracts "afternoon" and "20 minutes" from the utterance).

4 Methods

We conducted in-person user studies with participants using *GoalTrack* as a probe. Each participant engaged in a 90-minute in-person session comprising a tutorial, an experiment involving controlled and open-ended tasks, and a semi-structured debriefing interview. On the day before the actual in-person session, researchers made two phone calls to participants to reconstruct their previous day using the Day Reconstruction Method [37]. The study procedure was approved by the university's Institutional Review Board (IRB).

4.1 Participants

We recruited participants by reaching out to local stroke support groups, utilizing mailing lists and snowball sampling. We selected participants based on the following inclusion criteria: (1) 18 years or above; (2) had a stroke no less than 6 months ago; (3) have upper-limb impairment due to stroke; (4) score at least 18 points[3] in the Montreal Cognitive Assessment (MoCA) [63]; (5) own and use a smartphone outside texting and calls; and (6)

[3]The MoCA is a paper-based screening tool for detecting cognitive impairments, with a total possible score of 30 points. Given the nature of the in-person study, participants were required to follow a set of procedures delivered orally by the researchers. Therefore, we employed the MoCA to screen out stroke survivors with moderate or severe cognitive impairments. We followed the official test material's guidelines for assessing severity levels for the MoCA, where scores of 18–25 indicate mild cognitive impairment, 10–17 indicate moderate cognitive impairment, and scores below 10 indicate severe cognitive impairment [33]. Based on these guidelines and recommendations from rehabilitation professionals received during our *GoalTrack* design feedback, we set the cutoff point range for the MoCA as 18 points or above to recruit stroke survivors with no or mild cognitive impairments.

Table 2. Participant Demographics. Each participant's last level of education, age, gender, current occupation, MoCA score, complications resulting from stroke, time passed since last stroke, time passed since last stroke therapy, and dominant hand.

PID	Education	Age	Gender	Occupation	MoCA	Complications	Last Stroke	Last Therapy	Dominant Hand
P1	Some College	61	Male	Retired	29	Left Hemiparesis	19 years	18 years	right
P2	Some College	70	Female	Sporting Event	21	Left Hemiparesis	22 years	10 years	right
P3	Masters	70	Female	Retired	27	Left Hemiparesis	8 years	3 months	right
P4	Some College	64	Male	Retired	25	Right Hemiparesis	3 years	3 years	right
P5	Masters	41	Female	Retired	25	Right Hemiparesis, Speech	2 years	4 months	right
P6	Bachelors	68	Male	Retired	26	Left Hemiparesis	9 years	3 months	right
P7	Bachelors	44	Male	Sales	29	Left Hemiparesis	9 months	1 month	right
P8	Bachelors	72	Female	Retired	28	Left Hemiparesis	1 year	On-going	right
P9	Some College	58	Female	Retired	22	Left Hemiparesis	6 years	On-going	right
P10	Masters	67	Female	Retired	27	Left Hemiparesis	6 years	On-going	right
P11	Masters	43	Male	Retired	28	Left Hemiparesis	9 months	On-going	ambi-dextrous
P12	Bachelors	33	Female	Retired	30	Left Hemiparesis	2 years	On-going	right
P13	Doctorate	65	Female	Retired	22	Left Hemiparesis	3 years	On-going	right

identify as having no severe aphasia. When an interested person contacted the research team, we first scheduled and conducted an in-person screening session to administer the MoCA and check eligibility. The first author is a certified MoCA rater and conducted all the screening sessions. Once we verified eligibility, we guided the potential participant through the consent form, ensuring they understood all aspects of the study. If the potential participant was interested in continuing, we obtained written consent and scheduled the actual study.

Of the 21 stroke survivors who expressed interest, 14 participants qualified for the study. Among the 14 participants, we conducted one pilot study to make necessary changes to the study protocol, such as adjusting interview questions. All thirteen participants in Table 2 were from the vicinity of the first author's institution in the U.S., with ages ranging from 33 to 72 (*Mean* = 57.6, *SD* = 12.8). Most participants had left hemiparesis, affecting their non-dominant side, with the exception of P4 and P5, whose dominant hand was affected by the stroke. Six participants were still in stroke therapy (e.g., occupational or physical therapy), and only P5 reported as having mild aphasia. All participants except for P2 and P7 reported as being retired.

4.2 Procedure

Our study spanned two consecutive days. On the first day, we called participants twice to reconstruct their day. The following day, we conducted user studies in-person, offering participants the choice of meeting on campus or at their homes due to challenges with mobility. We initially planned to conduct user studies in a controlled setting to minimize variance and disruptions, ensuring consistency in how participants interacted with the probe. However, many participants found traveling to campus inconvenient (e.g., arranging transportation and caregiver), while a few preferred it. To accommodate participants who preferred to engage from their homes, researchers traveled to their residences bringing the necessary equipment. For those who preferred to come to the lab, we asked them to interact with the probe naturally, simulating their typical usage as if they were at home

Table 3. The two example activities used in Task 1 as a reference for participants.

Label	Time of Day	Activity Details	Activity Difficulties
Personal Hygiene	Morning, 50 minutes	I took a shower and got dressed for work by myself	It was difficult to move into the shower booth
Social	Evening, 90 minutes	I wrote a letter to my niece using the dining table in the living room	It was difficult to write with only one hand

(e.g., holding their phone as they normally would). Out of the thirteen participants, four participants traveled to the user study lab on campus (P1, P6, P7, P11) and nine opted to participate in their homes. After completing the study, each participant received a $100 cash compensation.

We adopted an exploratory approach in our study, using *GoalTrack* as a tangible probe for participants to think about how they could articulate goals based on activity journaling. Our study diverged from traditional usability testing methods [46], as we did not define explicit failure states for tasks. Instead, participants had the freedom to enter any information that they deemed appropriate for the given task. Our emphasis was on understanding how stroke survivors use multimodal interfaces to articulate personalized rehabilitation goals, rather than evaluating a prototype. We provide more details on the study procedure in the following.

4.2.1 Day 1: Day Reconstruction Method. We employed the DRM [37] to reconstruct a participant's day before the actual study session. The rationale for using DRM was to minimize recall biases and help participants remember the activities they did on the day before the in-person sessions. We modified the DRM to make the study more accessible for stroke survivors: we verbally delivered prompts over the phone and took note of the responses instead of asking our participants to fill out a packet. We made two phone calls to capture morning and afternoon activities, and a final call on the day of the in-person session to extract evening activities.

4.2.2 Day 2: User Study. The user study comprised three stages: (1) a tutorial for using *GoalTrack*, (2) in-person experiments where stroke survivors participated in controlled and open-ended tasks using *GoalTrack*, and (3) a semi-structured debriefing interview. We provided an Android smartphone with *GoalTrack* preinstalled for participants to use instead of their personal devices. Accessibility features prebuilt in the Android smartphone were not enabled for the study, since not all participants were familiar with Android's accessibility suite. However, the default predictive word suggestion was enabled for the smartphone based on our previous discussions with rehabilitation professionals. A camera was set up behind the participant to record their interactions with the smartphone. Each session lasted up to 90 minutes.

App tutorial. We introduced our study and guided the participant through a 15-minute tutorial on using *GoalTrack*. We used three distinct example activities, which were printed on paper for participants to view. The first example showcased *GoalTrack*'s touch interface, the second example introduced its voice interface, and the third example demonstrated the combination of both voice and touch. The tutorial was interactive; a researcher first demonstrated, then participants were asked to repeat using *GoalTrack*. After the tutorial, participants had at most 5 minutes to freely explore *GoalTrack*.

Experiments with controlled/open-ended tasks. The experiments consisted of five tasks. Before the study, researchers reminded participants that they were not being personally evaluated and encouraged them to complete the tasks independently before seeking assistance. Tasks were presented verbally, and participants could ask clarifying questions. Participants were encouraged to express their thoughts while completing the tasks. We set a seven-minute time limit for each task to provide sufficient time for participants to complete the tasks without causing excessive discomfort, while ensuring at least 30 minutes for the semi-structured debriefing interview. We derived this duration by running the study protocol with the research team, who are non-disabled, and allotting four times the amount it took them. We confirmed that seven minutes was sufficient by conducting a pilot study with one stroke survivor participant. All participants completed the tasks within the time limit.

Task 1 was a controlled task, where participants were given two distinct example activities (different from those in the tutorial) printed on paper. Table 3 shows the two example activities that participants used to complete Task 1. Participants P1–P5 were instructed to log the two example activities, first using touch, and then using voice. We then counterbalanced the modality order by having P6–P13 use the voice interface first, then touch. For example, a participant would log the two example activities first using touch only, then log the same two examples using voice-only.

Tasks 2, 3, and 4 were open-ended tasks. Participants were asked to choose one activity from the previous day that they wanted to improve or focus on, and log that activity using *GoalTrack*. Task 2 asked participants to log a morning activity; Task 3 an afternoon activity; and Task 4 an evening activity. To help participants recall what activities they had done the previous day, we provided a printed copy of the previous day's DRM form. Throughout these tasks, participants could choose any combination of voice or touch input.

Task 5 was an open-ended task. Participants were prompted to reflect on activities that they had not performed the previous day and log only one they wished to improve or focus on. As with Tasks 2–4, participants could opt for any combination of voice or touch input.

Semi-structured debriefing interview. Following the experiments, participants engaged in a 40-minute semi-structured debriefing interview. Participants provided their perspectives on choosing different modalities during Tasks 2–5, their rationale behind selecting specific activities, their thoughts on *GoalTrack* in the context of setting personal stroke rehabilitation goals, and their experiences with goal-setting in therapy.

4.3 Data Analysis

We collected both quantitative and qualitative data, including interaction logs (e.g., timestamps of when each data entry was entered), video recordings of participants using the study phone, video recordings of the smartphone screen, and audio recordings of the study session. We detail our analysis method below.

4.3.1 Logged Data Analysis. We first summarized the descriptive statistics of activity data entries and their input modalities. Then, we calculated two quantitative metrics from interaction logs: words-per-minute (WPM) and the error rate for the final transcribed string. WPM was calculated using the following formula: $WPM = \frac{|T|-1}{t} * 60 * \frac{1}{L}$ [76] where T is the written text for a data entry and L is 5.0 [76]. We measured time t differently for each input modality: for touch, t was measured from the first character entry to the last [76]; for voice, t marked the interval between pressing the mic button to pressing the confirm button. We calculated the error rate of the final transcribed string based on the minimum string distance (MSD, also known as Levenshtein distance) between the written text and "correct" text: $errorrate = \frac{MSD(P,T)}{max(|P|,|T|)}$ where P is the presented string and T is the transcribed string from the participant. We opted to use an MSD-based error calculation method for the final transcribed string instead of other metrics, such as the word error rate (WER) [78], to provide a fair comparison of the two modalities: touch-only and voice-only. WER analysis commonly used in text entry research often accounts for the input stream where actions such as deletions, substitutions, and insertions are considered while the final string is being transcribed [92]. While touch-only input allows logging of the aforementioned actions during the input sequence, the voice-only modality provides only the final transcribed string without the input stream. We calculate the error rates for unstructured data entries in Task 1 where we have a ground truth (i.e., provided example activities) for the presented string P. Despite the availability of model-based metrics such as the BERT score [93], which can calculate the similarity score for the reference activities written in the DRM and

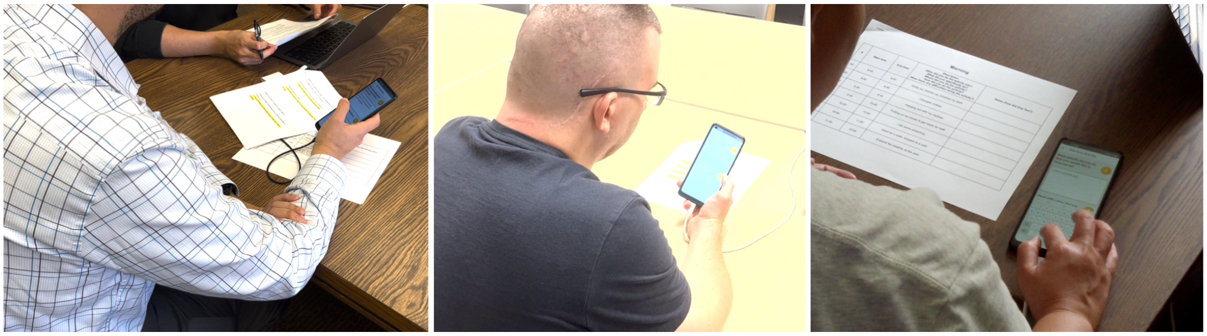

Fig. 3. Examples of how participants interacted with the study phone during the usability study. From left to right: P7 logging activities using their thumb while holding the smartphone, P11 logging activities using their voice while holding the smartphone, P12 logging activities using their index finger while laying the smartphone on the desk.

the activities logged for Tasks 2–4, the open-ended nature of Tasks 2–4 did not guarantee that participants would use the provided modalities equally.

The WPM and error rate measures were calculated from the 8 unstructured data entries (i.e., text entries for activity details and difficulties) logged by each participant while completing Task 1. Each participant had a WPM and error rate for two modalities: touch-only and voice-only. We used R to conduct statistical tests, using the `anova_test()` function from the `rstatix` package. We conducted repeated measures one-way ANOVA to compare the differences of means for each modality group: touch-only and voice-only.

4.3.2 Qualitative Analysis. We video recorded the tasks-related part of the study and audio recorded the interviews. We used video recordings to capture how participants interacted with the smartphone physically in a sitting context. We used this information to contextualize the codes and themes that surfaced from the interview transcripts. The first author transcribed verbatim and conducted a reflexive thematic analysis to analyze the interviews [13, 14]. The analysis approach was largely inductive and experiential, where the focus was on exploring the lived experiences of participants in the context of our research questions. The first author coded the transcripts and subsequently discussed the codes and initial themes with the research team during regular meetings. The codes were both semantic (e.g., "autocomplete helps touch input") and latent (e.g., "articulate goals based on past experiences"). The team reviewed and refined the codes and contributed to generating themes. For example, some initial codes were further elaborated into multiple codes (e.g., "self-tracking can support reflection" to "articulating rehab goals with reflection," "interface flow helps articulate goals," and "prompts helps articulate goals"), and others were renamed (e.g., "difference between captured data vs. goals" to "unrelated to rehab"). When presenting the findings from our qualitative analysis, we clustered themes into relevant research questions.

5 Findings

In this section, we present our findings, first exploring participants' use of *GoalTrack*'s multimodal interfaces (RQ1), and then report on participants' perspectives on using *GoalTrack* for articulating their stroke rehabilitation goals (RQ2).

5.1 RQ1: Supporting Accessible Multimodal Activity Journaling for Stroke Survivors

As described in the previous section, participants logged example activities during Task 1, and activities that they performed the previous day during Tasks 2–5. For Task 1, all participants successfully logged the example

Table 4. Number and percentage of structured (time and duration data fields) and unstructured (activity details and difficulties data fields) data entries that were completed by each modality for the open-ended experiments. Data fields for logging activity labels are not included.

Modality	Activity Details and Difficulties (Percentage of Entries)	Time and Duration (Percentage of Entries)
Touch Only	13 (13.4%)	26 (55.1%)
Voice Only	72 (74.2%)	17 (34.7%)
Touch + Voice	12 (12.4%)	5 (10.2%)
Total	97	49

activities as instructed. For Tasks 2–4, all participants except for P4 logged morning, afternoon, and evening activities. P4 opted to not log the activities from the day before because he felt that there were no activities that needed improvement, but logged an activity for Task 5.

During the user study, all participants interacted with *GoalTrack* using their non-affected hand. Motor coordination was easier with participants' non-affected hands, as P7 explains: "*it's just my left hand is so slow. My right hand just completely takes over.*" Nine participants (P2, P3, P4, P6, P8, P9, P10, P12, P13) laid the smartphone on a flat surface to enter data using their index finger on the non-affected hand. Among them, only P4 interacted with the phone with his non-dominant hand (left side) and other participants used their non-affected dominant hand (right side) to use the smartphone. Two participants (P7, P11) held the smartphone in their dominant, non-affected hand and used their thumb to interact with the touch interface. P5, whose hemiparesis affected her dominant hand, interacted with the smartphone interchangeably; for some entries, she held the smartphone in her non-dominant hand and used her thumb to log activities, and for others she laid the smartphone down on a flat surface to log activities. P1, who significantly recovered motor coordination in both hands, held the phone with both hands and used his thumbs to interact with the smartphone. Fig. 3 provides examples of how participants used the phone to log activities during the usability study.

5.1.1 Hemiparesis and Data Input Preferences. Stroke survivors have different modality preferences based on the data entry format. Table 4 shows how participants used speech and touch to log information during our usability study. A majority of participants (74.2%) opted to use the provided voice interface to log unstructured information (i.e., text). Although none of the participants used voice dictation for text input in their daily smartphone activities, all participants used the voice interface when logging unstructured information. Participants used touch input (13.4%) and both modalities (12.4%) similarly when logging unstructured text. However, participants mostly used only touch when logging structured data (55.1%). Voice only was the next popular input modality, which accounts for 34.7% of all logged instances. Few entries were logged using both modalities for structured input (10.2%). When participants used both modalities for logging both structured and unstructured data, all instances were logged by first using voice input to log initial information, then touch was used to modify small parts of the information.

Participants preferred using voice-only input when logging text entries due to its relative speed compared to touch-only input. Quantitative analysis from the gathered interaction logs supports this explanation, where we measured the average words entered per minute (WPM) when participants logged activities during the controlled experiments. From the calculated WPM measure, we conducted repeated measures one-way ANOVA for voice-only and touch-only modalities on the WPM measure. The WPM was significantly higher for voice-only input, $F(1, 12) = 202.76, p < 0.001, \eta_G^2 = 0.81$. The first box plot in Fig. 4 illustrates this case.

Themes from our thematic analysis further suggest that voice input lowers data capture burden due to its efficiency. Participants reported how the voice input was preferred due to motor impairments in their upper-limb extremities. When asked why P2 preferred voice to touch, she replied: "*Because I got it done faster. I know texting takes me a long time.*" P13 also noted: "*recovering from the stroke, I feel it's necessary to use the voice... It is doing things fast.*" P4 also preferred to use voice input because it was faster, since using the touch input *"you use one finger, that's time consuming"* which *"could be frustrating because you have to think that you only have one hand."*

Participants also preferred voice-only input for text entries due to its accuracy. Quantitative analysis of calculated error rates from text entries from controlled experiments supports this case. To understand how the means of error rates differed between voice-only and touch-only input, we did repeated measures one-way ANOVA based on the two modalities. The error rates were significantly lower for voice-only input, $F(1, 12) = 11.40, p = 0.006, \eta^2_G = 0.17$ Although the effect size was small, spelling mistakes were often found in unstructured data entries for touch only input. The second box plot in Fig. 4 displays how the means differed.

During the debriefing interviews, participants described how using voice input was accurate when logging data. For example, P7 remarked: "*It's (voice) very, very accurate ... I think the accuracy I would give it an A plus.*" Challenges in hitting the right keystrokes when logging unstructured data contributed to touch input's low accuracy compared to voice input. Participants felt more confident in using voice to log unstructured data compared to touch-only input due to its high accuracy (P2: "*When I'm texting and I hit the wrong key, I know I make mistakes. But I feel if I'm speaking at the time it must be OK.*") Voice input's high accuracy helped reduce the burden of logging unstructured data. P8 explains that voice input "*was so easy that I think I would almost prefer doing the voice rather than the (touch) input*" and appreciated the accuracy of the transcription: "*it was sensitive enough that it was really picking up everything that I said, so that made it easier to input.*" This was a common sentiment among participants, where P11 shared that stroke survivors are always "*intentionally finding ways to make it easier*" when interacting with technology.

Although all of our participants had motor impairments in their upper-limb extremities, this did not always manifest into preferring an input modality that required less touch. This was the case when participants had to log structured data (e.g., time of day, activity duration), where buttons and icons were provided. Instead of going through the effort of having to think and verbalize the time of day and duration, many participants opted to use only the touch interface to log structured data. P1 further explained: "*Using the arrow buttons it's just easier to get to the right time ... If it's (voice input) not correct then... it wasn't even worth trying to figure it out. There was a faster way of doing it.*" Similarly, P7 reported that buttons "*just seemed more convenient because the timing is morning, afternoon, or night, so with my thumb placement it's literally moving in like quarter of an inch to select whatever I want.*"

5.1.2 Considering Multimodal Interfaces for Aphasia. P5, who identified as having mild aphasia, provided interesting insights into how multimodal input affects activity journaling for certain people with mild aphasia. The stroke affected P5's ability to verbalize complete sentences, where she needed time to speak words. Despite this, P5 opted to use only voice when logging six unstructured data entries out of a total of eight. When probed about the reason, P5 reported that the voice interface was accurate enough for her to use. P5 also noted how voice input could help her spell words, which she had trouble with due to her aphasia: "*So with aphasia I. I can't, you know. The words. I can't well. I spell now I couldn't spell when you know... You know, butterfly, you know. It, you know. I knew the word.*"

Despite the fact that P5 preferred voice input when participating in the open-ended experiments, P5 reported difficulties when using voice to log data. P5's stroke affected her ability to produce speech at a faster rate, where there were silences in between words. However, *GoalTrack*'s voice input function would wait at most 5 seconds until it closes due to inactivity, which caused inconveniences when P5 was entering data. P5 elaborated how the voice input, once activated, would close too soon: "*And it cut off on me because I wasn't talking. And I had*

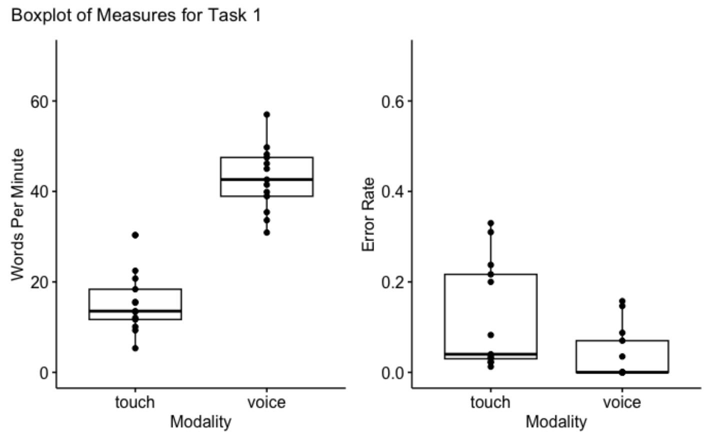

Fig. 4. Boxplots of measures words-per-minute (WPM) and error rate for two modalities from unstructured data entries in Task 1.

to repeat. It all over again." The need for setting accessible default time-outs for people with disabilities is also echoed in findings from Kane et al. [39]

5.1.3 Addressing Memory-related Issues and GoalTrack's Data Capture Burden. Participants also reported that having predictive text was helpful when using touch to log unstructured data with the virtual keyboard. Participants found that having predictive word suggestions at the top of the virtual keyboard can help reduce burdens associated with memory issues post-stroke. For example, P11 explains how the suggested words were convenient when logging sentences: "*Now post-stroke I just can't use as many words and like you know that word choice stuff, it's like now I'm just using whatever is suggested because it's easier.*" Predictive word suggestion was also helpful for participants who used both voice and touch to log unstructured information. For example, P7 would first input text to describe their activity using the voice interface, then made further adjustments using touch: "*I used the voice, saved it, then I deleted, and then I went to manually type it in and then the words were popping up, so I was able to select the words... That made it a lot quicker and easier.* "

Participants also expressed how they would like to change certain design choices in *GoalTrack* to alleviate data capture burden. P1 reported how inconsistency in modality choice for data fields was inconvenient: "*It didn't have the voice interface with choosing the activity labels. So I had to switch from just talking to hold it in one hand to the other when talking*" Also, some participants didn't feel the need to log time and duration of activities that they would like to improve on, which increased the data capture burden. P11 said: "*so like time shouldn't be a requirement because it's not always applicable. So maybe have a checkbox or something that says does not apply.*"

5.2 RQ2: Exploring Patient-Centered Goal-Setting with Activity Journals

Participants logged activities that they would like to improve on, and provided their perceptions on how activity journaling can support them in articulating personalized rehabilitation goals during the in-person sessions. We discuss stroke survivors' perspectives on using activity journaling for articulating rehabilitation goals.

5.2.1 Building Goals with Self-Reflection. Activity journaling can be an effective catalyst for self-reflection and self-learning [27, 53]. Participants reported how activity journaling promoted self-reflection, and helped them identify and articulate rehabilitation goals from their daily lives. Participants found text prompts in *GoalTrack* to

Table 5. Examples of activities that are directly related to stroke rehabilitation, logged by participants during open-ended tasks (Tasks 2–5).

PID	Time of Day	Activity Details	Activity Difficulties
P1	*Afternoon*	*I had lunch with my wife. We ate crabs and I picked several crabs for her*	*It is difficult to pick the crabs with my limited mobility. I would like to make that easier and find a better system for doing*
P11	*Morning*	*Making breakfast*	*It is so hard to make breakfast I want an easier way of going through and preparing to make the meal Without the challenges of getting everything ready just to do the actual cooking*

be helpful with self-reflection. P1 explained how the text prompts that ask the details of an activity followed by probing for challenges led him to think about how he could improve daily activities further:"*It makes me think about it [activity] instead of them being to something I don't really think of as goals.*" Similarly, P8 reported how the text prompted self-reflection on activities that could potentially be overlooked: "*I love the fact that the app is then saying what was difficult about that activity because that makes you think maybe didn't think about it when you were doing the activity.*" The prompts ultimately promoted self-reflection, where P6 found it helpful when *GoalTrack* asked for activity difficulties, they reflected on improvements to articulate: "*It gives you a chance to put like a positive thing, with a described activity and then to have an improvement to explain and improve it. To make it, you know, easier (to explain).*"

During the task-based experiments, most participants logged activities that they perceived as directly related to stroke rehabilitation. All logged activities during the open-ended tasks can be found in our supplementary materials. While journaling such activities, participants reflected on personal experiences to identify meaningful goals. For example, P11 reflected on the personal challenges he faced when preparing a meal. P11 described a story that illustrated the challenges he faced: "*Even the simplest thing like getting the noodles out of the box, I mean you use two hands to do that, right? But I only have one hand. So how am I going to get the noodles out of the box with the right measurement, right?*" Recalling such personal context helped P11 log the morning activity, "*making breakfast*" (Table 5), which was personally meaningful to him: "*I chose to put it (making breakfast) down here because it relates to me personally.*" Such personal contexts were articulated as stories by participants, which helped them identify priorities in their felt lives. P1 recalled a story on how he learned to pick crabs efficiently from a friend, and how he wanted "*to be efficient*" when eating crabs with his wife. Eating crabs was a rare treat and an important occasion for P1, since he enjoyed "*being able to make her (wife) happy.*" Activities journaled with deep personal context suggest that the resulting goals articulated by stroke survivors are personally meaningful, which can support patient-centered goal-setting with therapists.

Similar to findings in prior work [56], using the voice input to verbalize activities promoted self-reflection. P9, where better time management was her rehabilitation goal, said that "*just talking about it into the phone*" made her "*realize that you know, maybe I can reach my goal of saving the time, for the time management.*" P8 also shared similar thoughts, where they found that "*if you say it and verbalize,*" *GoalTrack* can "*make you think about improvements.*" P1 also found that the voice interface was helpful for drafting out initial thoughts, which he used to further refine what he wanted to articulate for his personal rehabilitation goal. P1 explained: "*It (voice input) allowed me some time to reflect and I don't do that generally. ... Just pausing, and then I would look at it (the initial dictations) and realize exactly how I want to say. And then, just re-record. ... It was kind of like a notebook before I turned in the final draft.*"

Table 6. Examples of activities that are not related to stroke rehabilitation, logged by participants during open-ended tasks (Tasks 2–5).

PID	Time of Day	Activity Details	Activity Difficulties
P2	*Afternoon*	*Friend came by to clip my fingernails.*	*Could have been a little bit more social when my friend came by to clip my nails. I didn't even offer her any refreshments*
P3	*Evening*	*I had conversation with my step sister-in-law*	*It was hard to be supportive and honest at the same time*

5.2.2 Barriers in Developing Rehabilitation Goals. Participants also reported several challenges when articulating personal rehabilitation goals with their therapists. Forgetfulness due to stroke can be a barrier in organizing goals. For example, P12 expressed how the stroke affected her memory: "*... my brain, it's hard to remember things, because after the stroke that's difficult.*" Being forgetful can lead stroke survivors to feel unprepared when meeting to discuss goals with their therapists. P11 felt that failing to remember what he needed to discuss impeded his progress, since he "*have to wait until next week (to meet my therapist).*"

Some participants, although instructed to log activities that relate to stroke rehabilitation goals, opted to journal ones that were not directly related to recovery. For example, P3 was uncertain how her afternoon activity (Table 6) related to stroke rehabilitation, which she perceived as being related to her ability to focus: "*my preparation time was longer than I thought. That's, I don't know if that's stroke related or not, but it might be.*" P2 also opted to journal activities not related to stroke rehabilitation (Table 6). For example, P2 wanted to improve her social skills when meeting her friend, which took the highest priority: "*that was really the one I needed to change the most out of everything, to be more social*". Both participants expressed that although stroke rehabilitation was important, it was not the only priority in their lives. P2's main focus was managing her diabetes, saying that "*the only main goal in my life is to control my diabetes*" and wanted to use *GoalTrack* "*to help me control my diabetes*". P3 also had other priorities in life other than increasing functional motor capabilities, where she was "*so far out from the stroke*" and was already familiar with the "*relationship between difficulties and challenges versus what I could legitimately put as a goal for therapy*". A common theme among certain participants was their acceptance of the challenges they faced due to their impairments. This acceptance resulted in logging activities with priorities different from stroke rehabilitation.

5.2.3 Empowering Stroke Survivors during Patient-Clinician Communication. Participants also reported how activity journaling can support them during goal-setting in therapy sessions. Participants (P4, P7, P11, P12) commonly discussed using *GoalTrack*'s data to initiate conversations with their therapists. For example, P11 viewed *GoalTrack* as "*my portal to my therapist*" where the logged data would be the starting point of the conversation. P12 also appreciated how logging data in *GoalTrack* can help her be more prepared during her sessions with her occupational therapist. P12 provided an example: "*you could go back and look at your activities and say 'Oh yeah, I need to talk to my therapist about my trouble on the computer and how can that get better.'*" Being better prepared and initiating conversations with therapists can help stroke survivors be more engaged with the goal-setting process, which can better support patient-centered goal-setting.

Findings suggest that the very act of activity journaling, which allows stroke survivors to recall in-situ context, can also be helpful in driving patient-centered goal-setting during meetings with their therapists. While discussing past therapy experiences, P1 described his problem: "*I think the problem I have is I will think of something and not write it down or put it somewhere and then an hour later I'm like, what was that?*" P1 appreciated how *GoalTrack* can support in-situ logging where he said: "*I think with this, this is very immediate. When I see a challenge, when I encounter something, I can say this (the voice interface).*" Some participants (P1, P2, P4, P9) reported how voice input can help with in-situ activity logging, where using the voice input can alleviate tracking burden and log data better situated in the daily context. For example, P4 explained that with the voice interface, he could log his activity riding an exercise bike in-situ without significant interruption: "*with the microphone, if I'm going to ride the exercise bike, I can say I'm ready to ride my exercise bike... (as opposed to) trying to type all that in, well, I'm not going to ride the bike now because I got to type all this information then first.*"

6 Discussion

In this section, we present implications for designing accessible multimodal input for stroke survivors based on our findings. We then reflect on how activity journals can be used for patient-centered goal-setting, where we also touch on tensions between accessibility and medical research. Finally, we discuss lessons learned from conducting in-lab user studies with stroke participants, and present different avenues for future research based on the limitations of our study.

6.1 Designing Accessible Multimodal Input for Stroke Survivors

For stroke survivors with significantly reduced motor function on one side, the ability to use a smartphone's touch input is adversely affected, where they either have to work with the smartphone laid on a flat surface or with one hand. Such interactions can lead to slower input and higher error rates, which we found was the case for our study. Providing additional options for input such as voice is helpful for self-tracking purposes to alleviate touch input barriers. Although participants found voice input to be helpful in drafting initial sentences for logging unstructured data, touch input was still needed to correct mistakes by making small modifications (e.g., adding or changing words in a sentence). Some participants had difficulty moving the cursor to an appropriate part of the sentence to make corrections, and wanted better methods. We echo Luo et al.'s [58] suggestions on providing flexible data editing by minimizing touch interactions and enabling multimodal input. For example, instead of dragging the cursor in text fields, having the user touch a general part of the sentence and implementing voice commands (e.g., "*change morning to evening*") can help minimize difficult touch interactions.

Our study also provides insights into how voice interfaces can benefit certain people with aphasia, as described by P5. People with aphasia who have challenges in producing grammatically-correct sentences, can utilize speech recognizers and language models to construct full sentences for unstructured data entries. Since predictive word suggestions were helpful for stroke survivors, we suspect that utilizing language models can support people with aphasia in manually logging unstructured data. However, speech recognition accuracy may not be high enough to be practical for people with different aphasia profiles. There are efforts to improve speech recognition technology, such as collecting datasets from people with non-standard speech to personalize speech recognizers [30]. Further improvements to accessibility can be done by examining how voice interfaces can be used in combination with other modalities such as touch input.

Findings from our study also add to the growing discussion on examining accessibility issues for people with motor impairments. Multimodal interfaces offer valuable alternatives for people with upper-limb impairments by diversifying input modalities, thus reducing the effort on any single input modality [52]. Participants from our study also gravitated towards input modalities that required less burden due to their hemiparesis, such as using the voice interface when logging text data. However, modality preferences become nuanced based on the structure of the data being logged. For example, some participants preferred to use touch when logging structured time data since it required "less thinking" to touch a few buttons, while others used the voice interface. Thus, we recommend designers consider incorporating multiple input modalities for different types of data capture, which allows users with disabilities the freedom to choose. Similar to the findings from Motahar and Wiese's work in exploring technology adoption after spinal cord injuries (SCI) [62], it is evident that a one-size-fits-all approach to input modalities is inadequate. Systems should be flexible and adaptable to individual needs, incorporating redundant input modalities. While our findings are rooted in combining only two input modalities—voice and touch, it warrants further research to explore the extension of multimodal input to include other modalities, such as gaze tracking and gestures.

6.2 Navigating Stroke Survivor Perspectives to Support Patient-Centered Goal-Setting

Patient engagement is important for effective patient-centered goal-setting in stroke rehabilitation [45, 51, 74]. This work demonstrated the feasibility of stroke survivors' data capture and reflection through multimodal activity journaling, facilitated by *GoalTrack*. We suspect that such a tool can support stroke survivors to better engage in goal-setting. As shown in previous work [19, 54], we observed that logging activities offered opportunities for stroke survivors to self-reflect on their daily activities, and identify ones that they would like to improve on. Journaled activities could also be used in patient-therapist collaboration, as evidenced in our qualitative analysis. Furthermore, having activity journals that allow data collection in-situ can help stroke survivors capture more accurate context. This can also support memory issues associated with stroke, and help stroke survivors be more prepared when discussing rehabilitation goals with therapists.

During the experiments with open-ended tasks, some participants opted to log activities that were related to other aspects of their life, such as improving relationships for P3. These can be potential barriers to goal-setting using activity journals, since stroke survivors may capture activities not translatable to functional goals. However, one must take note that although articulated goals from such activities (e.g., "*I want to be more social*") may not be related to rehabilitation, it is nevertheless a personally meaningful activity. A stroke survivor's life priorities shift as time passes post-stroke, especially after the 6-month period where rehabilitation progress slows down significantly [34]. Such shifts in priorities may influence stroke survivors' identities, leading them to be accepting of their new capabilities. It is common for research in similar fields to focus on 'improving' people's disabilities, but such approaches often neglect how the person feels and creates unjust norms. If a person's identity includes their disabilities, is it just to categorize impairments as something that needs to be 'fixed'? Technology that takes part in a person's long-term journey after stroke should be sensitive to such issues, and be accommodating to individual disabilities.

6.3 Transforming Personal Activity Journaling into Collaborative Goal-Setting Practice

Independence during collaborative goal-setting is an important theme in our findings, where we found that journaling activities can empower stroke survivors to articulate rehabilitation goals based on their personal needs. We find parallels in related work in SCI, where assuring independence is a central concern for people with SCI [15, 16]. Büyüktür et al.'s work in SCI self-care finds that independence is collaboratively shaped by the care network, and despite the best intentions from each stakeholder, tensions can arise which can influence the perceived independence [16]. We build upon the recommendations of Büyüktür et al.'s work [16], advocating for stroke survivors to retain control over access to the journaled activity data within a collaborative rehabilitation network. Additionally, we recommend that future work on stroke survivors' journaling consider their daily routines and the dynamics of the rehabilitation care network. People with SCI adapt self-care plans from clinical plans, and semi-automated tracking can support the routinization of the plans [15]. Our findings reveal similar sentiments, with personal self-care routines such as stretching often adapted from therapists' plans. Enabling stroke survivors to track their goals can support these routines and promote autonomy in stroke survivors' rehabilitation journey.

6.4 Making the Study Protocol Accessible for Stroke Survivors

Lastly, we would like to reflect on our study design and elucidate the factors guiding key decisions. To conduct in-lab studies with stroke survivor participants, many considerations in making the study design accessible needed to be made. First, a reasonable cut-off point for the MoCA screening tool was needed to include participants with mild to moderate aphasia. During our discussions with rehabilitation professionals, a frequent comment on making the study accessible for people with aphasia was the need to make the cut-off score more lenient than the recommended standard. However, careful consideration was needed when deciding the minimum MoCA score to make the study more accessible while maintaining the rigor of the research. Since our study combined both quantitative and qualitative methods, the participants needed to be able to comprehend instructions and articulate thoughts sufficiently. We eventually settled with a MoCA score of 18, informed by discussions with rehabilitation professionals and literature comparing the Mini-Mental State Exam (MMSE, another frequently-used cognitive screening tool [28]) and the MoCA [83]. Future work in similar areas must consider accessible inquiry methods, such as including speech-language pathologists in the study [64], to make studies more accessible to a more diverse population.

Second, the logistics of conducting in-lab user studies must be carefully organized to make the study accessible for stroke survivors. An important factor to consider is transportation options. A researcher must take stock of accessible transportation options in the area (e.g., wheelchair-accessible taxis or paratransit[4]) and allow extra time before and after in-lab study sessions. The building where the study takes place should be accessible, with wheelchair-accessible paths, and must be within a short walking distance to transit drop-off areas or parking lots. Even with considerations for transportation, by structuring the protocol to be in-person, our study design raised the burden for participation for stroke survivors. Thus, we added an option where the researchers would visit stroke survivors at their residences, which a majority of our participants opted to use. Lastly, small details of the study required modifications to make the study accessible for stroke survivors. Due to hemiparesis, stroke survivors may perceive handwriting to be burdensome. To address this, we modified the DRM [37] to be delivered over phone calls instead of physical document packets. The lessons learned from our study echo recommendations from Mack et al.'s work in human-centered methods [59]. Mack et al. identified four dimensions (communication, materials, space, time) when planning accessible studies, and found that a strategy of "anticipating with adjustments" to be helpful. In planning for our in-person studies, we considered space by allowing at-home participation, and materials where we opted for using phone calls instead of hand-writing activities while using the DRM. Based on the lessons learned from designing our study, we also echo Kabir et al's guidelines for conducting research with people with SCI [36]. Adapting the methods to include rather than exclude participants is important, and researchers should anticipate accommodations such as wheelchairs and accessible ramps when preparing in-person studies.

6.5 Limitations and Future Work

Our participants skewed toward stroke survivors who were already familiar with smartphones and technology, as our inclusion criteria required participants to own a smartphone and be comfortable interacting with apps beyond texting and calling. The rationale for this criteria was to ensure that we could mainly focus on examining the core concept of the GoalTrack—multimodal journaling and personalized rehabilitation goal capture—without being sidetracked by explaining basic smartphone interaction paradigms, such as screen navigation and common icons. Additionally, we did not collect demographic information on participant ethnicity and native language, which would be helpful to understand how participants interacted with the voice interface. Furthermore, the study protocol required participants to have a certain level of language proficiency with no moderate to severe cognitive impairments. Therefore, care must be taken when transferring our findings to the broader stroke survivor population. Additionally, all participants used their unaffected hand to interact with *GoalTrack* during our study, and a majority were able to use their dominant hand. Thus, perspectives from stroke survivors whose dominant hand is affected are limited in our study. Despite taking steps to increase our study's accessibility,

[4]Alternate modes of transportation for people with disabilities in North America.

further research is needed to include perspectives from stroke survivors with diverse profiles of aphasia and cognitive impairments.

It is also worth noting that our study setup captured only one day's worth of activities, making it challenging to understand the long-term perception and implementation of activity journaling in the daily lives of stroke survivors. Although the lessons learned from our study were insightful, future work involving a longer-term field study will be crucial to understanding real-world challenges and gathering insights for improvement. A critical aspect of this transition involves innovative methods, such as system-prompting logging, to further reduce the burden of stroke survivors' data capture. Additionally, we envision expanding GoalTrack to incorporate mechanisms for monitoring goal achievements over time and allowing for flexible goal adjustments based on user feedback and evolving therapeutic needs. We hope that addressing these aspects will enhance the effectiveness of patient-centered goal setting and contribute to the overall improvement of patient outcomes.

In considering the logical next steps for enhancing *GoalTrack*, several avenues for future work and design implications unfold. First, the transition of journaled activities into actionable goals requires a nuanced approach, warranting future studies to learn how to involve OTs in the process. It is imperative to conduct a comprehensive study to assess the feasibility of integrating the proposed goal-setting system into current therapeutic practices. This study should involve not only the perspectives of stroke survivors, but also that of OTs to ensure seamless integration with their workflow. Also, *GoalTrack* needs to have goal-sharing features to facilitate collaborative goal review sessions between stroke patients and OTs, either through synchronous or asynchronous discussions. This way, OTs could provide feedback on goals, ensuring continuous refinement and personalization.

7 Conclusion

This work reported the findings of in-lab user studies using *GoalTrack*, a tangible probe implemented as a smartphone app that utilizes voice and touch input to capture activity information to support stroke rehabilitation goal-setting. From the thirteen stroke survivors who participated, we offer an empirical understanding of how stroke survivors used multimodal input to log activity information. This work also provides an understanding of stroke survivors' perspectives on using activity journals when articulating rehabilitation goals, where we demonstrate that journaling promotes self-reflection and helps identify goals that are personally rooted in a person's daily life. We envision our work to provide a basis for designing accessible multimodal systems for stroke survivors, and expand novel avenues of research in stroke rehabilitation goal-setting. Future research should consider the lived experiences of stroke survivors when designing rehabilitation systems, and critically reflect on how the systems are presented to stroke survivors.

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A Thematic Analysis Codebook

A.1 Final Themes and Codes from Thematic Analysis

Table 7. Themes and codes related to RQ1, with descriptions for each code.

Theme	Codes	Description
Barriers in articulating goals	Difficulty in keeping track of goals	Responses explaining difficulties in keeping track of information related to their rehab goals
	No interest in journaling	Responses reporting no interest in journaling for stroke rehabilitation
	Passive goal-setting	Responses reporting how participants were not engaged or passive during goal-setting
	Prescriptive goal-setting in previous experiences	Responses for how goal-setting experience was prescriptive in the past
	Unhelpful interfaces	Responses on how a data field or interface element were unimportant on articulating goals
	Unrelated to rehab	Responses on how participants perceived their current rehabilitation stage and how rehab is not at the forefront of their lives
Collaboration with therapist	Articulate goals based on past knowledge	Responses on how participants built up their goals based on their experiences with stroke therapy
	Assisting memory	Responses on how GoalTrack can help assist participants with memory
	GoalTrack to communicate with therapist	Responses on how participants wanted to use GoalTrack to communicate with their therapist
	In-situ logging and goals	Responses regarding in-situ data logging
Self-reflection and identifying personal goals	Articulating rehab goals with reflectio	Responses where participants identify important activities from their daily life for setting rehab goals. Implicit mentions are included
	Interface flow helps articulate goals	How various elements of the flow of the interface (e.g., text prompts, layouts) helped participants think about their goals
	Prompts helps articulate goals	Text prompts helped articulate goals by having participants reflect on challenges on activities they do
	Logging and motivation	How activity journaling can help motivate rehabilitation
	Snapshot of past goals	Responses on how participants wanted to view how their goals changed over time
	Voice interface and articulating goals	How using voice to journal can help articulate rehab goals

Table 8. Themes and codes related to RQ2, with descriptions for each code.

Theme	Codes	Description
Accessibility and stroke	Autocomplete helps touch input	Responses on how participants found autocomplete feature to be helpful during logging
	Voice interface and social	Perspectives on using the voice input in public settings
	Voice supporting aphasia	Responses on how voice interface can support accessibility for people with aphasia
	Voice to support motor impairment	Responses describing how voice input supported activity logging for participants with motor impairments
Barriers in journaling activities	Barriers with in-situ logging	Barriers that can be obstacles with in-situ logging using GoalTrack
	Barriers with touch input	Responses describing various barriers with touch input
	Barriers with voice input	Responses explaining any barriers or perceived disadvantages in using voice input
	Interface should be consistent	Responses on how GoalTrack interface should have a consistent pattern (e.g., offering voice for all input, not just for some)
Input preferences	Multimodal input	Responses on how participants used both voice and touch in GoalTrack
	Preference for easier interfaces	Responses on how participants opted for input interfaces that required less mental thoughts
	Preferred touch	Responses on how participants preferred to use touch interface
	Preferred voice	Responses on how participants used voice interface