DESIGNING AN INTERFACE TO IMPROVE THE REHABILITATION PROCESS FOR KNEE SURGERY PATIENTS

by

Lauren Aberle

A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Computer Science).

Golden, Colorado

Date _____

Signed: _____
Lauren Aberle

Signed: _____
Dr. Tracy Camp
Thesis Advisor

Signed: _____
Dr. Katie Siek
Thesis Advisor

Golden, Colorado

Date _____

Signed: _____
Dr. Randy Haupt
Professor and Head
Department of Electrical Engineering
and Computer Science

ABSTRACT

Knee surgery patients often go through an extensive knee rehabilitation program that requires both clinic visits with a physical therapist and prescribed at home exercises; patients, however, have limited access to feedback on how well they perform during their at home sessions. We supplement a previously developed prototype wearable knee device, PT Viz, with an interface that displays at home session data and progress and allows patients to set goals and share their data with a therapist. We iteratively designed an interface using two paper prototypes by conducting a user study with 12 participants who had recently undergone knee surgery. We then confirmed participant preferences during a follow-up survey with the final prototype design, and implemented the PT Viz Mobile Android application to accompany PT Viz. We discovered that knee surgery patients thought viewing their progress and setting goals improved motivation to do prescribed exercises, and that patients wanted to involve their therapists in using the system. We hope that this system can both improve compliance and encourage concordance, and propose a field study to further investigate the usefulness of the system.

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ACKNOWLEGEMENTS

I would like to thank both Tracy and Katie, my advisors, for their guidance throughout this research. Katie's willingness to advise a student from another institution and work through all the ensuing issues allowed me to perform research in this field, and I appreciate her patience throughout the process. Tracy's attention to detail in the revision process was invaluable, and she has been a wonderful mentor throughout both this thesis and the rest of my time at the Colorado School of Mines. I would also like to thank the other members of my committee, Dr. Rader and Dr. Bach, for their input and perspectives on my research. Finally, I would like to thank my friends and family for supporting and encouraging me throughout this past year, and being understanding through the frustrating afternoons and late nights.

CHAPTER 1

INTRODUCTION

Physical therapy treats a disease or injury with alternative methods such as exercise and massage rather than medications. Physical therapists prescribe regular exercises for their patients to improve strength and mobility; however, because patients only see their physical therapists a few times a week, the success of physical therapy is largely related to how well the patient can perform prescribed exercises at home. These exercises must be performed without a physical therapist's guidance on form and extent of movement. With the exception of body sensor networks, entertainment consoles, and TheraNetwork, there is little technology designed with a focus on assisting patients in their physical therapy exercises at home.

The Wellness Innovation and Interaction Lab at the University of Colorado – Boulder developed a prototype wearable knee device, PT Viz [1], for use during at home physical therapy sessions for patients who underwent knee surgery or had chronic knee problems. The primary purpose of PT Viz is to give immediate feedback on the form and extent of movement of two of the most common knee exercises: the knee flexion and knee extension exercises. The knee flexion exercise involves sitting on the edge of a chair with the leg straight, then gradually flexing it until bent. The device includes a bend sensor to calculate knee angle, and currently provides a minimal visualization composed of an electroluminescent wire that lights up based on how far the leg is flexed. The knee extension exercise is similar, but instead of bending the leg, the patient starts with the leg bent and attempts to straighten it. Preliminary user studies with PT Viz revealed that the device helped patients understand the extent of movement during their exercises and had minimal wearability issues. These studies also concluded that the device would

be much more useful with an interface that both the patient and physical therapist can use to better visualize performance and progress over time.

Previous work utilizes new technologies to create unique physical therapy and bio-monitoring solutions to a variety of health care problems. The specific contributions of this thesis are:

- Results of a user study on creating a user interface that allows patients to track knee rehabilitation goals and view progress over time.
    - An evaluation of two paper prototypes that assess patient preferences for checking at home exercise session data, setting goals, and viewing progress.
    - An analysis of how setting goals and viewing progress affects motivation in the rehabilitation process.
    - A discussion of how patients seek to involve their therapists while using such an interface.
- A smartphone application, PT Viz Mobile, that assists patients in their at home knee rehabilitation exercises using a previously developed device, PT Viz.

CHAPTER 2

RELATED WORK

A variety of both commercial and research-related bio-monitoring systems that have applications in physical therapy already exist, spanning everything from tracking motion with invasive sensors to displaying muscular activity. These systems are designed both for therapists and patients, and can be used in the clinic or at home.

2.1 Technological Physical Therapy Solutions

Physioplux is a compact commercial device that measures and displays muscular activity during rehabilitation sessions. Its main purpose is to transmit data to be analyzed by the physical therapist in the clinic, so it does not have useful applications for the patient while performing exercises at home [2]. Entertainment consoles that also track motion show promise as technological solutions to provide better physical therapy experiences at home. For example, an Xbox and a P5 gaming glove were used to develop a game to facilitate stroke rehabilitation in the hand and fingers [3]. Patients with brain injuries that used a system that incorporated the Nintendo Wii Balance Board experienced significant improvements in static balance over a control group that did not [4]. Unfortunately, these products are more expensive, take longer to set up, and are less portable than PT Viz.

Healthcare research has also developed an array of bio-monitoring systems. One such result is wearable sensors, which have been used to monitor therapy. Applications include classifying limb movements [5], making gait analysis possible over longer time periods by installing sensors in shoes [6], and determining postures and transitions between postures in stroke patients, older people, and people with hip fractures [7]. While this research has the

potential to address a wide variety of health problems, its focus is on the algorithms and sensors required for the systems rather than how they affect the patient's experience.

There has also been research related to body sensor networks, which employ sensors throughout the body to transmit data to the physical therapist. One application uses these sensors to offer better health monitoring, with possible applications including providing feedback during post-stroke and orthopedic rehabilitation, supervising recovery of heart patients, or alerting patients to emergencies during at home rehabilitation [8]. Another application utilizes accelerometers to measure limb movements and visually display them both in the home and remotely in a medical facility [9]. While body sensor networks can provide feedback for the patient in the home and also transmit data to the therapist, they can be inconvenient due to the number of sensors required, their intrusive nature, or both.

More interactive methods exist as well. One uses shoes with sensors and interactive musical feedback to encourage correct motion [10]; another consists of a tele-rehabilitation system that employs a multimodal sensor network to analyze motion so the therapist can provide instantaneous feedback without the need for the patient to be physically present in the rehabilitation clinic [11]. Furthermore, a system called Thera-Network is designed to assist knee pain patients and their therapists by allowing therapists to monitor the rehabilitation process remotely. This remote monitoring helps to reduce healing time because it motivates the patient to perform his or her rehabilitation using an online buddy network ; it does not, however, emphasize correct performance of the patient's at home exercises without therapist observation [12].

PT Viz was developed as a portable, simple, patient-centered device to improve a patient's home recovery [1]. It is a prototype wearable knee device developed for use during at home physical therapy sessions for knee rehabilitation patients. The primary purpose of the device is to give immediate feedback on the form and extent of movement of the knee extension exercise or knee flexion exercise.

2.2 PT Viz

PT Viz consists of three pieces which can be easily attached around the knee. Two are Neoprene pieces that are lined with polyester on one side and Spandex on the other, which attach to the upper thigh and calf. The other is a bend sensor, composed of Neoprene, Velostat, and conductive thread [13], which connects to the thigh and calf pieces with Velcro. Because there is a linear relationship between the resistance of the bend sensor and the knee angle, the bend sensor can be used to approximate knee angle. Velostat, a carbon-impregnated polyolefin that is commonly used for anti-static storage bags for electrical components, is piezoresistive (pressure sensing) instead of bend sensing; thus, even after extensive usage at greater than 90 degree bends, it gives reliable, consistent readings. It does, however, need to be calibrated before use, but then gives linearly correlated values across physical therapy sessions once calibrated [14]. The thigh piece holds embedded electronics, including a small lithium ion battery, an Arduino Pro Mini microcontroller, several circuit components, and two colors of electroluminescent (EL) wire. The EL wire provides a basic interface for the user that consumes little power, remains at a comfortable temperature, and is flexible. As the knee is flexed, more bars of the EL wire illuminate; when the knee is fully bent, all bars are lit. A blue illuminated circle of wire surrounding the EL bars indicates to the user that the device is powered on. PT Viz is shown in Figure 2.1 (modified from [1]).

Figure 2.1 PT Viz

PT Viz (version 1) underwent a preliminary user study to ascertain the device's perceived necessity and wearability, as well as the effectiveness of the EL bar visualization. There were six participants between the ages of 20 and 37 (two males and four females) from local rehabilitation clinics and the University of Colorado campus community who were currently attending or had attended physical therapy for knee rehabilitation for at least six months. Four had undergone surgery after a knee injury, and two were suffering from chronic knee pain [1]. The study started with a background questionnaire to collect information about demographics, technology use, rehabilitation history, and experiences with physical therapy. It also included a think aloud usability session with PT Viz where the patient was given a set of tasks to complete (e.g., put on the device and perform the knee extension exercise ten times). It ended with a semi-structured interview to understand the patient's overall experience, determine what parts of PT Viz were useful and what could be improved, and explore their thoughts on sharing their data with their therapists [1].

All six participants emphasized the importance of immediate feedback on performing exercises correctly at home. They stated that PT Viz calmed fears of overextending the knee by

increasing awareness of the proper angle at which to bend, as the EL wires provided a visual marker that reduced the cognitive strain of estimating the ideal knee angle that they were shown by their therapist [14]. Both surgery patients and those with chronic conditions reported that PT Viz helped them understand the extent of movement during their exercises. The two chronic patients stated they had difficulties visualizing their progress because of the coarse granularity of the bend sensor, but surgery patients reported that it would help them visualize their progress at home [1]. The study hypothesized that the needs of the two patient types were most likely different because chronic patients were bored with their exercises after long periods of little improvement, while surgery patients recovered much faster and were motivated to regain the mobility they had in the past. The study concluded that PT Viz in its current form is more appropriate for patients who are recovering from a recent knee surgery [1].

As far as wearability is concerned, the patients determined that the device was portable, small, and the use of multiple pieces made it easy and minimally painful to attach. The only wearability issue was in attaching the bend sensor to a Velcro strip, as patients were expecting specific connection points rather than connection areas [1]. Participants emphasized the importance of the portability of PT Viz. With prescriptions that sometimes require three physical therapy sessions a day, it's likely that busy lifestyles will lead to at least one of those sessions being performed at work, school, or 'on the go'. Adoption of the device is a fundamental part of its ability to help users recover faster; since a patient will do physical therapy for months to recover from knee surgery, it must be convenient for the patient to transport [14].

Another part of the usability study involved asking users to evaluate visualizations for an LCD that might accompany PT Viz. Half of the participants agreed that, in addition to the EL visualization, a text-based LCD with the knee angle displayed would be useful, allowing patients

to know how far to bend between EL bars. The other half, however, said that a text-based LCD is not the best way to visualize knee bend [14]. Users also thought an LED that displayed a horizontal line of increasingly lit lights as more repetitions were completed would allow the patient to understand their progress within the session. However, another participant noted that, while a lit repetition bar would be convenient, it is valuable to focus on the therapy during the session, and keeping track of the sets or repetitions is an important part of this focus [14]. This comment agrees with research in promoting physical activity. The researchers concluded that automated data collection relieved users of the need to reflect on their data, but collecting more data also provided better feedback. The likely solution was either having the system proactively show data to the user, or setting regular times to require users to reflect on their data [15]. The semi-structured interview also asked participants to draw their own wearable interfaces. The participants drew displays that included hold time, repetitions, and knee angle, but also incorporated bimodal feedback, including an auditory signal to indicate that the ideal knee angle was reached, and a vibrating timer to help patients measure rest time between sets [14].

Participants also saw PT Viz as a motivational tool. The therapist pushed one patient farther than she thought she could bend her knee in the clinic, and she observed that using PT Viz at home might also drive her to work harder than she thought possible. By setting a goal to get a specific EL bar to light up, the patient could ensure that she was pushing herself during her at home sessions. The EL bars were also considered a motivator across sessions, as getting more bars to light up in successive weeks would be a sign of progress over a longer period of time [14]. While the EL wires proved to be intuitive and successful, an improved user interface has the potential to aid patient progress even more. For example, by adding more bars, smaller amounts of progress can be seen more easily and should improve chronic patients' experiences

[1]; this type of improvement, however, is beyond the scope of this thesis. Participants also requested a method to track sets, repetitions, and hold time to view their progress over time, with surgery patients especially focused on the hold time and repetitions of their current session [1]. Our work concerns creating an intuitive user interface to meet these needs.

An important question is how to create this user interface for knee rehabilitation patients. Participants in the preliminary usability study preferred the EL visualization over a real-time smartphone application, as they were concerned that texts and phone calls would distract them from their therapy; they also expressed concern with having to prop the device up [14]. They agreed that the current EL visualization displays enough information during the exercise session, and it would be less distracting to have it "all in one" device [14].

One positive side effect of storing data from a wearable knee device such as PT Viz is the opportunity to improve patient-therapist communication. The therapist can track exactly how much progress a patient has made over time, which has the potential to promote collaboration and help the patient and therapist work together to achieve the patient's health goals [1]. Concordance, the idea of the patient and health professional sharing decision-making and goal setting, has been proven to lead to better results than enforcing compliance [16]. Concordance is ideal for knee rehabilitation, as the patient can choose how quickly they want to improve without life or death consequences. The data transmitted by the wearable device can assist the therapist in understanding how well the patient is performing exercises at home and adjust the therapy accordingly [1]. The user study revealed, however, that the idea of having stored data from exercise sessions accessible by the physical therapist makes patients uneasy because lapses in activity appear too. Nevertheless, participants believed that knowing the therapist will see any

lapses will hold them accountable to do their exercises and be beneficial in the long run. Some patients even suggested that sharing their data be mandatory [1].

CHAPTER 3

APPROACH

Our interface, PT Viz Mobile, incorporates the data metrics that knee rehabilitation patients requested in [1], namely knee angle, repetitions, sets, and hold time. It also allows patients to see their progress over time, enables patients to share their data with their therapists (if desired), and facilitates setting rehabilitation goals. One necessary step in the creation of an effective interface for PT Viz is performing a user study on a variety of different user interfaces. Using the Rapid Iterative Testing and Evaluation (RITE) method, described below, we tested two paper prototype interfaces on 12 participants in user studies to iteratively create an effective interface. These prototypes are detailed in Section 4.8. After analysis of the data from these user studies, the prototypes were redesigned into one final smartphone application. The last step in the iterative design process consisted of an online follow-up survey with the same participants in order to ensure that the final mocked up interface meets their needs.

Participants in the user study completed a background questionnaire, participated in a prototype design activity, performed a set of tasks on two paper prototypes, and answered questions in a semi-structured interview. Chapter 4 describes each part of the user study in detail.

Our user study utilized paper prototypes to design the interface because one of the most effective, low-cost methods of developing a high-quality user interface in a short period of time is through low-fidelity paper prototyping [17]. A paper prototype takes much less time to develop and modify than a traditional, partially functional prototype; in addition, because the user is not shown a completely stylized interface, he or she is more likely to comment on big picture design issues than cosmetic concerns such as color or font. A paper prototype session

consists of the user completing a set of written tasks, with the facilitator acting as the computer, e.g., changing screens and labels as if they were on a real screen [17].

The RITE method allows facilitators to administer changes as soon as a problem and a valid solution are identified [18]. RITE uses think aloud methods to discover issues, and classifies issues into four different categories: “an obvious cause and an obvious solution that can be implemented quickly”, such as changing the text on a button, “an obvious cause and an obvious solution that cannot be implemented quickly or within the timeframe of the current test”, such as difficult new features or current features that require substantial design changes, “no obvious cause and therefore no obvious solution”, and “other factors”, such as test script problems. Depending on the type of issue found, changes can be implemented accordingly (if possible). Before the study begins, it is important that facilitators agree on a minimum set of functions that the user must be able to perform. Facilitators must be able to make changes rapidly, and the final iteration must also be tested on enough users to ensure that no new usability issues arise [18].

By using paper prototyping and the RITE method, we developed a new interface from a detailed user study with 12 participants. Because we used paper prototypes, solutions that would be difficult to implement on a high-fidelity prototype were relatively easy to implement. We created two paper interfaces and tested them on participants, and we made a few easy modifications between participants. After one to four participants, we analyzed the data, identified common problems, and fixed them before the next set of users. After several iterations, we are reasonably confident that we created an effective user interface.

At the conclusion of the user studies, the video recordings were transcribed and analyzed. See Section 4.7 for a full description of analysis techniques used. We incorporated participant feedback from the user studies and designed a final prototype. The final prototype design is in Section 6.1.

Before developing the final prototype into a fully functional application, we wanted to ensure that the prototype includes useful, intuitive features. We, therefore, distributed an online survey to our 12 user study participants via email, personalizing each invitation link in order to correlate survey responses to data collected in the user studies. Participants who completed the survey were entered into a raffle to win a $15 gift card. Details and results are in Section 6.2, and the full survey is in Appendix D.

CHAPTER 4

METHODS

PT Viz Mobile needs to provide users with information they care about in an intuitive manner. In order to determine what users desire in an accompanying interface, we conducted a user study consisting of a background questionnaire, a paper prototyping design session, a usability session with two separate paper prototypes, and a semi-structured interview. Each session lasted approximately 60-75 minutes, and was video recorded with participants' consent. The study was conducted with 12 participants, and each participant was compensated with a $15 gift card. The study was approved by the University of Colorado's Institutional Research Board.

4.1 Background Questionnaire

Participants first completed a background questionnaire that collected basic demographic information, technology usage, and knee injury history. The questionnaire, shown in Appendix A, focused on discovering the participant's general physical therapy experiences and any difficulties that the participant might have had during their post-surgery rehabilitation.

4.2 Paper Prototype Design Session

We then showed the participants the PT Viz prototype, explaining that the participant could use it at home or in the clinic while doing their exercises, as well as download the session to an interface afterwards. They were shown how the EL wire bars light up as the knee is bent for instant feedback, and how the bend sensor could be used to approximate knee flexion (knee bent) or extension (knee straightened) angle. The participants were also shown that PT Viz could track the number of repetitions and sets they performed and how long they held a certain flexion or

extension angle. We also clarified that PT Viz is not a real-time application, but that they would be able to visualize their data after the session was complete.

The participants were then asked to list metrics that they would be interested in tracking throughout their therapy. We asked each participant why a metric was useful, and which ones they considered most useful. We then requested that the participant incorporate these metrics into a rough sketch of an interface that would be useful in visualizing his or her progress. We then explored why certain pieces of information were included or excluded from the drawing, and why he or she laid out the interface as drawn. We also asked the participant which platform he or she preferred for looking at the aggregate data (smartphone app, tablet app, or website).

4.3 Paper Prototype Usability Study

After the paper prototype design session, we asked each participant to complete a usability session using the think aloud protocol with a task list and two paper prototypes. The prototypes are in Section 4.8, and the task list is in Appendix C. After a participant completed the set of tasks, we asked various questions to determine which parts of the prototypes the participant found confusing or intuitive, what information was extraneous, and what data he or she thought was missing. We asked each participant for suggestions to improve the interface, and asked if the interface would be helpful in motivating the participant to set and meet their exercise goals. We repeated this task with two different sets of paper prototypes. We then requested that the participant compare the two sets of interfaces to determine which aspects of each one were more intuitive and useful, and asked for more feedback to improve the prototypes. We note that participants often offered this comparison information while answering general questions about the second interface. Our final question asked the participants if they wanted to make modifications to their previously drawn paper prototypes.

4.4 Semi-Structured Interview

The last stage of the usability session asked participants a variety of questions, shown in Appendix B, in a semi-structured interview format to determine how PT Viz Mobile might assist them in their rehabilitation. We explored how setting and meeting goals as well as seeing progress affected motivation during the rehabilitation process. We inquired how willing participants were to share their at home physical therapy session data with their therapists, and what their therapists might use that data for. We tried to determine how useful participants considered a system like PT Viz and PT Viz Mobile, and asked when they would use the interface. Finally, to direct future research, we queried whether a real-time smartphone application would be beneficial to view their desired metrics during an at home physical therapy session.

4.5 Participants

We restricted the study to participants over the age of 18 who were currently attending or had attended physical therapy for knee rehabilitation after surgery in the last two years. Users for this study were recruited from the Colorado School of Mines (CSM) campus by distribution of flyers on bulletin boards in academic buildings, the student center, and the varsity athletic gym and training room. CSM athletic trainers also encouraged students they knew who fit the criteria, and an email was sent to all current varsity athletes. We also utilized snowball recruiting by asking participants to talk to others who fit the criteria.

We recruited 12 participants, 7 females and 5 males, of ages 18-24 years. Eleven were full time students at the CSM, and the other was a full-time engineer who recently graduated from CSM. Every participant carried a mobile phone with them at all times, 11 owned a smartphone (7 iPhones, 2 Androids, 2 others), and all felt comfortable using their phones to do

typical day-to-day tasks. Only four participants owned tablet computers, and only carried them some of the time. Most participants used the internet on both a computer and mobile device multiple times per day.

Ten participants underwent anterior cruciate ligament (ACL) reconstruction. Of those 10, four needed surgery that also involved meniscus reconstruction; of those four, two medial collateral ligaments (MCL) were repaired. For the other two participants, one underwent surgery for a torn meniscus and the other underwent surgery for cartilage damage and full lateral release of the patella. Five participants had undergone surgery from more than one knee injury, and the length of time spent in rehabilitation for any given surgery ranged from 1 month to 11 months, with most expected recovery time in the range of 6-11 months. Seven of the 12 participants were current NCAA Division II varsity athletes from six different sports, and three of the remaining five had previously been varsity athletes at CSM. Eleven of the 12 participants saw their therapists multiple times a week, typically for 1-1.5 hours. Prescribed exercise for at home sessions was typically 30-60 minutes 5-7 days per week, but ranged from 15 minutes 3 days per week to 2 hours every day.

4.6 Study Flow

The study lasted approximately two months, from the end of September 2013 to the end of November 2013. In accordance with RITE methodology, which suggests making modifications between user studies to increase the likelihood of finding more problems [18], changes were made to both sets of paper prototypes as issues and potential solutions were uncovered. Modifications were made after about every 3-4 sessions, but if serious issues were found or solutions to previously known problems were discovered, changes were made sooner. These changes are described in Section 4.8.

4.7 Analysis

Basic statistical analysis was performed on the quantitative data from the background questionnaires. The video recording from each session was transcribed, and responses and interactions were coded into a variety of different categories to find patterns in participant responses. Most codes were determined deductively; a code was created for each question asked in the semi-structured interview, and for each screen in both paper prototypes. Further codes were created to specify participant perspective (positive or negative). A few codes were generated using the grounded theory approach, in which codes are developed as concepts become apparent in the data [19]. Additionally, participant drawings were coded using the grounded theory approach. A variety of qualitative techniques were used to analyze the data once coded. We analyzed participant preferences for each question asked and each prototype screen. We also discovered relationships between the codes, related participant preferences to demographic differences, and developed theories about any patterns that emerged.

4.8 Prototypes

Two separate paper prototypes were created to determine user preferences towards different methods of displaying data. The initial version of each prototype allowed users to upload their exercise session data to the interface, send their data to a therapist, and view progress and set goals for five metrics: sets, repetitions (reps), angle, hold time, and duration.

4.8.1 Initial Prototypes

Initially Prototype A had three screens. The progress screen displays the user's progress over the last six days as a set of bar graphs that can be shown or hidden (see Figure 4.1). The progress screen allows users to group together all metrics from each session, but also easily hide information they do not need. The flexion angle and extension angle for a particular session is

shown in the progress screen with a green angle visualization in an attempt to help users better visualize their range of motion. The screen also displays the user's next two goals to show progress towards these goals.

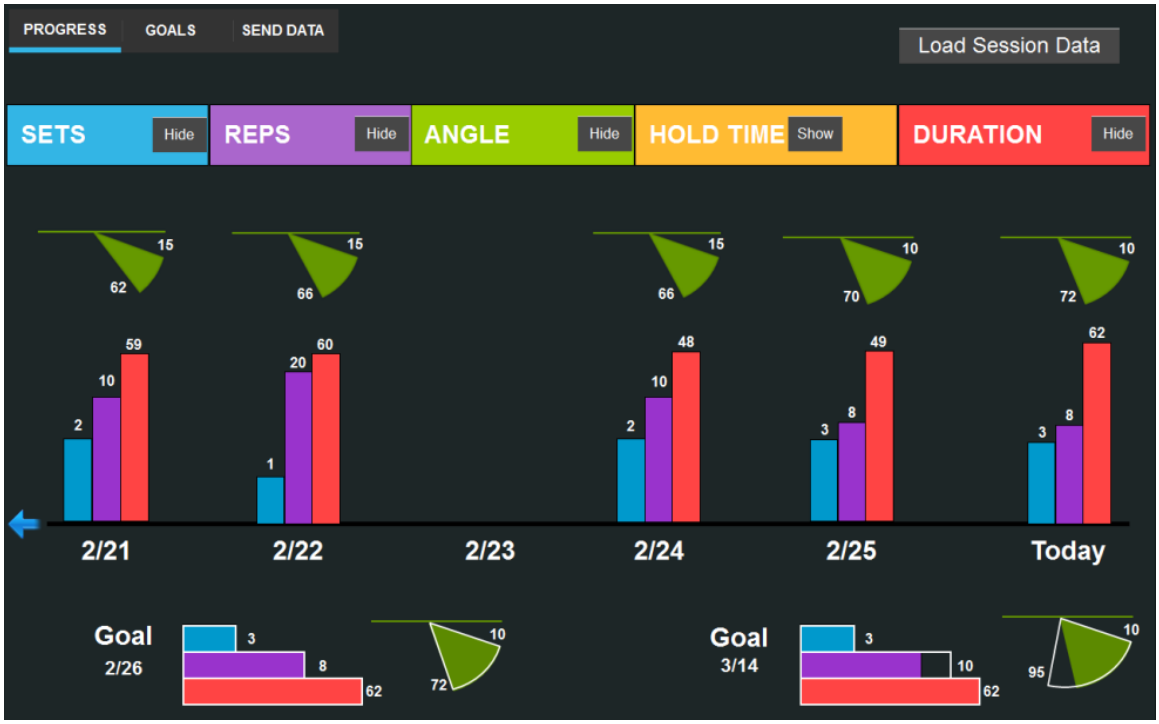

Figure 4.1 Prototype A Initial Progress Screen

The goals screen allows users to set and view goals in a table format. Each goal is a grouping of metrics; in other words, it is possible to set a goal that involves several different metrics. For example, users might want to set a goal to achieve a flexion angle for a specified number of sets and repetitions by some date, and our initial interface for Prototype A interface allowed users to do so. Figure 4.2 shows how a user would set or edit a goal in Prototype A.

The table on the goals screen chronologically lists each goal (see Figure 4.3). For each goal that is past, the goals screen shows either a check mark or X to provide the user instant feedback as to whether or not the goal was met. The goals screen also shows the value the user achieved for each metric, allowing the user to tell by how much they met or missed each goal.

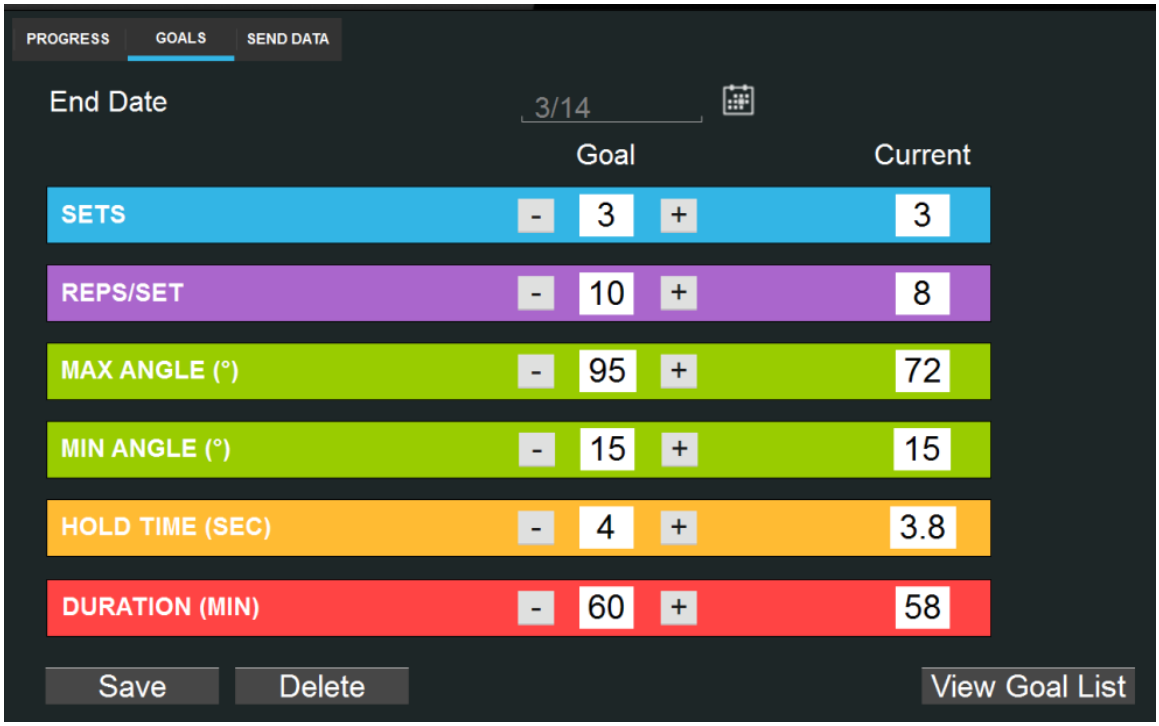

Figure 4.2 Prototype A Initial Edit Goal Screen

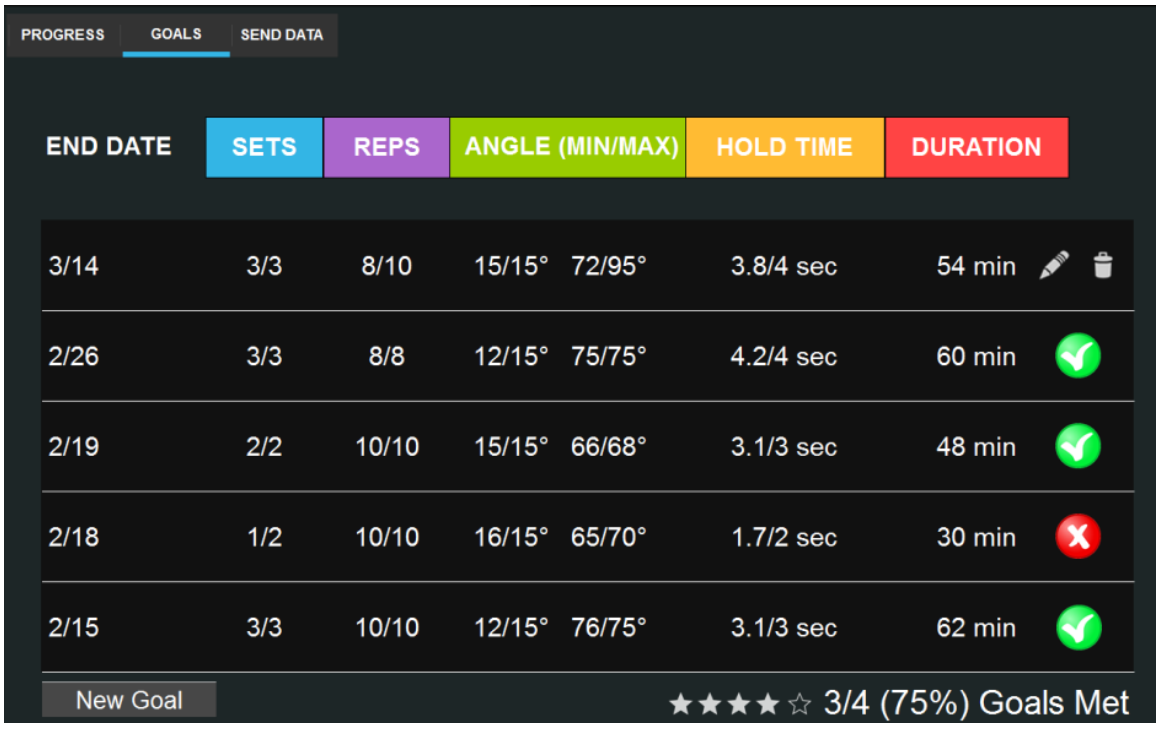

Figure 4.3 Prototype A Initial Goals Screen

For each goal with a future end date, the user's current progress towards that goal is shown; additionally, the user has the ability to edit or delete the goal. The goals screen in Prototype A also displays a percentage of goals met to provide users an overall picture of how well they are meeting their rehabilitation goals.

The send data screen allows users to select specific days of exercise sessions to send to a therapist. In order to test if users prefer selectively sending specific dates, we provide checkboxes in Prototype A to allow users to pick and choose which days to send. The send data screen also displays detailed information on what metrics would be sent for each day, as well as the goal for each metric (e.g., 66 degrees of flexion achieved for a goal of 68 degrees). The send data screen is in Figure 4.4.

Figure 4.4 Prototype A Initial Send Data Screen

Prototype B also initially had three screens. The progress screen offers users the ability to select a date range over which they can view their progress, rather than the fixed range approach

of Prototype A. The progress screen also provides a series of line graphs that can be expanded or collapsed via drop down arrows, which contrast Prototype A's bar graphs. For each metric, the "last" measured value is displayed in order to provide users a current snapshot of their progress; an average over the selected interval gives the user a picture of how consistent they were over this time frame. The progress screen also shows goals over the current selected interval in order to allow users to see how well they met their goals during that time frame. Future goals are also displayed to show progress towards upcoming goals. Additionally, the progress screen serves as the interface for users to send their session data to a therapist, as we wanted to test whether or not users preferred having a separate screen to send data. We also wanted to gauge users' preferences regarding selective sending of their data, as this progress screen only allows users to send all sessions in a selected interval. The progress screen is in Figure 4.5.

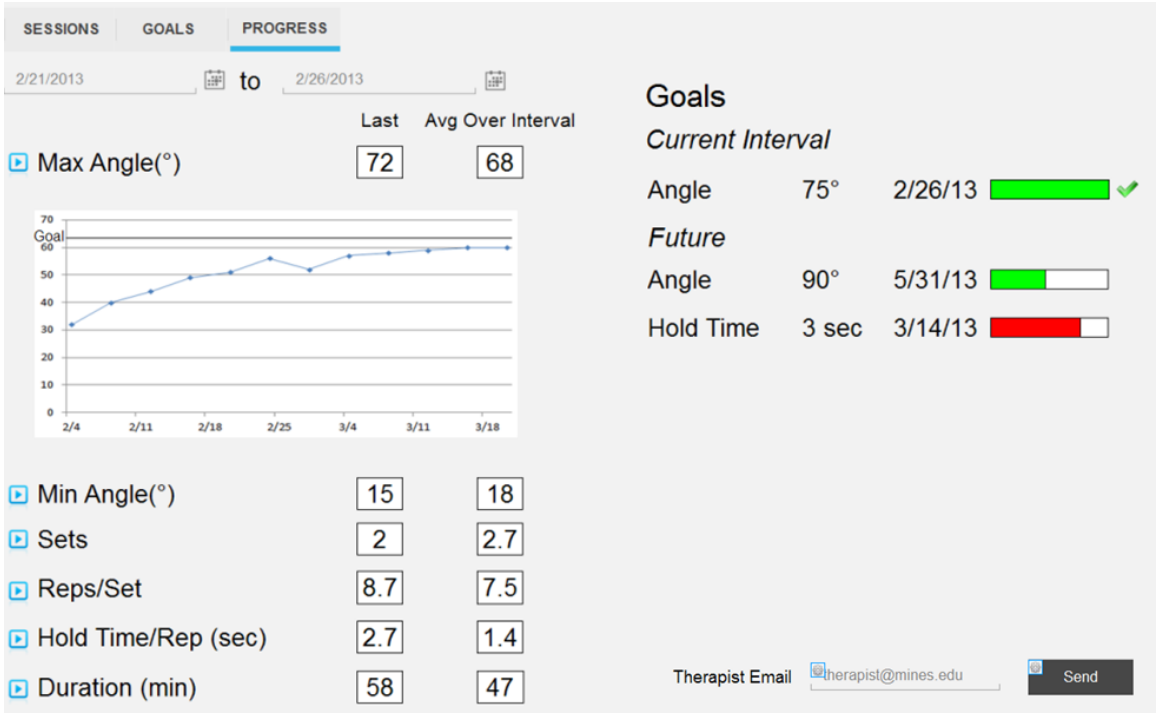

Figure 4.5 Prototype B Initial Progress Screen

In contrast to Prototype A, the goals screen in Prototype B only allows users to set a goal for one metric at a time. The goals table in Prototype B is sorted by metric, or type, with only the most recent goal for each type showing (unless the drop down arrow is clicked to expand past goals). There is also a progress bar for each goal which is colored red, yellow, or green depending on the end date for that goal and how close the user is to achieving the given goal. The end date for the goal is also shown, and users have the ability to edit, delete, or add notes to a goal. Similar to Prototype A, a check mark or X quickly shows the user if they met or failed to meet a goal. The goals screen allows users to set goals without having to go to a different screen; the screen also allows users to view their past goals while setting a new goal. Because the goals are not listed chronologically, a timeline is provided to allow users to see a snapshot of how they are doing over a period of time, with pop ups that detail each goal (if the user wants more information). The goals screen is in Figure 4.6.

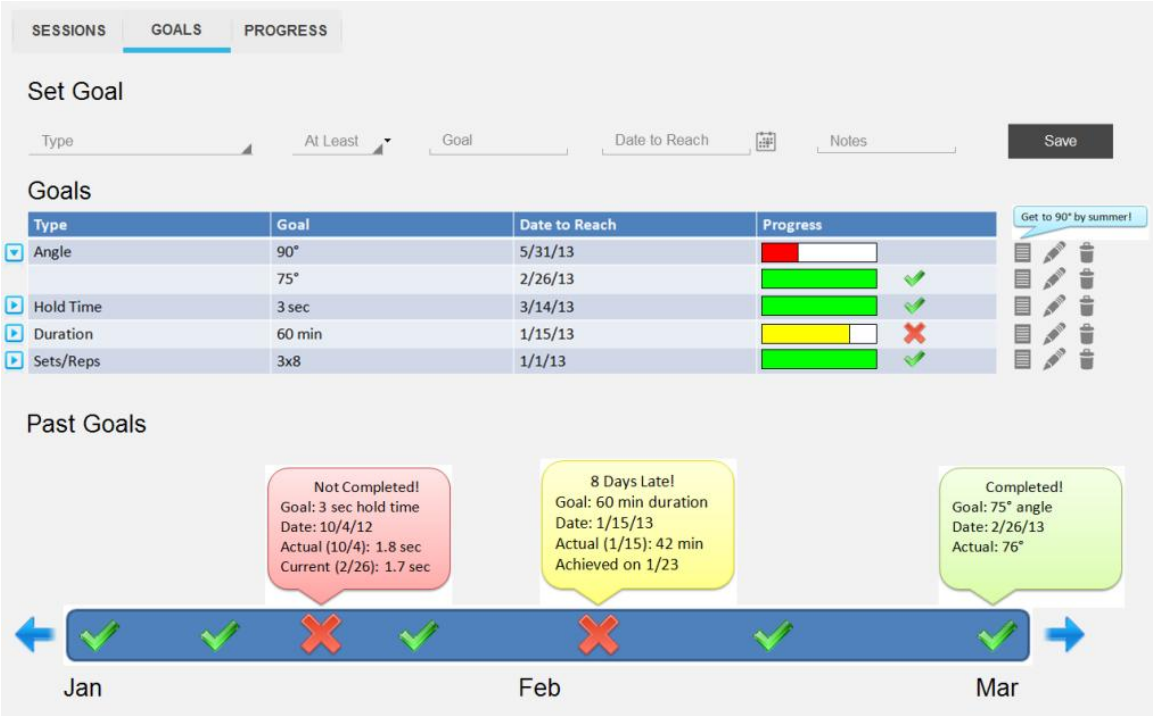

Figure 4.6 Prototype B Initial Goals Screen

To determine whether or not users find being able to look at a specific exercise session in detail useful, Prototype B includes a sessions screen that Prototype A does not have. This sessions screen is in Figure 4.7. Users can view metrics for a given session via a drop down menu that selects the date. The sessions screen also provides a graph where the user can visually see each repetition in a session. The purpose of this graph is to determine whether users want to see extremely detailed session information, or if users just want to view summary metrics.

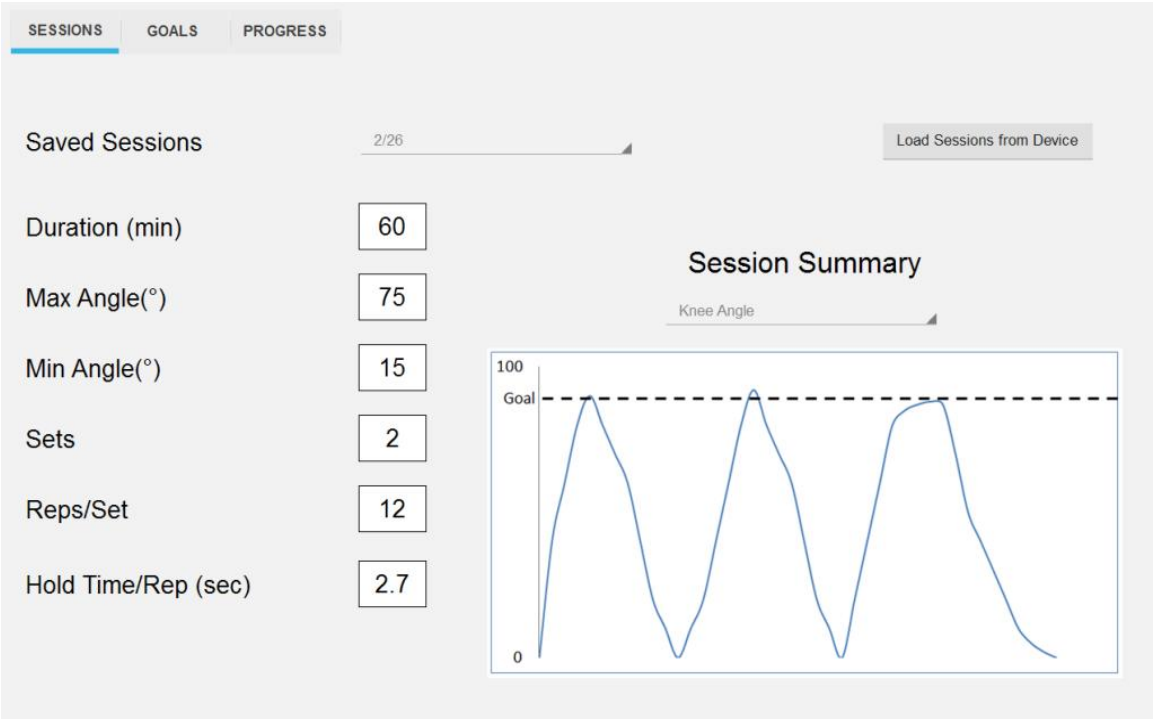

Figure 4.7 Prototype B Initial Sessions Screen

4.8.2 Prototypes After Three Participants

In accordance with the RITE methodology, changes were made to the paper prototypes before all participants completed the user study. These changes, based on participants' feedback, improved the paper prototypes so that we could receive more useful feedback from future participants. We note that in some cases, minor modifications were also made to the task list, which is found in Appendix C, to reflect changes made to the paper prototypes. After three

participants completed the user study, we determined a few problems and their potential solutions, and we made changes as we saw necessary. Table 4.1 shows modifications that were made to Prototype A after the first three participants completed the user study. Table 4.2 shows modifications that were made to Prototype B after three participants completed the user study.

Table 4.1 Prototype A Changes After Three Participants

Changes	**Screen(s)**	**Motivation**
"Min angle" reworded to "extension angle". "Max angle" reworded to "flexion angle".	All	Participants referred to range of motion measurements as flexion and extension, not max and min. Participants indicated that flexion angle and extension angle would make more sense than max angle and min angle.
Added functionality to disable metric(s) when setting and displaying a goal.	Goals, Edit Goal	Participants were told to complete a task that sets a goal for 3 sets of 10 repetitions of a knee extension exercise, with a flexion angle of at least 80 degrees. The edit goal screen allowed users to set goals for these metrics, but also forced them to set goal values for extension angle, hold time, and duration. The disable button added to the edit goal screen allows users to set a goal with only desired metrics.
Changed the label for the "Current" column to read "Today".	Edit Goal	Though participants mostly understood what the "Current" column meant, it took participants extra time to discern its significance, distracting them from their primary task of setting or editing a goal. The "Current" label seemed to cause participants the most confusion, so we changed it to "Today" in an attempt to relieve the cognitive burden on the user.

Table 4.2 Prototype B Changes After Three Participants

Changes	**Screen(s)**	**Motivation**
"Min angle" reworded to "extension angle". "Max angle" reworded to	All	See motivation for this change in Table 4.1.

Changes	Screen(s)	Motivation
"flexion angle"		
Error in flexion graph was remedied.	Progress	Due to a last minute change, the flexion graph showed the wrong date range. The drop down arrow also indicated that the graph should have been collapsed, rather than expanded. These errors caused some confusion for participants.
Added an extension angle goal to the goals list to be consistent with the goals screen.	Progress	This error did not cause confusion for participants, but was not consistent with other screens in the prototype.
Changed "Last" and "Avg Over Interval" columns to the start and end date in the selected interval (e.g., 2/21 and 2/26).	Progress	Participants were confused by what "Last" meant. They also expressed interest in having values for the start and end dates in the selected range, in order to compare the two. P3 said, "You're getting from there to there. And then, I don't know if you necessarily want your average, because I don't know what that would help you with. You don't really need your average of those, you kind of want your progress. If you have anything, I'd probably just have the difference of the two, see how many degrees you have increased from that date to that date."
Removed the "At Least"/"At Most" drop down menu. Changed Angle type to "Flexion Angle" and "Extension Angle" and added rows in table for these new types.	Goals	Participants missed this drop down menu, or took some time to figure out its purpose. The motivation for this menu was to allow users to specify that they wanted to be under a value (e.g., spend less than 45 minutes or have an extension angle of less than 5 degrees), but it caused confusion. Allowing users to select "Flexion Angle" and "Extension Angle" as a goal type, instead of "Angle" with "at least" or "at most", should relieve this confusion.
Changed the "Knee Angle" drop down menu above the graph to a label for just "Knee Angle".	Sessions	The purpose of this drop down menu was to allow users to choose a graph for a different metric, but P3 noted that it would not be useful to show a graph for any metric other than knee angle.
Moved the duration value from	Sessions	Participants emphasized that flexion and

Changes	Screen(s)	Motivation
the top of the screen to the bottom of the screen.		extension angle were the most important metrics, and duration was less important.

4.8.3 Prototypes After Seven Participants

Initial changes were made to the prototypes after three user studies. We then interviewed four additional participants to determine any new issues. We found further problems and their potential solutions, and made changes accordingly.

Most modifications in this revision stem from adding the concept of an exercise to the prototypes. Four of the seven participants interviewed before this change expressed confusion concerning the sets and reps metrics shown in the prototypes. Because knee surgery rehabilitation patients perform a variety of exercises, the participants were unsure of which exercise the sets and reps displayed were associated with. P3 stated that he thought the data showed sets and reps for the heel slide exercise, which would not need a hold time because it primarily focuses on increasing flexion angle. Other participants said that while hold time is not useful for exercises that improve flexion angle, it is useful for any exercise that focused on improving extension angle, as patients are frequently asked to hold an extension angle for a specified amount of time. Allowing users to specify which exercise they are performing allows them the flexibility to set goals specific to the exercise.

Table 4.3 shows modifications that were made to Prototype A after seven participants completed the user study. The progress screen and goals screen underwent major changes, and are in Figure 4.8 and Figure 4.9, respectively.

Table 4.3 Prototype A Changes After Seven Participants

Changes	Screen(s)	Motivation
Added a home screen (see Figure 4.10).	Home	Both P5 and P7 expressed strong interest in a home or welcome screen. We added a home screen as a place to upload session data and provide a snapshot of the most recent and relevant data for a user. More motivation for this addition is in Section 5.12.
Added a sessions screen (see Figure 4.11).	Sessions	After introducing the concept of an exercise, we wanted to provide patients with more detailed information about each session and the exercises completed. In Prototype A, the most logical place to include this information was by adding a sessions screen.
Reorganized bar graphs into column data, listing the day's best flexion and extension angles, duration, and sets, reps, and hold time for each exercise performed.	Progress	The addition of exercises to the prototype led to major changes on the progress screen. Since sets, reps, and hold time needed to be attached to an exercise, the only metrics that applied to an entire session were flexion angle, extension angle, and duration. This change removed the need for bar graphs, as flexion and extension angles were represented in the angle visualization, and each session was separated into its constituent exercises, with reps, sets, and hold time displayed for each exercise.
Added degree symbol (°) for any angle measurement shown on the screen. Changed "Today" label to "2/26".	Progress	Participants who said they had a hard time finding flexion and extension angles suggested adding a degree symbol for angle measurements to more quickly identify them as angles. The "Today" label was changed to be more consistent with Prototype B.
Removed one future goal to show only the next goal. Added average flexion, extension, and duration values in its place.	Progress	A few participants said it would be useful to see averages over the range of dates shown. Participants also said that they only needed to see their next goal, not their next two goals, so it made sense to substitute averages in place of one of their next two goals.
Changed "View Goal List" button to "Back".	Edit Goal	The "Goal List" referenced by the button is more of a table than a list in this prototype iteration. "Back" tells users that they will go

Changes	Screen(s)	Motivation
		back to the previously seen goals screen, and better communicates the purpose of the button.
Added exercise row with a drop down menu to select exercise. Indented sets, reps, and hold time.	Edit Goal	See previously discussed motivation for adding exercises. Indenting sets, reps, and hold time communicates that sets, reps, and hold time apply to that exercise.
Moved "New Goal" button to top of the screen. Moved "% Goals Met" to top of the screen.	Goals	A few participants had minor difficulties finding the "New Goal" button. Moving it to the top of the screen should allow users to find it more quickly. We relocated "% Goals Met" to the top of the screen as well to conserve screen space.
Added exercise column and changed separate sets and reps columns to a single Sets x Reps column.	Goals	See previously discussed motivation for adding exercises.
Changed Angle label from "Angle (Ext/Flex)" to two columns reading "Ext" and "Flex".	Goals	A few participants commented that it was difficult to distinguish extension and flexion in the goals table. A few participants were also confused as to why there were four numbers in the "Angle" column instead of two numbers. Adding separate columns for flexion and extension angles should allow users to better distinguish the two.
Added dashes to any columns with future date goals.	Goals	Participants seemed to have trouble distinguishing past goals from future goals. Dashes show participants that they do not have data for whether or not they achieved a future goal, which should help them quickly determine that they are viewing a future goal.
Added an exercise column and drop down arrows to expand/collapse exercises for each day.	Send	See previously discussed motivation for adding exercises.
Changed "Send Data" to "Send".	All	Adding two more screens to Prototype A created more tabs, and results from the user study thus far indicated that users would likely want a smartphone interface. We changed the title of this tab to something more concise to

Changes	Screen(s)	Motivation
		assess if the remaining participants still understood the purpose of the tab. A more concise tab name would also be beneficial for a smaller screen.

Figure 4.8 Prototype A Progress Screen After Seven Participants

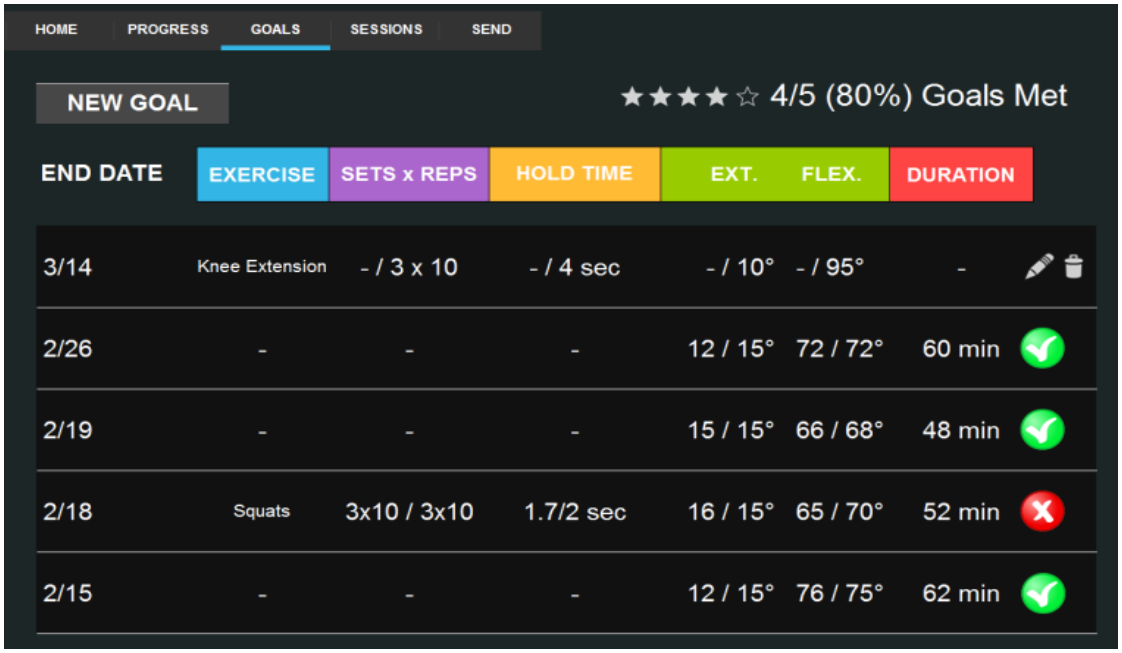

Figure 4.9 Prototype A Goals Screen After Seven Participants

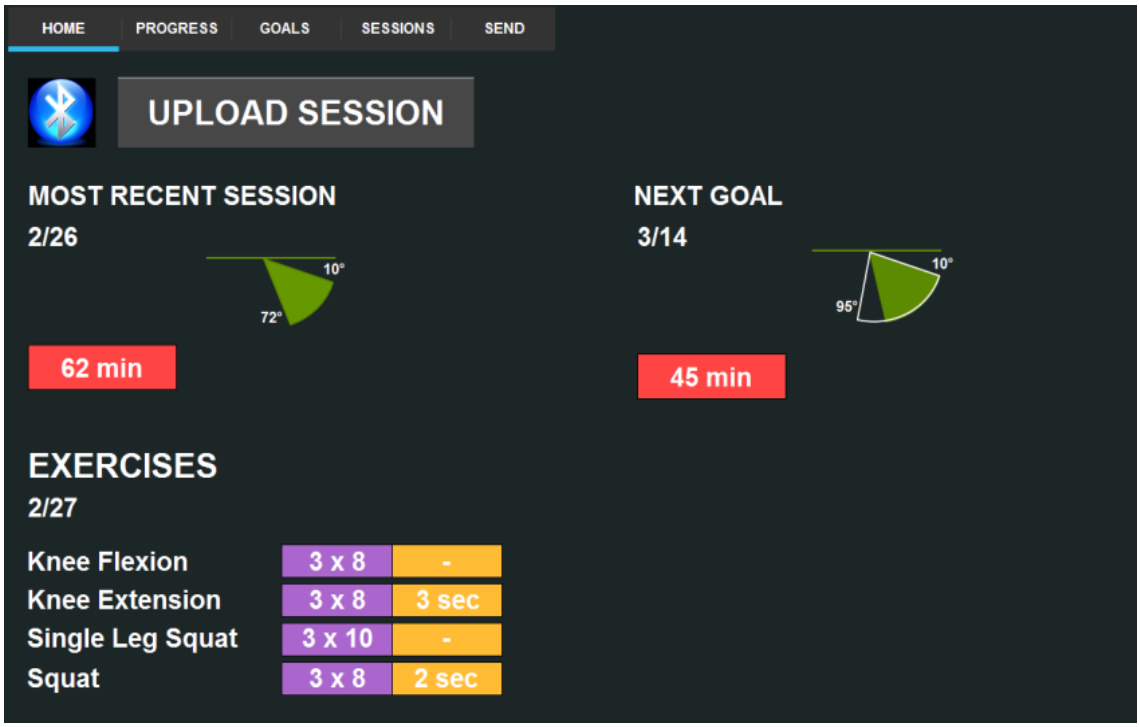

Figure 4.10 Prototype A Home Screen After Seven Participants

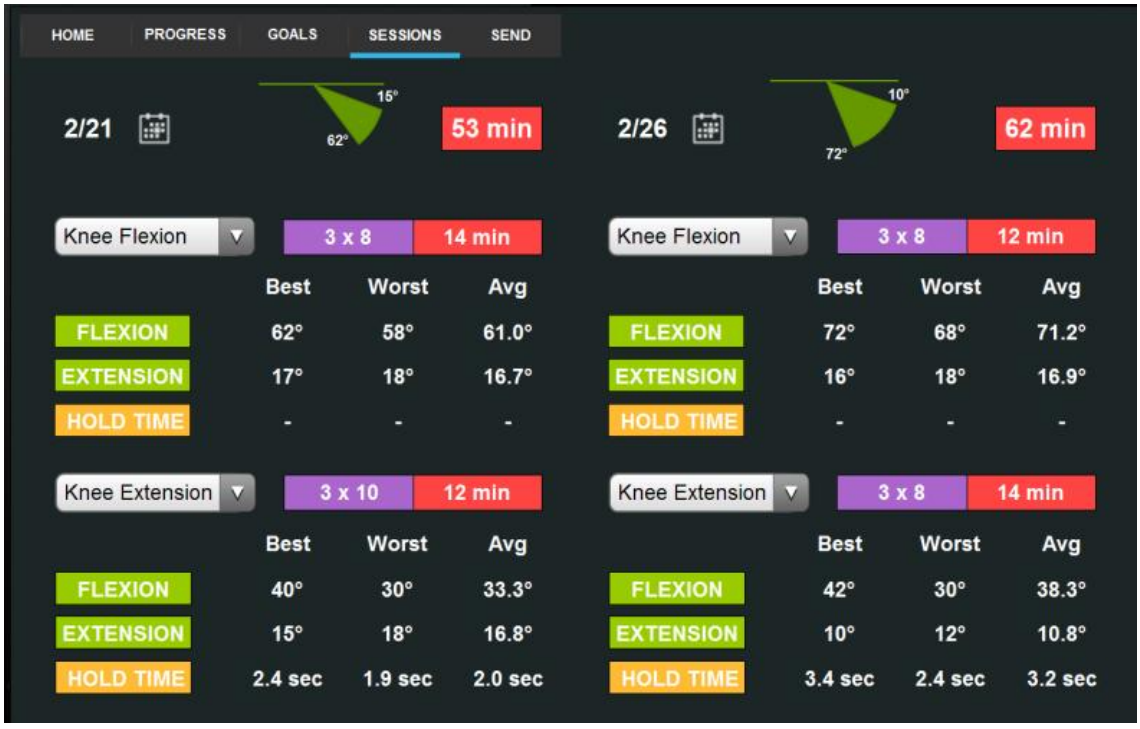

Figure 4.11 Prototype A Sessions Screen After Seven Participants

Table 4.4 shows modifications that were made to Prototype B after seven interviews were completed. The sessions screen and the goals screen underwent major changes, and are in Figure 4.12 and Figure 4.13, respectively.

Table 4.4 Prototype B Changes after Seven Participants

Changes	**Screen(s)**	**Motivation**
Added a home screen (see Figure 4.14).	Home	See motivation for adding a home screen in Table 4.3.
Added best and worst value columns for flexion and extension angles.	Sessions	Participants expressed interest in seeing both the best and worst values for flexion and extension in a single session. They cited that their worst values usually occurred at the beginning of the session, and it was helpful to know the angles at the start of a session to see how they improved within the session. They also indicated that they wanted to know the best angle for a session to gauge their progress from session to session.
Added calendar icon to select date instead of drop down menu.	Sessions	Because both the progress screen and sessions screens select dates, using a calendar icon to select a date instead of a regular drop down menu makes the sessions screen more consistent with the progress screen.
Modified screen to show only one exercise at a time. Added arrows on sides of screen to scroll between exercises.	Sessions	See previously discussed motivation for adding exercises.
Added labels (time and degrees) to axes on the graph. Added dotted extension angle goal line on the graph.	Sessions	Participants that experienced confusion with the graph suggested adding labels to the axes to clarify the graph's meaning. Additionally, participants said it would be helpful to have goal lines for both flexion and extension, so they could see if they were consistently reaching their goals on each repetition.
Removed sets, reps, and hold time graphs.	Progress	Sets, reps, and hold time are associated with an exercise. Thus, graphs across sessions only make sense for flexion angle, extension angle, and duration.

Changes	Screen(s)	Motivation
Added average (over selected interval) value box.	Progress	A few participants said it would be useful to see averages over the range of dates shown.
Moved future goals above current interval goals.	Progress	Participants indicated that it was more important to see their future goals than their past goals.
Made columns in table sortable. Removed drop down arrows to expand/collapse goals.	Goals	A few participants requested that the columns in the goals table be sortable, as this would allow them the flexibility to view goals by either type or date. Sortable columns would enable the user to view their upcoming goals or all goals for one metric (e.g., flexion angle). Allowing users to hide less relevant goals was the primary purpose of the drop down arrows. Sorting by date achieves this purpose, as it allows the user to view only the most current goals.
Removed pop ups above the timeline. Removed bubble that shows notes.	Goals	Participants commented that they were confused or distracted by the pop ups above the timeline. Participants had similar comments about the bubble that showed the note for a goal. Both items were, therefore, removed.
Made the “Type” drop down menu look more like a typical drop down menu.	Goals	One participant noted confusion with appearance of the “Type” drop down menu.
Allowed users to set a goal for an exercise. Added exercise column to goals table.	Goals	See previously discussed motivation for adding exercises.

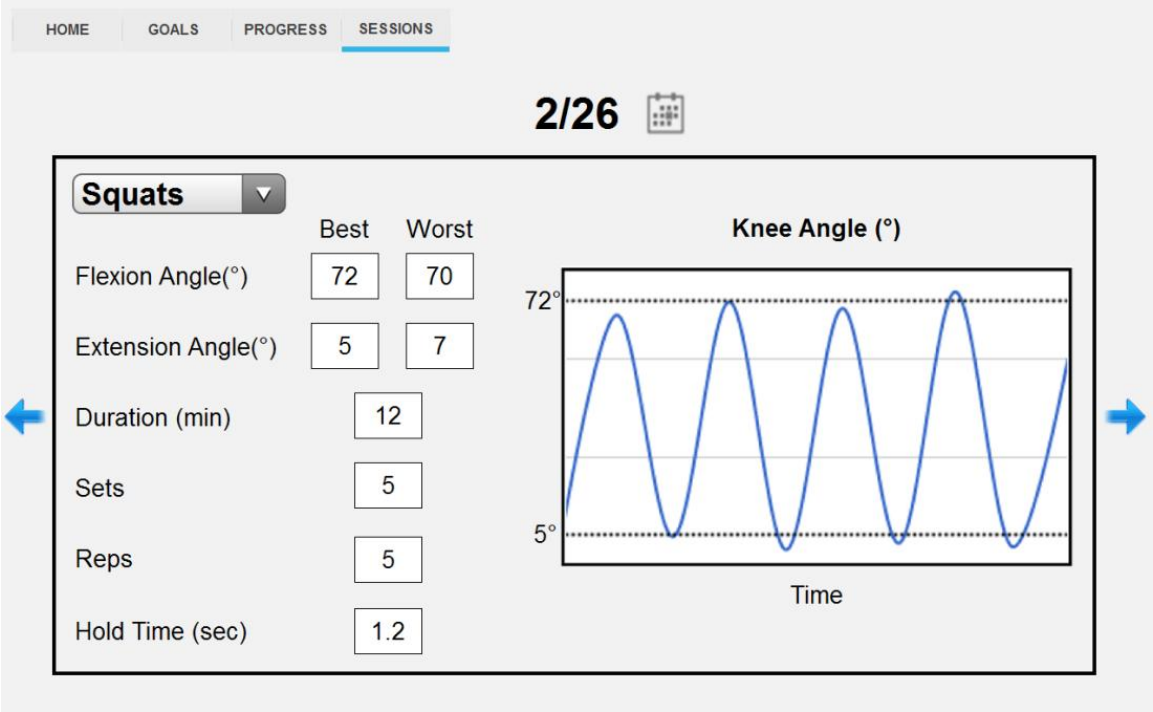

Figure 4.12 Prototype B Sessions Screen After Seven Participants

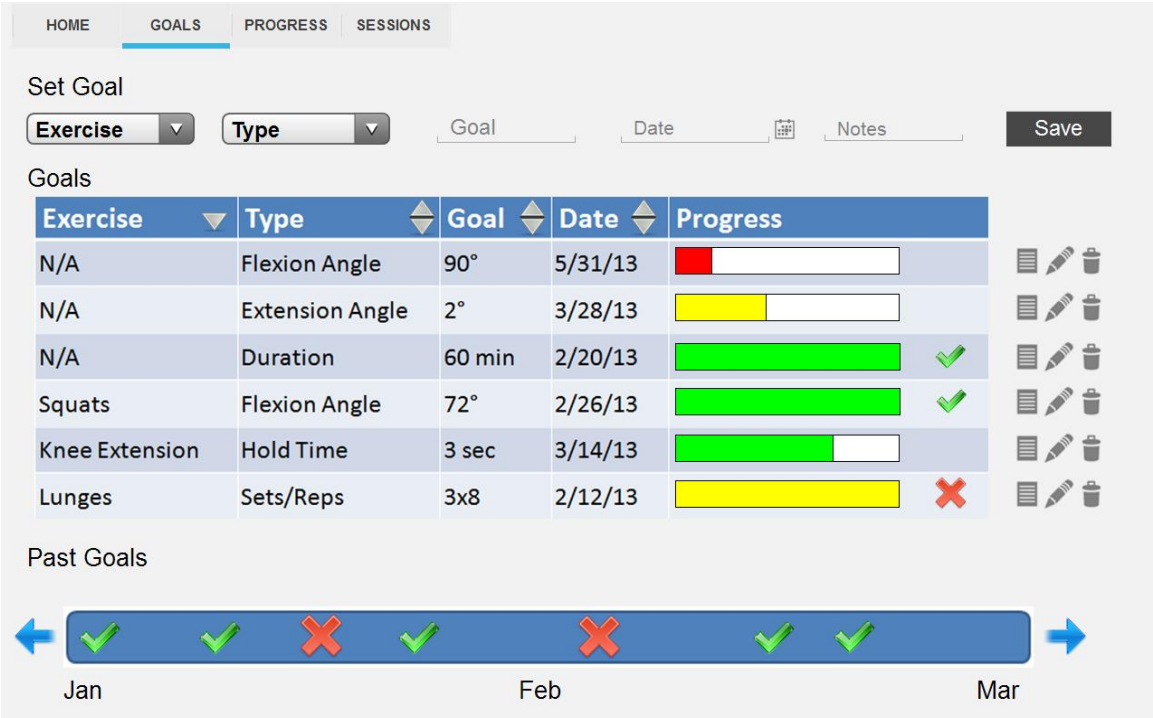

Figure 4.13 Prototype B Goals Screen After Seven Participants

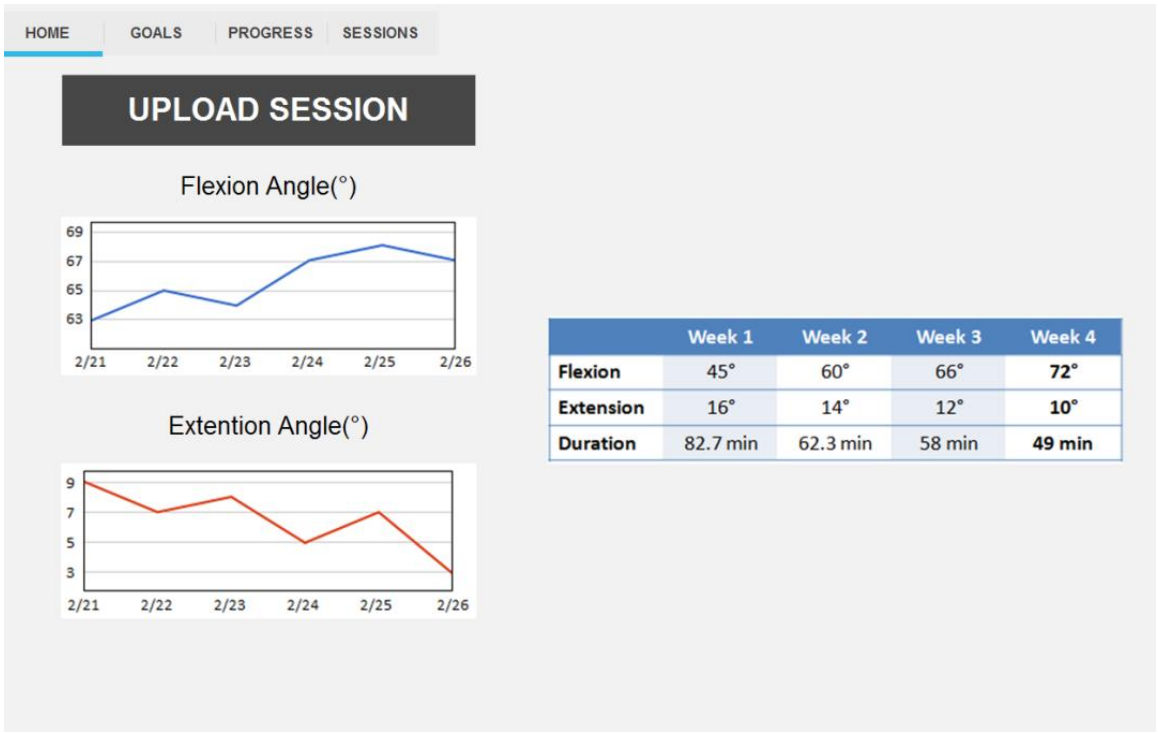

Figure 4.14 Prototype B Home Screen After Seven Participants

4.8.4 Prototypes After Nine Participants

After previous changes were made, mainly to introduce the concept of exercises, we interviewed two more participants. We iterated again, addressing problems with any obvious solutions. While we previously interviewed three or four participants before making changes, we saw a few obvious problems with simple solutions at this point; thus, we made changes after the ninth participant in order to receive as much feedback as possible on these changes. Modifications to Prototype A are detailed in Table 4.5, and modifications to Prototype B are detailed in Table 4.6.

Table 4.5 Prototype A Changes After Nine Participants

Changes	Screen(s)	Motivation
Reworded “Knee Flexion” to “Heel Slides” and “Knee	All	Participants noted confusion with the exercise names chosen for these sample exercises. They

Changes	Screen(s)	Motivation
Extension” to “Leg Raises”.		did not consider “Knee Flexion” and “Knee Extension” exercise names.
Added labels for sets, reps, and duration.	Sessions	While participants understood which metrics the displayed values were associated with, they stated that adding labels would help them understand the screen more quickly.
Added labels for angle, duration, sets, reps, and hold time. Added labels on the “Next Goal” section to identify current flexion and extension angles as well as the goal angles.	Progress, Home	See previously discussed motivation for adding labels to the sessions screen. Participants also commented that labels on the partially filled angle visualization, which shows them how close they are to achieving their next goal, would be more useful.

Table 4.6 Prototype B Changes After Nine Participants

Changes	Screen(s)	Motivation
Moved arrows from the sides of the screen to next to the date (for scrolling between session dates). Added part of the next exercise below the first exercise in order to show that scrolling down shows more exercises.	Sessions	Participants tried to use the arrows to scroll between session dates instead of between exercises as intended. We modified the screen to indicate that vertical scrolling shows more exercises, which is more intuitive for participants.

4.8.5 Prototypes After Ten Participants

We completed a final round of modifications before receiving feedback from the final two participants. P10 uncovered a few new problems, and offered new suggestions to address previously found but unresolved problems. We, therefore, modified the prototypes in order to receive feedback on these changes. Modifications to Prototype A are detailed in Table 4.7, and modifications to Prototype B are detailed in Table 4.8.

Table 4.7 Prototype A Changes After Ten Participants

Changes	Screen(s)	Motivation
Added labels to an angle visualization to indicate that the top number is extension angle and the bottom number is flexion angle. See Figure 4.15.	Progress	Participants who experienced confusion related to the angle visualization reported that these labels would increase their understanding of the angle visualization.
Removed duration from the "Next Goal".	Home	P10 was confused by the duration goal. She said she would not set a goal for her exercise session to exceed a certain duration.
Added best, worst, and average flexion and extension values for each session (in addition to already existing values for each exercise).	Sessions	Participants expressed interest in seeing best, worst, and average values for flexion and extension in a single session. Participants commented that an average value helps them determine how consistent they were throughout the session, and that they can compare their best value to previous sessions. Participants also wanted to see improvement from the beginning of the session, stating that their worst values usually occurred at the beginning of the session. We previously provided these metrics for each exercise; herein, we also display these metrics for the session as a whole.

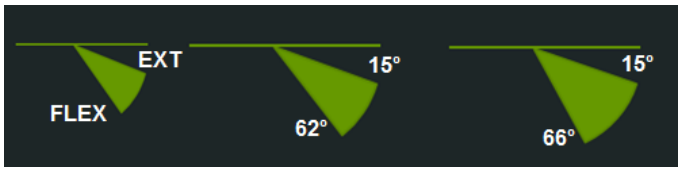

Figure 4.15 Prototype A Progress Screen Angle Visualizations After Ten Participants

Table 4.8 Prototype B Changes After Ten Participants

Changes	Screen(s)	Motivation
Removed progress bars for goals past the end date.	Goals	Participants expressed confusion with the progress bars that existed for past goals. P10 suggested we remove the progress bars once the date had past.

Changes	Screen(s)	Motivation
Added average values for flexion and extension angles. Added best, worst, and average values for hold time.	Sessions	These values are shown in Prototype A. We added them to Prototype B to provide a consistent comparison.
Added best, worst, and average flexion and extension values for each session (in addition to already existing values for each exercise).	Sessions	See previously discussed motivation for adding these values to Prototype A.
Changed “Current Interval” goals to “Past” goals.	Progress	Participants often referenced future and past goals. Thus, we changed the labels to better reflect their terminology.

CHAPTER 5

USER STUDY RESULTS

Results from the user study can be separated into three categories. The first category (Sections 5.1-5.9) discusses responses to questions asked in the background questionnaire and the semi-structured interview. The second category (Sections 5.10 and 5.11) reviews findings of the prototype design activity, and the final category (Sections 5.12-5.16) presents comments made about the paper prototypes.

5.1 Exercising at Home

Part of the background questionnaire asked participants how closely they followed their prescribed exercises and if they had any difficulties performing them at home. Eight of twelve participants said they followed their prescribed exercises at home very closely, two followed them somewhat closely, one did not follow them very closely, and one was not prescribed at home exercises. P7 cited motivation problems due to pain and perceived lack of benefit, saying, "I can walk normally on my injured knee… it hurts sometimes when I do some of my rehab… so since I can walk already I'm kinda like, do I want to go hurt myself and do knee rehab, even though it might be better for me?" P5 also had some motivation problems, stating that he "was kind of going through the motions at home." P9 expressed concern in not having a therapist to check her form at home. Of the other participants who reported difficulties doing exercises at home, most were minor problems that did not interfere with their recovery, and stemmed from lack of equipment, pain, and time constraints.

A few participants who had motivation problems reported that these problems started after they had regained mobility and range of motion. P12 said at first she did not have problems

doing her prescribed therapy, “It didn’t matter at the beginning because I wanted to get (my range of motion) back. I would put off school… I would put off everything just so I could get back.” But after she had her range of motion back, she would put less time into doing her exercises and said, “Sometimes I take a break if I have a busy week… I don’t do the full (exercise session)... It seems like my mentality has changed.” P7 had similar comments, stating that though he progressed quickly through the first part of his rehabilitation in order to get back to golfing sooner than expected, his expected last month of recovery took three months; he stated that since he had achieved his goal of returning to golfing, he had no reason to finish the rest of his rehabilitation quickly. P10 said that after she could walk, she did not focus on her physical therapy because “I was in no rush to get back to playing, and they told me that your chances of tearing it in the next two years is higher, so that’s why I’ve been in no rush because I don’t really plan to get back that soon. And I’ve been busy, I work, so I didn’t have time to have sessions with the physical therapist all the time.” Both P10 and P12 are former varsity athletes, and were not actively returning to play on a varsity team. Once they had regained most of their range of motion to return to everyday life, they were less focused on the rehabilitation.

5.2 Progress

Although participants were not directly asked how they defined “progress”, the concept came up frequently throughout the semi-structured interviews, and participants had many different ways of determining if they were making progress. The general consensus was that a metric was only useful if they were comparing it to something else, whether that be a previous date, typical recovery times, or their healthy leg.

Many participants wanted the ability to compare one session to another session side by side, in order to see improvement or stagnation between two dates. The time frame of a week

came up frequently, as participants stated that day to day progress was harder to see. P2 said, "I didn't care day by day, just at the end of the week I improved this much." Some participants wanted to know their best, worst, and average for a metric in any given week. P11 stated, "You write down everything you did each day, but at the end of the week, you kind of lump it all together because a single day doesn't make or break physical therapy."

Several participants referred to knowing if they were "where they should be" in the recovery process based on information they received from their therapists. Rehabilitation milestones, such as reaching a certain range of motion, walking, running, and lifting weights, will occur at different times for each patient, and these milestones are determined by factors such as age, weight, height, gender, and type of surgery. P7 and P12 requested that the interface display typical recovery milestones, or flexion/extension angles personalized for their recoveries, so the patients could visually see if they were "where they should be".

The other form of progress that participants strived for was returning their newly repaired knee to the same level of ability as their "good leg", in terms of metrics such as flexion and extension angle, as well as hamstring and quad strength. P10 explained that her therapist would test her good leg and then compare the result to her injured leg. P1 summed it up well stating, "The goal is always to get it back to whatever the good leg is… I like being able to compare the two because… there's a difference in strength, there's a difference in the way I walk just because of the angle of my knee." Participants suggested that the ultimate goal of rehabilitation is to return to as much range of motion and strength as their uninjured leg, and being able to see how close they are to reaching this goal is a good indicator of progress.

5.3 Setting Goals

Participants were asked if setting and meeting goals was important in physical therapy, and every participant said it was important. They emphasized that goals provided something to be working towards and looking forward to, providing a purpose for the physical therapy as opposed to aimlessly going through the rehabilitation process. Setting and meeting goals helped them both mentally and physically, because a short timeframe in which they were actively working towards a goal challenged them to continue to work hard; in addition, meeting a goal boosted confidence that they could make it through rehabilitation and kept them moving forward. P1 said, "Every physical therapist and doctor I've talked to... the first thing they tell you is the mental side of it is going to be harder than the physical side of an ACL recovery. And it's really one of those things that is mentally trying. I never thought it would be, but it really is. So setting those goals and being able to meet them and someone saying, 'Yep, you're making progress, you will get back', I think is extremely important, because it's a long process."

Participants reiterated that goals were closely tied to motivation, and that the next goal is always something to be working toward. P7 explains, "It's way too easy to just go through the motions without a goal, and when you're doing that you don't see improvement as quickly, and you can easily lose motivation later. My first stint through rehab I had so many goals to start off with, because I wanted to walk as soon as I could, I wanted to run as soon as I could, and I wanted to get back to golfing as soon as I could. And I got back to golfing about 2 months before any doctor expected me to. So through about 4 months they said I was at about the 8 month mark in my rehab because I had set so many goals. But it's usually a 9 to 12 month total recovery, so that last month of my total recovery probably took me another 3 months just because I'd gotten to a point where I had no longer had those goals. So I was just going, and not worrying about it,

and I didn't do it consistently. So goals are absolutely I think the most important thing about this." P11 also agreed by saying, "Lots of the exercises that you do, it's not like you fail, it's that you aren't motivated enough to do them. The reason that you don't do your exercises is not because you say 'Oh man, I couldn't do another leg lift' … if putting it in your goals might make you actually do it, then it's probably a good thing to have them." Overall, participants agreed that goals were an important motivator in physical therapy, and without them progress would be slower.

5.4 Motivation

In the semi-structured interview, participants were asked how important it was to see their progress. Several participants commented that sometimes they were frustrated, because it felt like they were not making any progress, as it was difficult to see day-to-day improvement. But they also agreed that being able to see their past progress would motivate them to keep pushing, because they could see that they were moving in the right direction. P5 summed it up well by saying, "If I'm not improving, it's pretty discouraging, and seeing that progress definitely keeps me motivated, keeps me going, shows me that light at the end of the tunnel that I am doing better, I am going somewhere with this. And having something like (PT Viz Mobile) at home, the progress bars, there definitely would have been a lot more motivation to do it at home, whereas my therapist did it for me at the clinic, showed me how I was improving, rather than having me doing it at home, and that's I guess why I wasn't motivated to do it at home." P12 stated a similar view, "Sometimes you can't see it physically, you can't feel it physically… You don't have any muscle, and you're just going to therapy and you feel like nothing's working. I didn't see my muscle come back for two weeks, and the whole two weeks all I kept thinking was 'I'm just working for nothing'... No one wants to go through that pain. But if it's going to get

you better, then you'll have more motivation. So if you see that it's getting better, then you'll deal with the pain." Participants also noted that seeing stagnation would push them to work harder. P3 said, "If you're not getting close to what you're supposed to for your goal, you obviously have to push yourself harder... Your progress is important just to see how you're doing and how much more you have to push."

5.5 Therapist Involvement

In the semi-structured interview, participants were asked if they would want to share their data with their therapists. Every participant saw benefits in involving their therapists in using PT Viz and PT Viz Mobile; however, P3 and P5 noted that their therapists might not want their at home data since they did their own record keeping, so they would only send the data if requested by their therapist.

Six participants indicated that it would be helpful for their therapist to have more data. P2 commented that it would supplement what her therapist was already doing, "They take notes when you're doing physical therapy, they take all this stuff down when you're doing it, and it's just more data they can use and more progress points that they can see. So if you can only get in there once a week, it would be super useful." Participants commented that their therapists would know what to do with the extra data and could adjust treatment accordingly. P9 noted that it would have helped her therapist diagnose problems faster, "I was doing (my exercises) too much for where I was at with my recovery... And it took them awhile, until I started developing hip problems for them to ask the question, 'How many times are you doing this? ... That's your problem, your body's not ready to do that.' So it would help them figure out that problem sooner." Participants also mentioned that sometimes they worked hard and performed their prescribed exercises but did not make as much progress as their therapist thought they should.

Having the extra data would show their therapist that they were indeed doing the work; perhaps the therapist could then adjust treatment to drive faster progress.

Seven participants directly mentioned that PT Viz/PT Viz Mobile would help improve communication, between patient and therapist, patient and doctor, and even therapist and doctor. A few participants commented that it would be helpful to set goals with their therapists. P7 stated, "I think it would help me communicate to them, I'd be like, 'Look, this is the app I've been using to track my progress. I'd like to continue tracking it. I need another goal. I need somewhere to be.' Because they know the goals, they just don't always tell you what they are." P12 similarly stated, "It'd be nice to show her, I'm actually doing my work, this is where I am, where do I need to be? And I don't think you know where you need to be unless you ask them, so it might be a good talking point for some people to talk to their therapist and ask questions." P6 and P7 even recommended that therapists be given the ability to log in to upload exercises and goals for patients; P11 took it farther and suggested that the therapist be given the ability to log in to view a patient's progress at any time, so that the patient does not have to remember to send the data.

A few participants also noted that it would help focus their clinic sessions and save time. P11 commented, "There won't be that wasted time, that 10 minutes every session where they ask you, 'How much did you do? How did it feel?' You can put that it your notes, and put that in your logs and they can review them." P10 stated, "They always ask me how I'm doing, and I don't really know how to tell them that. So I'll tell them if I have significant amounts of pain, but sometimes I'm just like, 'I'm struggling' but having those numbers I think would show them that I am struggling." P9 noted that having data from PT Viz would make it easier for her to ask questions about difficulties she had during her at home sessions, "Sometimes I have questions

and it's hard to remember what the issue was or what exactly I was doing that made the issue... It'd be nice to be able to say, this is what I was doing, this is what weight I was at, this is what rep I was at, good pain or bad pain?"

P3 and P9 specifically mentioned that they would send their data to their doctor, as they did not see their doctors as often as their therapists. P9 said the data would help show her doctor her progress over the six weeks since she'd seen him, rather than relying on her perceptions of her progress. P9 also commented that PT Viz/PT Viz Mobile could improve doctor-therapist communication, and said, "I think that would help the communication between the physical therapist and the doctor. Because then the physical therapist can bring up the graph and say here's what we've been doing this time, this is where she's at, this is where we want her to be at, what can we do to steepen this graph or keep it going how it is."

Participants were also asked if they would be uncomfortable if they were required to share all of their at home sessions with their therapist, or if they would like to be able to selectively share only certain sessions. Seven of the twelve participants agreed that they would be more comfortable with selectively sharing their data. P1 emphasized that it should be her choice what to share by saying, "There's going to be a day when you don't do something and your physical therapist understands that, but at the same time, it's your information… I think that's your business." Others made similar points. Specifically, they would not want their therapist knowing if they were not doing their prescribed exercises; in fact, participants indicated that they would probably only send their good days.

A few participants that argued for the ability to selectively send sessions admitted that it would be better for the therapist to see the whole picture rather than just sessions here and there.

P1 summed it up well, “If you’re not doing your homework you don’t want your teacher to know. But your therapist has to know, otherwise you’re endangering your knee because they think you’re somewhere where you’re not. Because if you’re not doing it at home, the two hours you spend with your therapist is absolutely worthless, you’re not gonna improve, and you’re gonna digress and it’s important to have someone keep you on track with this, otherwise you’re never gonna get there.”

The other five participants did not have a problem with sharing all of their data with their therapists. P3 and P11 said they did not care if their therapists saw days where they were not diligent with their exercises. P4, P7, and P11 noted that being required to send all their data would hold them more accountable to performing their exercises at home. P4 summed it up well, “It’s just one more thing to motivate you to doing it. This would just make sure that I got everything. Because there’s no way I would go into the physical therapist and show him something that I was supposed to do that I didn’t do.” P7 also emphasized that reporting to his therapist would hold him accountable; he commented, “What would help me with my motivation the most out of this would be if I actually had a therapist who wanted the data every day, who is checking up on me, which is kind of childish, it's like your mom checking up on you all the time. But... I think it would help… I think this would not so much motivate an individual... if I was just like, ‘I'm gonna go download this app for fun’, I wouldn't do that. But I think if my therapist was involved in doing it with me, this is something I would do with a therapist. I think it's just because it has such an accountability factor.” P7 was not alone in this sentiment; as nine participants, including ones who liked the option to selectively send at home sessions, agreed that sending their data would motivate them to do their at home exercises. Our participants’ comments on sharing data with their therapists match what was indicated by participants in [1].

5.6 Expected Usage of PT Viz Mobile

Part of the semi-structured interview asked participants when they would look at the aggregated data from their sessions. Almost every participant said they would upload their data from PT Viz to look at it immediately after each session, as a way to see how well they did during the session, review their progress, and check how close they were to reaching their goals. Most participants also said they would review the previous session and progress for the week before a session in order to prepare for the workout. Several participants mentioned they would also view the data before seeing their therapist or at the end of a week. A majority of the participants did not see a need for using the interface during their exercise session; in fact, a few participants mentioned that, depending on the exercise they were performing, using the interface during a session might be distracting.

5.7 Usefulness of PT Viz Mobile

Another question asked participants if PT Viz and an accompanying interface (PT Viz Mobile) would help them regularly do their exercises, track their progress, and achieve their goals. Responses were positive; in fact, most participants said it would be a huge motivational tool, allowing them to see how well they were doing or if they needed to work harder. In addition, the goal setting capabilities were emphasized by a majority of participants. P2 said, "I think it would keep you on track and the biggest thing for me would be the goal setting, because that was my biggest motivator." P5 stated that having a system like PT Viz and PT Viz Mobile would have helped him recover more quickly, because it would have motivated him to do his exercises and achieve his goals. P7 mentioned that sharing his data with his therapist would make him much more accountable to his at home exercises. Lastly, P9 said that breaking down the long recovery process into more manageable goals would make it easier to stay on track.

Seeing the "baby steps" of progress was also mentioned several times, as some participants only talked with their therapists about their progress once a week. Participants liked the ability to track their progress, especially in the first stage of rehabilitation which is primarily centered on gaining range of motion back.

Several participants also commented on the potential for PT Viz/PT Viz Mobile to improve their communication with both their therapist and their doctor. P9 said, "They only know what you tell them, or what they see you do in the office"; she felt having this data would allow the therapist to better visualize her progress, and allow her to discuss potential courses of action with her doctor to improve treatment.

Only one participant, P11, said he would likely not use PT Viz/PT Viz Mobile, as he did not need the help in staying motivated or reaching his goals. He kept his own workout log and had good communication with his therapist, so he did not see a personal use for the system.

Many participants noted that PT Viz and an accompanying interface would be extremely useful for the first 4-6 weeks of rehabilitation after surgery, as most range of motion is recovered during this time period and one of PT Viz Mobile's primary purposes is to collect and display data on the flexion and extension of the knee. Of course, this amount of time is dependent on the type and extent of the surgery; for the majority of participants, who underwent ACL reconstruction, 4-6 weeks was when the most range of motion was recovered.

Several participants concluded that they would not use PT Viz much after they had regained their range of motion. P2 stated, "I feel like this would be useful until you get all your bending and straightening back, but then after that point it's probably not going to be useful, because I don't worry about bending anymore, because I had already gotten my full range of

motion." P7 stated that he would use both PT Viz and an accompanying interface more often when he was trying to restore his range of motion; after he was mobile, he felt PT Viz would be less useful, and he might only use the device when he was approaching a goal or curious about his flexion and extension angles. Participants noted that after they had range of motion back, they moved on to different types of exercises, primarily to strengthen their quadriceps, hamstring, and calf muscles, as well as improve stability of the knee.

5.8 Real-Time Smartphone Application

One of the semi-structured interview questions asked participants if they believed a real-time smartphone application to accompany PT Viz would be useful. Participants were divided, with many acknowledging the benefits and recognizing potential pitfalls. Specifically, participants saw the availability of real-time repetition counting as a huge plus, and noted that having real-time angle data would help them push themselves to get to a flexion or extension angle goal that they might not have otherwise reached. Participants also mentioned, however, that pushing themselves too far could be harmful. P5 said, "You might push yourself to try to do more than you're capable of, rather than what you should be doing because you're trying to meet that goal quicker or run up the angle measurement just because you're a competitive person."

The participants also noted that constantly looking at their phone could be distracting, and that this distraction might sacrifice their good form. P7 summed it up well by saying, "I would start paying too close attention to the real-time option instead of actually performing the exercise. I'd just be looking at my phone instead of squatting." Participants also noted challenges in propping up the device. These concerns were also voiced by participants in [14]. Several participants commented that while it could be distracting for some exercises, it would not be distracting for others, e.g., simple flexion exercises. P12 did not view a real-time smartphone

application as distracting; instead she envisioned a real-time application that would walk the user through the exercises, counting repetitions and hold time and prompting the user to perform the next exercise when appropriate.

5.9 Platform Preference

Citing reasons of convenience, 9 of 12 participants said they would prefer that PT Viz Mobile took form as a smartphone application. P5 summed it up well, saying "It would just be more convenient than pulling out my laptop... I can just look on my phone, it's always with me, it's always more accessible for me." Participants in favor of a website pointed out that it would be able to show more data, and some participants that preferred a smartphone application said that an accompanying website might allow for an expanded look at their data, though they would use it less often. Several participants commented that a tablet application might be useful as well because it is also portable and has the ability to display more information, but many participants did not have a tablet or did not always carry it with them.

5.10 Metrics

At the beginning of the prototype design activity, participants were asked to list metrics that would be useful to track during knee rehabilitation. All 12 participants listed flexion angle and extension angle as important metrics to track, and many said that they were the most important metrics, especially for the first few weeks of therapy. P10 commented, "I'd say fresh out of surgery, the angle would have been nice to know, because that was all we were measuring, was getting my range of motion back." Participants also said that seeing their best, worst, and average values across a session for these metrics would be useful. P7 stated, "I'd like to see the average angle that I kept getting down to, to see how consistent I was."

The idea of strength came up frequently as well, as six of the participants listed quadriceps and/or hamstring strength as important to track in the rehabilitation process. Participants cited different methods for measuring improvement, stating that therapists could measure the circumference of the muscle, count how many repetitions of a body weight squat they could do, or track how much weight they could squat.

Six participants noted that duration would be an important metric to track. A few of these participants said that completing their exercises in less time showed improvement. P12 stated, "I want to do all these exercises in less than 20 minutes together… Because that means you're getting better at them." P7 and P9 wanted duration for the session to be listed by exercise, to allow the user to see improvement for each individual exercise. Along with duration, participants wanted to know how many sets and repetitions of an exercise they were performing.

Participants also mentioned a variety of other metrics, many of which would be difficult to measure with PT Viz; however, participants could manually enter these other metrics in a notes section for each session. Specifically, three participants wanted to track their swelling, as swelling affected their ability to complete their exercise sessions successfully. P6 stated, "That's a huge part of this right now. I stop when it starts to swell and I kind of go back, and then once I've got the swelling under control I can push it more." Three participants said tracking how much weight they could lift during exercises such as squatting would be useful. Two participants said stability was important, and two others commented on the importance of lateral movement. Three participants mentioned that knowing if exercises were completed with good form was valuable. Other desired metrics included a method to track compensation by the uninjured leg, hamstring flexibility, conditioning, pain levels, and hold time for a leg raise.

5.11 Prototype Design Activity

Participants were asked to mock up an interface to help them track the metrics they listed. While participants structured their drawings a variety of different ways, a few themes emerged.

Six participants incorporated at least one graph into their interface. Three participants drew line graphs that compared their progress on some metric (e.g., flexion angle) against time. P10 emphasized that a graph would help her compare her most recent session to her previous performances and said, "I would mostly be looking at this graph, seeing how fast of a rate I'm improving." Two other participants drew graphs that also represented some metric vs. time, but in bar graph form. To help easily identify important statistics, P7 added minimum and maximum point labels to his bar graph, as well as a horizontal line that indicates the average value that was reached in the time frame shown on the graph (see Figure 5.1). P12 drew a graph that showed the movement of the knee as it flexes and extends through each repetition, similar to what she would later be shown on the sessions screen. She added horizontal lines to represent her goals for flexion and extension so she could see if she was reaching her goals on each repetition. She described these goal lines as "where you're supposed to be", based on factors such as age, gender, type of surgery, and how much time has passed since surgery.

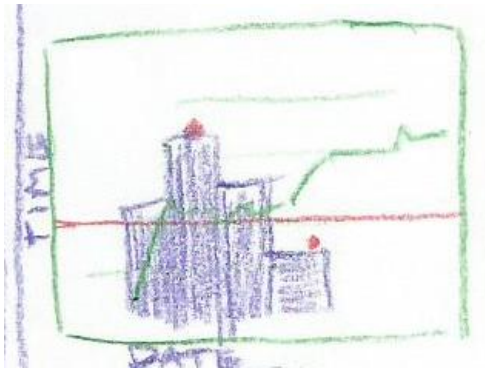

Figure 5.1 P7 Drawing

Six participants drew an interface with a navigation panel consisting of tabs. Three participants created a tab for each metric they listed as important, and added an extra tab that represented some other important function. Specifically, P2 included an additional "Compilation" tab to summarize the important data from her different tabs (see Figure 5.2), P5 added a goals tab, and P7 detailed an exercise log tab that displayed detailed information broken down by exercise. The remaining three participants created tabs that followed various formats. P11 included a goals tab, a workout log tab, and two tabs to display information about his surgery and surgeon. P4 drew past, present, and future tabs, and P6 said she would create separate tabs for her progress graph and list of exercises.

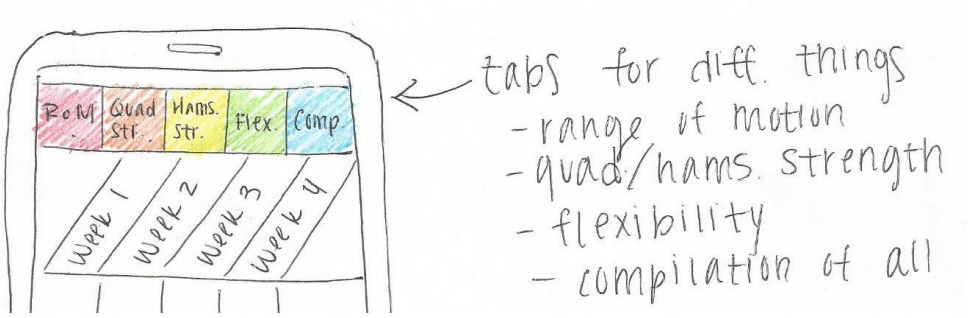

Figure 5.2 P2 Drawing

Five participants utilized a table to display their metrics. Specifically, P1 and P8 used a table to show each day's metrics, and P1 added a fixed column with data from her good leg to compare her progress against. P2 and P5 showed one value for each week in their tables. P5 supplemented his table with a line graph (see Figure 5.3), and P2 provided a row that calculated differences from one week to the next (e.g., +5 degrees flexion from Week 1 to Week 2). P8 also provided these differences from one day to the next to better show progress. P11 described that his workout log would be represented by a spreadsheet, in order to track at home exercise sessions as well as additional treatment he received in the clinic (e.g., electrical stimulation or massage).

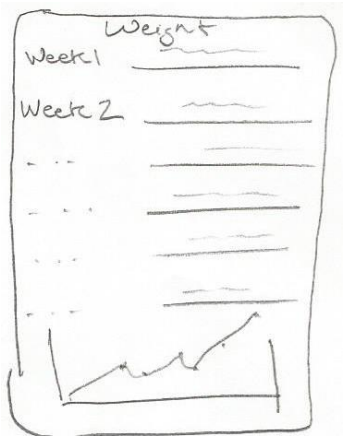

Figure 5.3 P5 Drawing

Three participants included a list of exercises in their prototype designs. P3's drawing, shown in Figure 5.4, depicted a table that listed the exercise, sets and reps to complete, and weight or time for the exercise. P6 drew a bulleted list of exercises for each week to keep track of how she was progressing from easy to more complex exercises. She said, "I've kept a list of all the things she's had me do on my phone. Some of these things I don't do anymore because I don't need to. I'm going progress more into these lifting ones, because she's allowed me to lift again." P10 included the number of sets and reps for each exercise on her design, explaining that she'd want to compare how many sets and reps of the exercise she could do today to the number she could do last week.

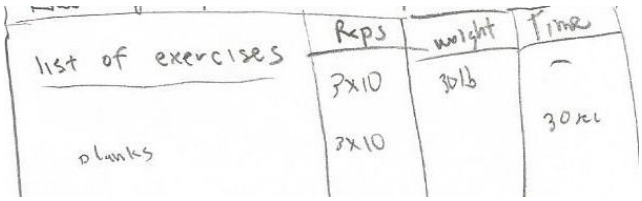

Figure 5.4 P3 Drawing

Three participants incorporated a visual representation of the knee into their drawings. P6 used a drawing of the knee to show range of motion progression, with increasingly faded pictures

of the knee showing past progress. P7 and P9 envisioned animations, with P7 describing a model of the knee bending through each repetition, and P9 illustrating an animation that allows users to watch themselves performing exercises such as jumping or squatting (see Figure 5.5).

Figure 5.5 P9 Animation Drawing

A few drawings incorporated ideas that were later introduced to participants, including P7's "Exercise Log" tab that provided detailed statistics such as those shown on the sessions screen. P4 described "milestones", or goals, and P11 provided a goals tab. P4 envisioned therapist involvement, as he wanted to be able to view his therapist's notes from his clinic sessions.

After interacting with the researcher-designed paper prototypes, participants were given the opportunity to make modifications to their drawings. Six participants did not suggest any modifications, and commented that they liked the paper prototypes they were shown. A few participants remarked that the paper prototypes embodied their vision for the interface but were better planned. Of the remaining six participants, five did not physically make any modifications, but described a few changes they might make to improve their mockups by comparing their drawings to the paper prototypes. P7 believed he should have broken his screens up into more

tabs, as done in the paper prototypes. P6 liked the angle visualization found in Prototype A, and stated that she would want her range of motion drawings to use the angle visualizations instead. She also commented that she liked the line graphs from Prototype B better than her previously drawn bar graph. Other participants offered further suggestions, such as P11, who suggested having a dual-login so the therapist could log in and view the data rather than relying on the user to send it. P7 suggested letting the user switch between bar and line graphs.

P5 was the only participant who physically added features to his mockup, supplementing his week by week table with a bar graph to show each day within that week's values. He also added a progress screen, found in Figure 5.6, with the angle visualization found in Prototype A and a line graph overlaying all the metrics he wanted to track.

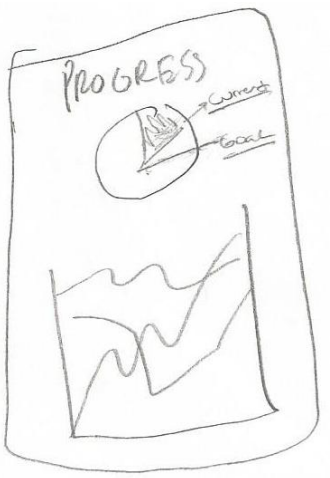

Figure 5.6 P5 Drawing After Modifications

5.12 Home Screen

The home screen was not part of the initial paper prototypes, but was added after both P5 and P7 expressed strong interest in a home or welcome screen. The home screen's main purpose is to provide a snapshot of the most recent and relevant data for a user to view in a quick glance; it is also a logical place to upload session data. Previously, the "Upload Session" button was on

the progress screen of Prototype A and the sessions screen of Prototype B. P7 stated, “I wish there was a home screen… Something that gives a general summary of the most recent things you’ve done. So you have it split up into sessions, goals, progress, (a home screen) just has a little thing on sessions, a little thing on goals, and a little thing on progress.” Additionally, several participants commented that they would look for a USB cord or Bluetooth connection when uploading their session data, and the home screen is an obvious place to inform the user that the Bluetooth is successfully paired.

Because the home screen was added late in the iterative process, only four participants provided feedback on the home screen. Participants emphasized that a home screen should display information regarding their most recent session, their next goal, exercises for their next session, and a quick graphical representation of their recent progress. P9 said, “It’s nice to know your most recent exercises. If you decide to upload a session, you can automatically compare to what you did last, because most of this is what you’re going to need at the time. So you can see your flexion, and you can see your next goal, what you’ve just done, and what your next goal is. So as you go to upload it, and then your most recent session comes up, you can see if you met your goal… But I think flexion and extension shouldn’t be the only thing you see.”

Prototype B tested participants’ preferences by displaying both a graph and a table that showed recent progress. The graphs were generally more popular, as participants stated that it was easier to visualize progress on a graph. Before the “Upload Session Data” button was moved to the home screen, P5 had difficulties completing the task of uploading session data from PT Viz; he stated, “That was confusing... because that was just in the corner hidden. If you’re looking to load it, maybe that’s the first thing that pops up... Make it a little bit more obvious.”

After it was moved to the home screen, all four participants completed the task without any issues. The final prototype design for the home screen is in Section 6.1.

5.13 Progress Screen

Prototype A's progress screen displays multiple bar graphs over a fixed number of dates (see Figure 5.7), while Prototype B's progress screen displays line graphs over a variable date range (see Figure 5.8). Participants articulated that the most important function of a progress screen is to provide a quick way to visualize their progress over a given time interval.

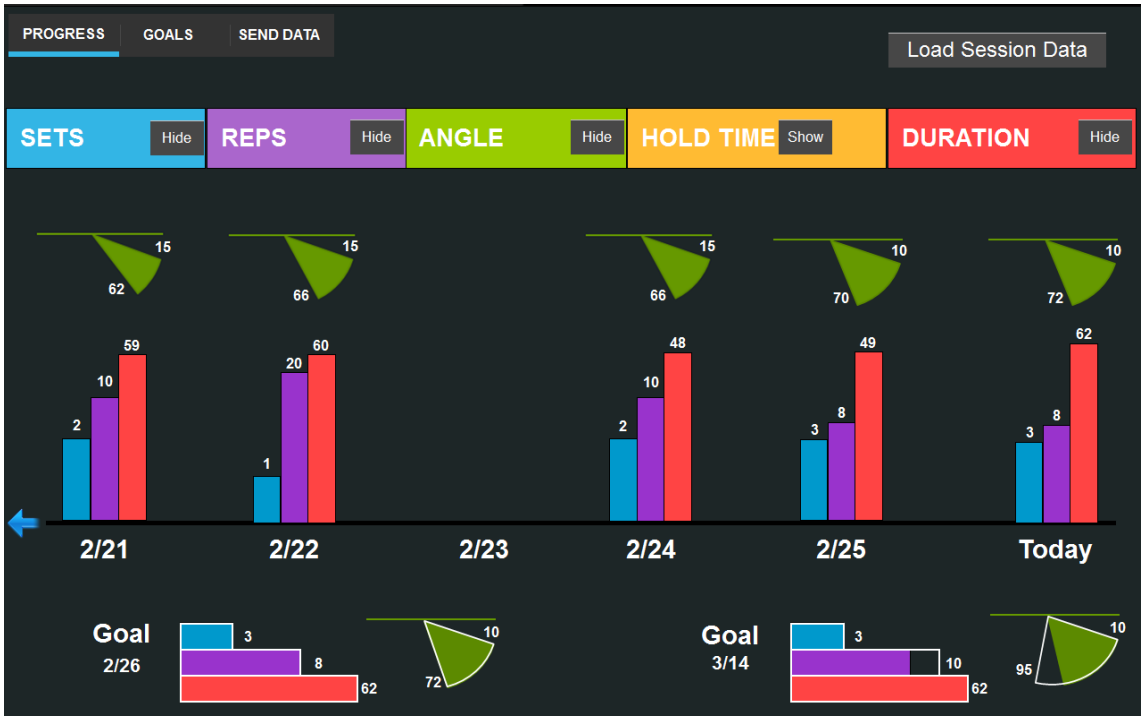

Figure 5.7 Prototype A Progress Screen

Participants interacted with the progress screen during several different tasks. Specifically, participants used the progress screen to (1) determine how much they improved over a specific time span (e.g., flexion angle improvement from 2/21 to 2/26), (2) discover their flexion angle for a specific date, and (3) learn how much time they spent on physical therapy on average over a given time range. Participants generally had few problems completing the first

two tasks; any difficulties in the first two tasks stemmed from confusion regarding the angle visualization (see Figure 5.11). The third task, however, gave participants some trouble, because they were looking for a displayed average that did not exist. Average values were added to the prototypes after seven completed user studies. (Chapter 4 details these changes.) The final four participants did not have any difficulties completing this third task.

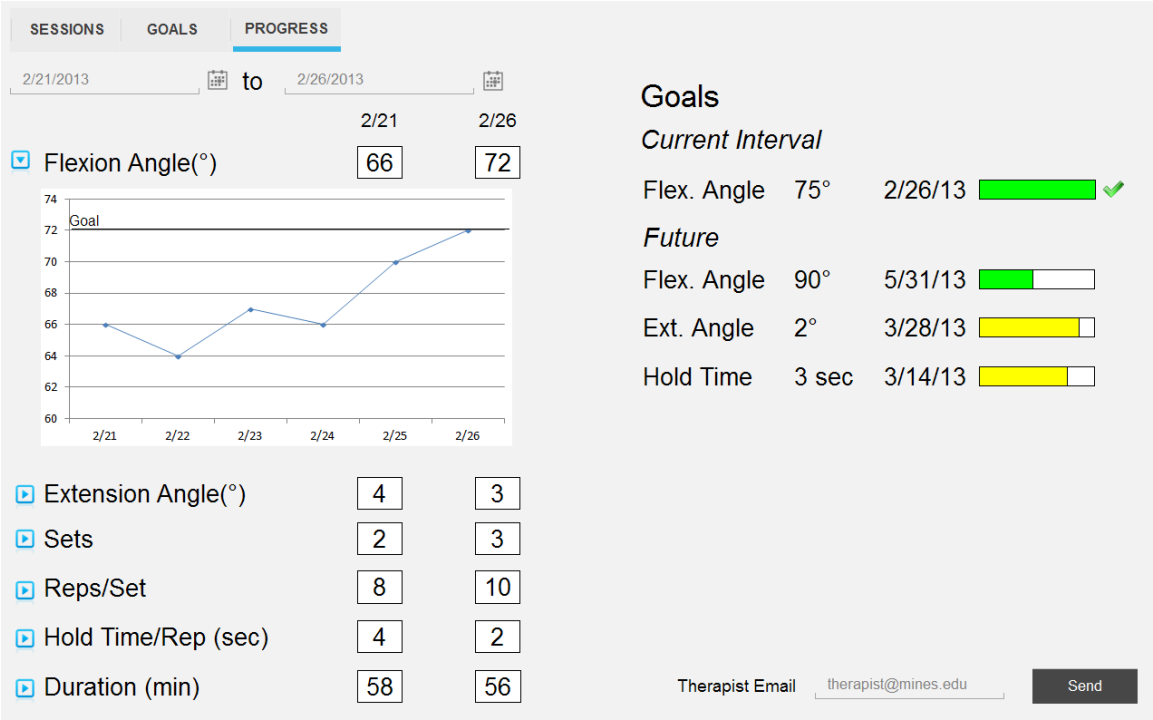

Figure 5.8 Prototype B Progress Screen

Participants were asked to compare the progress screens of the two prototypes, and Prototype A was generally less favorable than Prototype B. Participants wanted more labels on Prototype A, and a few participants commented that Prototype A was cluttered and harder to gather information from when compared to Prototype B. One feature of the progress screen that received positive feedback displayed the user's next goal (see Figure 5.9). Participants commented that they liked being able to graphically see how close they were to their next goal, and would be motivated to fill in the outline to achieve their next goal. P5 stated, "It's nice just

being able to work towards something and see… I'm here and I need to get 23 degrees more to get to my goal. So that's a little motivation just to fill the rest of that out."

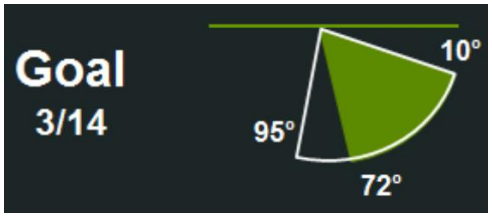

Figure 5.9 Angle Visualization for Next Goal

The majority of participants liked the line graphs used in Prototype B. Participants commented that the line graphs provided a visual snapshot of their progress, allowing them to quickly see trends of improvement or stagnation. P10 expanded on why she liked the line graphs better than the bar graphs by saying, "Just visually to see how I'm improving instead of having to compare each number on each date. Especially if they're kind of close or alternating, then it's nice to have the progress shown for me." A few participants suggested adding a "goal line" on the progress graphs that shows the next goal they are working towards. Participants also liked seeing the values accompanying each metric in separate boxes for the start and end dates in the range (see Figure 5.10), as well as an average over the current date range. A few participants commented that a box which displayed the difference between the two days might also be useful. P3 said that the difference between two dates was more important than the average among those days; he stated, "I'd probably just have the difference of the two, to see how many degrees you have increased from that date to that date." A few participants also mentioned that they liked being able to view their progress over a user-selected, variable date range. The final prototype design for the progress screen is in Section 6.1.

One of the most prominent features of the progress screen in Prototype A is the angle visualization (see Figure 5.11), and it appears on multiple screens in Prototype A. Initial

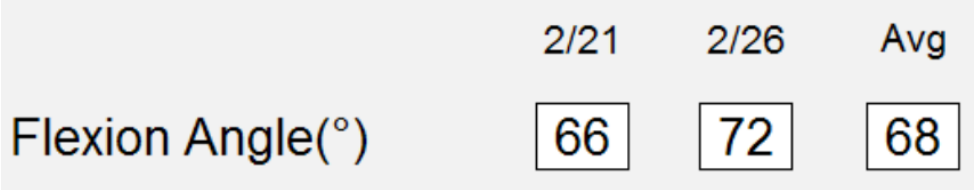

Figure 5.10 Values for Flexion Angle Displayed on Progress Screen for Prototype B

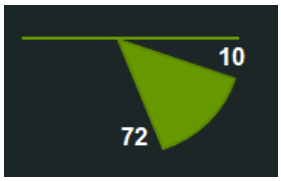

Figure 5.11 Angle Visualization

impressions of the angle visualization were mixed, but by the end of the user study, most participants liked the graphical representation of flexion and extension angles. Four participants immediately understood the angle visualization, and commented that they liked it. P6 stated, "I like… how you could see the angles… graphically how your knee is, because it looks more like the knee." P4 had similar comments, stating, "I think it's really intuitive for somebody who doesn't know what the difference is between extension and flexion, it kind of illustrates that. How close to… 0 on top and at least 90 on bottom… I like that." On the other hand, three participants stated that they were initially unsure of what the angle visualization was portraying, and then later commented that they liked it. P10 said, "I like this idea, of doing this graph, but I didn't know what it was originally." Three other participants took a little longer to understand the angle visualization, but were able to complete all tasks that involved obtaining flexion and extension values from the angle visualization successfully. Initial confusion for these six participants likely stemmed from insufficient labeling. P7 commented, "I think I would prefer some labels with these (angle visualizations). It took me a minute to figure out exactly what I was looking at... That kind of goes for the duration too… It's 60 minutes… that's pretty easy to understand, but at the same time I would have liked the label…That would actually clear it up

faster for me." In regards to the other two participants, one did not comment on the angle visualization and the other did not have a preference between the angle visualization and displaying the angle values as text.

Because most participants were able to learn what the angle visualization represented and users appreciated seeing a graphical representation of their flexion and extension angles, the angle visualization was incorporated into the final prototype design. According to participant suggestions, we ensured it was labeled well. It appears on every screen but the edit goal screen.

5.14 Goals Screen

The goals screen of Prototype A follows the idea that goals should be a grouping of multiple metrics (e.g., do 3 sets of 10 repetitions of the heel slide exercise and reach 75 degrees of flexion for each repetition), while the goals screen of Prototype B allows the user to set only one metric per goal. Participants were relatively split over which version they preferred.

All of the participants were able to set a knee flexion goal for a specified number of sets and repetitions that they would achieve by a certain date in Prototype A. Despite participants' success, several participants unintentionally set goals for metrics they were not instructed to include. Although about half of the participants successfully noticed the disable button on the edit goal screen after it was introduced in the second iteration of the prototype (described in Section 4.8.2), others were confused on whether they should disable certain metrics that they did not need to include in their goal. P11 said, "Nothing for extension, so I could I suppose disable extension, but I might as well track it if you're going to pay attention to what it was," communicating that he believed disabling a metric would mean not tracking the metric, rather than excluding it from the goal requirements. A few participants also noted that when metrics

were disabled for several goals, there was a lot of wasted space in the goals table. Because we need a method to allow users to set goals for only some metrics, we included the disable buttons in the final prototype design, but renamed the text to read "N/A" instead of "Disable", which should address some confusion participants had (see Section 6.1).

Participants were also instructed to edit an existing goal. Most participants had no problems completing this goal. A few participants attempted to edit the goal by clicking on the cell in the goals table rather than clicking the edit button for the goal they wanted to edit; however, when the participants learned they could not edit a goal that way, they quickly found the edit button and completed the task successfully. P2 commented, "When you try to go in and change a goal, I like if you could just click on it and change it right there, but this (edit goal screen) is also nice too, going to another screen."

The edit goal screen (see Figure 5.12) only appeared in Prototype A and was the more popular method of creating new goals and editing existing goals. Participants said that the edit goal screen in Prototype A was more straightforward than setting a goal on the goals screen in Prototype B.

A few participants, however, were confused by the metrics listed under the "Today" column; specifically, these participants were not sure if they were editable fields, values generated by the interface, or what the metrics signified. P11 said, "This column looks like what I accomplished… Flexion angle, my goal was 95, but what I hit was 72." Nevertheless, participants understood the rest of the screen, so this confusion did not keep them from successfully setting goals. A few participants noted that it was useful to see their past goals when setting their next goal, which they could do only in Prototype B. P12 commented, "You just look

down here (the goals table) and you're like, okay… he said I need to do the same for this one, what did I do for this one last week? Without having to go to a different screen." We chose the edit goal screen from Prototype A for the final prototype, but removed the "Today" column because it confused participants (see Section 6.1).

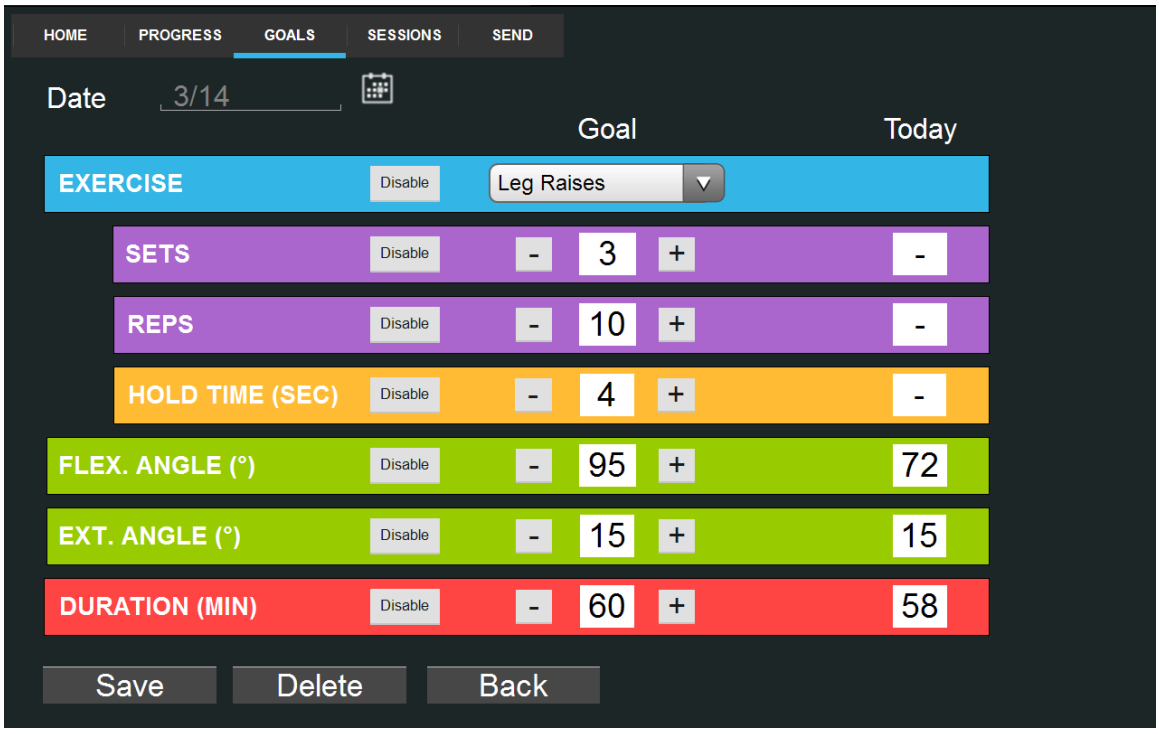

Figure 5.12 Prototype A Edit Goal Screen

A few participants stated that they liked the large amount of information they were shown in the goals table in Prototype A (see Figure 5.13); P11 noted, "This one (goals screen for Prototype B) doesn't tell you what you actually hit, it just tells you whether or not you got it. Goal successful, goal unsuccessful, whereas this one (goals screen for Prototype A) tells you goal successful, goal unsuccessful, and tells you by how much, so I would say that's probably a good idea to have." For this reason, we included the goals table from Prototype A in the final prototype (see Section 6.1).

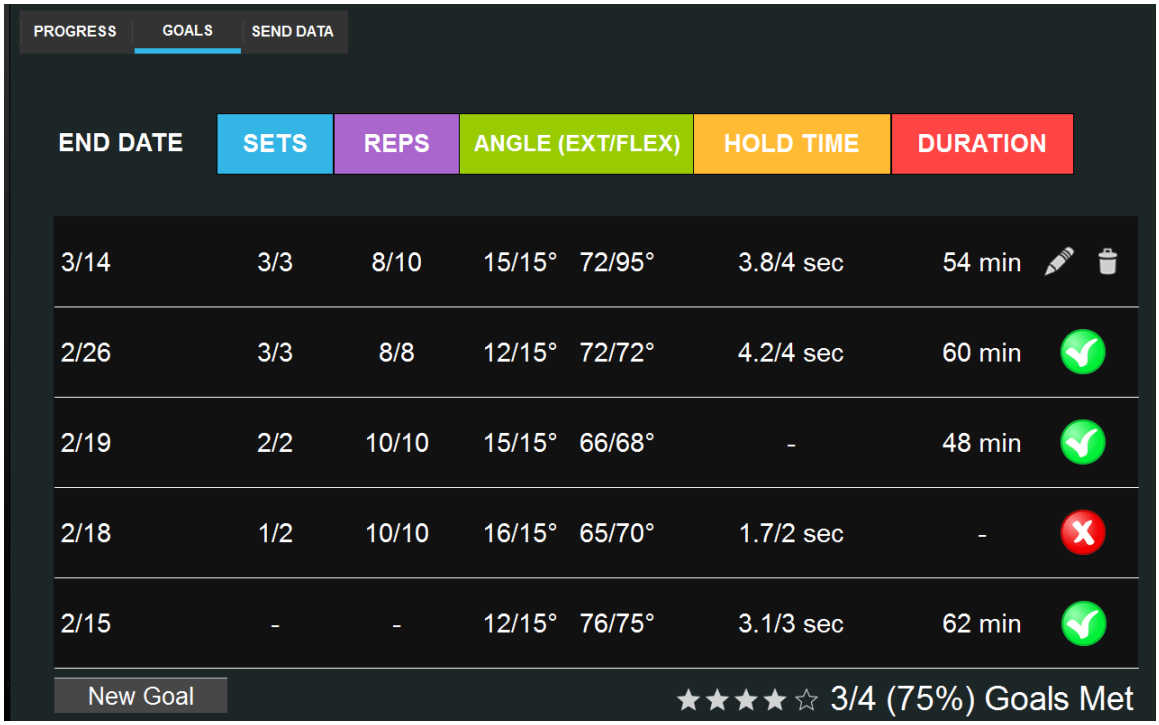

Figure 5.13 Prototype A Goals Screen

Both prototypes provided feedback on each goal by displaying a check mark or X on a completed or failed goal, respectively. Participants liked this feature, and P2 commented, "I like that it tells you if you've completed something." One popular feature of Prototype A's goals screen is a feature that displays the percentage of goals successfully completed. Participants commented that it was useful to provide an overall picture of how well they were meeting their goals throughout the rehabilitation process. The most popular feature on the goals screen of Prototype B was the progress bars for each goal in the table (see Figure 5.14).

The progress bars utilized a color scheme of green, yellow, and red bars based on progress toward the goal, which is defined by how close a user is to completing the goal as well as how much time is left to reach the goal. While the color scheme was intuitive to some, it was confusing to others. Nevertheless, the majority of participants said they liked the overall idea of a progress bar. P1 said, "I like this over here (progress bar), that you're making progress towards a

goal." Some participants expressed confusion with the progress bars, but were able to reason through the likely meaning of each color; however, these participants did not like that their interpretation could be incorrect. On the other hand, other participants did not have problems determining what the colors signified. P6 stated, "Oh. That's neat. You have to get a green (green progress bar), and you suck (partially filled red progress bar), and you're doing alright, but you need to work on it some more (mostly filled yellow progress bar)." The goals screen of the final prototype utilizes progress bars, but does not use a green, yellow, and red color scheme because it was not intuitive to many participants (see Section 6.1).

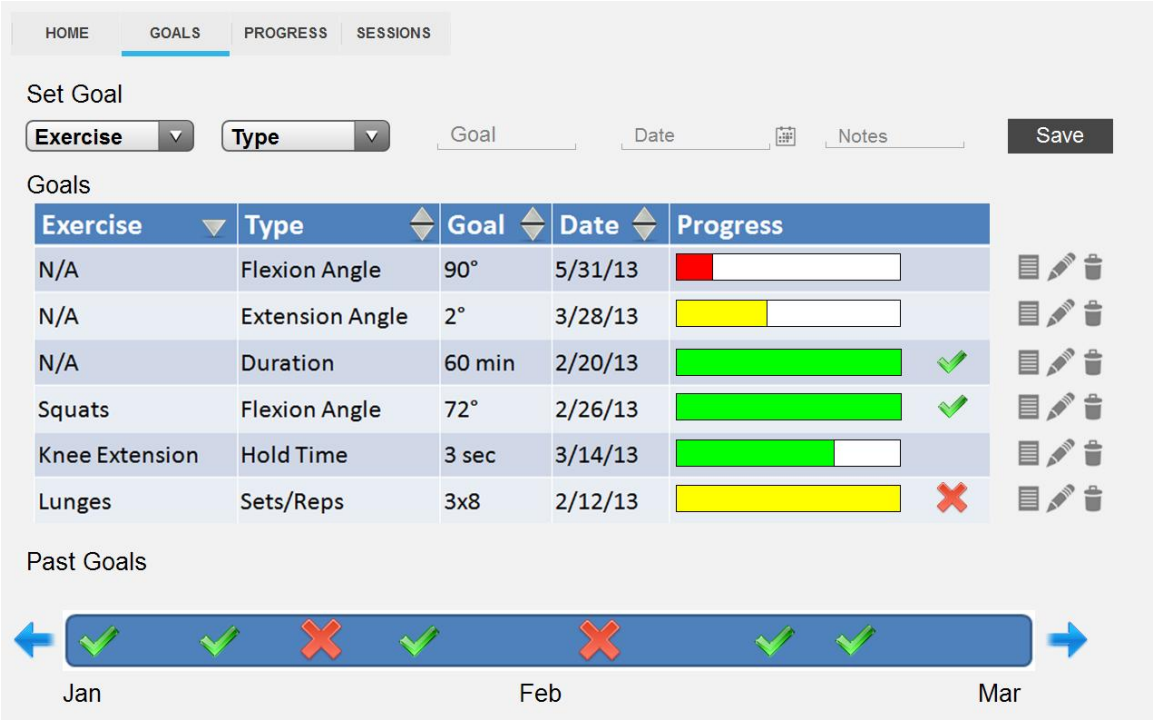

Figure 5.14 Prototype B Goals Screen

The timeline feature at the bottom of the goals screen for Prototype B received mixed feedback. A few participants did not find the timeline necessary, as they could use the table to see their past goals. P4 said, "I think it would also be nice if these (table columns) had an ordering button, where you could order it by the date or the type or the goal or progress… I think

that would really help to kind of serve this purpose (timeline), if you were able to order them by date." P7, however, argued, "At the very end of the entire thing I'd like to go back and look back through an archive or a timeline…I like the timeline because you can go back and look at it as a year-long progress. This was my surgery date, this is when I got to each of my goals. It's simpler than having to go back through and dig through… and find out when I hit each one. That's really not that hard, but visually it's more appealing to do it as a timeline for me." P7 was not alone in this sentiment, as other participants agreed that it was an easy way to understand how well they were meeting goals. Other criticisms of the timeline concerned space issues that would arise if multiple goals were set in a short time period, as it would be difficult to tap closely spaced goals in the timeline. P3 said, "I feel like if I had a bunch of days… if I did it every day for all of January, trying to figure out which one to click on there would be kind of difficult, instead of just having them all listed out." The goals screen of the final prototype, shown in Section 6.1, does not incorporate a timeline, primarily due to insufficient space. It does, however, list goals chronologically and show most of the information that was displayed in the timeline pop ups.

The biggest difference between Prototype A and Prototype B is whether goals are treated as a group of metrics or just one metric. Thus, it is important to know whether participants want to group metrics together or keep them separate. Three participants explicitly commented that setting a goal only made sense if you could group metrics together, such as 3 sets of 10 repetitions of a leg raise exercise, holding each repetition for 10 seconds. P2 stated, "My goal today is to get this angle, do this many reps, do this many sets. All together, one date. Whereas this one (goals screen for Prototype B) is like date, angle goal, date, duration goal. Separate stuff. I just don't really like that." Three additional participants did not mention the idea of grouping goals, but preferred Prototype A when it came to setting goals. P5 said, "This thing (goals screen

for Prototype B) confused the heck out of me, when I first looked at it. I didn't really know what was going on here." Three other participants liked it better broken up into one metric per goal, and pointed out that having multiple metrics required all metrics to be met in order to achieve a goal. P9 stated, "(Prototype A) is one overall goal, and if you don't accomplish parts of it, it's only 75% complete, whereas (Prototype B) clearly differentiates that they're all separate goals. (Prototype A) feels like you can only achieve part of it. You might miss some of it so you don't get the whole goal." The remaining three participants did not express a preference towards the goals screen of either prototype.

Users did not express a strong preference towards grouping metrics together or setting a goal with just one metric. If the final prototype only allowed users to set one metric per goal, they would not be able to group goals together. Thus, the final prototype treats goals as a group of metrics, because users who wish to only have one metric per goal can disable all other metrics if desired. Section 6.1 shows the design of the goals screen in the final prototype.

5.15 Sessions Screen

The sessions screen initially existed only in Prototype B, and was intended to provide the user with detailed information about a specific exercise session. Participants noted that it was convenient to have detailed information for one session listed on a separate screen; however, since the progress screen for Prototype B could be made to show similar data, most of the data on the screen did not add much value. Nevertheless, a majority of participants liked the graph (see Figure 5.15) on the sessions screen for Prototype B.

The graph in the sessions screen of Prototype B shows the movement of the knee as it flexes and extends through each repetition. Participants liked being able to graphically see each

repetition, as the illustration allowed the participants to tell if they were being consistent on each repetition, going too fast or too slow, or not flexing/extending far enough when tired. P9 said, "(I would use it) to see if I'm staying consistent with my reps, going all the way, doing my squats correctly. Or if I'm getting tired at the end I probably won't go as low." P11 commented, "As far as squats go, and heel slides, is then your therapist can see how fast you're doing things. They'll always tell you that you have to be in control when you're doing these things, and that you don't need to go fast, you actually should go slow. So they can at least look at it and say, 'Why are you doing squats as fast as you can? That's not good, you should slow down'." Participants emphasized that seeing their labeled goal line on the graph was important, and suggested adding axes labels and labels for maximum and minimum points on the graph.

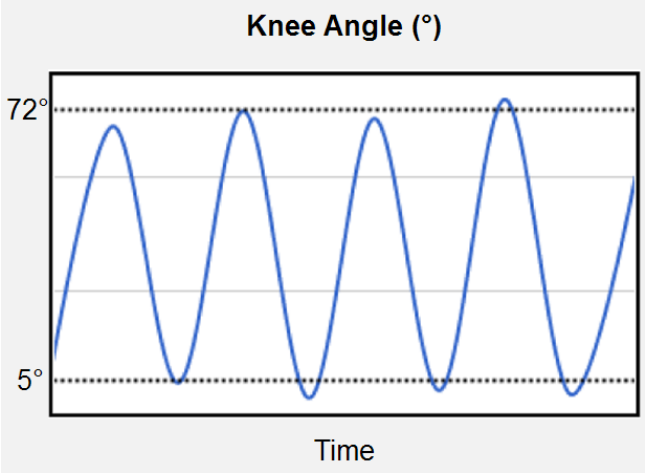

Figure 5.15 Prototype B Sessions Screen

Several participants also requested a notes section, commenting that it would be useful to note swelling, stability, techniques that were useful in the exercise session, or any difficulties they had. Participants also wanted to share this information with their therapist at their next clinic session.

When the concept of different exercises was added to the prototypes after user studies with seven participants were completed, the sessions screen took a different form in Prototype B (see Figure 5.16), and was added in Prototype A (see Figure 5.17) in order to differentiate between exercises (with accompanying sets, reps, hold times, and durations).

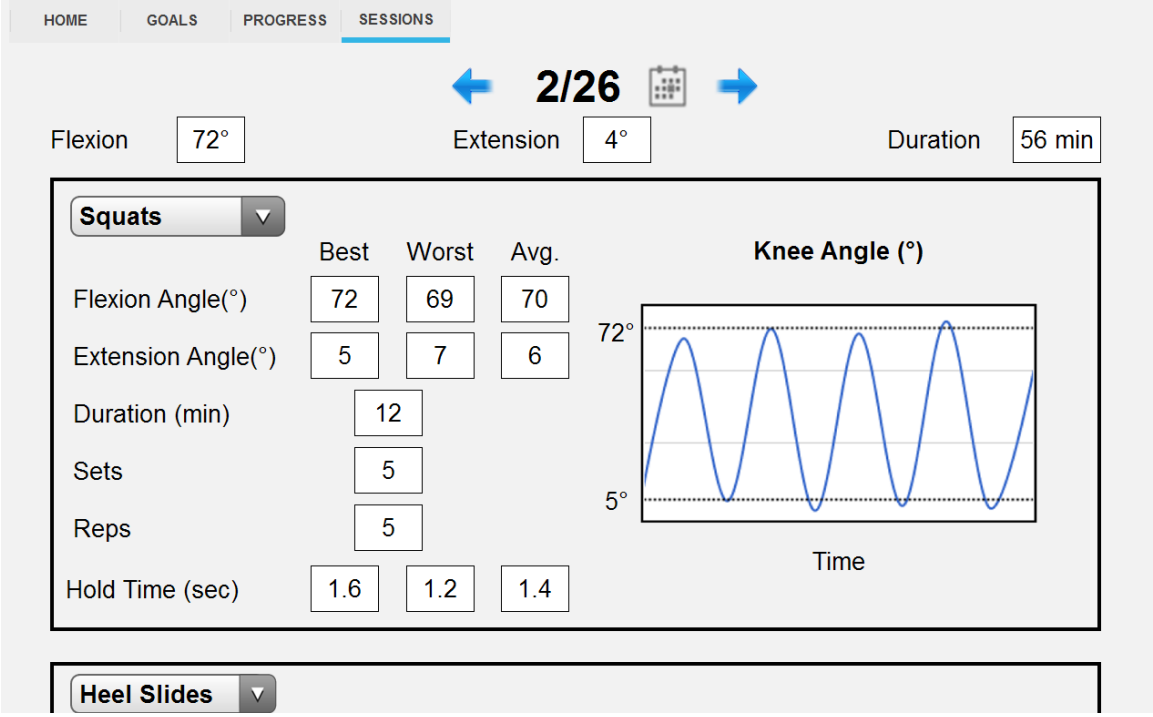

Figure 5.16 Prototype B Sessions Screen After Exercises Were Added

Participants P8-P12 did not have significant issues with the new layout, and liked having best, worst, and average values for the knee extension/flexion and hold time metrics. They preferred Prototype B's sessions screen because it was less cluttered; in fact, a few participants noted that while Prototype A allowed them to compare two sessions, the progress screen was better suited to compare two sessions. Overall, participants were happy with the detailed information they received, broken down by exercise, for a given session. The final prototype design of the sessions screen is in Section 6.1.

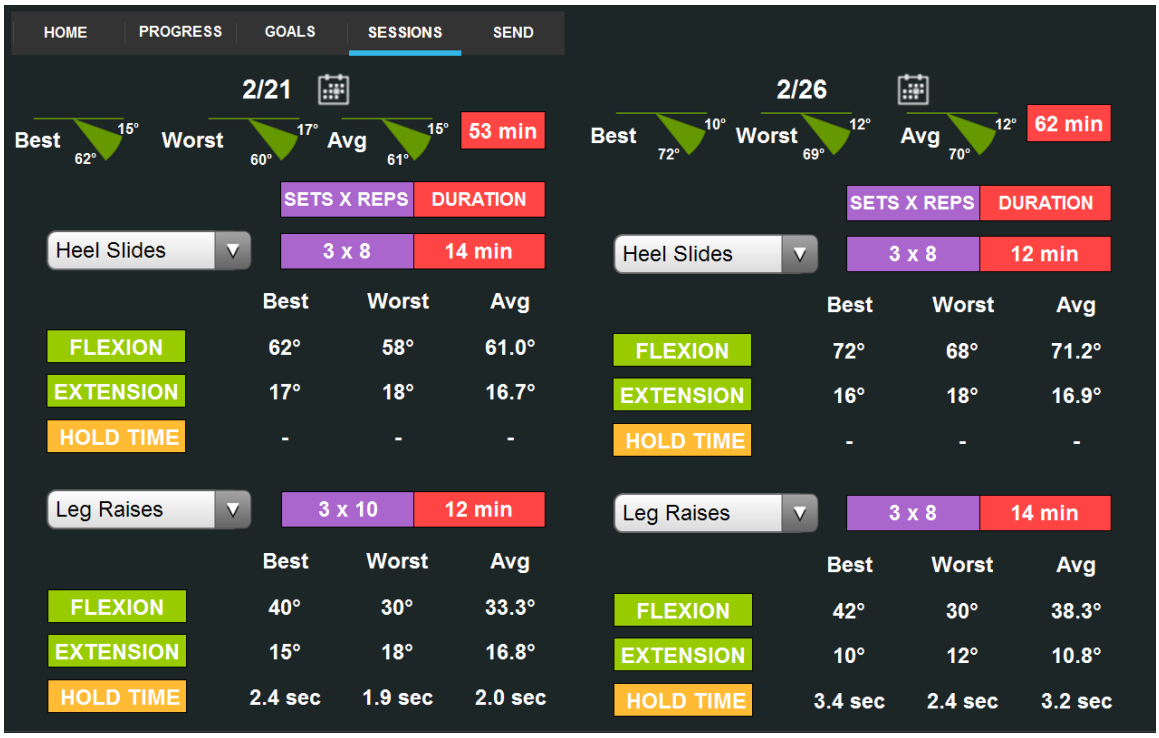

Figure 5.17 Prototype A Sessions Screen After Exercises Were Added

5.16 Send Screen

One task asked participants to send data from a single at home session to their therapists. All participants were successful in completing this task on both Prototype A and Prototype B. Participants favored being able to send data to their therapists (see Section 5.5), and even commented that they might also send data to a family member, doctor, or even themselves. Most participants thought the send screen on Prototype A was simple, and liked using the check boxes. P7 commented, "The reason I think I like (Prototype A) better is because I don't have to go through a calendar to pick my dates, I can come through and say I want to send this one, this one, and this one (gestures at check boxes), and send them, whereas I don't know how I'd do that with (Prototype B)." The check boxes also allowed participants to selectively share their data, which was slightly preferred (see Section 5.5).

A few participants had minor troubles sending data from Prototype B, which did not have a dedicated "Send" tab. These participants initially looked to send the data from a single session from the sessions screen. When they did not find it there, they immediately found the option on the progress screen. A few participants noted that they preferred having a separate send screen on Prototype A, because it was clear where to go to perform the task. P11 said, "I would say it's probably a good idea to have an entire tab for send, just so that it's there, completely separate, if you have to send something." A few participants commented that their confusion stemmed from being tasked to send data from a single session, but agreed that both use cases, sending just one session or sending a range of sessions, were common. Additionally, P3 was confused as to exactly what information was being sent to his therapist from Prototype B's progress screen, saying, "I don't know if the graphs would go with it or not." The send screen in the final prototype design is in Section 6.1.

CHAPTER 6

FINAL PROTOTYPE DESIGN AND FOLLOW-UP SURVEY

Following the analysis of the results from the user study, we designed a final prototype based on the participants' preferences. In order to confirm that the final prototype meets the needs of the participants, we sent an online survey to the same 12 user study participants. This survey collected participants' opinions on different features of each screen, asking if included features were important or confusing. A few minor modifications were made after this follow-up survey; these modifications are described in Section 7.2.2.

6.1 Final Prototype Design

Section 5.9 discussed that 9 of 12 participants preferred that PT Viz Mobile's platform be a smartphone application. Because both paper prototypes utilized the screen space of a tablet application or website, the biggest modification was adjusting the prototypes to fit a smaller screen.

The home screen provides a snapshot of the most recent and relevant data, and gives users a place to upload session data from PT Viz. Participants articulated that the most important features of a home screen included information regarding their most recent session, their next goal, exercises for their next session, and a short graphical representation of their recent progress (see Section 5.12). Figure 6.1 shows the redesigned home screen. It incorporates each of the important features articulated.

The final prototype design of the progress screen closely resembles Prototype B's progress screen. The progress screen incorporates line graphs for flexion, extension, and

duration, allows users to select the date range that the graphs show, and displays boxes with values for the start and end dates, as well as an average over the date range and the difference between the start and end values. The final prototype design of the progress screen is shown in Figure 6.2.

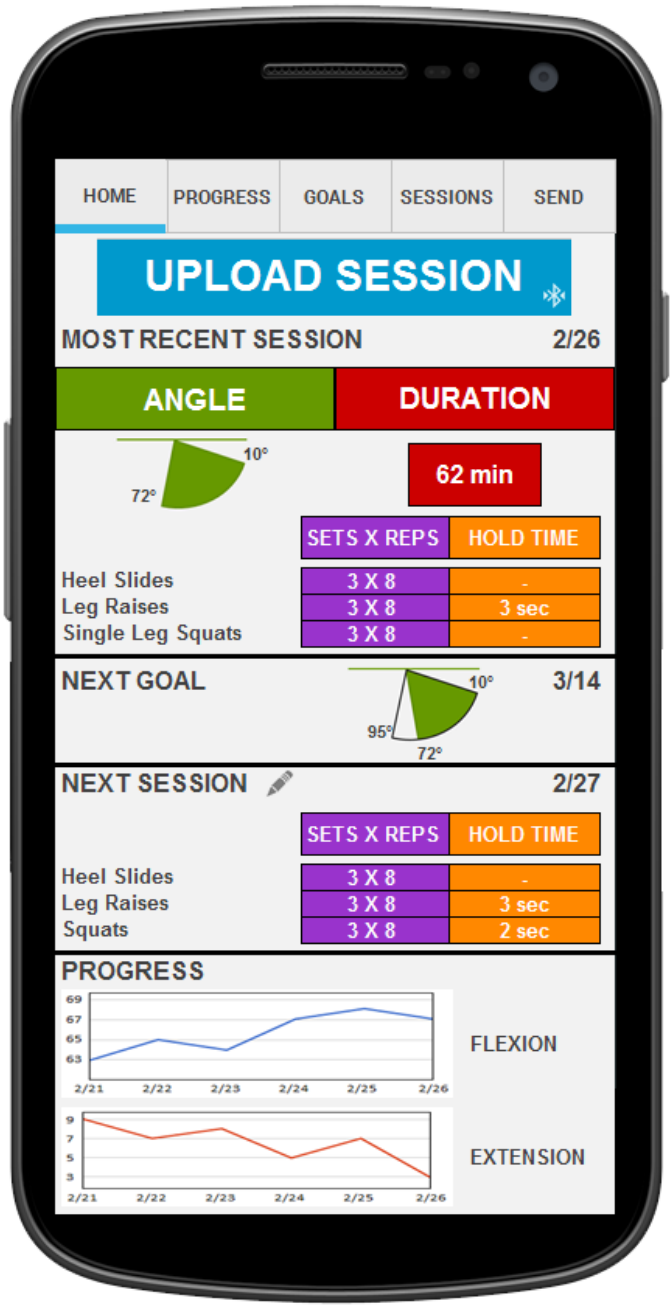

Figure 6.1 Final Prototype Home Screen

Figure 6.2 Final Prototype Progress Screen

The goals screen allows users to set and edit goals by grouping several metrics into one goal. It also lists detailed information about future and past goals. Future goals utilize progress bars to inform the user how close they are to achieving a goal. Past goals display either a check mark or an X to allow the user to quickly distinguish goals that were achieved from goals that were not achieved; past goals also employ partially filled bars to inform the user how close they were to goals that they did not achieve (or full bars for goals that were achieved). The goals screen is in Figure 6.3.

The final prototype design of the edit goal screen (see Figure 6.4) allows users to set new goals and edit or delete existing goals. Users can choose which metrics they want to include in a goal, and set values for each metric they include. Any metric that is not included in the goal is shown as a grayed out row, and rows that are left blank are also not included in the goal. The edit goal screen also gives users the ability to add notes to their goals.

The sessions screen for the final prototype closely resembles the functionality of Prototype B, but incorporates the angle visualization and color scheme from Prototype A. It displays angle and duration data for the entire session, as well as angle, duration, sets, reps, and hold time for each exercise performed during the session. It also allows users to add notes about the session. Additionally, the sessions screen includes the graph that shows knee angle through each repetition, as participants commented on its usefulness. The final prototype design for the sessions screen is in Figure 6.5.

The final prototype design of the send screen (see Figure 6.6) allows users to specify a date range from which they can select sessions using the checkboxes found in Prototype A. It also uses the angle visualization to display flexion and extension angles for each session. In order

to allow flexibility on what data is being sent, it also provides users checkbox options to send their graphs, goals, and full session data.

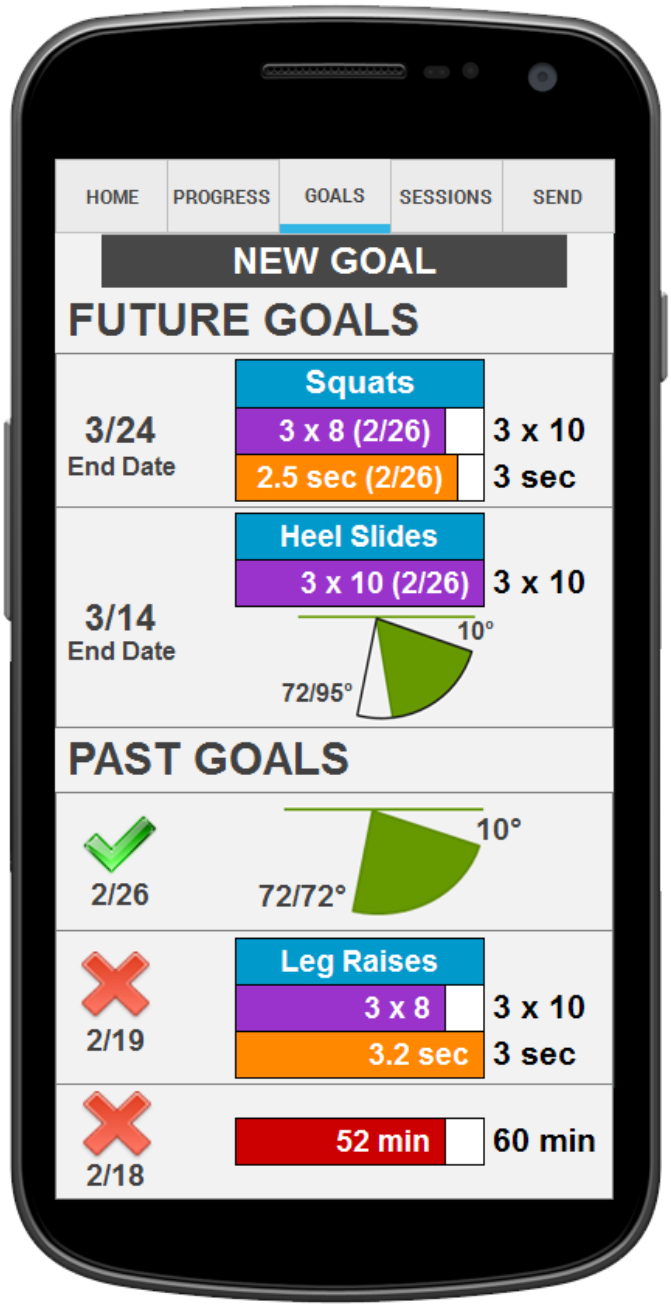

Figure 6.3 Final Prototype Goals Screen

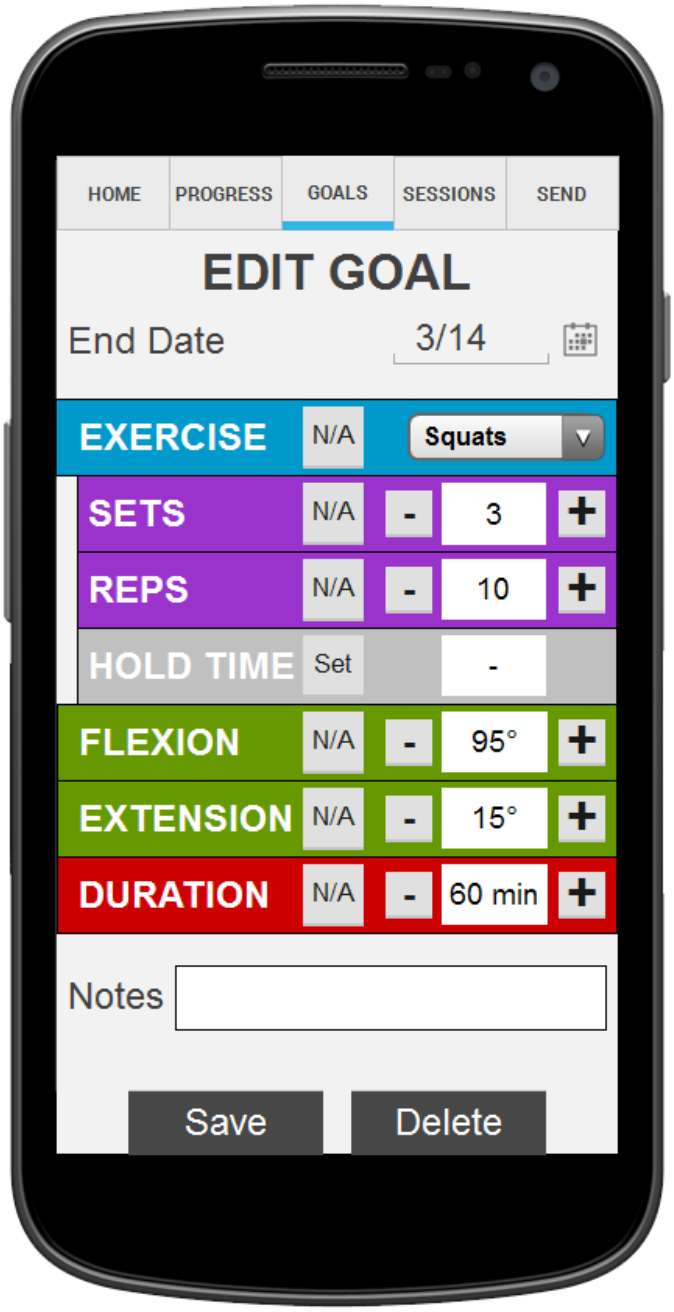

Figure 6.4 Final Prototype Edit Goal Screen

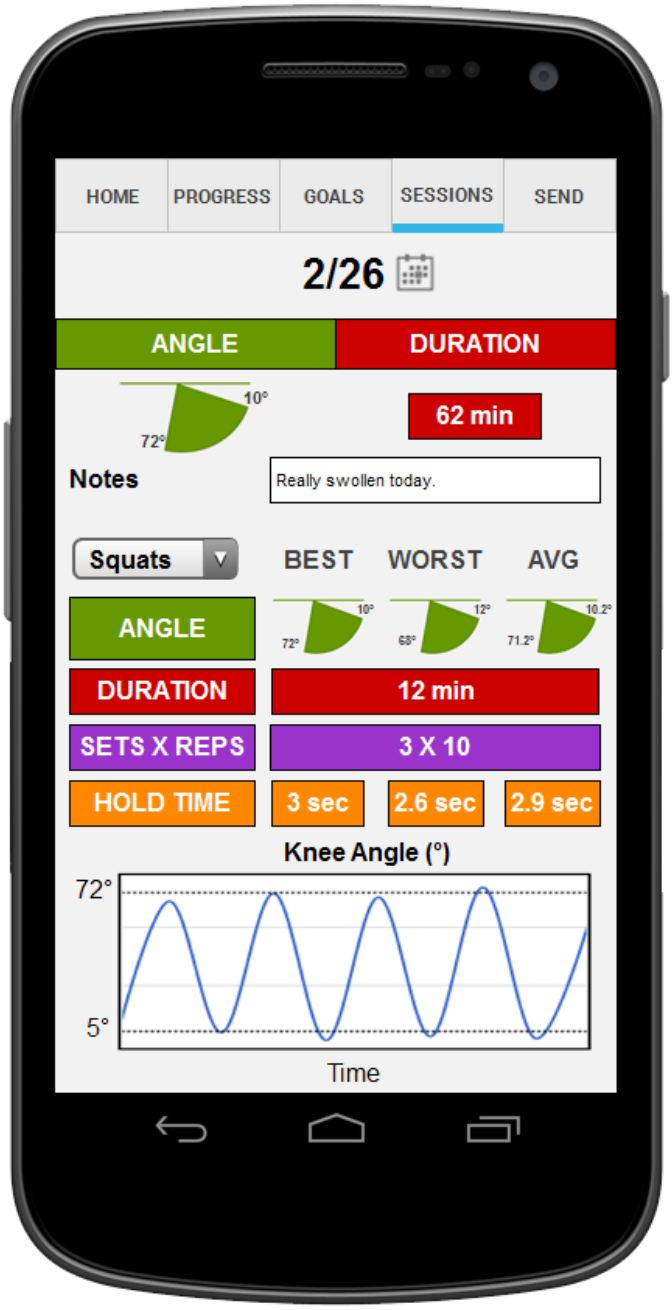

Figure 6.5 Final Prototype Sessions Screen

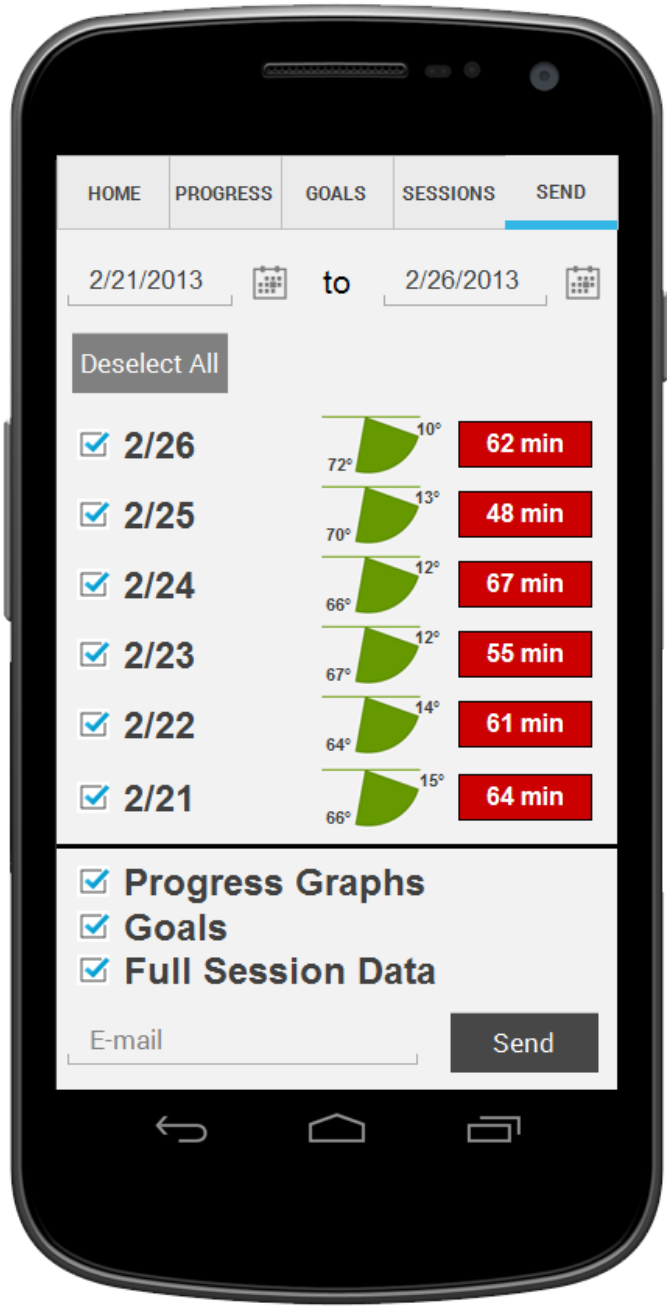

Figure 6.6 Final Prototype Send Screen

6.2 Follow-Up Survey

Participants were sent a follow-up survey to determine whether the final prototype design meets their needs. This survey, shown in Appendix D, collected participants' opinions on different features of each screen; participants were asked to rank each feature from "not very important" (1) to "very important" (4), and comment on why they found a feature important or unimportant. The survey also asked participants if they would add anything or make any improvements to the prototype shown. Eight participants responded.

6.2.1 Home Screen

Participants thought all features on the home screen were at least moderately important. P7 said, "I feel very strongly that all of the features checked as fours would be important in my development and in my recovery. Each would serve to help speed up the recovery process." He rated all features except the "Next Session" section as "very important". P8 stated, "I really like the appearance and what is on the home screen. It is simple and looks like it would be easy to use." Participant preferences for each feature are shown in Figure 6.7, and the most frequent response (mode) for each feature is in Figure 6.8.

The "Next Session" section was considered less important than the other features. P7 said, "I'm not so concerned with that as I will see it when I am doing the session." P8 had similar comments, and stated, "I don't think it is very important to see what the next session will look like, but rather what the last looked like and how it has progressed."

The "Upload Session Button" was considered important (rated a 3 or 4) by 6 of 8 participants. P12 said, "I think upload session could be highlighted more since it's the most important feature."

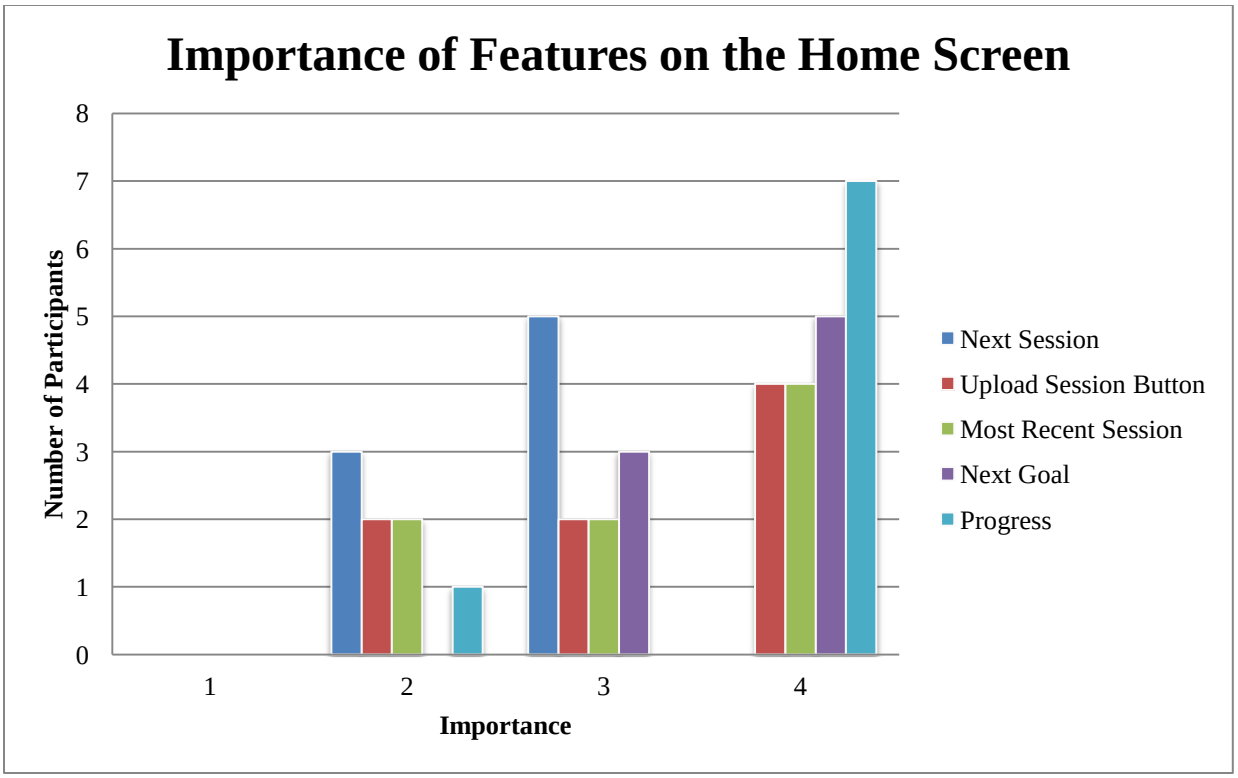

Figure 6.7 Importance of Features on the Home Screen

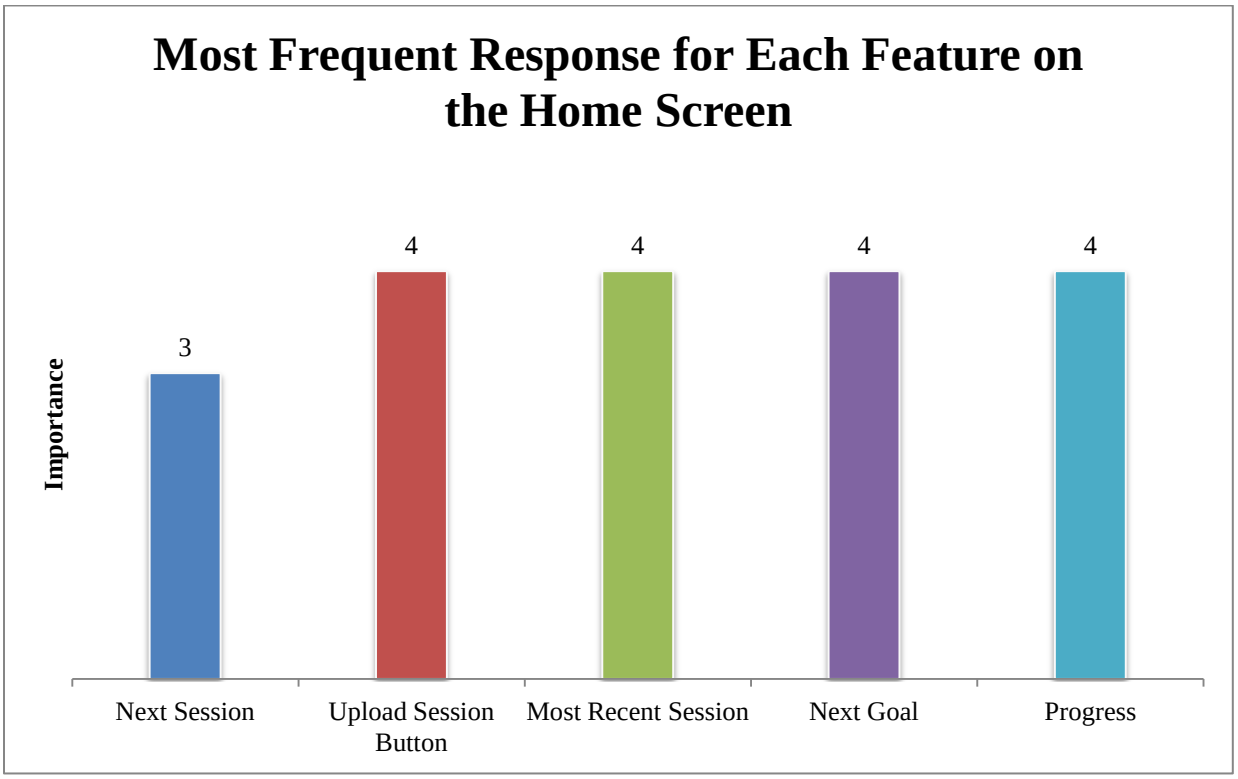

Figure 6.8 Most Frequent Response (Mode) for Each Feature on the Home Screen

The “Most Recent Session” section received similar ratings. P6 commented, “I like to see how well a session went”, while P12 stated, “Most recent session is not as important but it's nice to see all the information on the screen.”

All eight participants rated the “Next Goal” section important. P12 commented, “Progress and next goal go hand and hand to me. You can see how far you have come, while look[ing] ahead [at] what you are going to do.” P7, however, was confused by the “Next Goal” section, and said, “I feel like next goal could be displayed in a better way.”

Almost all participants stated that the progress graphs were very important. P9 said, “Gotta think big picture, recovery is slow and you need to get past the daily ups and downs.” The one participant that said it was less important, P4, commented, “I find what you have accomplished today [is] more important than what has been accomplished in the past as well as what will be accomplished in the future.”

Participants did not think anything should be added to the screen, and when asked what improvements could be made, comments were generally cosmetic. P7 stated, “I would change the line graph, so that it includes points on the dates. It is not always easy to determine the exact numbers without the data points.”

6.2.2 Progress Screen

Participants generally liked the progress screen. P8 said, “I really like the simplicity and how easy it looks to use.” Participants did not think anything should be added to the screen, and only one participant commented on an improvement; he stated, “I don't really like the font as all caps.” Participant preferences for each feature on the progress screen are shown in Figure 6.9, and the most frequent response (mode) for each feature is in Figure 6.10.

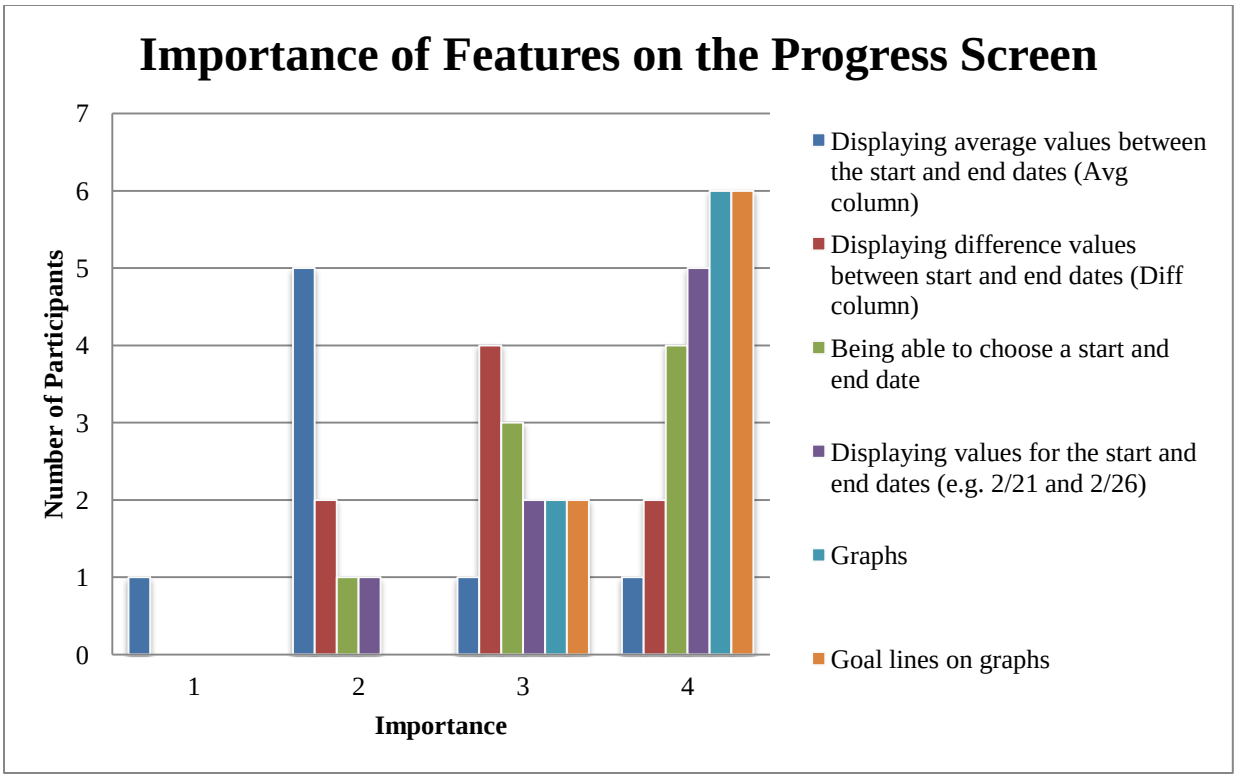

Figure 6.9 Importance of Features on the Progress Screen

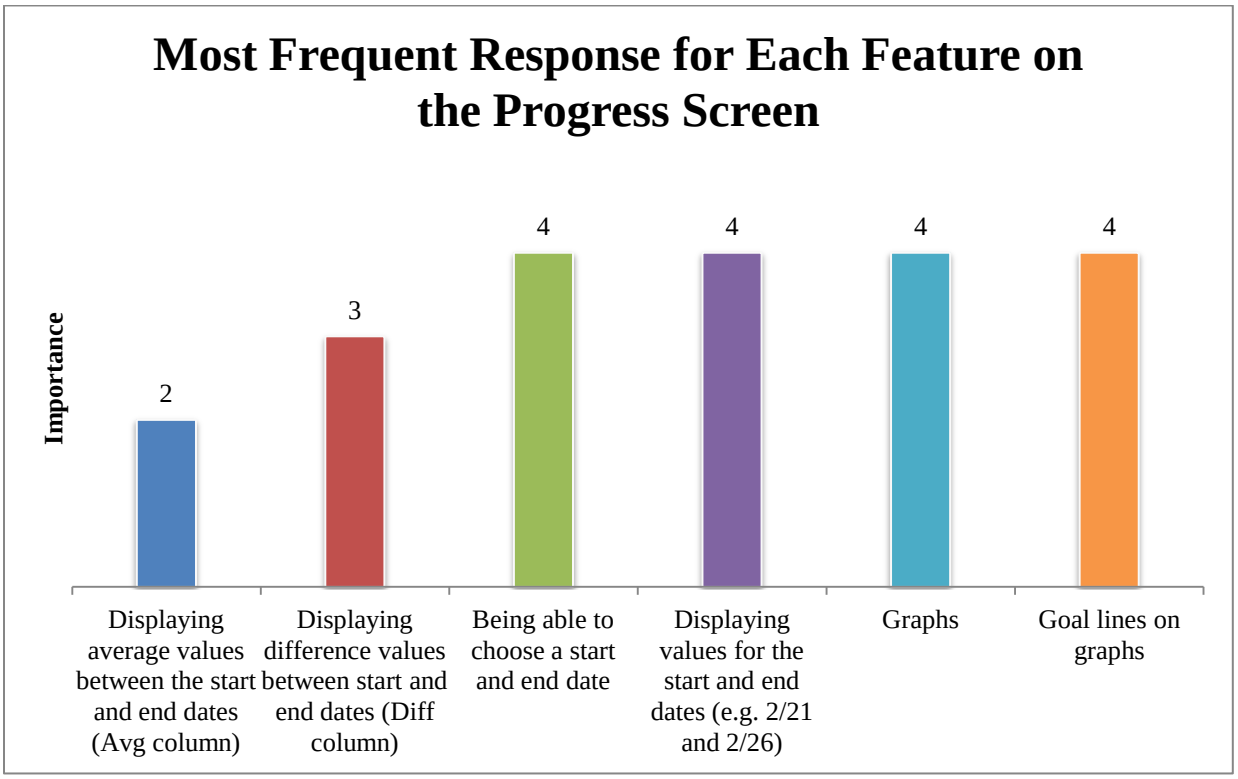

Figure 6.10 Most Frequent Response (Mode) for Each Feature on the Progress Screen

Participants rated “Displaying average values between the start and end dates (Avg column)” as least important. P7 said, “The averages aren't really that important to me, because typically maximum is all that I care about.” The average column confused P9, she stated, “What is it asking the average of? Average to reach goal depends on length versus average weekly progress. Average weekly progress would be more beneficial.”

“Displaying difference values between start and end dates (Diff column)” was more important than the average column, e.g., 6 of 8 participants said that the difference was important. P12 noted, “Graphs, goal lines, and difference are important because you immediately get an idea of where you are and where you should be.”

Participants believed that “being able to choose a start and end date” was also useful, as 7 of 8 participants said that this feature was important. P12 said, “Displaying and choosing start dates gives you flexibility.”

Participants also thought that “displaying values for the start and end dates (e.g. 2/21 and 2/26)” was important. Specifically, 7 of 8 participants rated this feature as important, and five said it was “very important”. P4 commented, “You NEED to layout the timeline so the start, intermediate, and end dates are all very important.”

The graphs and the goal lines on the graphs were rated the most important features; in fact, all eight participants said these features were important, and six said they were “very important”. P8 stated, “I think that the graphs of progress and graphs of the goals are important to have in order to visualize how well you are doing compared to your goals and what you would like to reach.” These sentiments agree with comments from the initial user study (see Section 5.13).

6.2.3 Goals Screen

Participants were more confused by the goals screen than the home screen and progress screen. Participant preferences for each feature on the goals screen are shown in Figure 6.11, and the most frequent response (mode) for each feature is in Figure 6.12.

The "check mark or X for past goals" was ranked as one of the least important features, i.e., 3 participants ranked it a 2, 3 participants ranked it a 3, and the other 2 participants ranked it a 4. Nevertheless, 5 of 8 participants said this feature was important. P4 liked the check marks, stating, "The past goals need to be checked off for a sense of accomplishment." P9 commented, "I don't like the red x for past goals not reached, you should merely be able to extend the goal date… The red x might be discouraging especially when it's a long rehab." P7 had similar thoughts, i.e., "You don't want negativity, so I would eliminate the check and X marks for goals."

Participants had identical ratings for the "End Date". P9 said, "End date is ok, but often times these dates can be pushed back, so sometimes it's unreasonable to put end date on them." P7 also thought the end date was less important; he commented, "What's important is the physical goal and if you have achieved it or not… I would just have the app follow the logic of: First what is your goal? Then when did you complete it."

"Past Goals" were considered slightly more important; specifically, 6 of 8 participants ranked this feature a 3, but the other two ranked it a 2. P8 said, "I think the least important thing would be to see past goals in general because the goal is to work towards new ones."

All participants said the angle visualization was important (5 participants ranked it a 3 and the other 3 participants ranked it a 4). P12 said, "It's important to show dates and the range

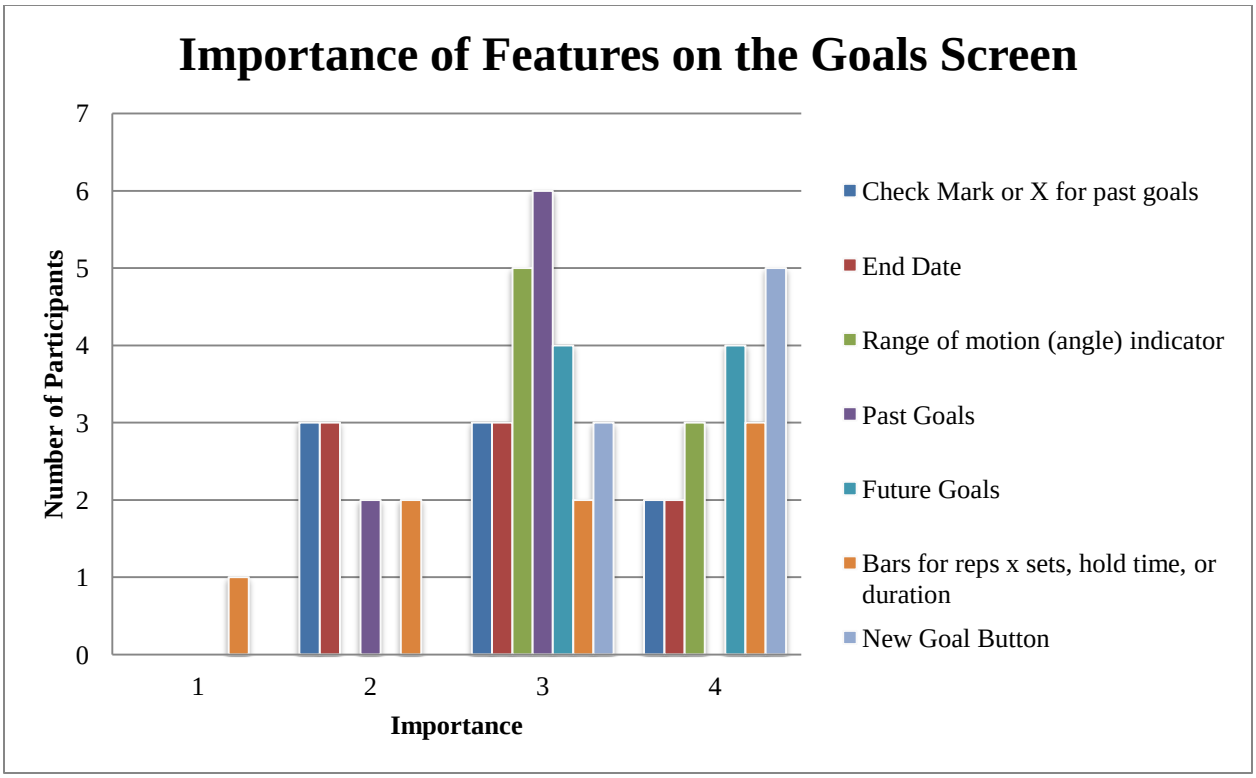

Figure 6.11 Importance of Features on the Goals Screen

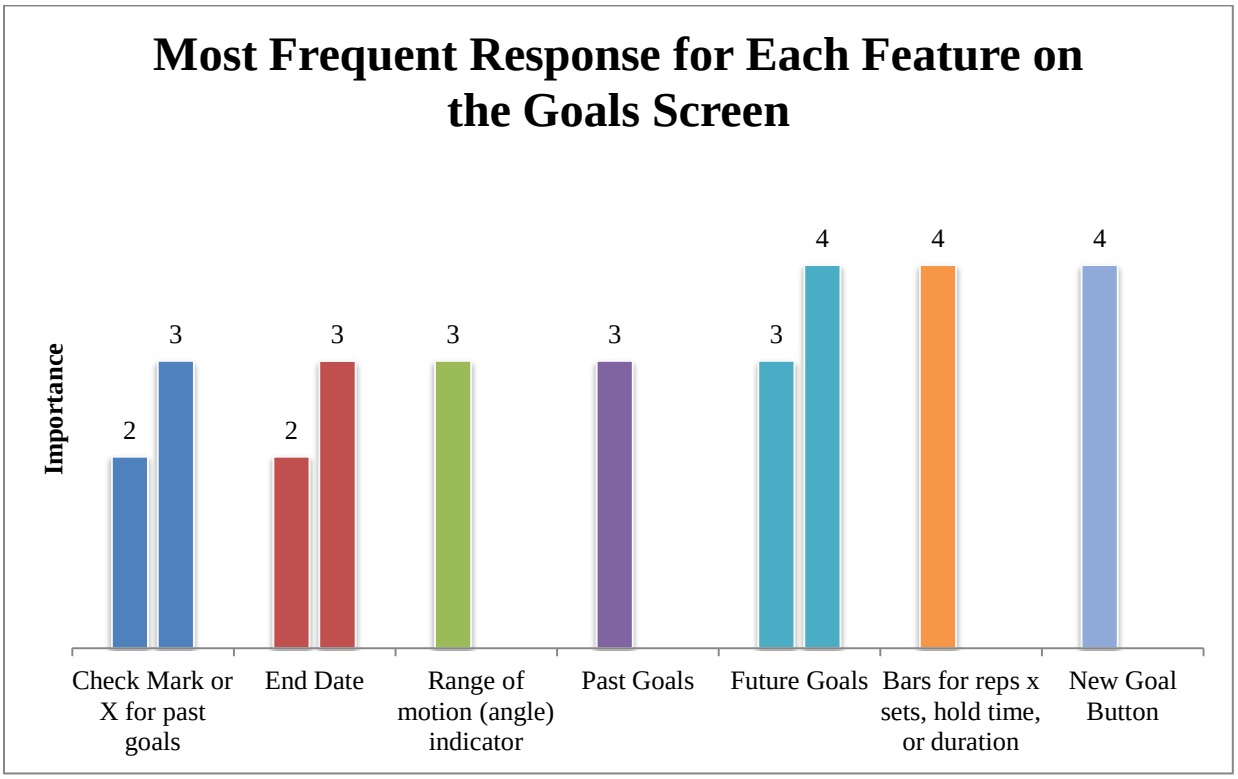

Figure 6.12 Most Frequent Response (Mode) for Each Feature on the Goals Screen

of motion for visual purposes." Three participants, however, reported confusion relating to the angle visualization. P7 stated, "I don't really like the angle indicator. I feel like there could be a better, simpler way of displaying the information… I would change the angle goal indicator to something else, like a simple bar graph or a complex leg that is bent or extended saying what you have achieved out of the target (like it is, but with a different indicator)." P8 overcame her initial confusion; she commented, "These were a little confusing at first, but once you look at the screen and examine what everything means, they became more clear."

Every participant rated "Future Goals" as important, and four participants said that future goals were "very important". P7 commented, "I think it's very important to have the goals easy to make and easy to see, because they are what drives you."

The most frequent response (mode) for the progress bars was a 4, as three participants rated them as "very important"; two participants, however, rated them a 2, and one participant ranked them a 1. P9 said, "I like the progress bars that are partially full very cool." P8 also thought they were important, i.e., "I think that is important to be able to see what goals are being met by the range of motion and bars for reps and hold time." P7, however, did not think the progress bars were important; he commented, "I do not think that bars for reps sets etc... is that important because that is almost never the goal. That is simply the rehab structure that you use in order to achieve goals." When asked for improvements, he stated, "I would get rid of the bars for reps and sets goals, because they aren't really relevant. The goals you are focusing on are mainly range of motion." Three participants reported that the progress bars were confusing. P8 stated, "Make the progress vs. goal a little more clear. The bars going sideways are a little confusing at first."

The “New Goal Button” also had a mode of 4, and all participants said it was important. In fact, five participants rated the “New Goal Button” as “very important”.

Participants had relatively few comments about the edit goal screen. P4 said, “This section is a necessity so I don't see any feature more or less important [than] another.” Participant preferences for each feature on the edit goal screen are shown in Figure 6.13, and the most frequent response (mode) for each feature is in Figure 6.14.

The “N/A Button” received mix reviews. P12 liked it; she commented, “End date and [N/A] are valuable because it makes your goal more specific and you are able to choose the right exercise.” P9 said, “The [N/A] button can be nice if you need [it as] some exercises don't have reps or a hold time.” P7, however, reported that he found the N/A button confusing; he stated, “I don’t know what the N/A button is for.” He later noted that he understood its purpose, but still did not like it, i.e., “I think I understand now that it is supposed to allow you to not set a goal for that parameter, but that seems silly to me. I think you should just have the option to pick things that you want to set goals for.” When asked for improvements to the screen, he commented, “I would get rid of the N/A button and implement a different system that allows you to choose which parameter you actually want to set a goal for. My goals are not all of these things at the same time, and should not be required to be achieved all at the same time… Don’t lump everything into one goal.”

The “Notes Section” had the same mode as the “N/A Button”; 5 of 8 participants rated the “Notes Section” as important. P6 stated, “Notes are very important because more helpful tips on exercises are useful.” P7 had similar sentiments, i.e., “The notes section is good for understanding what I need to do to achieve my goal.” P8 and P12, however, did not find the

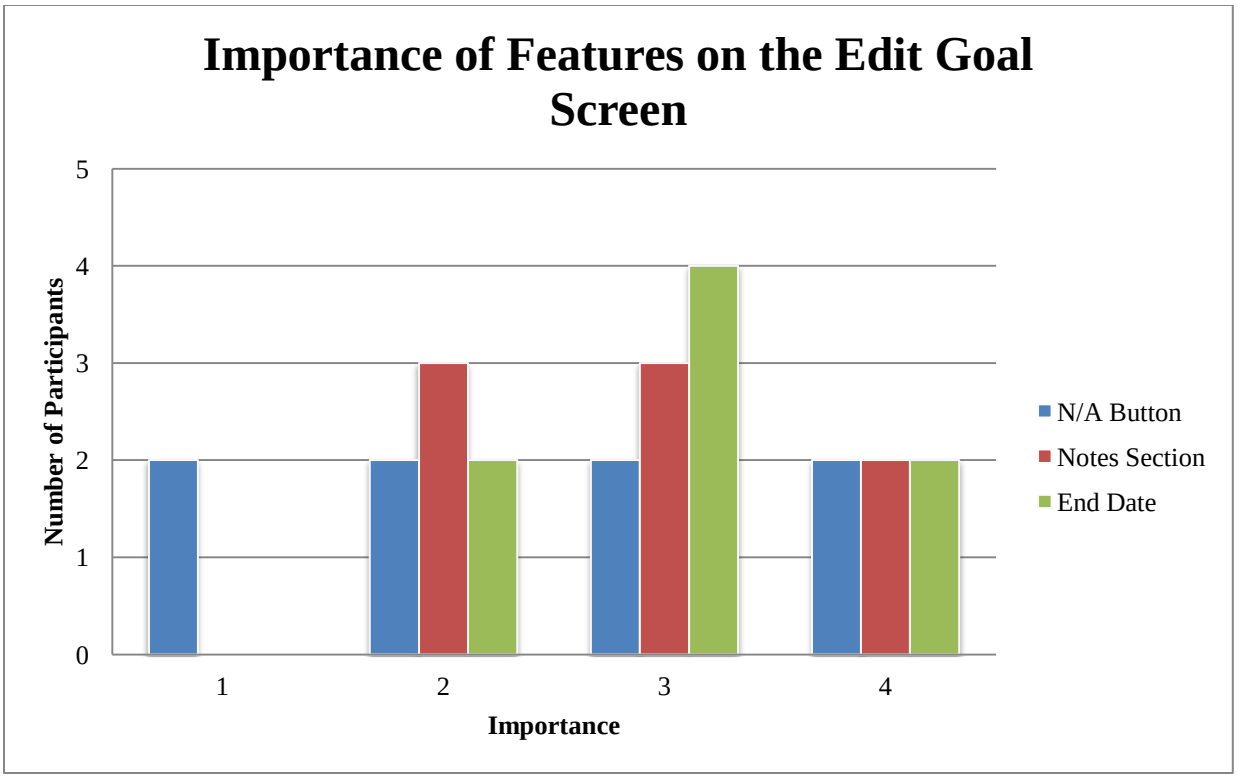

Figure 6.13 Importance of Features on the Edit Goal Screen

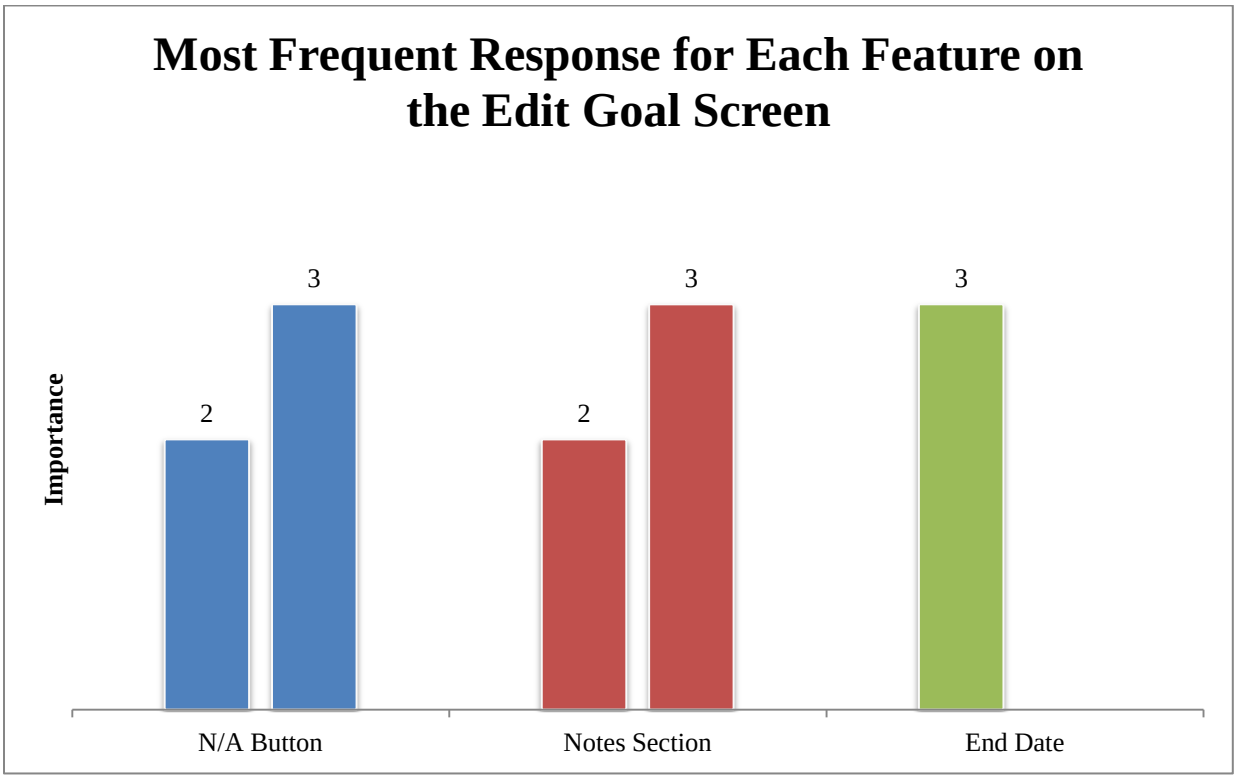

Figure 6.14 Most Frequent Response (Mode) for Each Feature on the Edit Goal Screen

"Notes Section" as important. P8 commented, "I don't think having notes is as important as being able to set reps, time, and an end date."

The "End Date" feature received a ranking of 3 from four participants, while two participants ranked it a 2 and the other two ranked it a 4. Participants that rated end date as unimportant on the edit goal screen also said it was not important on the goals screen. P9 said, "End dates change or sometimes it isn't easy to put a date on it because it's up to mother nature." P7 commented, "I don't think that the date is extremely necessary. I fe[e]l more inclined to set a goal, then record the date that I achieved it."

6.2.4 Sessions Screen

Participants did not say much about the sessions screen, but the most features were considered important. P12 said, "Tied everything together really nicely!!!" Participant preferences for each feature on the sessions screen are shown in Figure 6.15, and the most frequent response (mode) for each feature is in Figure 6.16.

"Angle for entire session" was rated as one of the least important features. P7 reported that he was confused by this feature; he stated, "It doesn't state that it is the max/min... To me this is an undefined parameter." "Notes for the entire session" was also rated low.

"Graph for each exercise" and "duration for entire session" were rated as important; in fact, only one participant rated each feature as not important. P9 said, "The graph can make sure you are reaching the required depth of the bend or flex in the exercise also and that you don't cut corners." P7 had similar comments, i.e., "Love the graph feature and the best, because they show you where your goals are."

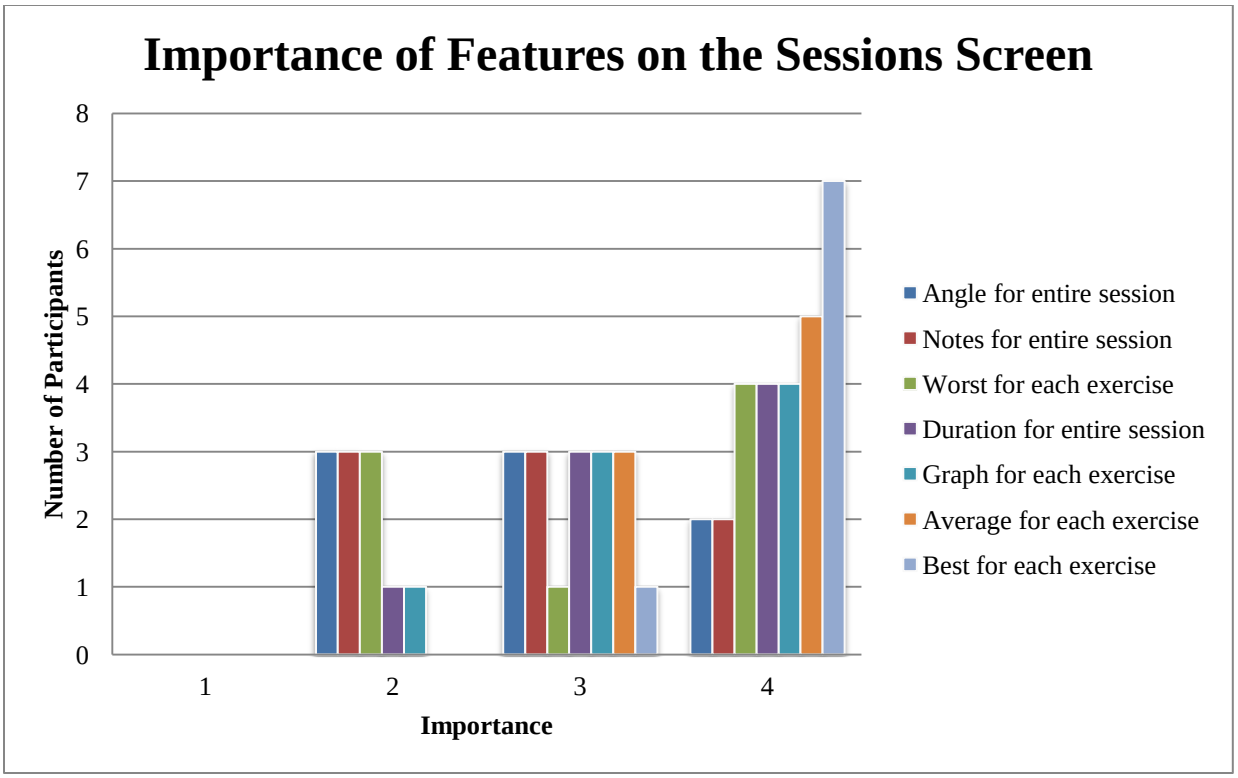

Figure 6.15 Importance of Features on the Sessions Screen

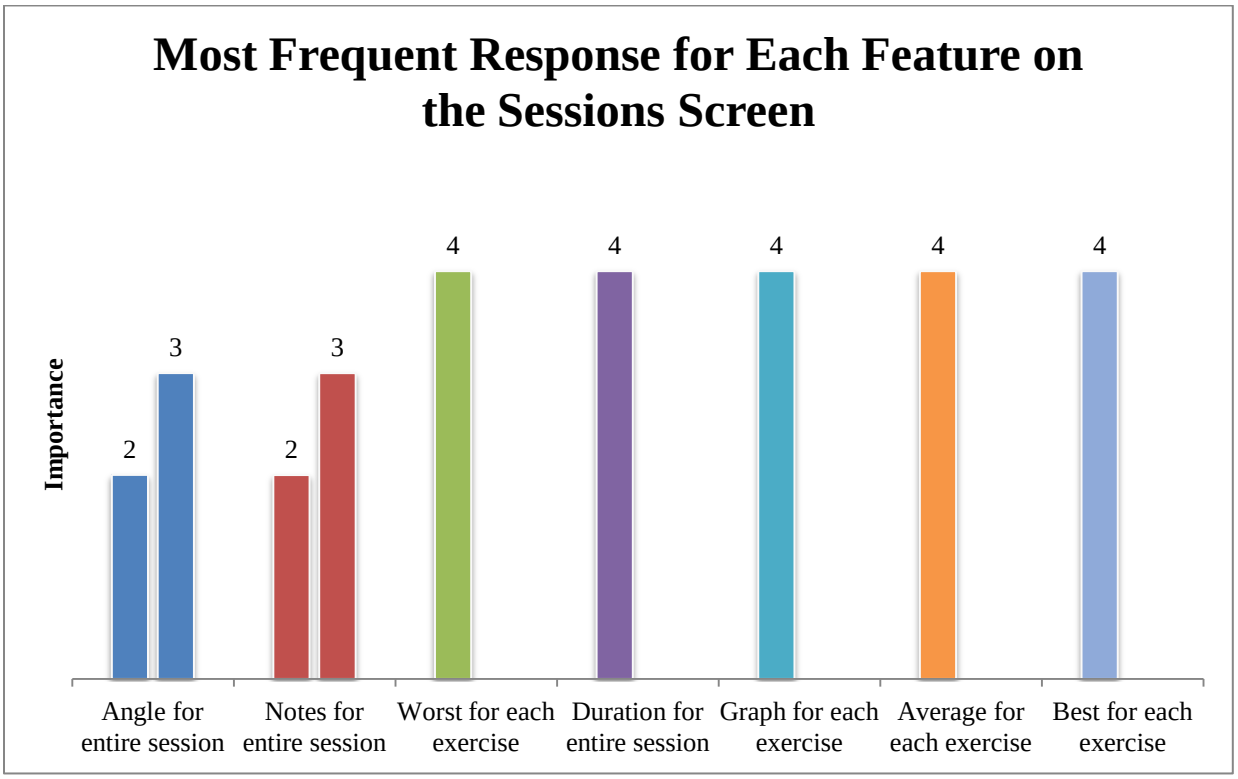

Figure 6.16 Most Frequent Response (Mode) for Each Feature on the Sessions Screen

"Average for each exercise" and "best for each exercise" were the only features that all participants rated as important. Three participants did not find "worst for each exercise" important. P7 said, "I don't really care about my worst." P9 commented, "Having best and worst is nice because you can see how you progressed through the workout and also how you did in general."

6.2.5 Send Screen

Participants liked every feature of the send screen, as the most frequent response for all features was a 4. P7 said, "I like all of these parameters a lot and feel that this page may be set up the best of all of them." P12 noted, "This is all useful information to provide your therapist." Participant preferences for each feature on the send screen are shown in Figure 6.17, and the most frequent response (mode) for each feature is in Figure 6.18.

"Being able to send goals" was one of the least popular features on the send screen, with two participants rating it a 2. P9 commented, "That is usually something you talk about with your physical therapist, so sending them wouldn't really be useful for the doctor to see (they only make sure the thing heals) and the physical therapist sets the goals." P6 had similar sentiments, and said, "Being able to send goals is not as important because they are usually discussed in person with the trainer or therapist."

Participants rated "being able to only select certain days (checkboxes)" as important. This matches earlier sentiments that users should be able to selectively send data to their therapist (see Section 5.5 for details).

Every participant rated "being able to send full session data" as "very important". P8stated, "It is important to be able to send all of the data and do it in a very simple way." She,

however, believed that it was not necessary to show the data on the send screen.

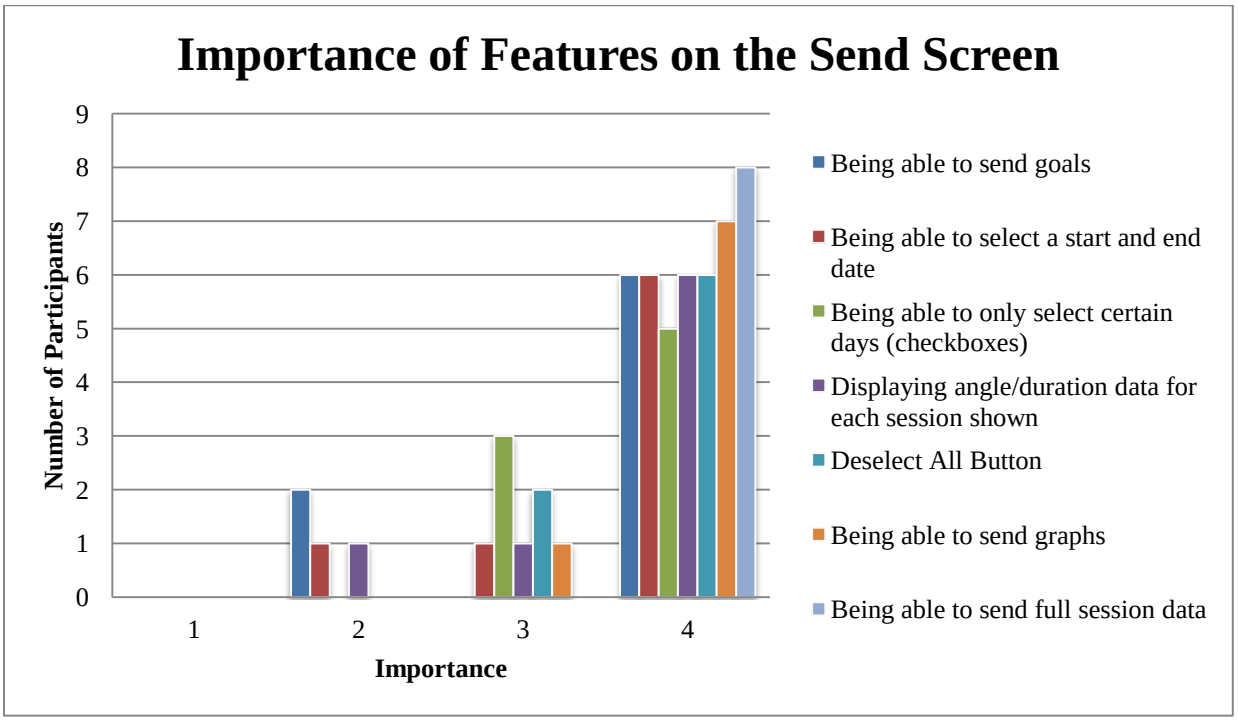

Figure 6.17 Importance of Features on the Send Screen

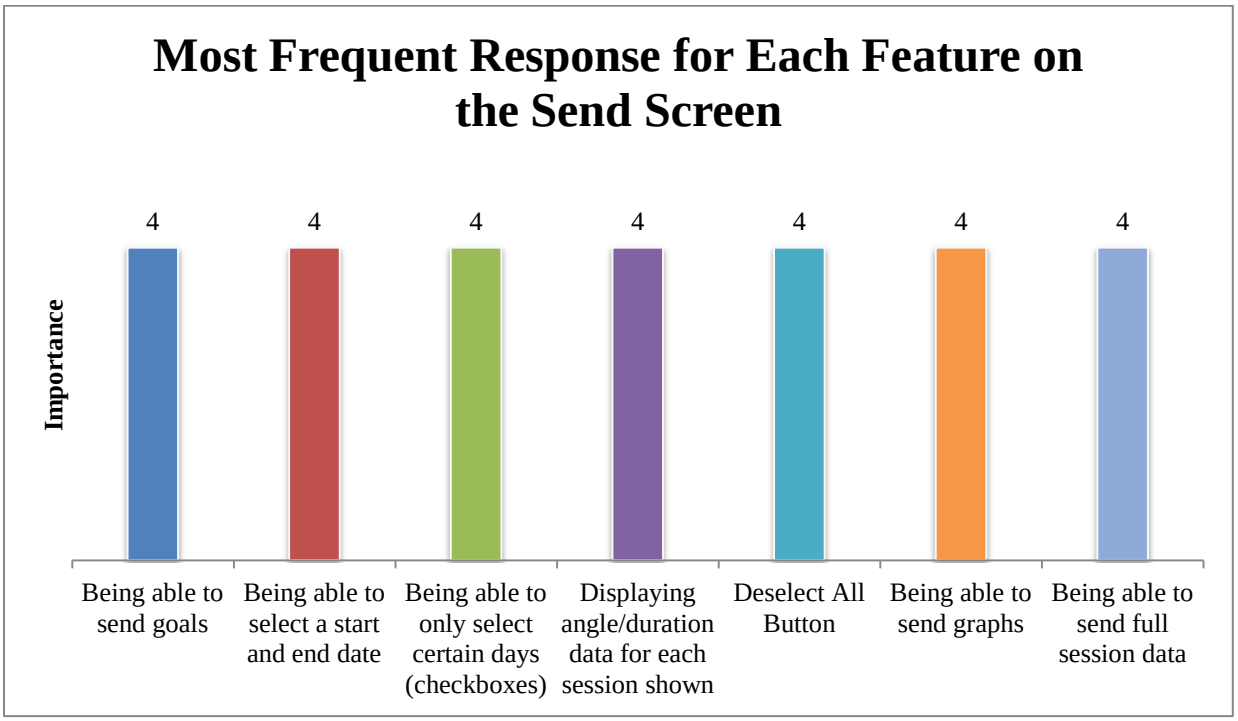

Figure 6.18 Most Frequent Response (Mode) for Each Feature on the Send Screen

6.2.6 Overall Comments

Participants were quite positive about the interface when we asked if they wanted to share anything else with us. P12 stated, “Very good job. You create a great app that can motivate and help a lot of people going through knee injuries.” P7 noted that the application’s success depended on therapist involvement; he commented, “Overall a good app layout, I would use it as long as my trainer was committed to using it.” P8 liked its simplicity, and said, “The overall design looks simple to use and makes a lot of sense.”

The send screen was the most popular, and the edit goal screen was the least popular. One feature had a mode of strictly 2, six features had a mode of both 2 and 3, five features had a mode of strictly 3, one feature had a mode of both 3 and 4, and 22 of 35 features had a mode of 4. Thus, we believe that the final prototype design fits our users’ needs. We made minor modifications based on the follow-up survey results to address confusion and better reflect participant preferences. These modifications are described in Section 7.2.1.

CHAPTER 7

SYSTEM DESCRIPTION

Nine participants preferred a smartphone application to a tablet application or website. Although 7 of our 11 participants with smartphones own iPhones and only two own Android devices, we chose to implement an Android application due to researcher familiarity with Android development and easier deployment.

The system consists of PT Viz (described in Section 2.2) and an Android application (PT Viz Mobile). The Arduino Pro Mini collects data during exercise sessions and sends the data to the Android application over Bluetooth.

7.1 PT Viz Mobile (Arduino)

The circuit consists of two major parts: the existing PT Viz embedded electronics (a small lithium ion battery, an Arduino Pro Mini microcontroller, several circuit components, and two colors of electroluminescent (EL) wire), and a Sparkfun BlueSMiRF Silver Bluetooth module. The Bluetooth module is attached to the Arduino Pro Mini microcontroller as shown in Figure 7.1.

The Bluetooth module is discoverable to nearby devices when PT Viz has power. Users can utilize the Android system's Bluetooth pairing interface to connect to the Bluetooth module, which is named "PT Viz". Each user only needs to pair PT Viz with his or her phone one time. When the user clicks the "Start Session" button on the home screen, the Android application connects to the paired Bluetooth module.

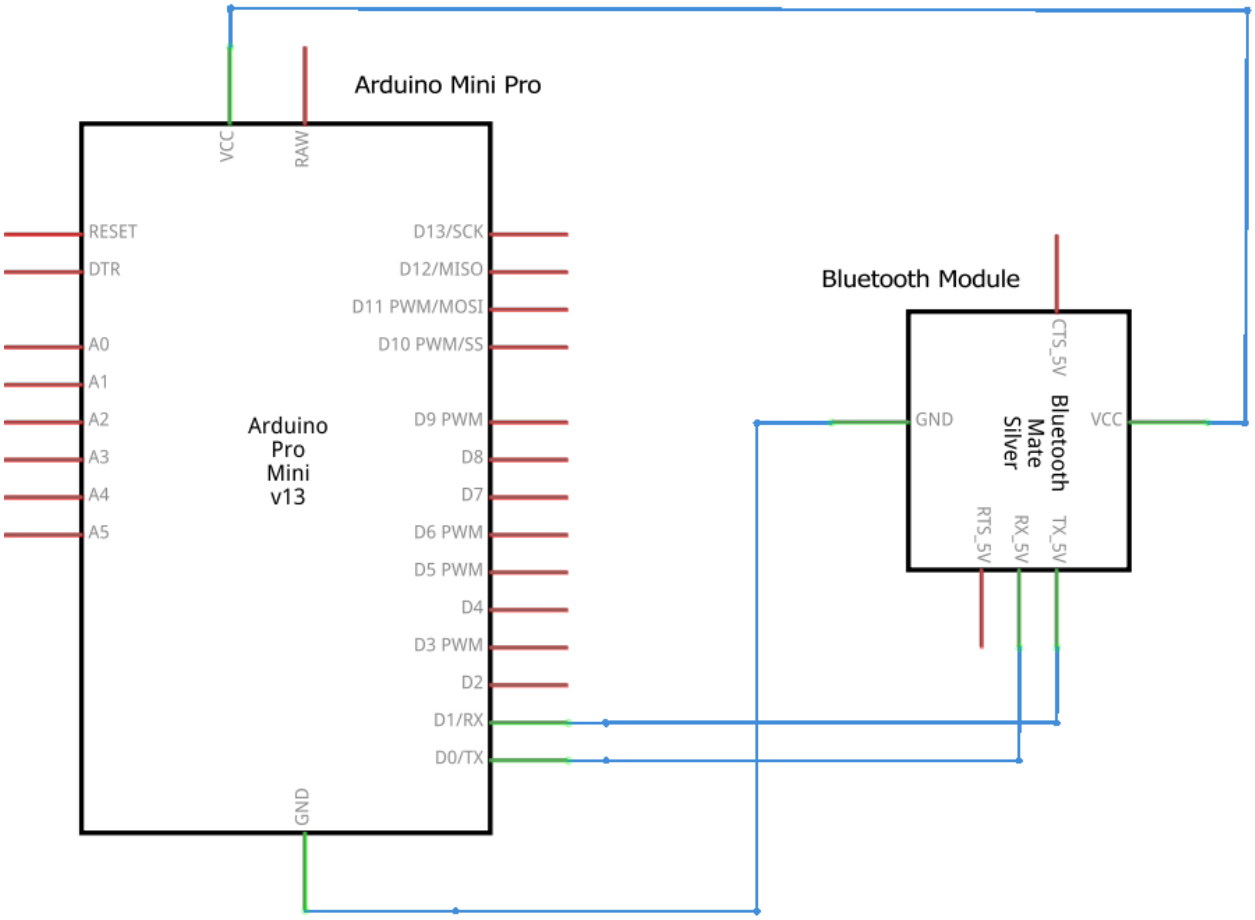

Figure 7.1 Microcontroller Schematic

When PT Viz is on, the Arduino runs code that makes the EL wire bars light up as the knee is flexed. The Arduino also collects values from the bend sensor every 50 milliseconds. If the user is currently in a session, the Arduino sends these values to the Android application over an open Bluetooth socket, and the Android application writes these values to a text file for future processing. When the user clicks the “End Session” button, the values are processed as described in Section 7.2.1 and inserted into the database. If the Bluetooth connection is lost, the text file is still processed and summary values are inserted into the database.

7.2 Android Application

The Android application was developed in Eclipse with the Android Developer Toolkit plug-in. Because the design is centered around the idea of five screens (home, progress, goals, sessions, and send), the code is also structured based on these tabs. We used Git as a version control system, and all code is located in a private Github repository at https://github.iu.edu/lkaberle/PTVizMobile.We utilized fragments to implement each screen of the design, and followed Android best practices whenever possible.

All code is contained within the edu.mines.ptvizmobile package. Within this package, sub-packages include customViews (i.e., classes that define views for the angle visualization and progress bar), screens (i.e., a Fragment for each tab in PT Viz Mobile), tabManagers (i.e., classes that define behavior for switching between screens), and util (i.e., dialogs and a class that manipulates dates). Layouts for each screen are defined via XML in the res/layouts directory.

PT Viz Mobile uses an external, open-source Android library (AChartEngine) to display all graphs. It also utilizes a SQLite database to store all session and goal information. The database schema is shown in Figure 7.2.

7.2.1 Processing Session Data

When session data is received over Bluetooth, it is written to a text file that is stored on the Android phone. This text file must be processed in order to report summary statistics for each session. First, values from the bend sensor must be converted into angle measurements. Because there is a linear relationship between the bend sensor and the knee angle, this is a simple calculation. PT Viz, however, must be calibrated with the bend sensor value at two known knee angles. The user can perform this calibration from the menu on the home screen. The application

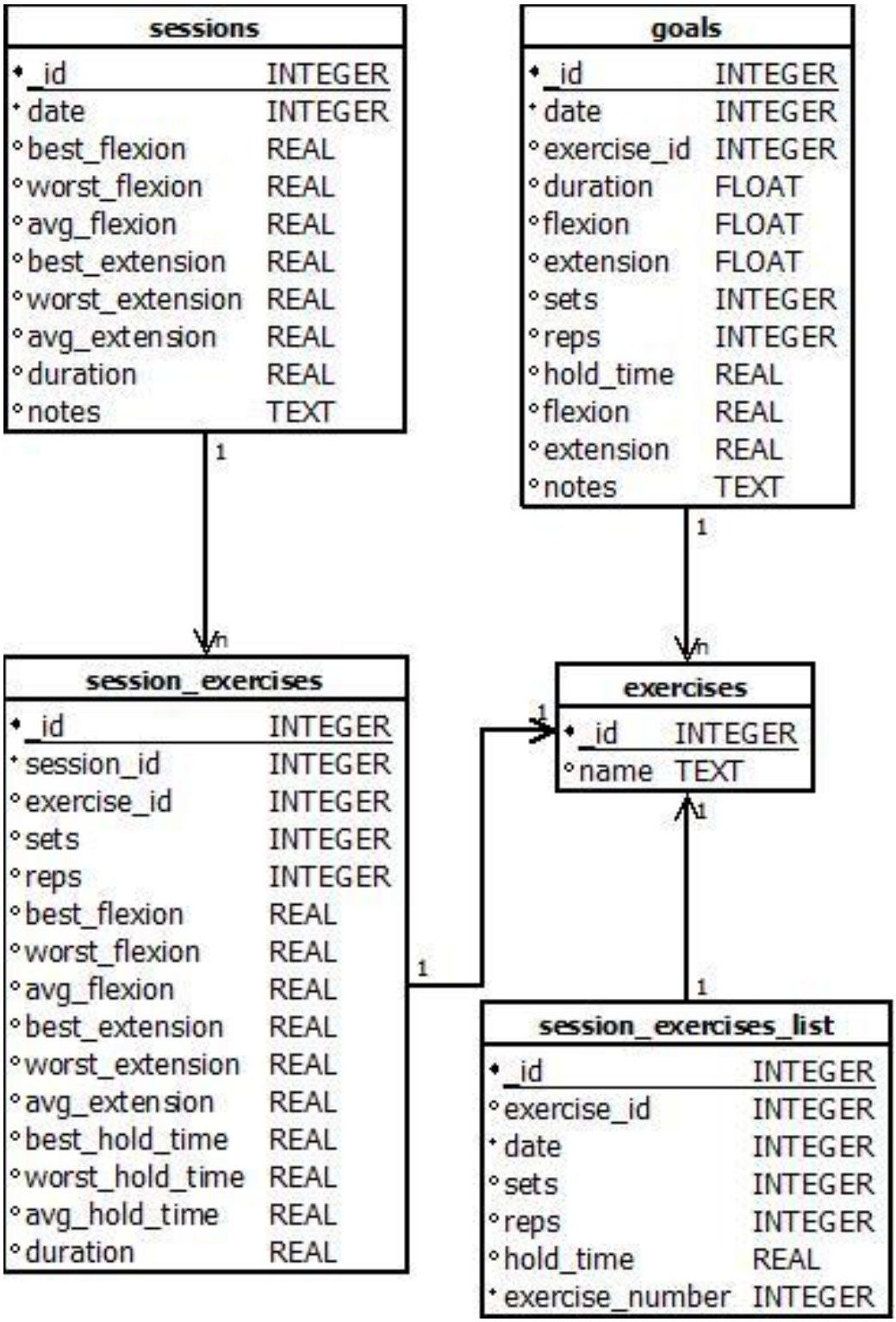

Figure 7.2 Database Schema

asks the user to hold the knee at 90 degrees and press a button, and then move to 0 degrees and press a button. If the user does not have this range of motion, the user can input two separate known angles (instead of 90 degrees and 0 degrees) to complete the calibration.

We must also determine how many exercises the user performed. This requires input from the user during the exercise session, as we cannot reliably distinguish a break in activity as a break between exercises or a break between sets. The user simply presses the "Start Session" button on the home screen at the beginning of the session to inform the application that they are starting a session, and then presses another button when they are moving to a successive exercise.

For each exercise, we define a break between sets as a relative lack of activity for more than 10 seconds. Within each set, a repetition is defined as passing some intermediate threshold value to reach a local maximum flexion angle or minimum extension angle, with a return past the threshold value to approximately the angle at which the repetition started. Hold time is more complex, as the user may waver a bit at an extension angle before completing the repetition. We calculate hold time as the amount of time spent within a threshold of five degrees of the minimum extension angle. We also gather maximum, minimum, and average flexion and extension angles for each exercise and session. The average is calculated over every maximum (flexion) or minimum (extension) knee angle. Duration is calculated for each exercise as well. Each session is stored in the sessions table of the SQLite database, with its constituent exercises stored in the session_exercises table. We create a new text file for each exercise; the text file is retained in order to generate the graph found on the sessions screen.

7.2.2 Screenshots

Unless otherwise noted, any differences between these screenshots and the mockup of the final prototype design are purely style differences between Android graphics and the wireframe application, which is called Justinmind, used to mock up the final prototype design. The only exception is the angle visualization, which was slightly modified so that the horizontal green line only extends to the start of the arc, rather than across the entire visualization. This change was implemented so that the angle visualization better emulates a graphical representation of the range of motion of a knee.

The home screen is shown in Figure 7.3. The progress graphs are omitted in this figure, as they are shown in the progress screen. The only modification made to the home screen after the follow-up survey was the substitution of the "Upload Session" button with the previously described "Start Session" button. The original design assumed that a text file stored on the Arduino during each session would need to be transferred to the Android after the session. Since values can be uploaded during the session and stored on the Android device, uploading a session after the session is no longer necessary.

The progress screen is shown in Figure 7.4. We note that the extension and duration graphs are shown when the screen is scrolled down. No modifications were made to the progress screen after the follow-up survey.

The goals screen for PT Viz Mobile is shown in Figure 7.5, and the edit goal screen is shown in Figure 7.6. We note that the screen title ("New Goal" or "Edit Goal", depending if the user is editing a goal) and the save button can be seen by scrolling up or down, respectively.

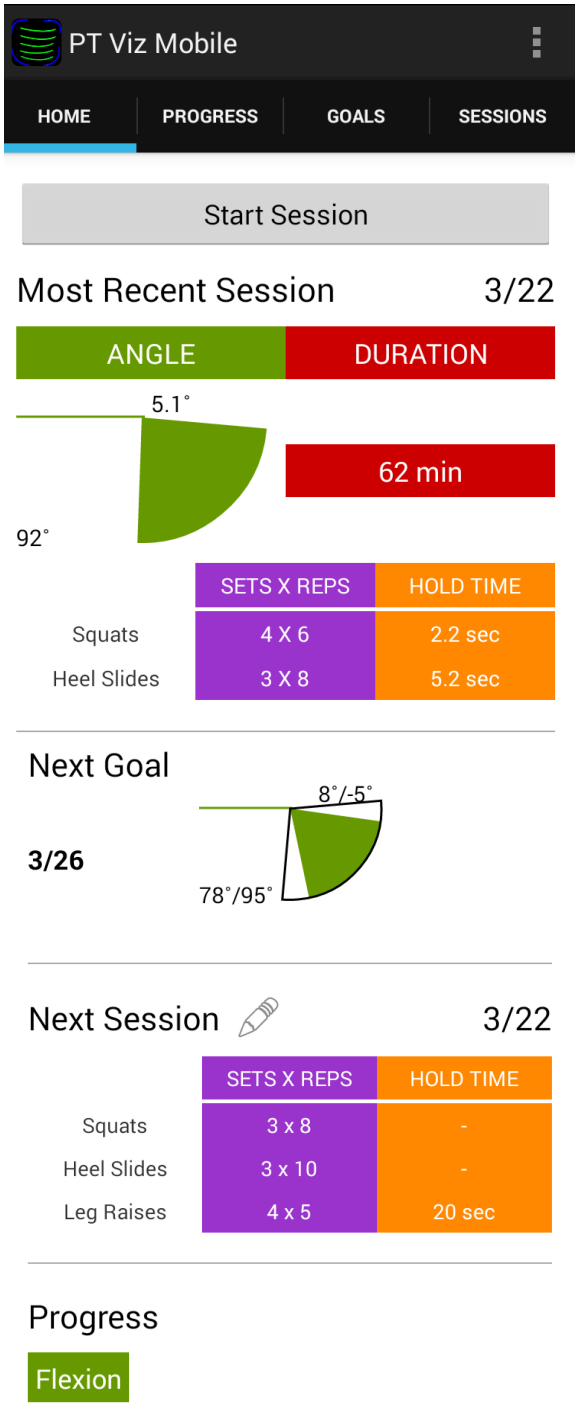

Figure 7.3 PT Viz Mobile Home Screen

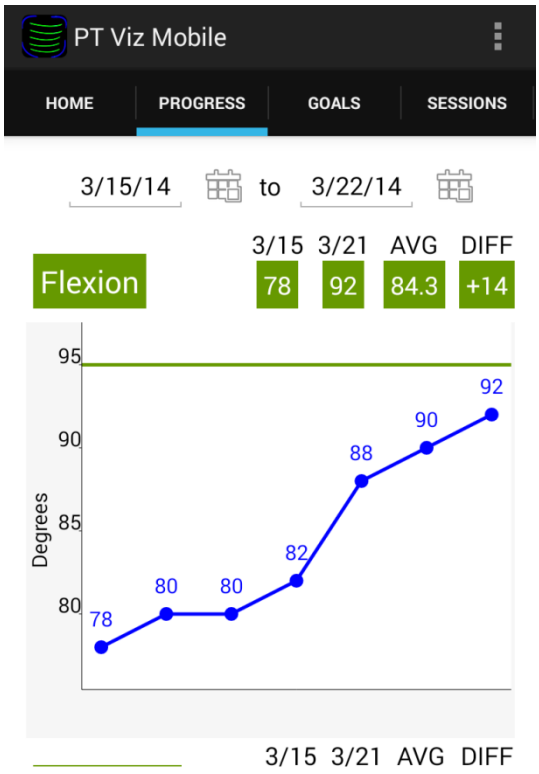

Figure 7.4 PT Viz Mobile Progress Screen

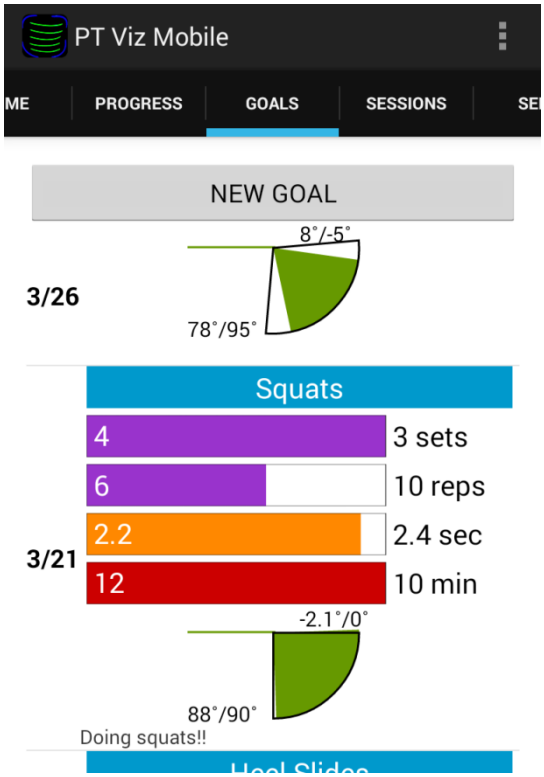

Figure 7.5 PT Viz Mobile Goals Screen

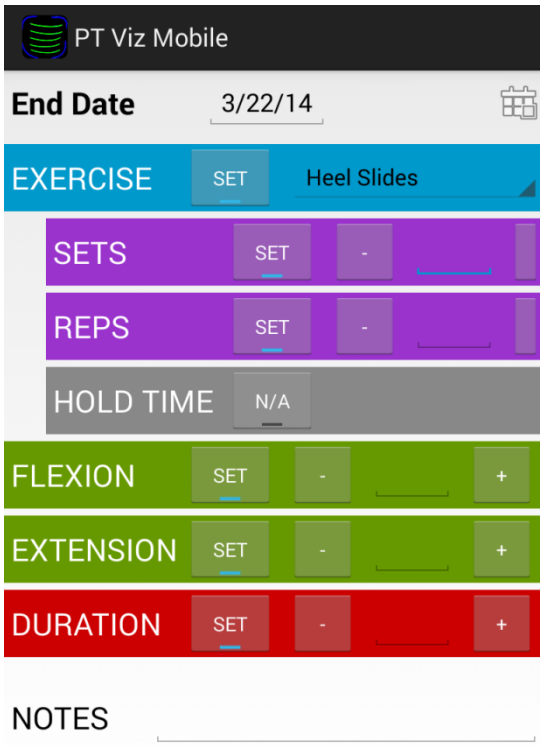

Figure 7.6 PT Viz Mobile Edit Goal Screen

Participants expressed concerns in the follow-up survey regarding the progress bars shown for sets and reps, the X for goals that were not achieved, and the N/A button on the edit goal screen. Thus, the progress bars are only visible for metrics that are set for that goal; if a user does not set goals that include sets and reps, they will not see these progress bars. We removed the X for goals that were not achieved because participants thought it was discouraging; however, we kept the check mark when a goal was achieved because this feature received positive feedback. The N/A button was slightly modified to better indicate its purpose, and metrics that are left blank are not incorporated into the goal.

The sessions screen is shown in Figure 7.7. No modifications were made to the sessions screen after the follow-up survey.

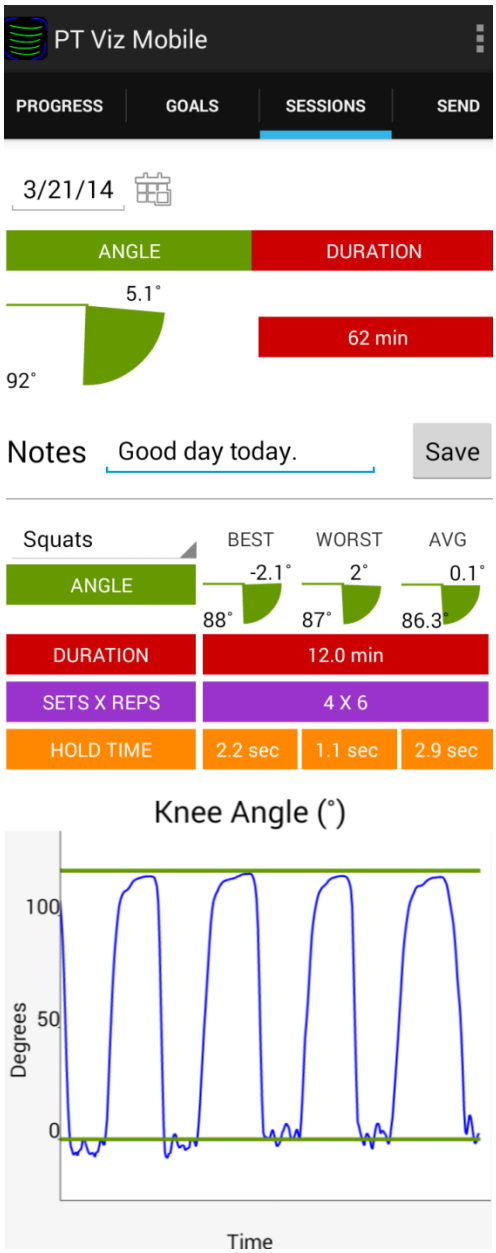

Figure 7.7 PT Viz Mobile Sessions Screen

The send screen is shown in Figure 7.8. No modifications were made to the send screen after the follow-up survey.

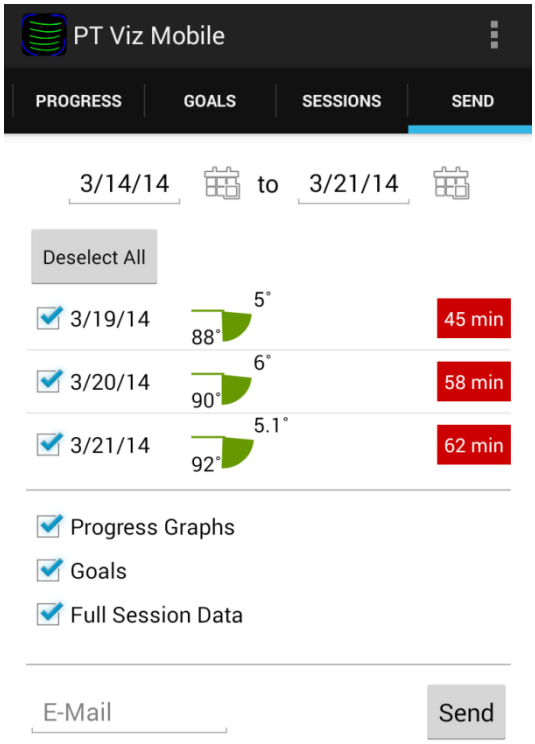

Figure 7.8 PT Viz Mobile Send Screen

CHAPTER 8

DISCUSSION

We have designed and created a useful interface that we expect will improve the rehabilitation process for patients. In this section, we discuss five design considerations for informing future technology in this space. We also consider future research that may further improve the knee rehabilitation process.

8.1 Motivation

The majority of our participants reported few problems following their prescribed exercises (see Section 5.1). This result is likely due to the fact that the majority of the participants were returning to varsity athletics or were previously involved in athletics. Many participants referred to working hard on their rehabilitation to "get back" to playing their sport. Three participants reported doing extra work in addition to prescribed exercises so they could regain mobility faster. We believe that young athletes are motivated to return to their previous level of play after an injury, and will often do whatever it takes to recover their previous ability as quickly as possible. Having participants that had few difficulties following their prescribed exercises was an expected consequence of recruiting mostly college-level varsity athletes. We acknowledge that this level of dedication is not typical of all knee rehabilitation patients. P11 described what we speculate might be a more typical rehabilitation process; he stated, "There's one guy at my work who also tore his ACL at the same time as me, and he had surgery 3-4 weeks before I did. And he was really still working on range of motion long after I was full range of motion, but he was older than me, didn't really care about sports that much. He had a wife and a kid, and so he just kind of fell by the wayside. He'd say 'Sometimes I went to physical

therapy', he'd go see his surgeon and get yelled at to do more physical therapy and so then he'd do it for a couple weeks and then he would stop."

Seven of our participants were current varsity athletes at CSM, and had access to athletic trainers and rehabilitation equipment in the training room every day. This access likely improved their ability to follow exercises closely, as some participants noted that lack of equipment caused some difficulties in completing their exercises. Not all knee rehabilitation patients have the same access to resources that many of our participants had.

College athletes also have coaches and teammates to motivate them to return to previous form more quickly. This encouragement from teammates can help athletes push through difficult stretches in rehabilitation; the goal of returning to play with their teammates is always fresh in an athlete's mind. This idea is supported by a study done in Houston to improve physical activity among women through use of pedometers and an accompanying mobile application [20]. Researchers found that both social pressure (i.e., buddies could see if a woman did not meet her goal) and social support (i.e., receiving congratulatory messages from buddies) improved the woman's motivation to reach her step count goals. Similar connections can be made to athletes recovering from a knee surgery; teammates can see if a patient is not working hard on his or her exercises or does not return to play according to the expected timeline. When a patient achieves a short-term goal (e.g., being able run), teammates will congratulate the patient on achieving that goal.

Even though most participants were motivated to work on their exercises, a few participants reported motivation issues at some point during the recovery process (see Section 5.4). P7 commented that he worked very hard to return to golfing faster than expected, but took

longer than expected to finish the entire course of rehabilitation because he had stopped setting goals. P12 said she would put off other commitments to do exercises until she returned to her previous range of motion, but she was not as committed to her exercises after getting her range of motion back. P10 had similar comments, saying that after she could walk, physical therapy was much less important to her.

Knee surgery patients come from a variety of lifestyles and have various injuries and, therefore, have different recovery times and treatment goals. Even within a small demographic of primarily college athletes aged 18-24, we noticed that motivation suffered after participants reached a satisfactory level of mobility. For varsity athletes, that level of mobility was being medically cleared to return to playing their sport. For former varsity athletes, a slower return to a slightly decreased level of athleticism was acceptable. For patients who are not involved in athletics, walking and a relatively pain-free lifestyle appeared to be the desired goal. We believe that most knee surgery patients are motivated to perform their exercises until they have regained most of their range of motion and the ability to walk and perform everyday tasks. Patients with more aggressive treatment goals will stay motivated until they are satisfied with their level of activity.

Thus, any technology aimed at improving compliance for knee surgery patients needs to keep the patient motivated past the point where they have regained a satisfactory level of mobility. Participants emphasized that having goals motivates them, so if patients set goals using PT Viz Mobile, it should provide extra motivation to perform prescribed exercises. At the later stages of rehabilitation, perhaps therapy is no longer at the forefront of the patient's mind; thus, P7 suggested adding push notifications to alert him to an upcoming goal or when he was not

exercising consistently. These push notifications could remind patients to continue with their rehabilitation throughout the entire recovery process.

Determining how to best keep these participants motivated until they have completed the entire rehabilitation process is an interesting area of future research. Perhaps creating some sort of avatar whose growth and emotions are based on a user's performance, as in [21], would encourage users to complete their prescribed exercise sessions. In this study, researchers found that most participants felt responsibility to care for their avatar, which increased feelings of guilt or happiness when their exercise performance negatively or positively affected their avatar. UbiFit Garden used a glanceable display as a mobile phone background [22]. Various types of flowers grew in a user's garden as she completed a variety of exercises (e.g., cardio or strength), and butterflies appeared for each goal a user met. Participants in UbiFit Garden liked a glanceable display that reset with the start of every calendar week because "(1) it gave them a clear deadline, (2) it provided a fresh start each week, and (3) it reminded them that being active was an ongoing process – something on which they had to stay focused" [22]. These ideas apply well to knee rehabilitation, as participants often referred to determining their progress at the end of each week. Specifically, a reminder to stay focused (i.e., that good progress last week does not mean the patient can slack off this week) might help motivate patients to continue their rehabilitation past their satisfactory level of mobility. Future work could incorporate a glanceable display with a weekly reset to determine if this method might be an effective way of continuing to motivate knee rehabilitation patients.

8.2 Progress

Participants emphasized that seeing progress is important because it was difficult to see day-to-day improvement throughout the slow recovery process. They commented that seeing

progress would help them stay motivated, and that seeing stagnation would push them to work harder. Participants viewed progress in a variety of ways, but often compared current metrics to previous sessions, their healthy knee, or typical recovery metrics for their stage in the rehabilitation process. Any technology that displays progress must understand how its users determine if progress was made. Knee rehabilitation patients compare their current state to past data points in their own recovery progress, others who completed the same process, and their healthy leg.

Comparing current metrics to past metrics is straightforward if enough data points are taken. Wearable technology like PT Viz improves the frequency at which data points are collected, as participants said that these measurements would not be taken very frequently in a clinic. More data, however, is often harder for a human to make sense of, so a simple and intuitive way of displaying this data is crucial. Participants articulated that line graphs would allow them to quickly recognize trends. Line graphs give users the ability to easily compare their current state to past data points in their own recovery process. Thus, line graphs are used to display progress in PT Viz Mobile.

Several participants referred to knowing if they were "where they should be" in the recovery process based on information they received from their therapists. Rehabilitation milestones, such as reaching a certain range of motion, walking, running, and lifting weights, will occur at different times for each patient, and these milestones are determined by factors such as age, weight, height, gender, and type of surgery. P7 and P12 requested that the interface display typical recovery milestones, or flexion/extension angles personalized for their recoveries, so the patients could visually see if they were "where they should be."

One area of future research is to help patients better know if they are "where they should be" by providing them with data on these milestones. Researchers held focus groups with breast cancer patients and providers to determine the needs of both groups in creating an online tool to organize a breast cancer care plan [23]. They discovered that patients wanted to see information about their original diagnosis and treatment plan, as well as a schedule of treatments. Patients also wanted to integrate their personal calendars and upcoming important events into scheduling these treatments. Furthermore, patients found it useful to see a graphical view of all their care in order to "visualize their entire care plan and where they were in the treatment cycle" [23]. Much of this information could be useful for knee rehabilitation patients as well. Perhaps a patient wants to return to walking as quickly as possible in order to attend an important event, so she spends additional time on therapy leading up to the event. The application could adjust her calendar of treatment accordingly to give her intermediate goals to achieve the desired milestone. The patient could also decrease their time spent on therapy during a busy week at school or work, and see how this decreased effort would delay achievement of future milestones and the end date of treatment. One requirement for an approach like this would be the data to create this patient-specific plan based on age, gender, weight, height, and type of surgery. Every patient is different, and this adjustable calendar approach requires sufficient data to reliably predict how quickly patients would realistically achieve a given milestone.

In addition to their regular clinic visits with the therapist, the application could also supply users with supplemental information about the recovery process. For example, researchers created HeartCare, a website that provides each patient with a tailored home page that provides information based on the patient's recovery period [24]. Similarly, we could display this information to knee rehabilitation patients immediately after knee surgery. It would

provide information about initial post-surgery care and what the patient should expect. Once the patient started physical therapy, the page could display upcoming expected milestones and other resources for their stage in the rehabilitation process.

The other form of progress that participants strived for was returning their newly repaired knee to the same level of ability as their "good leg", in terms of metrics such as flexion and extension angle, as well as hamstring and quad strength. Participants suggested that the ultimate goal of rehabilitation is to return to as much range of motion and strength as their uninjured leg, and being able to see how close they are to reaching this goal is a good indicator of progress. PT Viz Mobile currently allows users to meet this need by allowing them to set goals for any date in the future. The user, however, might not know what date they should reach this end of therapy milestone. Future work could explore methods to display this information to the user in an alternate way.

8.3 Goals

All 12 participants emphasized that setting goals is important in physical therapy because goals provide something to work towards and improve motivation. Participants stated that goals drive progress and achieving goals gives them confidence to keep moving forward. We expected participants to perceive goals as important to the recovery process.

Technology that aims at improving motivation should strongly consider incorporating goals. Our results agree with Locke and Latham's Goal-Setting Theory [25]. This work concluded that "specific, difficult goals consistently led to higher performance than urging people to do their best." Researchers found that individuals were more likely to achieve their goals when they were "committed" to their goals; that is, the goals were important to the

individual and the individual believed the goals were obtainable [25]. In knee rehabilitation, treatment goals vary from patient to patient, but the most obvious factors are decreasing pain, increasing mobility, and regaining previous lifestyle. For athletes, the goal of returning to competition is extremely important, and motivated many of our participants to perform their prescribed exercises.

Locke and Latham found that the importance of a goal could be increased by a public commitment to the goal or by providing an incentive (not just for goal attainment but also progress points in achieving the goal) [25]. For knee rehabilitation patients, making a goal "public" could include talking to their therapist about their goals. Several participants commented on the accountability that a system like PT Viz and PT Viz Mobile would provide if they were required to send their exercise data to their therapist. We consider sending goals and session data to a therapist or doctor to be a public commitment to a goal, and should therefore increase importance of achieving the goal. Users of PT Viz Mobile are shown a green check mark for each completed goal, providing a small incentive when the goal is achieved. They are also incentivized for achieving progress towards a goal, as the progress bars on the goals screen fill as the user advances towards the goal. Participants liked the progress bars, noting that the progress bars show how close the user is to achieving a goal; additionally, participants stated that they would be motivated to fill in the rest of the bar. These progress bars satisfy another facet of Locke and Latham's Goal-Setting Theory. They found that providing summary feedback to an individual is important, for if the individual does not know how she is doing, she cannot adjust her behavior to meet the goal [25].

While our participants all agreed that setting goals was important, they had diverse opinions about the best method to do so. Some participants wanted to group metrics together into

one goal, while others wanted to set one metric per goal. A few participants mentioned that they did not want an end date for a goal, as they were unsure how quickly they could achieve the goal. They stated that having the goal set and seeing past achieved goals was still motivating. Other participants, however, liked having an end date for each goal. More definitive conclusions on how knee rehabilitation patients set goals may be more evident after participants actually use the system (see Section 9.2.1).

As previously mentioned, knee surgery patients come from a variety of backgrounds and injuries. Thus, not every surgery recovery will be the same. Each patient has a desired level of mobility after surgery and therefore their own treatment goals. These treatment goals may or may not coincide with compliance to medical protocol for their specific surgery. Section 8.1 explored ways to motivate patients to complete the entire course of therapy, but we must also question our role as researchers in pushing patients past their goals. Should PT Viz and PT Viz Mobile focus on assisting patients in achieving compliance, or should the system be patient-centered, helping patients achieve their treatment goals but push them no farther than they are naturally motivated? In certain cases, compliance may in fact help patients reach their long-term goals. For example, if a patient's goal is to return to an athletic activity (e.g., skiing), they can complete a minimum amount of therapy to achieve that goal in a few months. If they, however, want to be able to continue to ski in the future, more therapy directly after surgery might be necessary so future surgeries or treatment are not required to maintain their knee's health. Ultimately, compliance is better for the patient, and many patients recognize that completing all therapy is beneficial in the long-term. As researchers, we must decide if we should motivate users to compliance (especially since users recognize that they should be compliant), or strictly aid patients in achieving their personal rehabilitation goals.

8.4 Therapist Involvement

Participants were willing to share their data with their therapists, and stated that the extra data would help their therapist better adjust therapy, improve communication with both their doctor and therapist, and save time during clinic sessions. We hoped that participants would agree that sharing data with their therapists would improve communication, as one of our goals for PT Viz is to encourage concordance. Participants noted that PT Viz and PT Viz Mobile provide a talking point to work together to set goals that both parties are satisfied with. PT Viz Mobile gives the therapist an idea of what the patient is doing outside the clinic, including lapses, to better understand how the patient is progressing, and what course of treatment is appropriate. The therapist can also see how much time the patient is committing to therapy and communicate with the patient how any lapses will affect milestones in their therapy (e.g., running). Patients and therapists may even agree on a less aggressive course of treatment if both parties agree that a slower pace is preferred. Conversely, if a patient is diligent with her exercises, her therapist may suggest more exercises to accelerate the recovery process. The application is a mediating artifact in this communication process – it allows both parties to voice any concerns they may have about the rehabilitation process and agree upon solutions together.

PT Viz and PT Viz Mobile also help users become more active in their roles as rehabilitation patients by providing data that can be used to ask questions of their providers. Many participants were passive in their therapy, simply following prescribed exercises closely but not questioning their role in the process. With PT Viz and PT Viz Mobile, patients will likely become more educated on how their knee is performing and talk to their therapists to set appropriate goals. The system automates data collection so that the user has the tools and data to become more involved in the process, but it still requires users to reflect on their data and goals.

We believe that patients will be more motivated to achieve their goals by becoming more involved in the rehabilitation process.

8.5 PT Viz Scope

Knee rehabilitation is a long, complex process, and can be substantially different depending on the patient and type of surgery. Participants reported that the entire rehabilitation process for ACL reconstruction generally took 6-11 months, and participants performed nearly 30 different exercises. Participants listed a variety of metrics that helped them measure progress, from flexion angle to quadriceps strength. Nevertheless, not all progress can be measured quantitatively; participants also said that an important part of the recovery process involved building confidence in their ability to complete exercises and perform everyday tasks.

Participants noted that PT Viz and PT Viz Mobile would be most useful while regaining range of motion because PT Viz collects flexion and extension angles, which are useful measures of progress during this stage of the rehabilitation process. The type and extent of the surgery dictates how quickly patients regain this range of motion; most participants reported that they recovered most of their range of motion 4-6 weeks after surgery. After participants had their range of motion back, they moved on to different types of exercises that improved muscle strength and knee stability. Thus, PT Viz and PT Viz Mobile would be most useful for about one month of recovery.

We recognize that wearable technology has a limited scope of usefulness in such a complex rehabilitation process. PT Viz provides users with instant feedback while performing an exercise; however, the device itself can only record knee angle over time. While we can extract several interesting metrics from this data (e.g., sets, reps, and hold time), we cannot measure

other metrics that participants wanted to track. Specifically, quadriceps strength, hamstring strength, stability, and lateral movement are useful measures of progress in later stages of rehabilitation. Technology such as PT Viz and PT Viz Mobile must acknowledge system limitations in order to use system strengths to provide more impact. We understand that PT Viz is useful in a limited context; therefore, we focused our attention on using PT Viz and PT Viz Mobile to improve the first month of rehabilitation.

CHAPTER 9

CONCLUSION

We performed a user study with 12 participants using paper prototypes to iteratively design an interface to accompany PT Viz. We analyzed the results and redesigned the interface, confirming participant preferences with a follow-up survey. We then implemented the designed system, and plan to test it in future work (see Section 9.2).

We discovered that knee rehabilitation patients thought that setting goals and seeing their progress was important in motivating them to complete their prescribed exercises. The patients wanted to involve their therapists, stating that it would improve patient-therapist communication and improve the quality of care they would receive. The system consisting of PT Viz and PT Viz Mobile was considered most useful during the first 4-6 weeks of knee rehabilitation therapy, as angle measurements collected by the bend sensor are most useful during this period of time. Participants were excited about having a system to help them track their progress and set goals, and believed it would motivate them to perform their exercises as prescribed.

9.1 Limitations

We recognize that our study only had 12 participants from a limited background – most participants were engineering students and many were high-caliber athletes. While a larger participant sample size from more diverse backgrounds might give us clearer conclusions for a broader audience of knee rehabilitation patients, we were still able to collect rich qualitative data with our small sample size. Our iterative prototype design process was developed to support our small sample size, and we are confident that we have built a useful, if imperfect, system.

Another limitation stemmed from using paper prototypes. Some of the confusion participants experienced was related to their interactions with a piece of paper instead of a high-fidelity prototype. Thus, some of the issues participants noted may not be problems when the system is deployed as an Android application, but others may arise when the user interacts with the system. This study shows that there is a need for a system like PT Viz and PT Viz Mobile, but the system itself is far from perfect.

We did not collect feedback from therapists in this study, which would prove valuable in designing a system that therapists will endorse. With input from both patients and therapists, the system could meet the needs of both parties to further improve the rehabilitation process for the patient.

We also did not have time to have users interact with the fully developed system. We would like to collect more feedback from users in order to determine which features are the most useful and which features cause confusion. This feedback will direct future iterations of the system. Future work that addresses this limitation is detailed in Section 9.2.1.

9.2 Future Work

Future research involves testing PT Viz and PT Viz Mobile in the field and collecting participant and therapist feedback on both successes and areas for improvement. There is also an opportunity for creating and assessing the usefulness of a PT Viz real-time smartphone application that assists knee rehabilitation patients during their exercise sessions.

9.2.1 Field Study

A short field study with a few participants is planned this summer to evaluate the effectiveness of the entire system. This study will provide useful feedback for both pieces of the

system, PT Viz and PT Viz Mobile, and test how well the two work together. This study will recruit 2-3 participants who are currently attending physical therapy for recent knee surgeries. They will be enrolled in the study as soon as they begin therapy to regain range of motion. The participants will work with a therapist for 1-2 weeks, and will be interviewed and shadowed throughout the process. The primary goal of the study is to assess the usability and usefulness of the device in improving the participant's at home recovery process. Feedback from both the patient and therapist regarding how the system affects patient-therapist interactions will also be collected and analyzed. Another goal is to determine how the system helps the participants achieve their rehabilitation goals.

This field study will determine which parts of PT Viz Mobile are useful for the patients and which are not. PT Viz Mobile will help patients track repetitions, sets, and hold time for each exercise they perform, as well as the duration of their exercise sessions and both flexion and extension knee angles over time. It will also allow patients to set goals and share their data with their therapists. After using the prototype smartphone application for 1-2 weeks, patients should be able to provide feedback on the utility of each portion of the interface and suggest improvements. We also want to survey whether PT Viz helps patients complete their exercises correctly. While the device itself cannot report on the proper form, it can track flexion angle, which is a crucial part of both the knee extension and knee flexion exercises. Beyond that, we plan to ask patients if they perceive the exercises to be easier to complete as they progress through their treatment.

We hope this field study will determine if the system improves compliance and encourages concordance in the knee rehabilitation process. The participants will be required to share their PT Viz session data with their therapists. Compliance will be measured both by how

well the patient completes the amount of sets and repetitions prescribed by the therapist and how successful they are at meeting their goals. Concordance is likely best measured by patient attitudes towards the rehabilitation process, satisfaction of the care they received, and their perceived cooperation with their therapist. A 12 question Likert-scale patient satisfaction questionnaire developed by Beattie et. al. [26] evaluates overall patient satisfaction with physical therapy. While this questionnaire contains a few questions that relate to the clinic environment, the others evaluate patient-therapist interactions. Thus, the field study planned this summer will use these questions to measure concordance.

9.2.2 Therapist Feedback

One limitation of the user study was the lack of therapist input, as we only interviewed knee surgery patients. The field study will focus primarily on determining the usefulness of the system to patients. Nevertheless, collecting therapist attitudes towards the system and suggestions for improvement will likely improve the system and rehabilitation experience for both patients and therapists alike. Ideally, the field study planned this summer will incorporate patients from at least two therapists, so they can provide diverse views on their patients' successes and struggles.

Participants also suggested that therapists could log in to view patient data and add new goals for the patient, removing the need for the patient to remember to send their session data. If therapists respond positively to this idea, this feature will be added to the existing Android application.

9.2.3 Real-Time Application

Participants were divided about the utility of a real-time smartphone application that would accompany PT Viz (see Section 5.8). Benefits discussed by the participants included real-time repetition counting and hold time counting to allow users to focus on good form while completing exercises. Real-time angle data could motivate users to push themselves to a flexion or extension angle they might not have otherwise reached. Additionally, the application could walk the user through their exercises, prompting them to take breaks when necessary and informing them of the next exercise to perform. Drawbacks discussed by the participants included the application taking a user's attention away from completing exercises with good form and risking further injury by pushing themselves too far.

Participants noted that although a real-time smartphone application could be distracting for some exercises, it would not be distracting for others, e.g., simple flexion exercises. A future study could test a real-time application that only allows users to do simple flexion and extension exercises. Because most participants believed that PT Viz would be most useful during the first stage of rehabilitation, when the patients are regaining range of motion and only doing simple flexion and extension exercises, a real-time application could greatly improve the usefulness of the system.

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APPENDIX A

BACKGROUND QUESTIONNAIRE

Participant _____

BACKGROUND QUESTIONNAIRE

The purpose of this questionnaire is to provide us with some background information about yourself, you medical history, and your experience with technology.

Instructions: The answers you give here and anywhere else in this study are completely confidential. We only publish aggregate results or de-identified responses from this study, so no one but the researchers in charge of this study will know what answers you put for each question.

About You

Age: _____

Gender: _____

Ethnicity: Hispanic or Latino

Not Hispanic or Latino

Race (Circle all that apply):

American Indian or Alaska Native

Asian

Black or African American

White

Unknown or Not Reported

Education Level:

Less than High School

Completed High School/GED

Some College

2-year College Degree (Associates)

4-year College Degree (BA, BS)

Master's Degree

Doctoral Degree

Professional Degree (MD, JD)

Work Status: Not Working / Part-time / Full-time / Student

If so, what do you do? _____

Technology

1. Do you own a mobile phone? Yes No

   If so, how often do you have it with you?

o	All the time
o	Some of the time. Please explain: _____
o	None of the time

2. What type of mobile phone you have? (Select all that apply)
   - o Basic phone (non-smart phones)
   - o Smart phone (Blackberry, Android, iPhone)
   - o N/A

3. If you have a smart phone, which platform is it (select all that apply)?
   - o Android
   - o iPhone
   - o Blackberry
   - o Other
   - o N/A

4. Does your mobile phone have Bluetooth?
   - o Yes
   - o No
   - o Not sure
   - o N/A

5. Does your mobile phone have Internet access?
   - o Yes
   - o No
   - o Not sure
   - o N/A

6. One a scale of 1 to 5 with 1 being *no confidence at all* and 5 being *complete confidence*, please check how confident you are at using the mobile phone for the following tasks (if you have never used a computer for a task, please check *never used).*

	1 No Confidence	2	3 Some Confidence	4	5 Complete Confidence	Never Used
Make / Receive phone calls						
Send / Receive text messages						
Take / Share photos						
Take / Share videos						
Download applications (games, etc.)						

7. Do you have a tablet computer?
   - o Yes
   - o No

8. If so, what kind?
   - o Android
   - o iPad
   - o Other
   - o N/A

How often do you have it with you?

o	All the time
o	Some of the time. Please explain: _____
o	None of the time

9. How often do you use the Internet on a computer (not a mobile device)?
   - o Many times per day
   - o Once per day
   - o 5-6 times per week
   - o 3-4 times per week
   - o 1-2 times per week
   - o Less than once per week

10. How often do you use the Internet on a mobile device?
    - Many times per day
    - Once per day
    - 5-6 times per week
    - 3-4 times per week
    - 1-2 times per week
    - Less than once per week

Medical History

1. For what reason are you attending or did you attend physical therapy?
    a. Surgery
    b. Injury
    c. Illness
    d. Chronic condition
    e. Other:_____

2. Briefly describe the problem for which you received or are receiving physical therapy.

    _____

    _____

3. How long ago did the problem occur?

    _____

4. Are you currently attending physical therapy?
    a. Yes
    b. No

If you answered yes to the previous question, go to question 6.
If you answered no to the previous question, go to question 5.

5. How long (total) did you attend physical therapy?
    a. 1-2 month(s)
    b. 3-5 months
    c. 6-11 months
    d. 1 year
    e. Over 1 year

Please proceed to question 8.

6. If you are currently undergoing therapy, how much time total do you expect the treatment to last?
    a. 1-2 month(s)
    b. 3-5 months
    c. 6-11 months
    d. 1 year
    e. Over 1 year

7. If you are currently undergoing physical therapy, how long have you been attending physical therapy?
    a. Less than a week
    b. 1 to 3 weeks
    c. 1-2 month(s)
    d. 3-5 months
    e. 6-11 months
    f. 1 year
    g. Over 1 year

Please proceed with the rest of the questions normally.

8. How often did you or do you see your physical therapist?
    a. Multiple times a week
    b. Once a week
    c. Every other week
    d. Monthly
    e. Other: _____

9. How long did your exercise sessions in the clinic last?
    a. 30 – 45 minutes
    b. 1 – 1.5 hour(s)
    c. Over 2 hours

10. How were you prescribed to practice your rehabilitation exercises at home by the physical therapist? Please provide us with how much time per day, how many times a week, and how long each home session lasted (e.g., Daily for 15-20 minutes for 1 year).

    _____

11. How closely did you follow the prescribed exercises routines at home?

    _____

12. If you had trouble practicing consistently at home, please briefly explain why:

    _____

13. If you faced any difficulties while performing the exercises at home, please briefly describe them:

_____

_____

APPENDIX B

STUDY OVERVIEW

Introduction

Facilitator introduces herself and the goal of the study

Consent Form (5 min)

Provide participant with the Informed Consent Form

Background/Demographic Questionnaire (7 min)

See Appendix A

START VIDEO RECORDING

Medical History Portion of Background Questionnaire (2 min)

- Did you have any problems at home? If so, what problems?
- Any problems practicing consistently? What prevented you?
- If there were problems, ask, "What do you think would have helped to practice consistently?"

Describe/Show PT Viz (2 min)

- Explain when patient would use it (at home, doing knee extension/flexion exercise)
- Explain what kinds of data it collects (bend sensor + time – angle, sets, reps, hold time, etc.)

Creation of Paper Prototype (15 min)

- Explain that they will be drawing mockups of data they would like to see when viewing home physical therapy sessions for the knee extension exercise. They are free to draw what they like.
- Some questions to help them draw:

- Explain what kinds of information the electronic prototype can track. What metrics do you want to track? For example, flexion angle. Have them list everything.
- What data do you consider most useful? Why?
- Ask them to draw how they would like to see the metrics they specified.
- Can you please describe your drawing?
- Ask them why they included/excluded certain information, why they drew what they drew, why they laid it out the way they did, etc.
- How would you like to see your interface?
    - Phone, tablet, or website?

Usability Testing of Paper Prototypes (15 min/interface)

- Present the task list to the participants
    - See Appendix C
- Ask participants to think aloud as they complete the tasks.
- Ask the participant to try to complete the task, no matter how difficult or easy they consider the task to be. If they cannot figure out the task, that is okay – they can stop at any time.

Additional Paper Prototype Questions

For each interface:

- Ask clarifying questions to see if they understand what they see.
    - Is it easy to understand?
        - What parts of the interface are confusing? Why?
        - What parts of the interface make sense? Why?
    - What information is extraneous?
    - What information is useful?
    - What information is missing?

    - Would the interface be helpful in motivating you to set and meet your exercise goals?
- How could this interface be improved?
    - What would you change? Why and how?
    - Discuss their thoughts on
        - Information Displayed
        - Intuitiveness
        - Complexity
        - Usefulness

General Questions (10 min)

This part of the semi-structured interview occurs after the usability testing with video still being recorded. The following questions elicit the participant's thoughts on the prototype after the usability session. For every "WHICH" and "WHAT," we have to find the associated "WHY".

- Which interface did you like the best?
    - What aspects do you like about them? Why?
    - How would you improve this interface?
- Would you like to make any modifications to your drawn prototype?
- Do you think setting and meeting goals is important for physical therapy?
- How important is it to see your progress throughout the rehabilitation process?
    - How does it affect your motivation to do exercises?
- What do you think about sharing your home physical therapy sessions with your therapist?
    - What if you were not doing exercises regularly, would you still want to share?

    - Do you think sharing data from your home physical therapy sessions is helpful?
        - Why?
        - Would you feel more comfortable if you could selectively share data with your therapist, or should it be mandatory to share all data?
- Do you think a device and interface like this would help you maintain your exercise routines at home?
    - Why? What aspects of it would make you exercise more regularly?
    - Would it help you track your progress?
    - Would it help you set and achieve goals?
- Would you want to have the interface with you while you're doing your exercises, or just the device?
- Would it be useful to have a real-time app while you were doing therapy, or would it be distracting?

Do you have any questions or comments you would like to share with us about physical therapy, home rehabilitation exercises, or general knee injury recovery?

Thank you for your time.

APPENDIX C

TASK LIST

1. You just completed your exercises for the day. Load them from the device to the interface.
2. Your therapist recommends 3 sets of 10 reps of your heel slide exercise this week (ending on 3/5). He or she also says that your flexion angle should be at least 80° by then. Put this goal into the interface.
3. Find out how much you've improved your flexion angle since 2/21, if today is 2/26.
4. You think your physical therapy session on 2/22 was unfocused, but you want to know how well you actually did. Find out your flexion knee angle for 2/22.
5. Find out about how much time you've spent (on average) per day on physical therapy since 2/21, if today is 2/26.
6. You made a mistake in entering a goal last time you entered it. Change your goal for 3/14 to have a hold time of 5 sec.
7. You set a goal to be at a flexion angle of 72° by today (2/26). Find out if you met that goal.
8. You have an appointment with your therapist. During your appointment, show your therapist your progress since the last time you saw him or her on 2/21.
9. Your therapist wants you to send him or her your data for 2/25. Use the interface to do this.

APPENDIX D

FOLLOW-UP SURVEY

Knee Rehab Phone App Survey

* Required

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Study Title: Physical Therapy Paper Prototype Interface Evaluation

Your participation in this research study is voluntary. Please think about the information below carefully. Feel free to ask questions before making your decision whether or not to participate.

Researcher Title and Contact Information

Lauren Aberle, Principal Investigator, Computer Science
(970) 581-0111
laberle@mines.edu

Katie A. Siek, Faculty Advisor, Computer Science
(303) 492-5066
katie.a.siek@colorado.edu

Tracy Camp, Faculty Co-Advisor, Computer Science
(303) 384-2184
tcamp@mines.edu

Swamy Ananthanarayan, Co-Investigator, Computer Science
(720) 310-5811
ananthas@colorado.edu

Amy Hegarty, Co-Investigator, Engineering
(720) 281-2989
ahegarty@mines.edu

Cyndi Rader, Co-Investigator, Computer Science
(303) 273-3195
crader@mines.edu

Purpose and Background

We created a wearable knee device to help patients undergoing knee rehabilitation perform their physical therapy exercises at home. The prototype can be used during physical therapy and can measure knee angle while the patient is performing the exercise. We hope to create an accompanying mobile interface so that the patient can visualize his or her progress over time, as well as set and track goals. We hope to answer these questions in the study:

- What kinds of information are useful to a knee rehabilitation patient to help them track progress and reach their goals?
- What is the best way to present this information in a mobile interface?
- How might patients want to create goals regarding this information?

You are being asked to be in this study because you have undergone or are currently undergoing physical therapy for knee rehabilitation and you have participated in a previous study trying to answer the same research questions. As a result, your point of view and feedback are valuable in helping us design a better system in the future.

Study Tasks and Procedures

If you agree to participate in this study, you will be asked to answer a series of questions about a smartphone application that will accompany the device described above.

Duration

The study should take approximately 20-30 minutes. You will complete all the steps in a single session.

Risks and Discomforts

There are no foreseeable risks associated with participation in this study as the survey asks about your opinions and preferences about a smartphone application. However, if you do not wish to continue the survey at any point, you may stop.

Benefits

You will not benefit directly from being in the study. However, this study will assist with the development of a system that can potentially improve physical therapy patients' current recovery practices and processes.

Confidentiality

These are some reasons that we may need to share the information you give us with others:

- If it is required by law.
- If we think you or someone else could be harmed.
- Sponsors, government agencies or research staff sometimes look at forms like this and other study records. They do this to make sure the research is done safely and legally.
- Organizations that may look at study records include:
    i. Office for Human Research Protections or other federal, state, or international regulatory agencies
    ii. The University of Colorado Boulder Institutional Review Board
    iii. The sponsor or agency supporting the study: Incentive funds are coming from Professor Katie Siek's start-up funds at the University of Indiana.

We will make every effort to maintain the privacy of your data. Data collected from this survey will be stored on Lauren Aberle's secure Google Drive account. This spreadsheet will be destroyed four years after the completion of the study. The spreadsheet will be identified with a unique participant number with no reference to the participant's name.

Other than the researchers, only regulatory agencies such as the Office of Human Research Protections and the University of Colorado at Boulder Institutional Review Board may see your individual data as part of routine audits.

Compensation

You will be compensated for participation in this study by being entered into a drawing for a $15.00 Amazon gift card. The winner will be contacted via e-mail once all survey responses have been collected.

Participant Rights

Taking part in this study is your choice. You may choose either to take part or not take part in the study. If you decide to take part in this study, you may leave the study at any time. No matter what decision you make, there will be no penalty to you in any way. You will not lose any of your regular benefits. We will tell you if we learn any new information that could change your mind about being in this research study. For example, we will tell you about information that could affect your health or well-being.

Contacts and Questions

For questions, concerns, or complaints about this study, call Lauren Aberle at (970) 581-0111 If you have questions about your rights as a research study participant, you can call the Institutional

Review Board (IRB). The IRB is independent from the research team. You can contact the IRB if you have concerns or complaints that you do not want to talk to the study team about. The IRB phone number is (303) 735-3702.

Documentation of Informed Consent

By clicking below and proceeding to the survey, you are verifying that you understand the information presented above and thereby voluntarily consent to take part in the study. You are encouraged to print this documentation for your records or reference.

I would like to... *

Proceed with the study

Continue »

12% completed

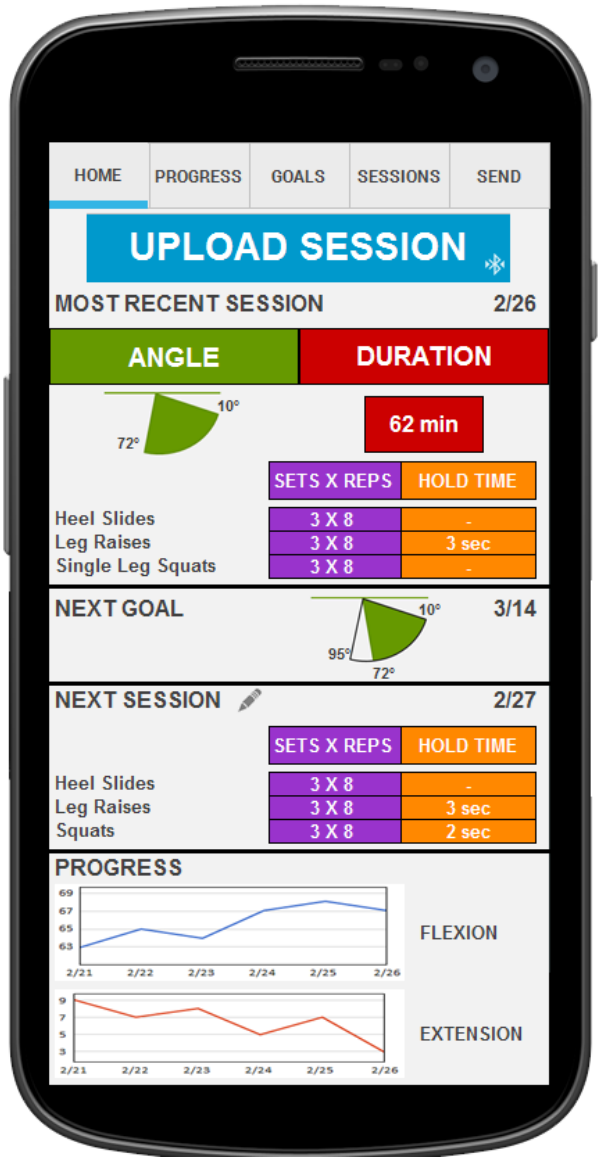
Knee Rehab Phone App Survey

* Required

Based on the feedback you gave, we have designed a smartphone application that lets you upload and view the data from your exercise sessions, set goals, and send your data. We wanted to get your feedback one final time to ensure that we include only useful features in the final product. We hope that you take a few minutes to provide thoughtful responses.

For research use only, DO NOT EDIT

Home Screen



Feature Importance

Please rank how important it is to have each feature on the HOME SCREEN.

Upload Session Button *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Most Recent Session *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Next Goal *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Next Session *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Progress *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Please explain your reasoning behind your highest ranked feature and lowest ranked feature.

Check any feature that is confusing to you. *

- ☐ Upload Session Button
- ☐ Most Recent Session
- ☐ Next Goal
- ☐ Next Session
- ☐ Progress
- ☐ I don't find any feature confusing.
- ☐ Other:

Please elaborate. Why are the feature(s) you checked confusing?

Is there anything that should be added?

What improvements would you make to this screen?

Other Comments?

« Back | Continue »

25% completed

Knee Rehab Phone App Survey

* Required

Progress Screen

Feature Importance

Please rank how important it is to have each feature on the PROGRESS SCREEN.

Being able to choose a start and end date *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Displaying values for the start and end dates (e.g. 2/21 and 2/26) *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Displaying average values between the start and end dates (Avg column) *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Displaying difference values between start and end dates (Diff column) *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Graphs *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Goal lines on graphs *

Please explain your reasoning behind your highest ranked feature and lowest ranked feature.

Check any feature that is confusing to you. *

- ☐ Choosing a start and end date
- ☐ Displaying values for the start and end dates
- ☐ Displaying average values
- ☐ Displaying difference values
- ☐ Graphs
- ☐ Goal lines on graphs
- ☐ I don't find any feature confusing.
- ☐ Other:

Please elaborate. Why are the feature(s) you checked confusing?

Is there anything that should be added?

What improvements would you make to this screen?

Other Comments?

« Back Continue »

37% completed

Knee Rehab Phone App Survey

* Required

Goals Screen

Feature Importance

Please rank how important it is to have each feature on the GOALS SCREEN.

New Goal Button *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Future Goals *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Past Goals *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

End Date *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Check Mark or X for past goals *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Range of motion (angle) indicator *

Filled completely or partially

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Bars for reps x sets, hold time, or duration *

Filled completely or partially

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Please explain your reasoning behind your highest ranked feature and lowest ranked feature.

Check any feature that is confusing to you. *

- ☐ New Goal Button
- ☐ Future Goals
- ☐ Past Goals
- ☐ End Date
- ☐ Check mark or X for past goals
- ☐ Range of motion (angle) indicator
- ☐ Progress bars for reps x sets, hold time, and duration
- ☐ I do not find any feature confusing.

☐ Other:

Please elaborate. Why are the feature(s) you checked confusing?

Is there anything that should be added?

What improvements would you make to this screen?

Other Comments?

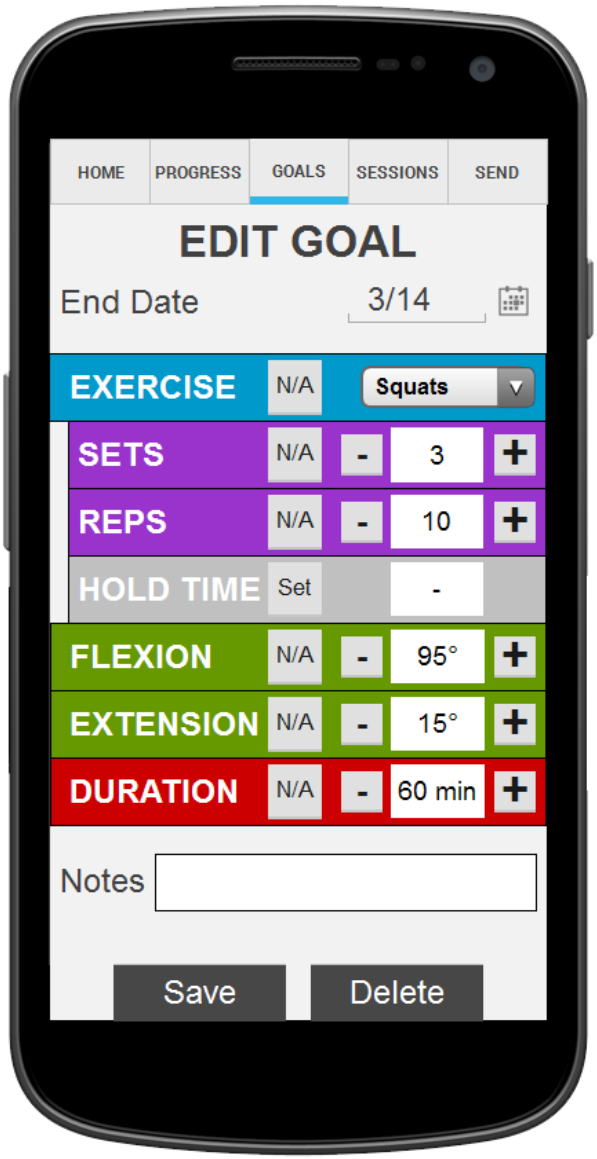
« Back Continue »

50% completed

Knee Rehab Phone App Survey

*** Required**

New/Edit Goal Screen



Feature Importance

Please rank how important it is to have each feature on the NEW/EDIT GOAL SCREEN.

End Date *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

N/A Button *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Notes Section *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Please explain your reasoning behind your highest ranked feature and lowest ranked feature.

Check any feature that is confusing to you. *

- ☐ End Date
- ☐ N/A Button

- [ ] Notes Section
- [ ] I don't find any feature confusing.
- [ ] Other:

Please elaborate. Why are the feature(s) you checked confusing?

Is there anything that should be added?

What improvements would you make to this screen?

Other Comments?

« Back Continue »

62% completed

Knee Rehab Phone App Survey

* Required

Sessions Screen

Feature Importance

Please rank how important it is to have each feature on the SESSIONS SCREEN.

Angle for entire session *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Duration for entire session *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Notes for entire session *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Best for each exercise *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Worst for each exercise *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Average for each exercise *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Graph for each exercise *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Please explain your reasoning behind your highest ranked feature and lowest ranked feature.

Check any feature that is confusing to you. *

- ☐ Angle for entire session
- ☐ Duration for entire session
- ☐ Notes for entire session
- ☐ Best for each exercise
- ☐ Worst for each exercise
- ☐ Average for each exercise
- ☐ Graph for each exercise
- ☐ I don't find any feature confusing.
- ☐ Other:

Please elaborate. Why are the feature(s) you checked confusing?

Is there anything that should be added?

What improvements would you make to this screen?

Other Comments?

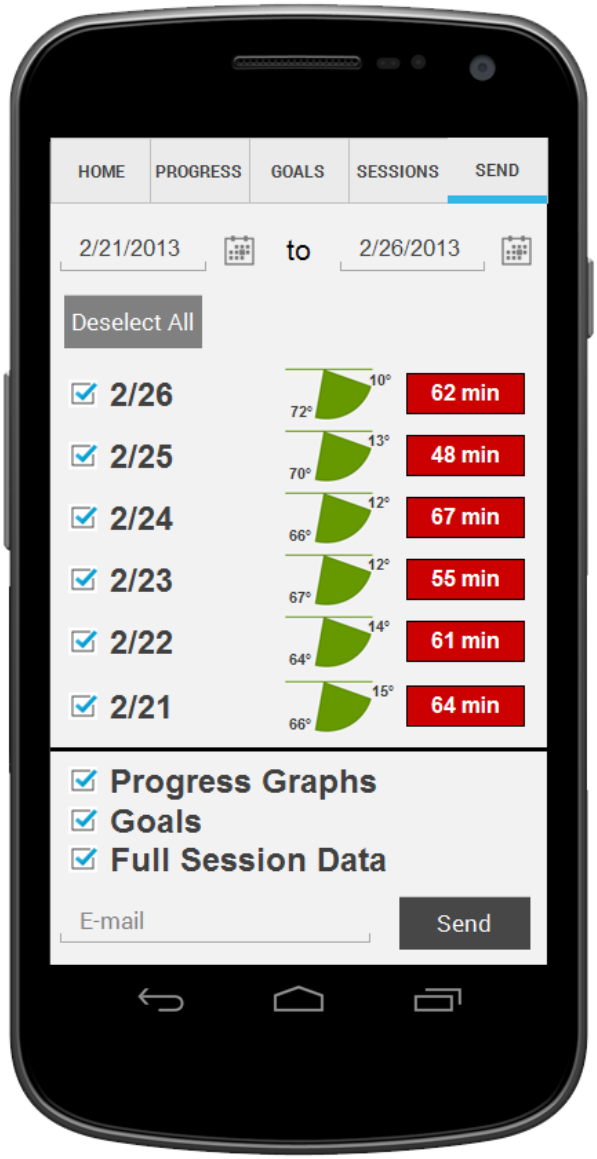
« Back Continue »

75% completed

Knee Rehab Phone App Survey

* Required

Send Screen



Feature Importance

Please rank how important it is to have each feature on the SEND SCREEN.

Being able to select a start and end date *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Deselect All Button *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Being able to only select certain days (checkboxes) *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Displaying angle/duration data for each session shown *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Being able to send graphs *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Being able to send goals *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Being able to send full session data *

	1	2	3	4	
Not Very Important	○	○	○	○	Very Important

Please explain your reasoning behind your highest ranked feature and lowest ranked feature.

Check any feature that is confusing to you. *

- ☐ Being able to select a start and end date
- ☐ Deselect All Button
- ☐ Being able to only send certain days (check boxes)
- ☐ Displaying angle/duration data for each session shown
- ☐ Being able to send graphs
- ☐ Being able to send goals
- ☐ Being able to send full session data
- ☐ I don't find any features confusing.
- ☐ Other:

Please elaborate. Why are the feature(s) you checked confusing?

Is there anything that should be added?

What improvements would you make to this screen?

Other Comments?

« Back Continue »

87% completed

Knee Rehab Phone App Survey

Other Comments

Anything else you want to share with us?

« Back Submit

100%: You made it.