Home Based Telerehabilitation for Patients with Osteoarthritis of the Knee through ICT Feedback

Avyay R Kashyap
15U130010

Guide: Prof. Swati Pal

Keywords: home based, telerehabilitation, osteoarthritis, knee, real-time feedback, ICT.

Declaration

I declare that this written document represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/ source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Avyay Ravi Kashyap
15U130010
IDC School of Design, IIT Bombay

Approval Sheet

The Interaction Design Project II titled “Home Based Telerehabilitation for Patients with Osteoarthritis of the Knee through ICT Feedback” by Avyay Ravi Kashyap, Roll Number 15U130010 is approved, in partial fulfilment of the Master in Design Degree in Interaction at the IDC School of Design, Indian Institute of Technology Bombay.

Guide

Chairperson

Internal

External

Date

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00 Index

01 Abstract

1.1 Introduction

In India, accessible and affordable healthcare are fundamental to ensure an ever increasing population remains healthy. Maintenance of quality of life is vital as one ages. This cannot be more true, especially when dealing with chronic diseases such as Osteoarthritis of the Knee. Rehabilitation is a treatment method that can help elevate the quality of life with minimal risk to the affected individuals.

Osteoarthritis of the Knee (OA Knee) is a degenerative injury caused by the wear and tear of the articular cartilage, which leads to its breakdown. This can result in rubbing of the bones against each other, causing painful bone spurs. It most often occurs in individuals over the age of fifty. The most common symptoms are pain and stiffness of the knee which affects the individual’s ability to do the daily activities. Given that it is a degenerative injury, there is no treatment that can cure it, but the symptoms can be managed.

One of the most common methods of managing the symptoms is through physiotherapy. But there are many barriers to appropriating physiotherapy in one’s life, such as lack of motivation to follow through with an exercise regime, time spent travelling, high costs, necessity to adjust schedules, ability to follow a complex routines.[1}[2}. Also, in many cases, individuals might not have access to a physiotherapist at a moment's notice, or might not even be aware that a physiotherapist is needed to help alleviate the problems they have.

Also, physiotherapy of OA Knee requires repeated completion of mundane exercises, diligently, to perceive any observable improvement in daily functioning. Reduced motivation leads to a lack of adherence to physiotherapy regimes, especially in cases of Home Programs.

Advancements in internet and communication technologies has made it possible to reduce costs involved in deliverance and distribution of content. This has increased access, improved affordability and made available services, to a larger audience. As with all forms of healthcare, accessibility, affordability and availability at all times is key in ensuring successful delivery. ICT allows users to appropriate clinical rehabilitation practices without having to worry about costs, schedules, or physical barriers such as fear of fall, commuting long distances, loneliness, etc.

1.2 Telerehabilitation

Telerehabilitation is the delivery of rehabilitation through the use of telecommunication technologies[1]. It enables higher outreach of rehabilitation to those who aren’t able to access it, either due to time constraints, disabilities, injury, or even costs.

India is home to one of the fastest growing smartphone markets in the world[11]. Combined with the invasion of high speed mobile internet, distribution of content and services has become much more accessible and affordable. This ability to access and afford services allows for the opportunity to make available to the masses a better quality of life through the delivery of relevant subject matter.

People who have affordability and access to physiotherapists often lack motivation and flexibility in schedule to adhere to commitments for extended periods of time, as required in the case of a degenerative disease such as OA Knee. Rigidity in appointments and time required to travel to avail said resources are barriers to having a regular exercise regime.

1.3 Osteoarthritis

Osteoarthritis (OA) is a form of arthritis that occurs as a result of wearing off the cartilage that cushions the ends of one's bones. Although the symptoms of osteoarthritis can be managed, the injury is irreversible. While osteoarthritis can theoretically affect any joint, more often than not, the joints of the hands, knee, hip and spine are affected.

Osteoarthritis of the Knee comes about as a result of the wearing of the Articular Cartilage caused by the release of enzymes that breakdown collagen and proteoglycans (constituents of cartilage). The rubbing of the bones against each other results in painful bone spurs.

The cartilage is a tissue with elastic and compressive properties, which comes about as a result of its extracellular matrix, primarily composed of collagen II and proteoglycans. Under normal conditions, the matrix is subjected to low levels of degeneration through the release of the protease inhibitor enzyme. This remodelling of the cartilage profile is accelerated in cases of Osteoarthritis, causing excess degeneration, without replenishing the proteoglycans and collagen in the matrix. In response to the loss in matrix, chondrocytes proliferate and synthesize enhanced amounts of collagen and proteoglycans. But progression in the disease prevents restoration of the cartilage leading to permanent damage[4].

The lower part of the femur, the patella or kneecap, and the upper part of the tibia make up what is called the knee. The ends of these three bones are covered with articular cartilage, which helps cushion the bones and provide smooth, frictionless movement.

The breakdown of this wedge shaped cartilage results in bone on bone rubbing causing bone spurs.

Physiotherapy for osteoarthritis of the knee aims to strengthen the leg muscles, especially the quadriceps, hamstrings, and calf muscles, which help pull up the kneecap, and reduce the amount of contact the kneecap makes with the tibia, thus reducing pain and in theory increasing the range of motion.

Relieving factors include

- placing ice on the knee
- wearing shock absorbing elastic bandages to reduce impact on the knee
- using ointments that provide pain relief and resting the knee

Aggravating factors include
- overexerting the knee
- climbing up stairs which places additional vertical loads on the knee
- bending the knee to the extent required while squatting

02 Research

2.1 Literature Review

There have been numerous applications designed to support home based telerehabilitation of a multitude of injuries. Research indicating the barriers to the adoption of these programs have been well documented[1][2].

While Home Programs are much maligned, techniques to motivate users to adhere to home programs have been developed as well[9]. Chandra et al. argue that technology can be used to support and supplement home programs and help reduce the negative impact of lack of adherence.

Motivation can be built through multiple techniques. These are further explored by Chandra et al.[9], with real time and post exercise information visualisation proving to be impactful[13].

From a technological standpoint, wearables to enable measurement and capturing of extreme sport activities is explored in [3]. Also, a low-cost force sensor-based posturographic plate for home care telerehabilitation designed with exergames as an outcome was developed by Arpaia et al., with a focus on manual and proprioceptive dexterity. This demonstrates the potential of a wireless, sensor based solution for home rehabilitation[5].

The attempt through this project is to address the following gaps:
- Existing solutions for osteoarthritis of the knee are expensive, clinic facing, and require large substantial infrastructure. These factors are not suited for resource constrained Indian contexts.
- Most studies that deal with home program based solutions have been developed for a western countries, and similar adoption behaviours might not exist amongst patients in India and the same needs to be studied.
- There is a dearth of solutions tailored for motivating patients with chronic disorders through visualisations, both real time and post exercise. The delivery of such information in a manner that will make sense to this audience will have to be studied.

The aim of this project is to provide affordable means of performing physiotherapy exercises for Osteoarthritis of the Knee from the comfort of the user's homes in cases of OA Knee, while addressing issues such as **motivation through visualisation of improvement, error-free execution of exercises, and keeping all the stakeholders informed in the absence of a physiotherapist**.

The project will consist of two parts:
1. A low-cost sensor to give real time feedback for in session correction of exercise
2. Post exercise graphs that will visualise improvements in range of motion, strength and pain.

Low-cost sensors will be used to track movements and ensure correct completion of the exercises through real-time feedback. The data captured will be used to generate the said visualisations for post exercise analysis.

2.2 Primary Research

Goals for primary research were:

- Understand the exercises, purpose, use cases
- Understand doctor's approach
- Gain insights from patients

The research is being conducted at Nair Hospital, under the guidance of Dr. Chhaya Verma of the physiotherapy department. The field study has primarily involved observing interactions between patients with osteoarthritis of the knee and physiotherapist. The patients are sent to physiotherapy department after being diagnosed by the orthopedic department or geriatrics department. The physiotherapists then aim to understand which muscles to work upon to help alleviate the pain.

After localising the source of pain in the individuals injured leg, the physiotherapists go about prescribing exercises. In an ideal situation involving appropriate follow-up, the physiotherapist guides the patient through the exercises that need to be done. As strength starts to build, the patient is prescribed a certain number of exercises for the Home Program. The Home Program is the set of exercises and movements the patient has to do when away from the physiotherapist's clinic. Given that most people have extremely rigid schedules that are hard to change for a developing injury such as osteoarthritis, the physiotherapist's on a regular basis inform the patients of the exercises they need to do on a daily basis till the next time the patient is available to meet.

The insights gathered were validated by the physiotherapists. The stakeholders identified were a) the patients and b) the physiotherapist.

Exercises

The first part involved understanding what exercises were required to be done by patients with OA Knee. This was followed by getting a grasp of what muscles are affected for various injuries and how each exercise is designed to help treat the condition.

The order of importance given while recommending exercises for the Home Program depends from patient to patient. In cases where the patient doesn't have any preference, the physiotherapist aims to build strength, alleviate pain, improve flexibility, and ensure ability to perform functional activities independently.

The exercises have three parts to them.

- Correct positioning
- Appropriate number of repetitions
- Ability to do multiple sets as a sign of strength improvement

On the next page are the exercises the physiotherapy course begins with. Some of these exercises are later dropped for slightly more advanced versions which focus on both strengthening and flexibility.

When it comes to remotely sensing these exercises, the ones that involve any discernible movement are the ones that can be quite easily tracked, with a greater degree of accuracy

Exercise Name	Action	Muscles Involved
Ankle Toe Movement	Ankle and toe face the ceiling and move forward and backward	Exercises the calf
Static Quadriceps	Tighten the Knee cap	Works on Quads, tightening required to activate
Heel Slides	Foot faces the ceiling, bend knee towards ceiling, slide up and down	Contraction of hamstring and quads alternately
Vastus Medialis Oblique	Keep cushion under the legs and straighten from the knee	Primarily works on the quadriceps
Core Activation	Breathe in hold stomach muscles to activate them	Works on core
Static Glutei	Sleep on stomach, tighten buttock muscles	Works on gluteus muscles
Prone Knee Bending	Sleep on stomach, bend knee at 90° wit thigh down	Primarily for the Hamstrings
Gluteus Maximus Exercise	Sleep on stomach, lift knee and thigh up straight and bring thigh down	Works on gluteus
Dynamic Quadriceps	Sitting, lift knee up 90°, bring down	Hamstrings

Goal of the exercises is to slow down the rate of degradation, increase mobility/flexibility, alleviate pain, maintain the range of motion. As the patient builds strength, weights are added to accelerate the strengthening.

Patients

Patients approaching Nair Hospital come from various backgrounds with different motivations to get better. Four patients from various backgrounds were interviewed. A basic categorisation was created based on intrinsic motivation to do physiotherapy:

- Labourers, whose daily wage depends on their physical capabilities, and thus, want to recover or at least lessen the pain as quickly as they possibly can.
- Individuals with desk jobs, who would like the pain caused as a result of OA Knee to reduce to lead a better quality of life.

Labourers and field engineers, are motivated to come to physiotherapy sessions at the clinic everyday, are willing to undergo a lot of pain to increase strength and improve flexibility. This is directly linked to their ability to continue working.

Individuals with desk jobs and home makers generally do not put a lot of strain on their knees. This reduces the amount of wear and tear they experience, but when they are required to perform activities such as walking or climbing stairs, the additional stress causes immense pain. Thus, pain alleviation is the primary motive behind taking up physiotherapy. Also, these are the set of patients who are more likely to adopt Home Programs, as physiotherapy appointments generally clash with their schedules.

Below are the two types of personas I interviewed:

Patient 1

Age 44, Female, Prof at Engineering college

- Had an accident which caused ligament tear
- 2 months of bed rest
- 9 months of recovery with physio
- Had to come in daily for the first month, but was not as much a problem because she lived close and was financially doing well
- The physio and accident made it difficult in commuting to college
- Initially prescribed 10 reps for each exercise. Over time was able to increase it to 15/20. Now maintains that rate
- After a month at the physio centre, was told to do it at home 3 times a day, but was able to do it only twice because of other commitments
- Finds physio fun, not boring
- Does it primarily while watching TV or talking to family. Welcomes distractions while doing physio as it keeps her mind off it while allowing her to do the exercises.

Patient 2

Age 53, Male, Field Engineer

- Went to see the doctor for knee pain in February
- Has a lot of pain, not constant though
- Feels relieved after physiotherapy
- Has been to multiple doctors, but the pain has not reduced
- Has full range of Motion but also has pain
- Does all the exercises told by himself. Has no difficulty remembering the exercises.
- Heads to work after finishing physiotherapy
- Travels alone, sometimes faces difficulty in getting off the train's seat when seated
- Tries to do the exercises twice a day, morning at physio centre and evening at home before dinner
- Prefers to concentrate on the exercises and wants no distraction.
- Likes physio as it helps him do his job
- Works from 9-8
- Has a wife and a daughter

Insights:

- Do not want to exert themselves unless absolutely required
- Initially motivated, but lose motivation when they fail to see improvement

- Change doctors and restart the process of recovery when they fail to see improvement
- Find it hard to remember all the exercises along with the number of repetitions and details such as not rotating the foot or keeping the foot facing the ceiling while exercising
- Looks at rehabilitation as more of a chore than a cure
- Would prefer not to travel and do exercises from home

As mentioned earlier, individuals with desk jobs are more likely to adopt Home Programs rather than schedule appointments at the hospital everyday. Also, there is generally a lag in adoption rates of technology among those in the lower rungs of the socio-economic ladder. Considering these factors, I decided to focus my solution towards individuals with desk jobs, given their need and likely technical acumen.

Physiotherapist

Treatments depend on the goal of the patient, what they want from the physiotherapy. As a doctor, the primary aim is to build strength.

Not all cases of OA Knee have a range of motion related problems. In order to assess the exercises necessary for recovery, activity levels of the patient, and expectations are considered for planning.
It is imperative to avoid rotation of the joints while doing the exercises, as it exercises the incorrect muscles.

Before prescribing exercises for the patients, the physiotherapist evaluates the condition and degree of development of the injury. Factors considered are:

- Pain - what is the site of the pain, which structure is paining. Tries to get the patient to pinpoint the pain. This gives differential diagnosis (is something OA Knee or just an inflammation at the knee joint that is getting impeded upon), and informs of the possible structures involved.
- Onset: conditions that might have resulted in the injury
- Duration of physiotherapy, and how much longer will it take with the recovery pace
- Progression of the pain - is the pain reducing, or the condition worsening
- Aggravating factors - What activities increase the pain (gives an idea of what muscles are involved in causing the pain and what muscles are bearing the load) - walking, climbing, etc

- Relieving factors - Factors that decrease the pain - icing, hot water, sitting, etc

When looking for progress, what is being checked?

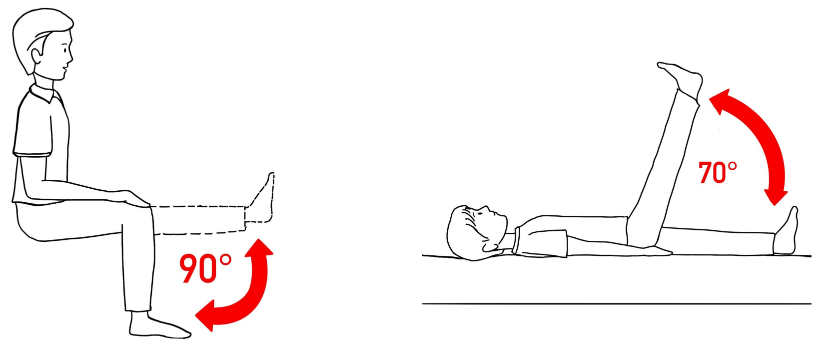
- Pain the patient experiences
- Swelling - How much swelling, measured with tape. Warmth at the inflamed joint
- Range of Motion - check from neutral to complete bend using a goniometer
- Posture - Examined from toe to head. Look to see whether toes point outward or inward, angle between foot and leg, gap between the two knees
- Muscle strength - how much resistance is the muscle able to overcome
- Tightness - how much is the muscle resisting force
- Walking (Gait) - The way the person lands and continues walking (heels first, foot next, toe for exit). Where the weight is getting shifted, from painful foot to uninjured foot through rotation and how much this is happening. Control of muscle (patient's ability to stabilise the transverse joint)

Insights:

"Not doing the exercise is better than doing it wrongly"

- Improving strength is essential to reduce degeneration
- Incorrect practice of exercise can cause accelerated degeneration of the capsule
- Exercises need to be repeated at least twice a day to see improvement
- While strength is the only measure of improvement, it will not be seen immediately
- Pain is the only other measure that can describe signs of improvement
- If pain and strength improve, everyday functional activities too will become easier to do

Based on the insights and discussions with Dr. Chhaya Verma, the exercises chosen to proceed with for the home based telerehabilitation program were **Dynamic Quadriceps** and **Straight Leg Raising**.



Dynamic Quadriceps *Straight Leg Raising*

Dynamic Quadriceps is a sitting based exercise that helps improve strength. Straight Leg Raising is an exercise done lying on one's back that can be indicative of improvement in range of motion.

2.3 Market Research

The current state of the art technology that is available in the market was studied. These applications aid in making more accessible telerehabilitation services.

Portea

Portea offers services that allow patients to access the treatment that they would avail at physiotherapy clinics at their homes. Physiotherapists arrive at the patient's homes when an appointment is scheduled and guide the patient through the necessary exercises.

Pros:

- Enables the convenience of being able to perform exercises from the comfort of one's home.
- There is no need to travel to the therapy clinic, thus saving on commute time and effort.
- Greater degree of personal input will be available as compared to a solution that offers greater remote capabilities.

Cons:

- Might not be affordable by all.
- Highly dependent on availability of physiotherapists.

Valedo

Valedo is a medical device that enables physiotherapy for back pain from home through digital means. It consists of two sensors that have to be placed on the back, which work alongside an ICT device to provide feedback and analysis.

Pros:

- Allows patients to perform exercises at their convenience.
- Provides real time feedback and limited post exercise analysis.
- Can be used both at the therapy clinic as well as separately at home.

Cons:

- Positioning of the devices in relation to each other is important for accuracy.
- Comes with a limited number of strips to attach the device onto the body, after which the patient will have to buy strips, thus increasing costs.
- Patient needs to be tech savvy to operate.

Explorations of the possible ways physiotherapy can be brought to patient's homes was being done simultaneously. Market research and the information gathered through primary research helped narrow down the scope much more quickly.

03 Explorations

In order to facilitate telephysiotherapy, understanding the elements that would allow for the patient to perform the exercises by themselves is necessary. I broke my explorations into three parts, which when put together, could make for a wholesome experience. The three areas of explorations were:

- Sensors
- Feedback
- Wearables

3.1 Sensors

Sensors were used to detect and capture the movements of the leg, to allow for feedback with regards to the correctness of the individual's practice of the exercise regime. I picked up two of the low-cost sensors that I know can, broadly speaking, capture movement in a 3D space.

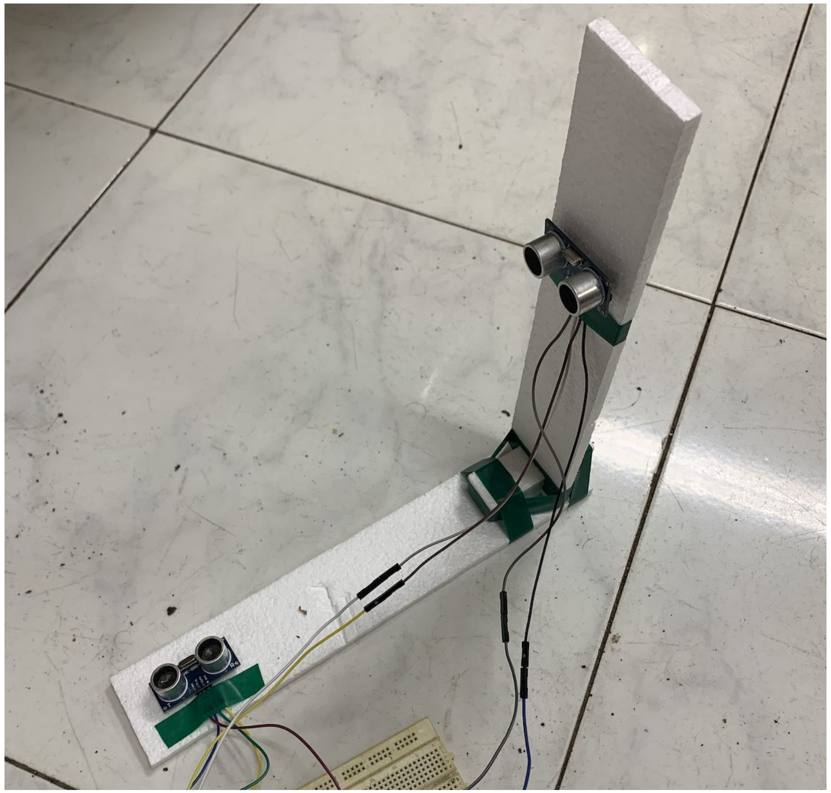
Ultrasonic Sensors

Ultrasonic sensor, HC-SR04, is an acoustic based sensor that consists of a transducer and a receiver. It can detect objects placed at a maximum distance of up to 400cm.

Both the exercises chosen, have movement that can be captured in two axes. As a concept, I chose to explore the use case of an array of ultrasonic sensors in capturing the X and Y positions of an object by placing them perpendicular to each other.

The pros of having such a set up is it allows the user to be free of any attachments on their body to detect movements, allows the user to operate without worrying about positioning for accurate values, and can be used for a wide number of physiotherapy exercises that include discernible motion in a two dimensional plane.

The cons of this setup is the conical detection zone tends to interfere with each other, drastically reducing the accuracy. While this is a problem that can be solved with some maths and better sensors, for greater accuracy, more sensors will be needed to map the space, which increases the costs. Also, this setup doesn't allow for 6 degrees of freedom and restricts the user to execute the exercises within the bounds of the detection zone.

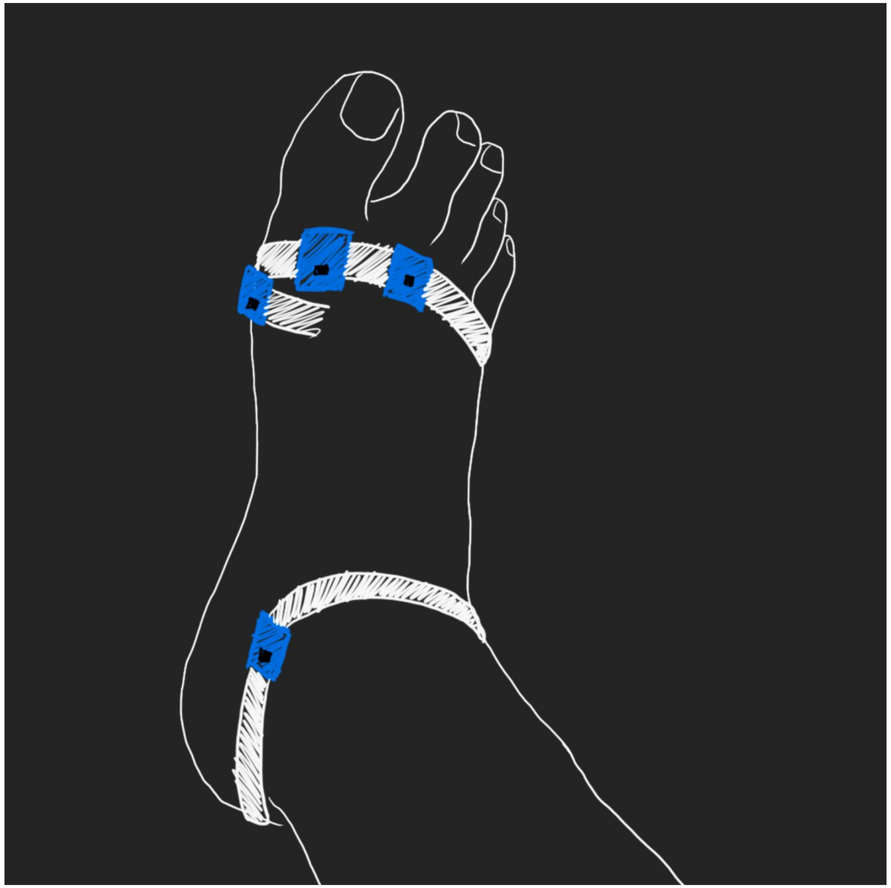


Accelerometer-Gyroscope

The MPU6050 is an accelerometer gyroscope sensor that is able to detect movements in 6 axes. Preliminary trials were conducted to gauge whether this could be used reliably to detect movements.

Various positions were tried and measurements were taken keeping in mind the motions needed for the exercises for OA Knee. The largest displacement was found to be at the foot for the selected exercises. Resulting graphs were observed for stability in readings while leg was in motion, and with movement of nearby appendages such as the toes.

- Positioning the MPU below the second toe provided stable readings plus the ability to help guide users in positioning the device accurately for correct measurements.
- Placing it below the big toe gave the largest disturbance in the readings, but did provide the best reference to position the sensor.
- The spot beside the big toe on the side of the foot also provided dependable readings, but does not provide a reference guide in itself to position the MPU.
- Near the ankle, the readings were consistent, but it was harder to account for error while performing the exercise, as there was very little lateral movement that was picked up by the sensor.



Different positions for gauging accuracy (in blue is the MPU)

Given the freedom that the MPU6050 provided, along with greater accuracy, it was chosen as the sensor to capture the movements recorded during the exercise regime.

3.2 Feedback

One of the advantages of capturing the movement of the foot is being able to inform the patient how they are currently doing the exercise and how it can be improved. This is the feedback that will be addressed in this section.

As the patient does the exercise, there are two types of feedback that can be provided. Real time feedback that the patient can immediately act upon, correcting their movements as necessitated, and a post exercise analysis of performance.

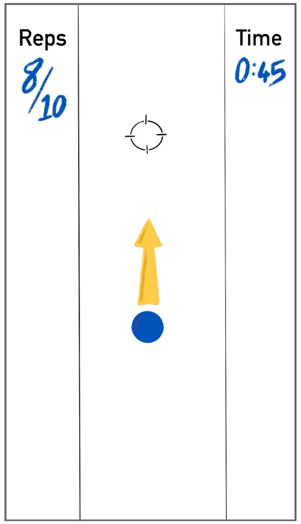
Explorations for providing real time feedback can be categorised into three parts: visual feedback, auditory feedback, and tactile feedback. Ideas for these feedback techniques were explored keeping in mind the following points:

- Ability to control the feedback input duration to prevent overexercising
- Easy and intuitive elements to reduce cognitive load
- Ability to provide feedback of rotational movement to prevent incorrect practice

Post exercise feedback was primarily looked at from the point of view of delivering synthesised data that can lead to actionable insights to the patient. Hence, this exploration is only visual, and exploratory in nature.

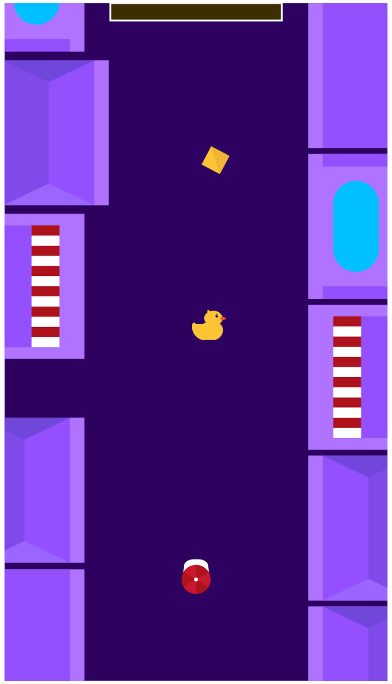
Visual Feedback

Two kinds of visual feedback techniques were developed. The first was a more technical depiction visualising the movement as is. Abstract elements such as squares and circles were chosen to represent the movement of the user's foot versus the ideal movement.



This form of feedback was further developed and tested in the pilot.

Further explorations were made that veered towards gamifying the exercise experience. A few sketches of infinite runner games with obstacles appearing rhythmically were explored, keeping in mind the continuity of motion the user is performing to what he/she is seeing on the screen. The primary goal while designing the games was to ensure feedback regarding rotational movement can be accurately given such that the patient is able to take immediate remedial action and prevent incorrect practice.



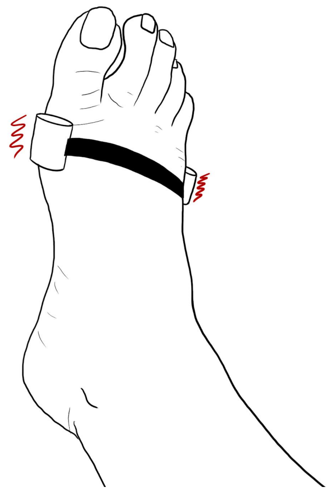
An infinite runner where moving the leg kicks the obstacles into the goal

Auditory Feedback

This is particularly for exercises that the patients will have to do while lying on their back. It is not easy to hold a phone over one's face while undergoing a lot of pain. Hence, providing feedback without the need to look at a screen seemed vital. Feedback with regards to incorrect doing is provided by using stereo audio, with the music getting louder towards the direction of rotation.

Tactile Feedback

Again, this was for exercises involving resting on one's back while exercising. A device with haptic feedback sensors would need to be worn on the foot. This would be used to give directionality to the patient's movements. If incorrect movement/ rotational movement is detected, the device can gently pat the patient, nudging them to correct the movement.



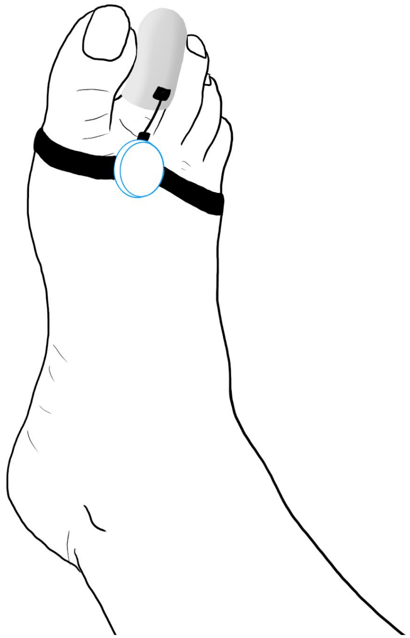
Tactile feedback through motors

3.3 Wearables

Going ahead with the MPU6050 meant a wearable had to be designed that would allow the user to position the sensor in the right position to be able to collect accurate measurement. Another consideration that had to be made was ease of use, the ability to just put on the sensor and start the exercise as one would do it if they were at the physiotherapist.

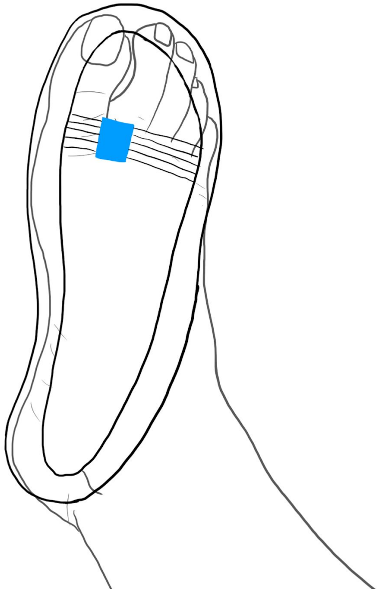
- *Strap with toe guidance*

This works like a three point harness. The second toe is used as a reference to position the sensor accurately. The strap around the foot secures this position and prevents it from moving around.



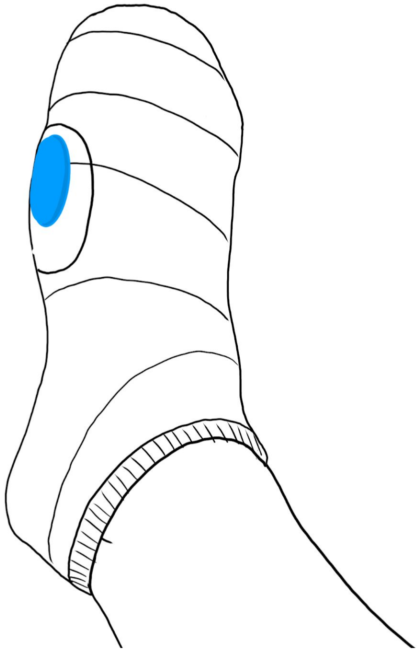
- *Insoles with embedded sensors*

Insoles take the position of the foot, and provide extra cushioning and firmness inside a shoe. This also means that once placed inside a shoe, the positioning of the sensor will remain stable and accurate.



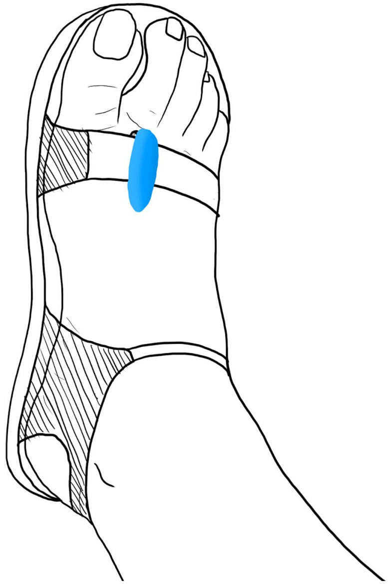
- *Socks with padding*

Socks are a well known household item, and with a sensor embedded in them, would make for a well integrated solution that would fit well in the user's life, while also providing great comfort. An extra padding on the inner side could help snuggly fit the sock onto the leg and correctly position the sensor. But the downside of a sock is they have to be regularly washed, which puts the device at risk of getting damaged.



- *External clip-on device*

An external device that can be clipped onto any footwear would provide the ultimate convenience. While this does allow the user to be free in the usage of the product, it makes certain other things such as positioning the device, ensuring no extra movement when the device is positioned, etc much harder to control.



These wearables were prototyped and evaluated on the basis of the following criteria:

- Ease of use
- Accurate fitting over time
- Maintenance
- Comfort
- Convenience

The ideas were scored out of five for each category, thus giving the highest possible score of 25 for any idea.

	Strap with toe guidance	Insoles with embedded sensors	Socks with padding	External clip-on device
Ease of use	3	3	5	5
Accurate fitting over time	5	4	3	1
Maintenance	5	4	1	5
Comfort	4	4	4	4
Convenience	4	2	4	3
Total	**21**	**17**	**17**	**18**

The Strap with toe guidance scored the highest for the ease of accurately positioning the sensor and maintenance. Another really important factor was the ability of the device not to have other dependencies, such as footwear, as this only leads to a greater inertia in adoption.

04 Design

For the patient to execute exercise regimes without the guidance of the physiotherapist, there are certain factors that have to be taken into consideration. These decisions are based on insights gathered from patients and physiotherapists.

This section will talk about the requirements considered, concept taken forward, and architecture of the system.

Requirements from the design:

- Low-cost device that can sense movement accurately
- Home based solution that is not massively outweighed by the benefits of going to a doctor
- Ability to provide feedback in real-time to prevent incorrect practice of exercise regime
- Ability to motivate by showing improvement through reduction in pain/ increase in range of motion

From the explorations, the accelerometer-gyroscope integrated into a wearable that fed data to an application to give real time feedback of the movement while also storing the data to generate graphs that enables the patient to understand where he/she can improve was chosen to take the concept forward.

Below are the specifications of the concept:

Sensor: MPU6050, accelerometer-gyroscope, allows for 6 degrees of freedom, possible to sample at high frequencies, thus getting very high resolutions.

Wearable: strap with toe guidance was chosen for two reasons. One, positioning the sensor right below the second toe provided data with minimal noise and maximum clarity of rotational movements. Two, the toe is quite a large and unmistakable marker, and so it is much easier to position the sensor accurately, than anywhere else on the foot.

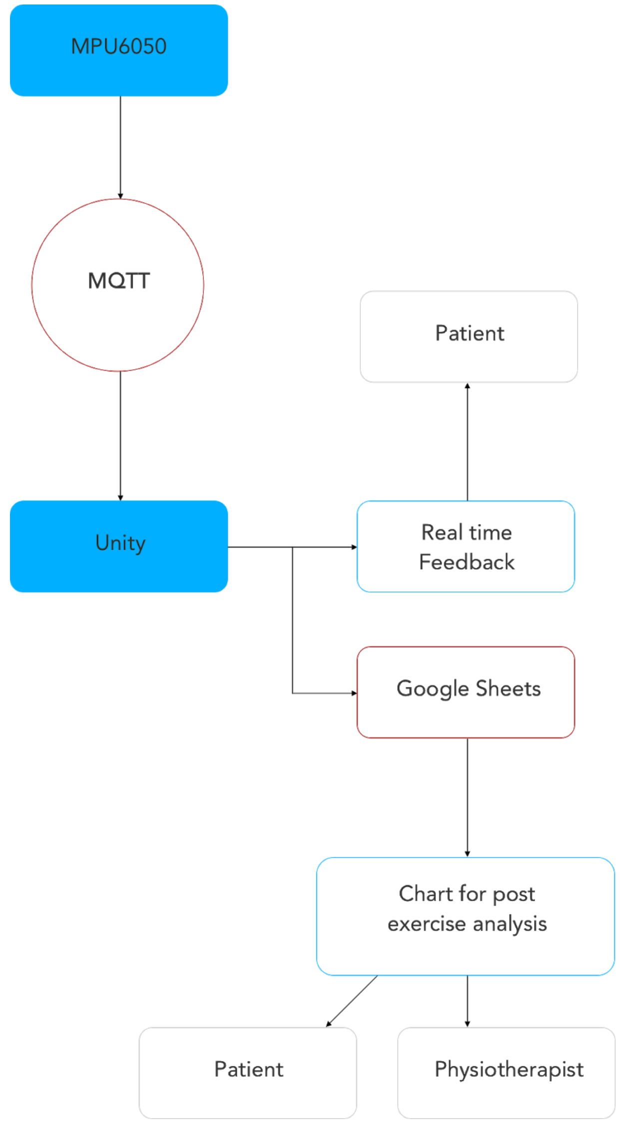
Real time Feedback: Abstraction will be the primary mode of giving real time feedback. The movements of the elements are mapped to the movement of the foot. This translates across a majority of the exercises the patients are supposed to do from home. These visuals are combined with auditory feedback, with a rhythmic tune guiding the patients through the exercise. Stereo audio is used to provide information regarding rotational movement.

Post Exercise Feedback: This will be available to both the patient and the physiotherapist. The patient will be able to view how each exercise session went and when and where rotational movement is occuring. As more sessions pass, there will be enough data to show trends and for the post exercise analysis to feed real time data feeds proactively to prevent incorrect execution of the exercise.

4.1 Architecture of the system

The proof of concept built for the Pilot test involves the accelerometer sending data wirelessly over the internet using a wireless protocol known as MQTT. MQTT allows for the relay of information sent by a single device to multiple devices as long as the receiver is on the same *topic* as that of the publisher.

The publisher is the MPU6050, streaming the data onto the internet. The receiver in this case is the application, which will use this data to provide real time feedback to the patient and transfer the data onto a google sheet for storage before generating graphs for the post exercise analysis on it.



05 Pilot Testing

The pilot test was conducted with two patients in the experimental group and two patients in the control group over 7 days. The goal was to check for:

- Adoption behaviours of Indian patients to technology based solutions
- Any possible improvement in strength, range of motion, or reduction in pain through the use of the device
- Effects of real time feedback versus post exercise analysis and possible ways to isolate the two variables

A pre-experiment and post-experiment evaluation of patients in control and experimental group for strength, range of motion and pain levels will be held to confirm if there is a significant difference with the usage of the device.

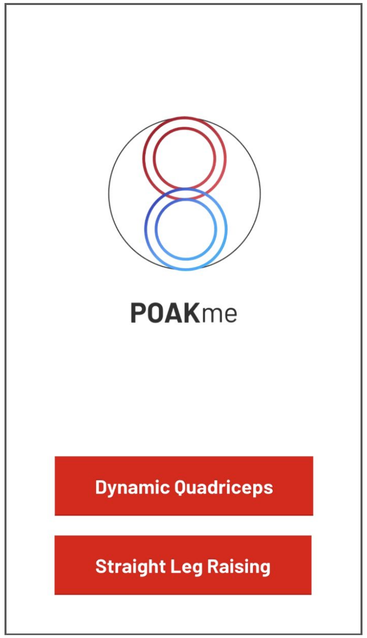
Sensor Module

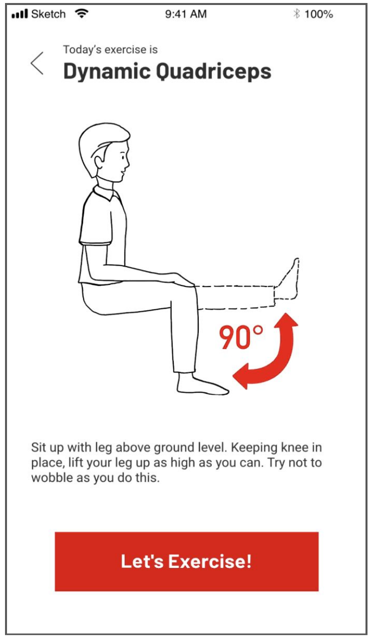
The module consists of one MPU6050 placed on the extreme left for patients with OA Knee in their right foot, and to the extreme right for patients with OA Knee in their left foot. This is so that the device neatly balances on the leg. The sensor is connected to the NodeMCU, which is the module that relays the data generated by the MPU6050 onto the internet. The rest of it is pretty standard with a switch and a battery to control when the device turns on and to power the device respectively.

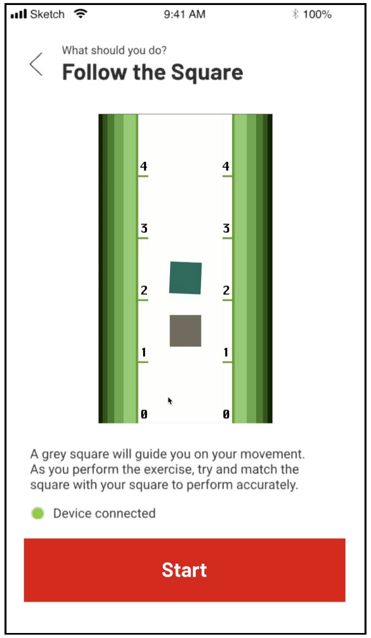
This board is attached to two harnesses. The first harness is placed right below the MPU6050, and is what the patient uses as a guide to position the device accurately. The second harness is as far back to allow for a fitting three point harness to keep the device in place.

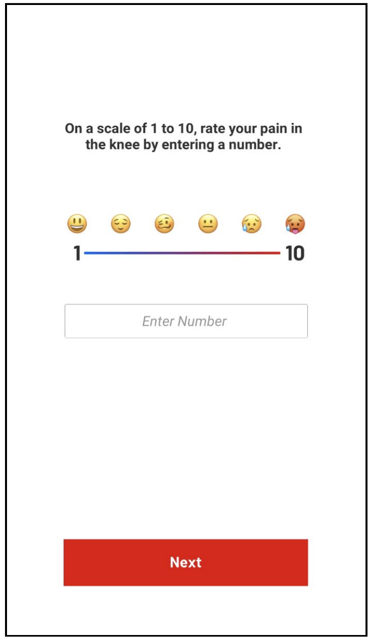
Application for real time feedback
The application for providing real time feedback was built on Unity. As discussed earlier, Dynamic Quadriceps and Straight Leg Raising were the two exercises selected for testing. The screens were quickly prototyped, and put together for the test.

The app gave an overview of what the exercise was about, a prompt to connect to the device, Upon detecting the connection, it gave instructions on how the feedback will be displayed and what the patient should do. Once the exercise is completed, the patient is prompted to feed the amount of pain they are feeling in their knee, which is one of the objective metrics recorded for the experiment.



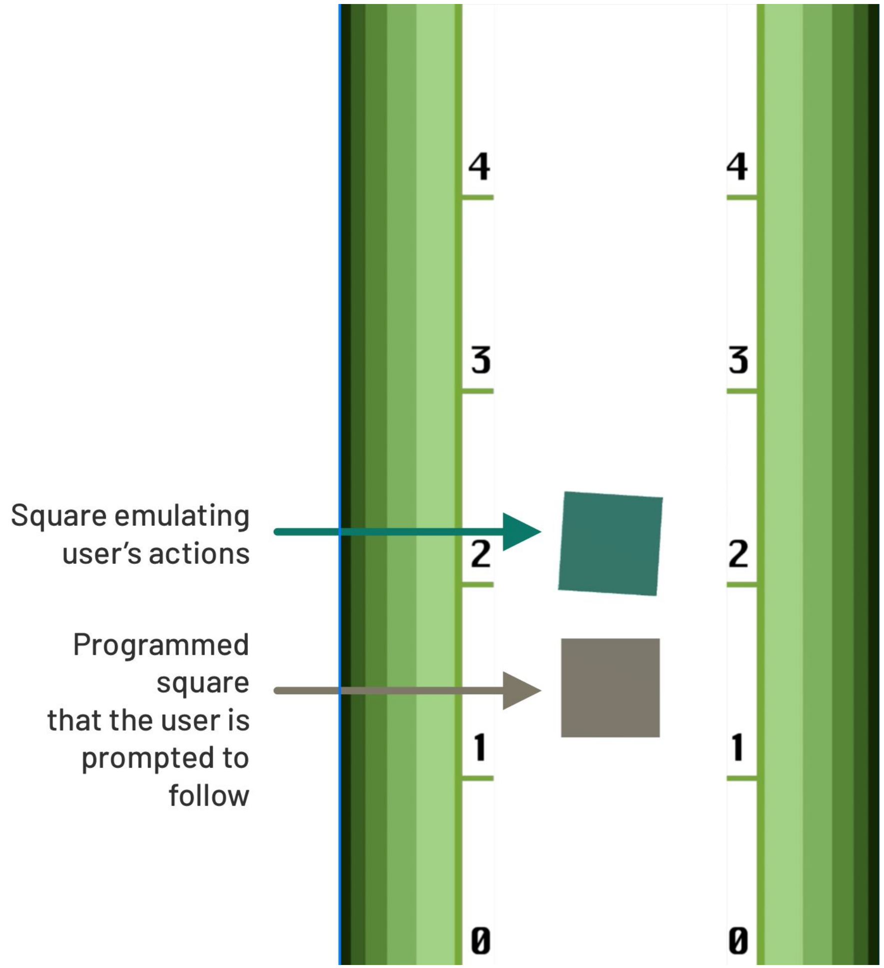






The screen that provided feedback was structured as such.

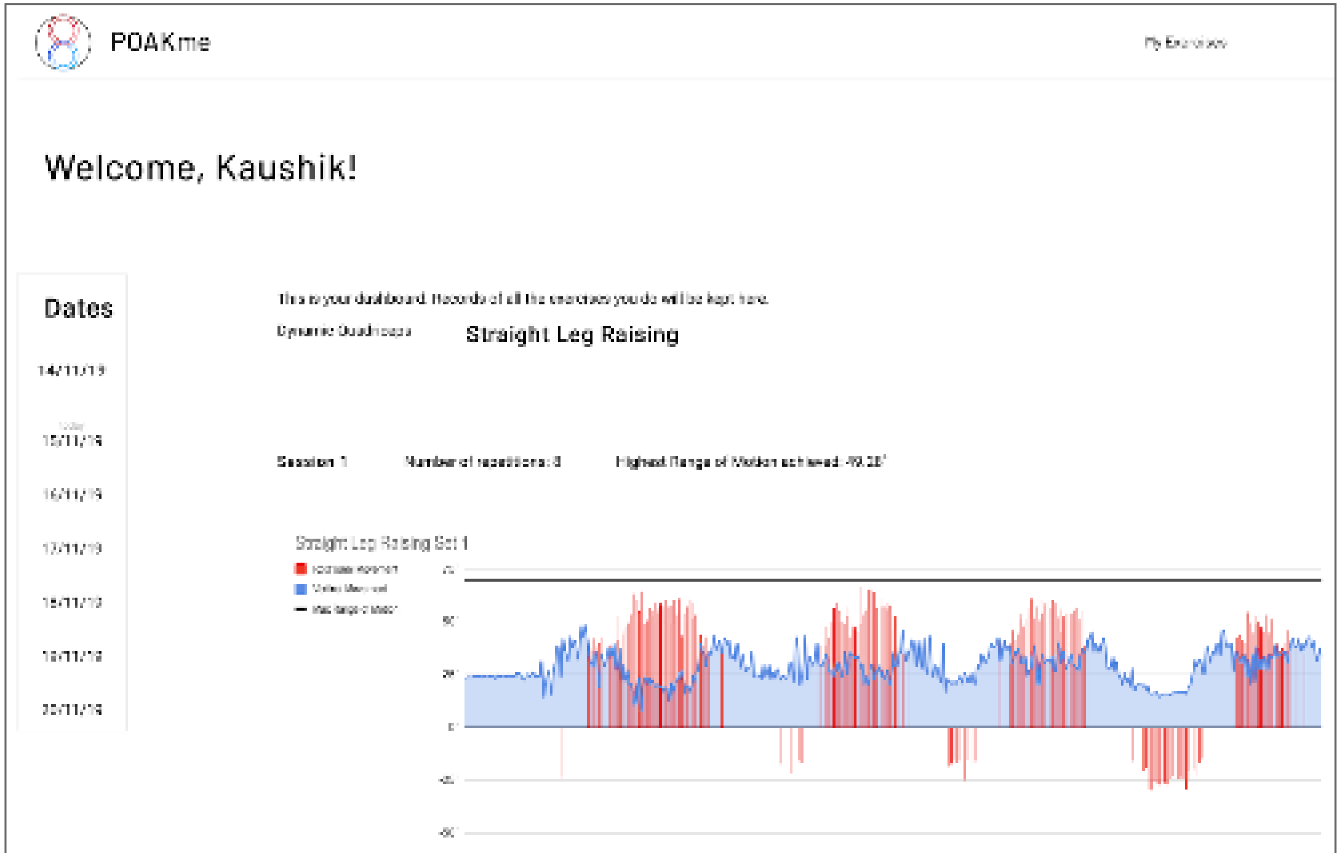
- A grey square would be programmatically controlled to dictate the pace of the exercise.
- The goal is to follow this square with an aquamarine coloured square of your own.
- There are markers on the edges of the screen to allow for visual coding of range of motion while performing the exercise. This is also accompanied by a musical score that is constantly rising step-wise, from note C through to note B as the grey square moves up. The notes start falling as the grey square descends.
- When the patient achieves his/her target range, the square turns green.
- As long as the patient is keeping pace with the grey square, the musical score is heard loud and clear. The further the patient is from the ideal movement, the softer the musical score becomes.
- But when the patient exceeds a certain threshold of rotational movement, the square turns red.



Dashboard for post exercise data analysis

A dashboard was created to visualise the data for post exercise analysis. The dashboard visualised patient information such as range of motion for the duration of the exercise, number of repetitions performed, highest angle achieved, and self reported pain. This was segmented based on sessions necessitated per day by the physiotherapist.

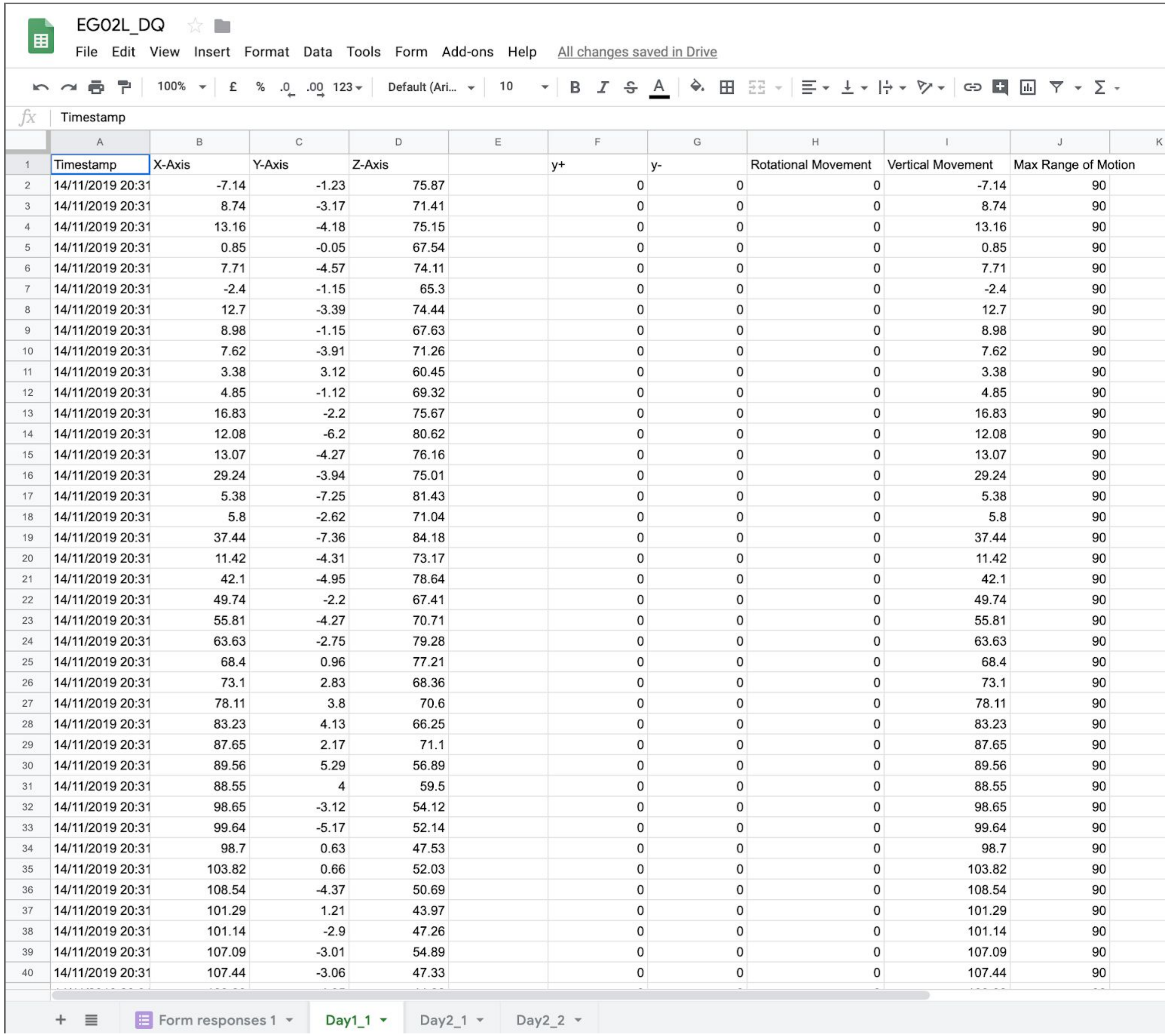
This allowed the patient to access more nuanced information such as the rate at which they were doing the exercises, when they had inward or outward rotational movement, and how much they rotated. They were also able to visualise pain trends, which is one of the objective measures of improvement.



The blue line is a record of the motion the patient recorded.
The red columns are rotational movements by the leg. The patient in this case is injured in his left knee, hence positive graphs mean inward rotational movement, and negative graphs mean outward rotational movement.
The black line is the maximum range of motion the individual can execute [12].

The visualisation and webpage shown is currently live and providing post exercise analytics to a patient participating in the experiment. The visualisation is also a limitation of the means by which I chose to enable the participants to visualise their data live. It is currently an <iframe>, pulled from Google Sheets, where the data is being stored.

In order to explore better means of visualising this data, I shall be reverting to standard prototyping tools such as Figma and Sketch. This will also enable tighter integration of data with the experience of the application.



	A	B	C	D	E	F	G	H	I	J
1	Timestamp	X-Axis	Y-Axis	Z-Axis		y+	y-	Rotational Movement	Vertical Movement	Max Range of Motion
2	14/11/2019 20:31	-7.14	-1.23	75.87		0	0	0	-7.14	90
3	14/11/2019 20:31	8.74	-3.17	71.41		0	0	0	8.74	90
4	14/11/2019 20:31	13.16	-4.18	75.15		0	0	0	13.16	90
5	14/11/2019 20:31	0.85	-0.05	67.54		0	0	0	0.85	90
6	14/11/2019 20:31	7.71	-4.57	74.11		0	0	0	7.71	90
7	14/11/2019 20:31	-2.4	-1.15	65.3		0	0	0	-2.4	90
8	14/11/2019 20:31	12.7	-3.39	74.44		0	0	0	12.7	90
9	14/11/2019 20:31	8.98	-1.15	67.63		0	0	0	8.98	90
10	14/11/2019 20:31	7.62	-3.91	71.26		0	0	0	7.62	90
11	14/11/2019 20:31	3.38	3.12	60.45		0	0	0	3.38	90
12	14/11/2019 20:31	4.85	-1.12	69.32		0	0	0	4.85	90
13	14/11/2019 20:31	16.83	-2.2	75.67		0	0	0	16.83	90
14	14/11/2019 20:31	12.08	-6.2	80.62		0	0	0	12.08	90
15	14/11/2019 20:31	13.07	-4.27	76.16		0	0	0	13.07	90
16	14/11/2019 20:31	29.24	-3.94	75.01		0	0	0	29.24	90
17	14/11/2019 20:31	5.38	-7.25	81.43		0	0	0	5.38	90
18	14/11/2019 20:31	5.8	-2.62	71.04		0	0	0	5.8	90
19	14/11/2019 20:31	37.44	-7.36	84.18		0	0	0	37.44	90
20	14/11/2019 20:31	11.42	-4.31	73.17		0	0	0	11.42	90
21	14/11/2019 20:31	42.1	-4.95	78.64		0	0	0	42.1	90
22	14/11/2019 20:31	49.74	-2.2	67.41		0	0	0	49.74	90
23	14/11/2019 20:31	55.81	-4.27	70.71		0	0	0	55.81	90
24	14/11/2019 20:31	63.63	-2.75	79.28		0	0	0	63.63	90
25	14/11/2019 20:31	68.4	0.96	77.21		0	0	0	68.4	90
26	14/11/2019 20:31	73.1	2.83	68.36		0	0	0	73.1	90
27	14/11/2019 20:31	78.11	3.8	70.6		0	0	0	78.11	90
28	14/11/2019 20:31	83.23	4.13	66.25		0	0	0	83.23	90
29	14/11/2019 20:31	87.65	2.17	71.1		0	0	0	87.65	90
30	14/11/2019 20:31	89.56	5.29	56.89		0	0	0	89.56	90
31	14/11/2019 20:31	88.55	4	59.5		0	0	0	88.55	90
32	14/11/2019 20:31	98.65	-3.12	54.12		0	0	0	98.65	90
33	14/11/2019 20:31	99.64	-5.17	52.14		0	0	0	99.64	90
34	14/11/2019 20:31	98.7	0.63	47.53		0	0	0	98.7	90
35	14/11/2019 20:31	103.82	0.66	52.03		0	0	0	103.82	90
36	14/11/2019 20:31	108.54	-4.37	50.69		0	0	0	108.54	90
37	14/11/2019 20:31	101.29	1.21	43.97		0	0	0	101.29	90
38	14/11/2019 20:31	101.14	-2.9	47.26		0	0	0	101.14	90
39	14/11/2019 20:31	107.09	-3.01	54.89		0	0	0	107.09	90
40	14/11/2019 20:31	107.44	-3.06	47.33		0	0	0	107.44	90

Insights:

- The pilot had no control settings to manage pace of doing the exercises. This is very important as patients have different speeds at which they perform the exercises, and this is something that varies inherently when a physiotherapist is present.
- Inward and outward rotational movement varies with respect to injured legs in the Pilot. It is easier to understand the direction of rotation if it is visualised rather than encoded.
- The patient doesn't get any feedback with regards to how they are pacing the exercise versus how it ideally should be paced.

06 Final Concept

POAKme

POAKme logo

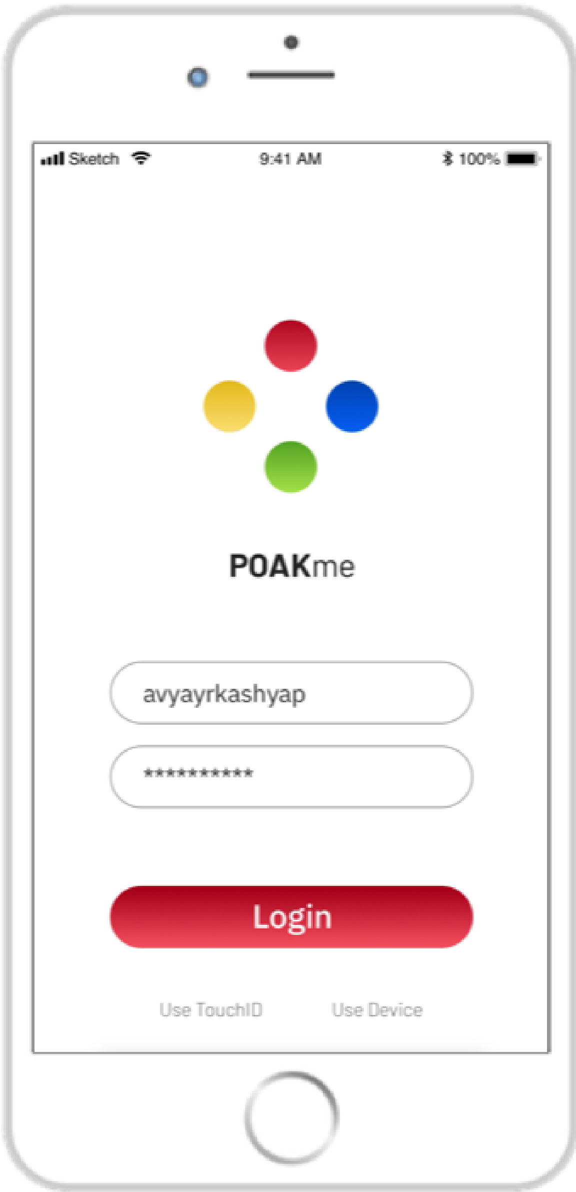
POAKme is the culmination of this design process. It is an app that will demonstrate the use case for a home based physiotherapy solution, enabled by a device, POAKY, that captures the movement of the foot.

POAKme is an acronym for **P**hysiotherapy for **O**steo**A**rthritis of the **K**nee for *me*. The device POAKY comes bundled in a sleek box as shown in the figure, which coupled with the app will allow the user to perform physiotherapy independently, whenever and wherever they are.

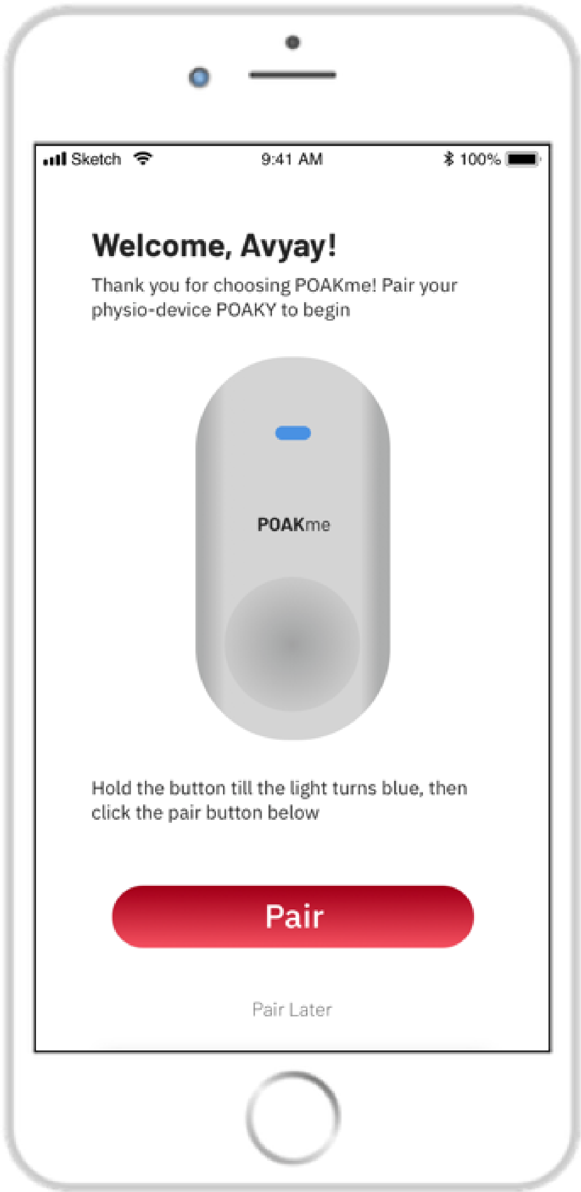
The flow of using the app is demonstrated in the next section.

6.1 **POAK**me

The splash screen has a neat animation to welcome the user to the app. The user is prompted to type their login ID. There are alternative options of using the secure on-device login biometric options or to use the device to directly log into the app. But these alternatives appear only after the first login.



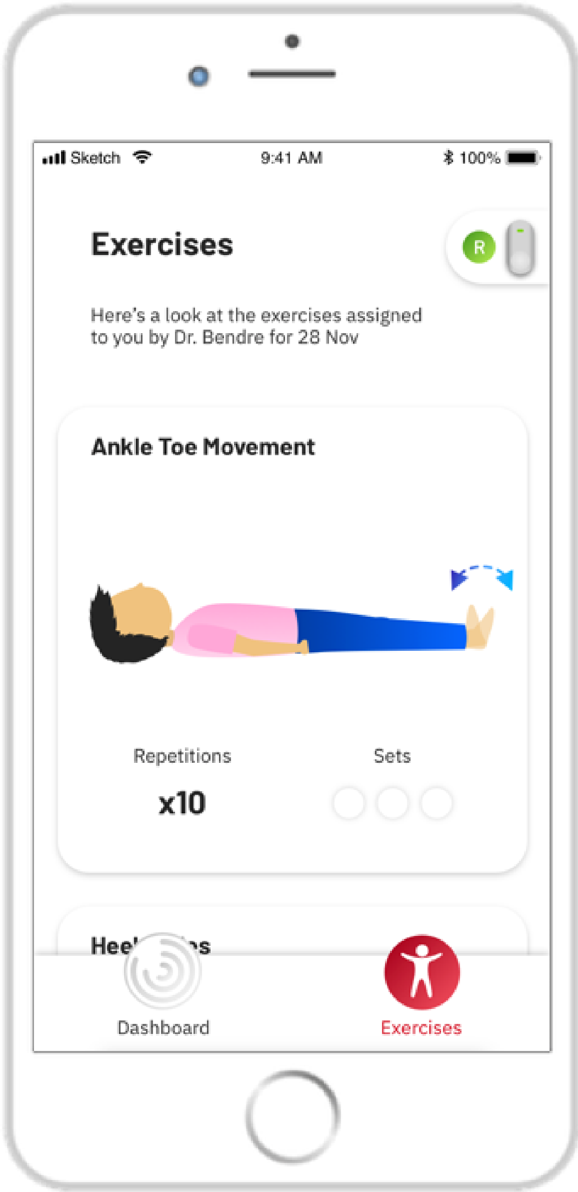
The user is prompted to pair their device to the app upon logging in. This is a simple process where the button on the device is pressed along with tapping on the "Pair" button. An animation displays the connection status.



Once the device is paired, the user can configure the preferences such as the name of the device and which foot it is meant for immediately by clicking “Next”.

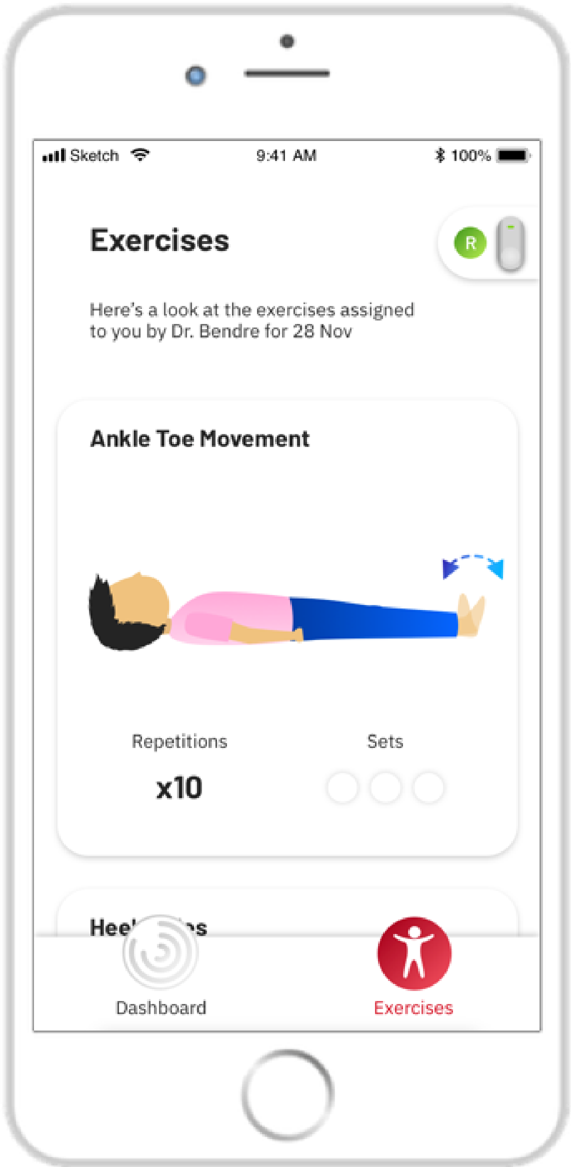
The app prompts the user to select which foot the device is meant for, which can also be setup later. This is information that the physiotherapist can upload onto the patient's profile as well.

Once the foot is selected, the user can get into the app and use its various features which will be described below.

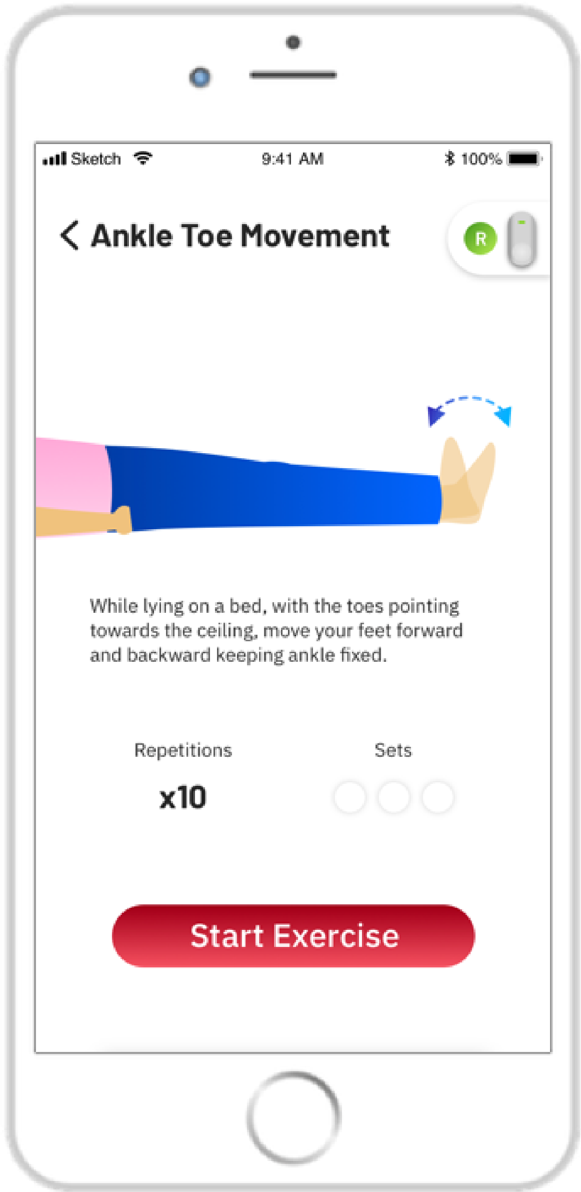


The app then proceeds to show the exercises that have been assigned by your physiotherapist to you. There are cards which have the exercises listed on them, along with graphics and information about the number of reps and sets.

To the top right of the screen, there is an indicator to let the user know whether the device is connected or not and which foot it is connected to. The bottom navbar reveals two sections, the exercise section, which we are on, and the dashboard, which we will get to in a few moments.

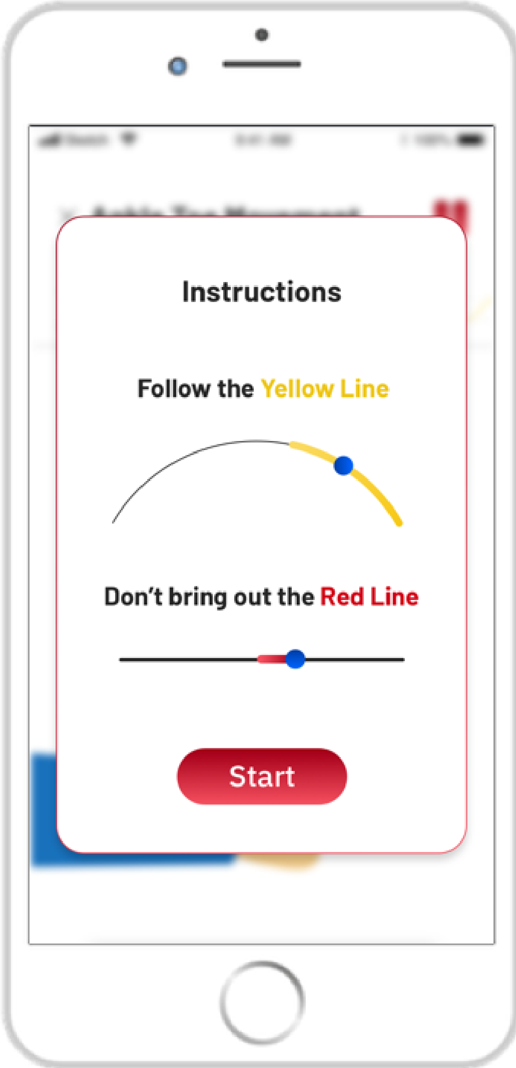


Clicking on the card takes the user into the exercise screen. This gives details about what is supposed to be done. The user can click on “Start Exercise” to begin the exercise.

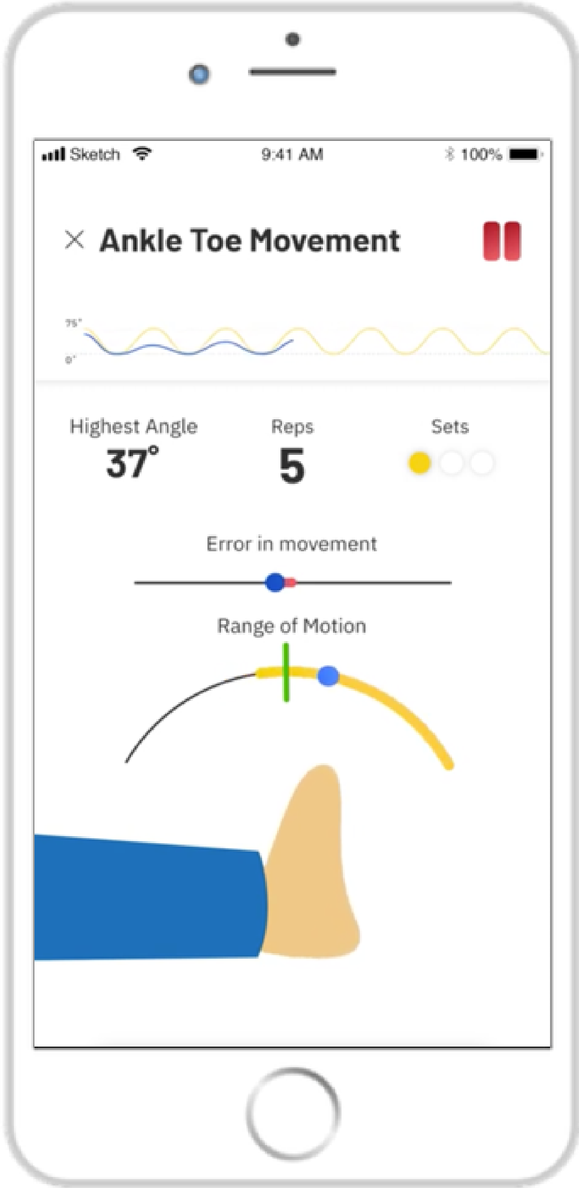


If POAKY is not on the foot, the user is prompted to wear it.

Then, a simple instruction set allows the user to understand what they are to follow to perform the exercise correctly.

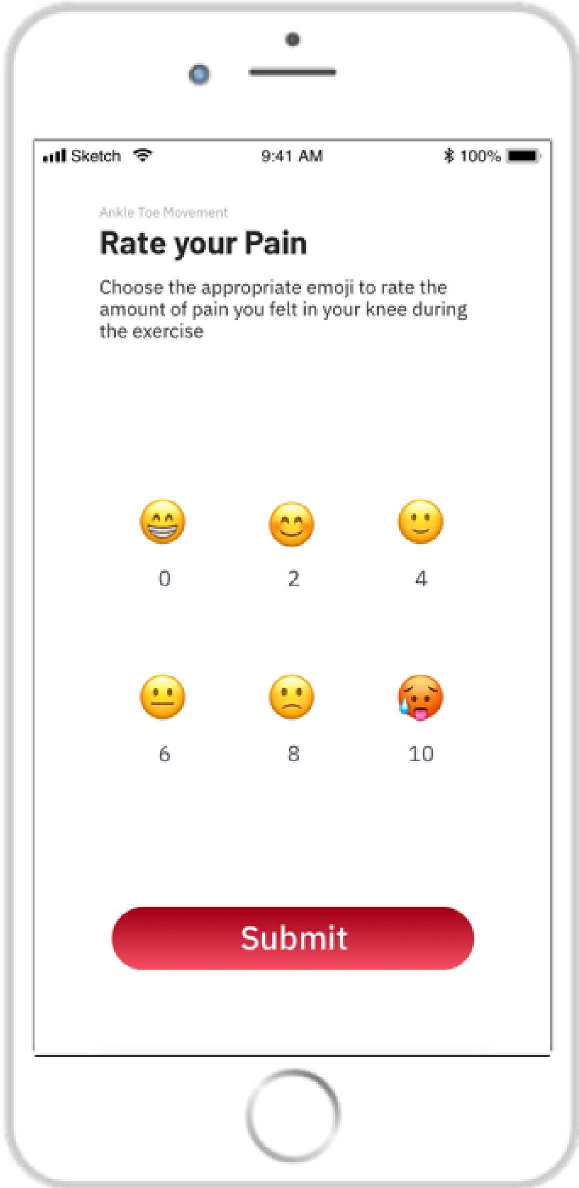


The Exercise feedback screen has a few elements to keep an eye on. The blue dot corresponds to the user's movements. The yellow angle bar indicates the pace at which one is supposed to be doing the exercise. The red bar indicates any error in the movement to allow the user to correct in real time. At the top, there is an indicator of the overall progress in the exercise. There is also an option to pause the exercise in case the user feels tired or in pain. There are a few motivators as well, such as the highest angle achieved, shown in green on the angle bar, the total number of repetitions done, and which set the user is on for the day.



Post the exercise, the user is asked to rate the amount of pain they felt when doing the exercise to allow the physiotherapist to alter the program to better suit the needs of the patient.

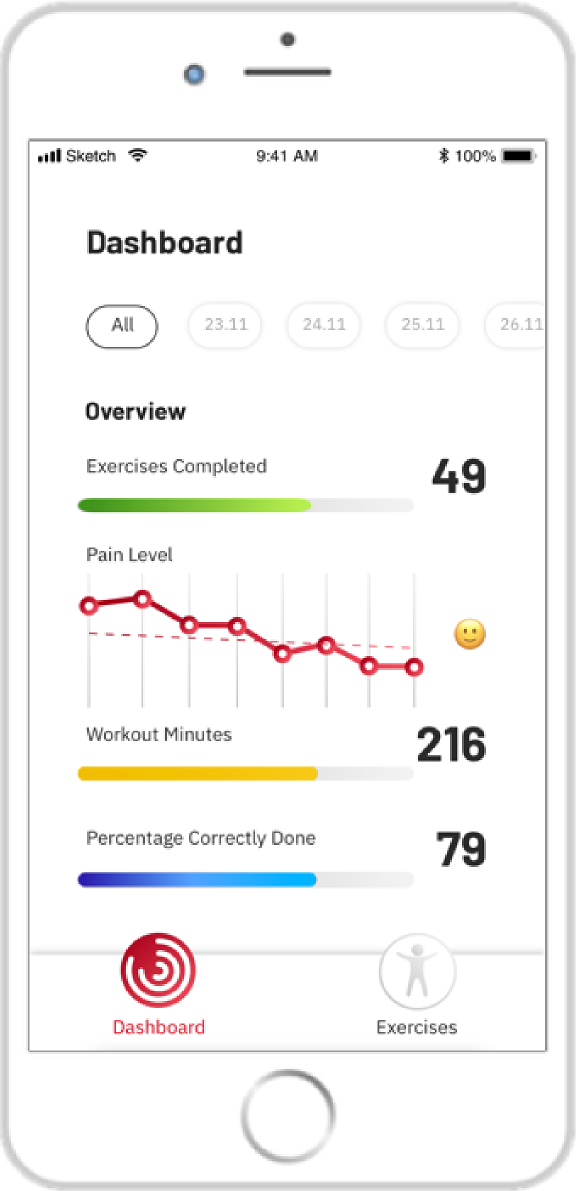
The patient can return to the Exercise screen where it will now reflect that one set of the exercise has been done for the day.



The Dashboard section has a record of all the exercises done in the physiotherapy program so far. It also uses the data available to create stats that help motivate the user to go further into the program.

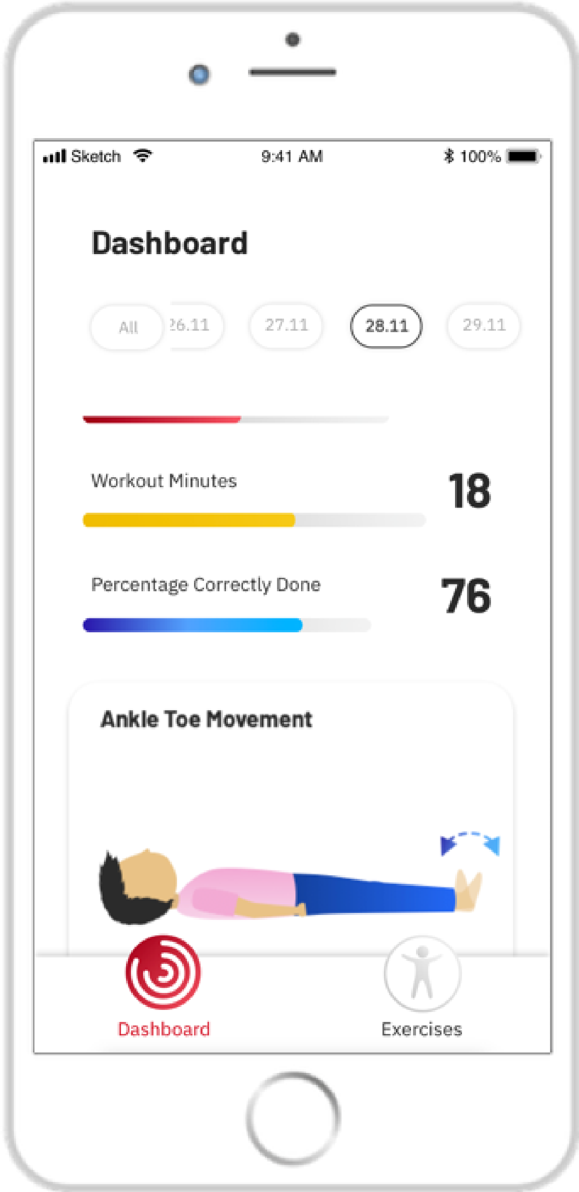
The “All” section is the cumulative data from all the exercises done from the beginning.

The user can navigate through the dates to get an idea about what their physiotherapy program entails.



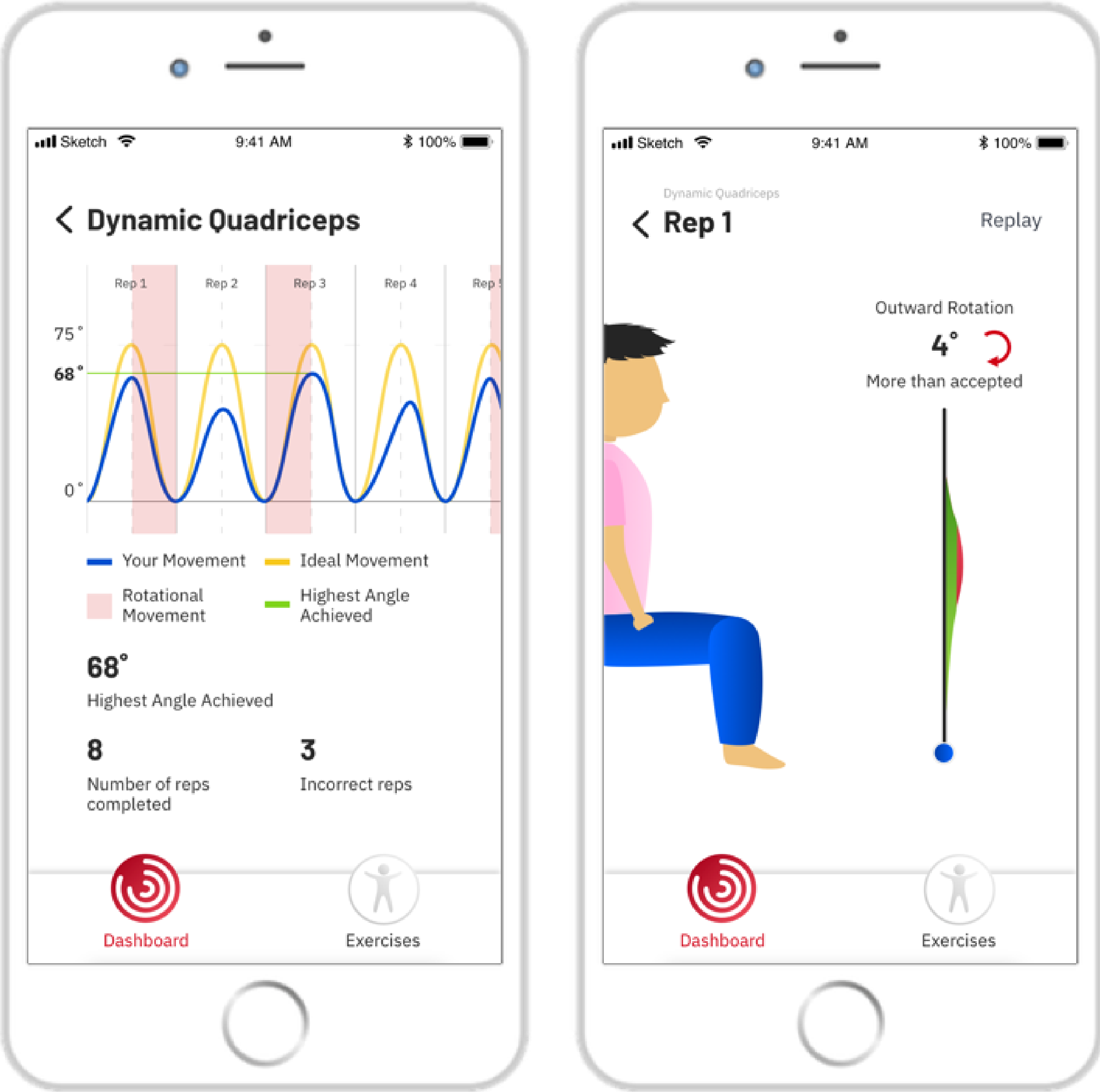
When the user selects a particular date, the stats for that particular day are shown, along with details of the various exercises done.

The navigation structure is similar to the Exercise Screen. There are exercise cards which depict the different exercises done that particular day. Only the exercises that had been attempted are displayed here. Clicking on the exercise card reveals more details about the exercise.

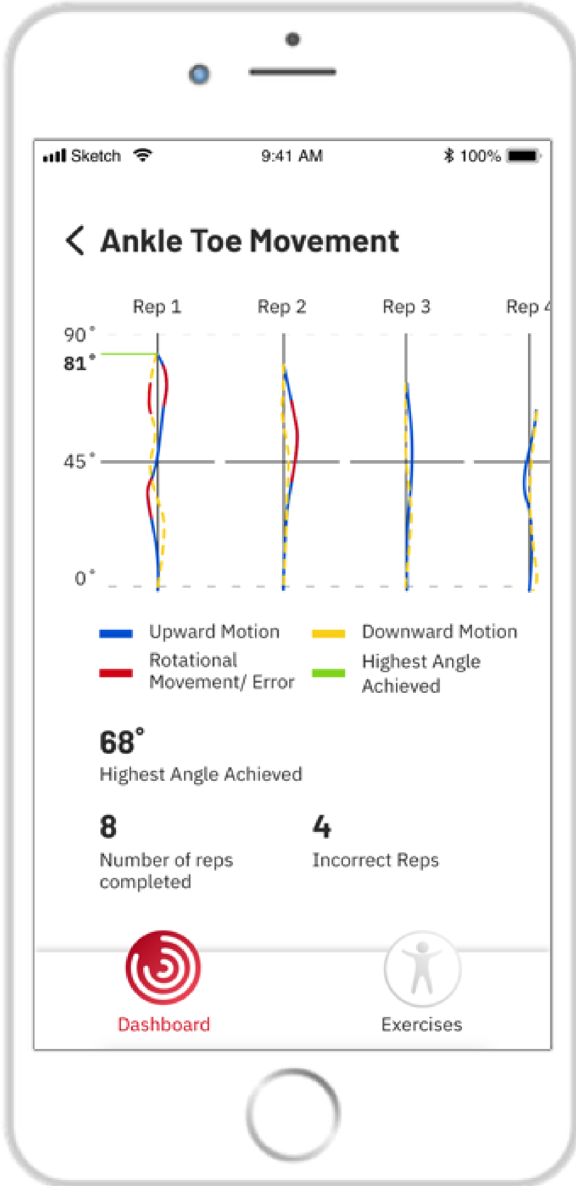


For beginners, a simplistic graph with the expected motion range, personal motion, and errors, if any, are shown. This easily lets the patient know how close to the expected motion they were able to achieve and also sets a goal for the patients to look forward to.

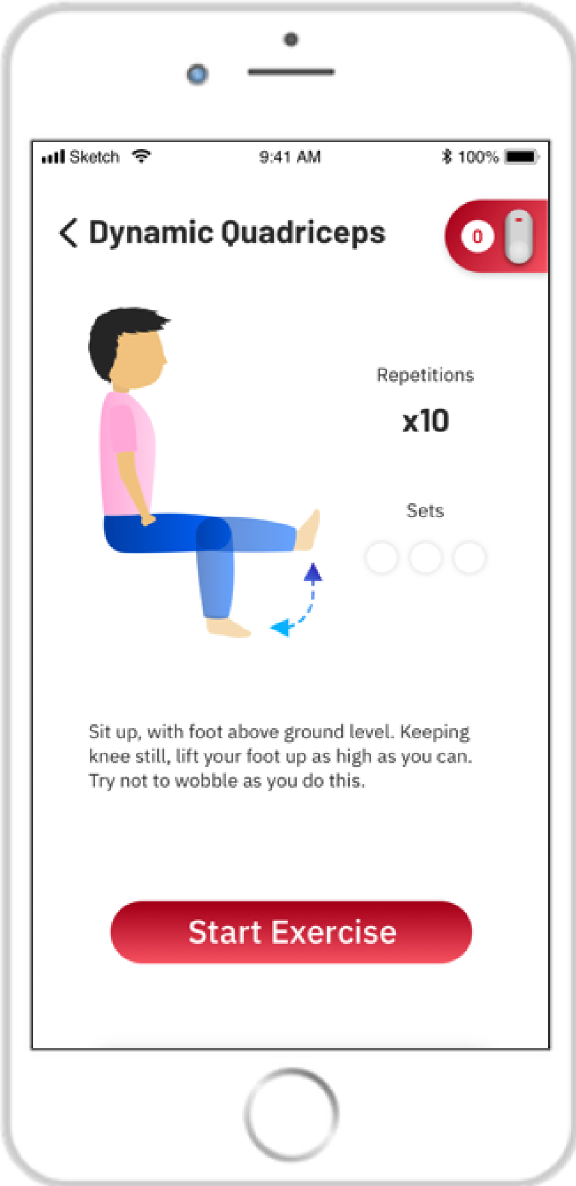
The error is shown with a red background. Tapping on the bar allows the patient to visualise an animation of their movement during the particular rep and possible corrective methods they can take to avoid the error.

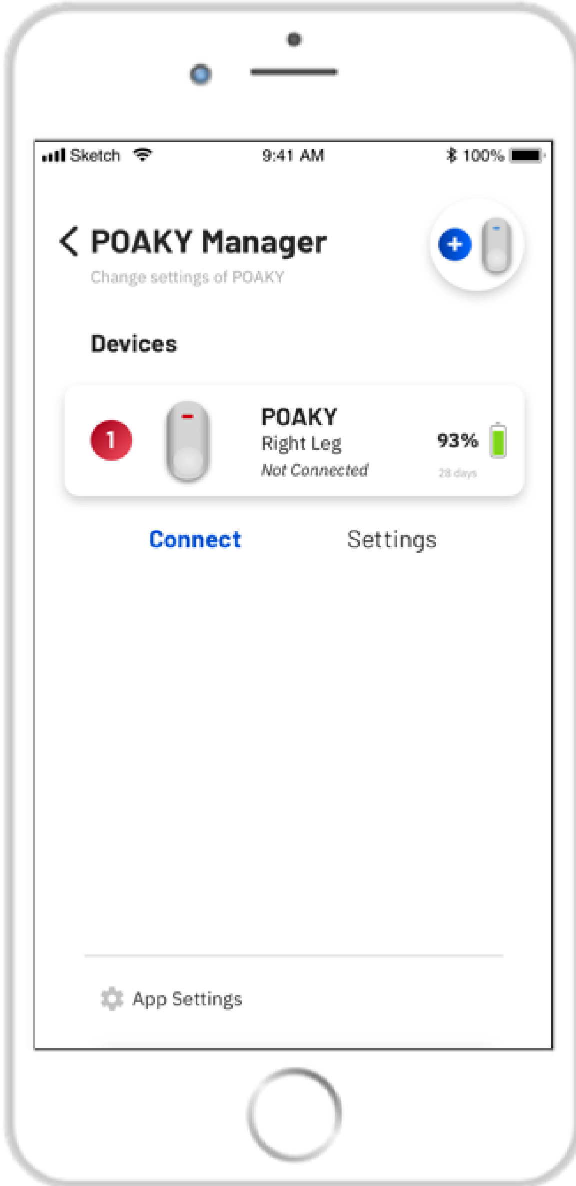


As the user gets more advanced, a more nuanced version of the graph is shown to allow the user to grasp more information in a short span of time. The graph has a X and a Y axis, with upward movement, downward movement, and rotational movement highlighted in the graph.



If POAKY is not connected, the device tab at the top right corner turns red to indicate the same. The user is prompted to connect the device. The user taps the tab to enter the device manager. This shows the list of devices that are connected, the battery percentage of the devices, and the leg the device is configured to. Here, the user can reconnect their existing device, or add a new device to the application.





07 Evaluation

Evaluation was conducted in two parts. The first evaluation evaluated the perception of a remote work flow with the addition of a device and an app through semi-structured interviews with participants of the pilot. The second evaluation was directed at understanding the perception of the high fidelity click through prototype of the POAKme app.

7.1 Pilot Evaluation

The pilot was conducted with two participants, one in the control, one in the experiment group. This was primarily limited to the people who agreed to participate in the study, with the Declaration of Helsinki based Informed Consent being administered. The data was collected over a 7 day period.

The device was given to the participant in the experiment group along with the configured application. The participant used it for seven days. The participant in the control group was given a sheet with a diagram of the exercises to be done to refer to. Strength and self reported pain measurements were taken on the 0th day and the 7th day of the experiment.

There was a marked increase in strength of the participant in the experiment group over the participant in the control group, although this was primarily attributed to increased adherence due to being watched by the investigators.

Strength Measurement
Experiment group
0th day: 16.5kgf
7th day: 22.5kgf

Control Group
0th day: 18kgf
7th day: 20kgf

Self Reported Pain Measurements
Experiment group
0th day: 5/10
7th day: 1/10

Control Group
0th day: 3/10
7th day: 0/10

Questions regarding the usage of the device, application, and understandability of the visualisation provided over the web were asked.

The findings were as follows:
Device
- The device was easy to use
- It was quite light, so didn't affect exercising
- The toe guidance made it easy to correctly place the device
- Sometimes, it would pain to wear the device as I needed to bend to reach over to the foot

Application
- Didn't read the information too carefully, but the graphics helped
- With regards to real time feedback, the square would go red immediately, so I could correct the movement immediately
- Didn't listen to the music, only followed the grey square
- Felt the grey square was moving too fast for comfort

Visualisations
- Accessing the visualisations was no problem with the website
- Accessed it only on mobile, no laptop
- Didn't understand if the rotational movement was outward or inward from the website, but the app had shown outward, so I knew it meant that

7.1 Application Evaluation

The high fidelity application was given to 7 potential users and 4 physiotherapists. The evaluation conducted primarily focused on Momentary perception, Episodic perception, and Learnability. The questions asked also revolved around these topics. Another factor considered for the final application was delight. It was important that the user returns to use the application, so it was also important to understand their preferences.

The findings from the conversations with potential users were as follows:
- All users said the application is good and will be useful to them
- All said it was easy to use, but only for educated people who have used smartphones before
- 1 user found the language used to describe exercises unfriendly
- Information provided would help ease the things they have to remember so, from that point of view, the application was useful
- 3 users said they would not refer to the real time feedback daily, and would prefer to look at how they did the exercises in the Dashboard instead
- But all of them acknowledged that the showing of the error would be immensely helpful in correcting movements and not doing the exercise incorrectly
- 2 users said they don't like graphs, so would not use the visualisation part of the application
- But nonetheless, found both the graphs easy to understand given the legend
- 3 users said they would come back to the app only if they saw some kind of improvement
- 2 others said it makes them answerable, and gives them no chance to bluff to the physiotherapist, so it in some ways forces them to come back to the application
- Overall, everyone found the application simple enough of required to use on a daily basis

Questions to the physiotherapists also delved into understanding whether the information provided was appropriate or if more/less should be given. Findings were as follows:
- Found this application to be a good supplement to the Home Program for the basic exercises
- Felt it complemented the treatment of the physiotherapist quite well

- All said it was easy to navigate, but only for people who are used to smartphones
- All felt the information being displayed in the real time feedback was appropriate and simple enough for patients to understand
- One physiotherapist said that she incorporates “hold time” in her exercises when asking the patients to do it from home, which is a feature this app doesn’t have
- With regards to the visualisations, all of them said it will help them to point out exactly how the user should change their movement to do the exercise correctly, information they earlier did not have
- All of them felt the graphs while simple, would take the users some getting used to before being effective in taking action
- Felt the integration of device with the app was intuitive

08 Conclusion

8.1 Limitations

While there were many decisions taken in this project, there some factors that were either overlooked or came to light as the evaluation took place. Some simple things such as allowing the user to manipulate the pace of the exercise, having a choice when selecting a song, providing more interactive feedback either in the form of a game, or with greater visual cues or haptic cues, and many more were not included in the Pilot test. This was primarily due to the lack of time, and, given that this was my first attempt at building software and hardware that interface with each other, lack of technical know-how. Other factors such as adding a “hold time” to all the exercises were completely overlooked and came to light only when the evaluation was done with the physiotherapists. With regards to the experiment, getting both longitudinal and horizontal data was hard to come by, with many factors such as patients downright refusing to participate in the study resulting in a loss of time to start the experiment.

8.2 Future Scope

The immediate need in the future, one that was not worked on in detail in this project, is to develop an interface for the physiotherapist to interact with their patients remotely. This would entail many things such as figuring out how to manage the multiple patients, how to tweak the right settings for each exercise, setting up many things such as different programs for different levels of patient rehabilitation and different injuries as well. In this particular project, the immediate focus was on working on exercises that include large movements, but many actuator exercises for activating muscles were not included as movement is minimal and recording electrical activity at the muscle would be the only method of recognising the same.

Other factors such as multi-language support, inclusion of voice and haptic feedback to help make the device and application more accessible to elderly can be looked at in future outcomes.

8.3 Learnings

Telerehabilitation is a field with potential for massive disruption in the rehabilitative medicine industry. This project aimed at minimising clinical contact while maximising remotely supervised home care. The focus was primarily directed at understanding the workflow of an individual while at home, and intervening in the identified space. One of the findings from the literature review was the abundance of clinic facing solutions, with not enough efforts directed at using infrastructure available at homes. Contextualising this factor to Indian homes was a complex task, which ultimately led to some compromises and forced the scoping down of the possible target market. But with the largest growing mobile internet market, the potential for such an intervention to take off is quite high.

On the technical side of things, this was my first attempt at designing and developing software, let alone one that interfaces with an external hardware over a network. This was quite challenging and the learnings have only emboldened me to try more with such technologies. There was a lot learnt as I spent the nights soldering devices that could be handed over to participants for the experiment. This along with getting a sneak peak into the healthcare industry has made a strong impression upon me that I hope to carry forward as I explore this space in greater depth.

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