An.

Exercise to Fight Ankylosing

Interactive Full Body Exercise Experience for people affected with Ankylosing Spondylitis

Semester IV Project Report

Guide : Prof. Girish Dalvi

Jayati Bandyopadhyay
146330004

Industrial Design Centre,
IIT Bombay.

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Jayati Bandyopadhyay.

Dedicated to Tista, for always falling asleep while exercising…

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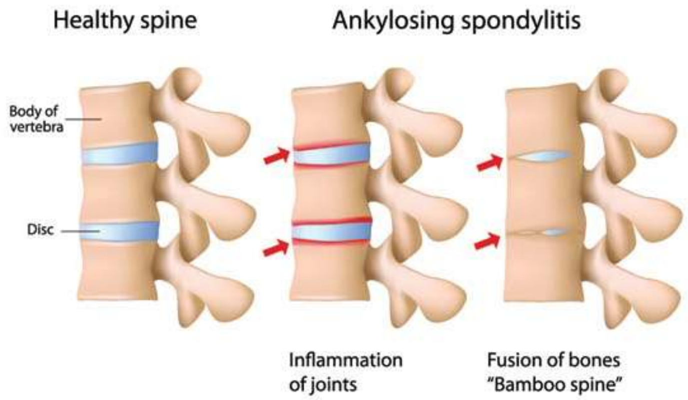


Fig 1. Fusion of Bones

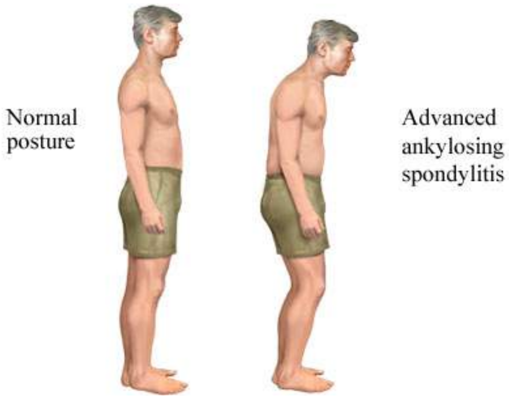


Fig 2. Bamboo Spine

2. Introduction

Rheumatology is a super specialty of Internal Medicine that deals with arthritis and rheumatism. Rheumatism indicates pain arising from joints or other elements of musculoskeletal system. There are over 100 rheumatological disorders classified by the World Health Organization. Shortage of trained rheumatologists in India has led to management of these diseases by untrained doctors, practitioners of alternative medicine and quacks. Under appreciation of rheumatological problems arise due to lack of knowledge about these conditions [3].

Spondylarthritides are group of diseases characterised by affected spine and other joints. Ankylosing spondylitis is a subset of these diseases. Other causes of spondylarthritides in adults and children include psoriasis, inflammatory bowel diseases, genitourinary and bowel infection. Rigidity of spine is a common sequelae of these diseases. Around 0.25% population in India is estimated to be affected by spondylarthritides.

2.1. Ankylosing Spondylitis

The word Ankylosing Spondylitis comes from Greek ankylos, crooked; spondylos, vertebra; -itis, inflammation [9]. It is strongly correlated with the histocompatibility antigen HLA-B27 which is a protein that is found on the surface of white blood cells. About 83-94% Indian patients of ankylosing spondylitis are HLA-B27 positive. The symptoms of the disease are usually first noticed in late adolescence or early adulthood; the median age in western countries is 23. In 5% of patients, symptoms begin after age 40. Studies on the incidence of AS are sparse and indicate an annual incidence of 6–7 per 100,000 persons in caucasian populations [1]. The most affected joints are sacroiliac, neck and rib-spine junction (shown in Fig 3).

The initial symptom is usually dull pain, insidious in onset. It is felt deep in the lower lumbar or gluteal region. The pain is accompanied by low-back morning stiffness which lasts for a few hours. The condition improves with increased joint activity but returns if the joints are immobile. Within a few months, the pain usually becomes persistent and bilateral. Nocturnal exacerbation of pain often forces the patient to rise and move around. Some of the aggravating and relieving factors of AS are highlighted in Fig. Early diagnosis is the key to successful disease management. An Indian study [10] demonstrated diagnostic delay of almost 7 years for patients with Ankylosing Spondylitis.

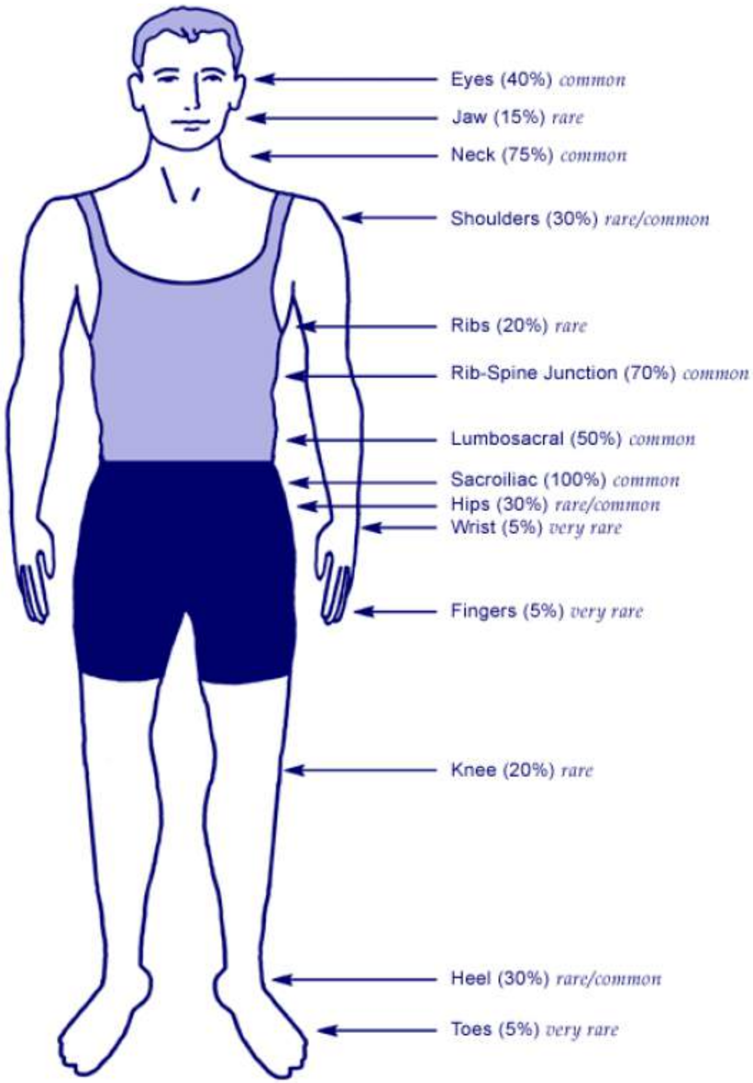


Fig 3. Joints Affected

The course of the disease is extremely variable. It ranges from the individuals with mild stiffness and normal radiograph to patients with totally fused spine and severe bilateral hip arthritis. Disease progression can be estimated clinically from loss of height, limited chest expansion and spinal flexion, and occiput-to-wall distance.

Nonsteroidal anti-inflammatory drugs (NSAIDs) are the first line of pharmacologic therapy for AS. There is evidence that daily NSAID therapy slows radiographic progression and many patients with AS continue to have symptoms and develop deformity despite NSAID therapy. Anti TNF alpha therapy block a key protein in the inflammatory chain reaction responsible for joint inflammation, pain, and damage in ankylosing spondylitis [4]. It is given intravenously and can lead to lowered immunity, reactivation of hepatitis B, tuberculosis and central nervous system disorders. These drugs are expensive and needs to be taken under strict supervision of a rheumatologist. On rare occasions, patients may benefit from surgical correction of extreme flexion deformities of the spine. From the pharmacologic therapies currently available, it is evident that the drugs involve substantial amount of side effects leading to reduced kidney functioning and nephropathy. Hence, patients seek non pharmacological solutions (Fig. 4) like physiotherapy, swimming and anti inflammatory diet. Despite persistence of the disease, most patients remain gainfully employed. Some studies have suggested that AS shortens life span when compared with the non-affected population.

Lack of physical activity proves detrimental to patients suffering from AS. This leads to a rapid fusion of joints which precipitates into partial or complete paralysis. Hence for AS patients, exercising is a matter of survival and should not be missed throughout life [2]. It has the potential to reduce the baggage of side effects that comes along with the clinical anti-inflammatory drugs available in the market.

Relieving Factors	Aggravating Factors
Warm Weather	Humid / Cold Weather
Moderate physical activity	Poor Sleep
Local heat	Physical Inactivity
Starch free diet	Anxiety / Stress
Mental relaxation	Jerks

Fig 4. Relieving and Aggravating Factors

2.2 Physical Activity

A common misunderstanding among people is considering daily exercise regime as an optional feature of everyday life [6]. Exercising is correlated with 'health conscious' people and is observed as an individual attribute. It becomes a daunting task for people who are not motivated to maintain a healthy lifestyle.

Ankylosing spondylitis patients have an impression that clinical treatment is their only way to combat the disease. This indicates a clear lack of knowledge regarding the different alternatives of managing the disease. Rheumatologists, their primary source of information, are more inclined towards pain management and have a very low threshold of prescribing drugs. Remote supervision of physiotherapists is an explored option with the emerging popularity of computer games and novel input sensors like 3D depth cameras (Fig. 6), balance boards (Fig. 5) or accelerometers [5] but lack of availability of such solutions in the market indicate that this approach is still at its nascent stage.

Applications with partial or incidental focus on physical activity is known to have succeeded commercially in form of E*xergames*. However, it largely fails to cater to the needs of people with limited and restricted range of joint motion. Rehabilitation games, on the other hand have not yet gained impetus commercially due to divergent requirements that need to be taken care of for each therapy [6]. Section 3 covers in detail an analysis of the existing solutions to enhance exercise experience and motivate patients unaware or doubtful about the importance of exercising.

Fig 5. Balance Boards

Fig 6. Kinect with depth cameras

3. Literature Review

Multiple applications have been developed in the form of 'Exergames', facilitating active lifestyle and motivating people to exercise. Research indicates the positive impact of exergames on rehabilitation patients and non-affected health conscious people.

Synchronous and asynchronous monitoring of physical activity is a well practiced trend in exergames. Exergames usually have with goal setting, feedback and social influence components [6]. This caters to the behavioural and motivation aspect. The behavioural components are supported by theoretical frameworks such as game design and persuasive models, and are driven by both intrinsic and extrinsic motivation parameters.

Computer games and simulations have been recognised as a motivational tool in rehabilitation (e. g. neuro-rehabilitation, physiotherapy) for almost a decade [8]. But the lack of commercial games or applications for individual therapies indicates the need of a framework with active expert involvement.

Mainland and Siek agues that feedback presented typically consists of raw activity levels, progress towards goals, or comparison with peers. It is not enough to motivate people and should be augmented with additional information that conveys the value of physical activity [6]. For caregivers, the target users for the study, furnishing raw activity levels might be of little interest. But for ankylosing spondylitis patients, providing feedback in terms of increased range of motion has potential to act as an intrinsic motivator.

In [5], the authors describe an assistive technology to encourage and motivate stroke patients to practice their gaits. Use of virtual reality for rehabilitation has gained impetus and its benefits have been leveraged in multiple studies. In [5], streets of Hong Kong were animated into a gaming environment. A proper move was only registered when a correct gait posture and sequence were measured. Pressure pads, goniometers and a digital camera was used to track the users. Information was stored in a database from which the therapists could study and assess the progress of individual patients remotely. Remote supervision and tracking makes the system robust and helps in giving accurate feedback. However, apart from the setup cost, the use of multiple devices might create an entry barrier for people who are naive users. Using these devices to carry out a daily exercise regime might gradually demotivate patients because of its elaborate pre-exercise preparation. It can help patients gain confidence in walking on the streets patients are familiar with. But direct simulation of streets reduces chances of repeat play due to the lack of a concrete gameplay. It also increases the necessity to personalise the environment for individual patients.

Mini-games promise an affordable way of developing games for rehabilitation. [8] highlight the need for additional support, software tools and specialized input devices to develop games for rehabilitation. The lack of these tools make the development complicated and increases entry barrier of the end users. A recent European project, titled REWIRE, focused on building a cheap in-home system for rehabilitation. The primary concern of using games for exercising is that it might lead to ambiguous interactions and result in patients identifying trick movements to move ahead within the game. Patients with limited range of motion might not be able to play the game accurately which might demotivate them from playing. Initial calibration can solve this problem but it might be a heavy compromise from the game mechanics perspective. Use of extrinsic motivation could fail to address repeat play issues.

Chittaro and Zuliani explore the use of audio storytelling techniques that provides prompt feedback through a narrative as a response to the player's activity and saves them from looking at the screen during their exercise session. The audio feedback is an important feature which enhances player experience by not adding visual distraction in form of exercise feedback on a digital screen. The need of narratives could be appropriate to motivate non-affected players, but for patients with serious diseases, it might be an unwanted embellishment. In [7], the authors have used mobile phone exergames, which they argue is the only audio exergame other than Zombies, Run!.

Exploring different hardware mediums was also important to understand the feasibility of setting them up in a household environment. Space, investment, entry barrier and learning curve to operate the system were some of the identified concerns. The available mediums were Wii Sports, Microsoft Kinect, Playstation which already have existing applications to make players exercise. These applications were evaluated by analysing the demonstration videos uploaded by IGN.

Nike + Kinect :

This application (Fig. 7) is a purely instructor based gym experience with no motivation aspect. The instructor guides the player step by step to different exercises with an elaborate demonstration. First time users require a detailed calibration process which might demotivate the users. The constant intervention and monologues by the instructors can also be unpleasant for players. The audio input takes a lot of time to get recognised and the player has the reluctance to move around in between demonstration and tracking.

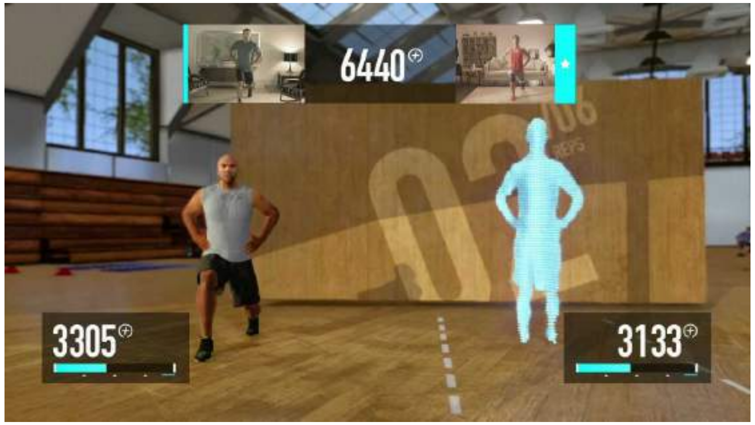


Fig 7. Nike + Kinect Interfaee.

Dance Central 3:

Dance Central 3 (Fig. 8) by Xbox is an application which makes players exercise while dancing to hip hop music. An addition to this version of Dance Central is a narrative which allows time travel and has a collection of 40 years of hip hop songs. The application allows players to slow down the demonstration of moves to get a better understanding. One of the major problems with this application is the need to rehearse for an hour minimum before starting the actual session. The feedback is not elaborate and only the on-screen limbs light up to indicate error.

Fig 8. Dance Central 3

Dance Dance Revolution :

Dance Dance Revolution (Fig. 9) is a cross platform application with a pressure sensing pad with regions which the user has to step on depending on the visual clue provided on screen. In spite of of being a good exercising application, it requires constant eye leg coordination and rigorous practice to match with the tunes perfectly. Moreover, the durability of the pads are also a cause of concern for the players.

The Biggest Loser : The Ultimate Workout

This is an exercising application with body analysers, before and after statistics and also embed recipes of healthier food and active lifestyle. The before and after statistics could act as an intrinsic motivator for patients with restricted range of motion.

Fig 9. Dance Dance Revolution

Fig 10. The Biggest Loser : The Ultimate Workout

Your Shape : Fitness Evolved

Your Shape: Fitness Evolved (Fig. 11) is a cross platform application that allows players to workout with an instructor. This application eliminates the gamification component and focuses purely on workout. It uses player projection technology to scan the player and then creates custom menu around the player. Though it has a few technical glitches which slows the application, it is by far one of the most exhaustive exercise applications with tracking, feedback, improvement statistics, online integration. It also has an option of gym games where the players can play mini games if they feel the need to switch. But the technical problems sometimes fails to track players, thereby giving wrong feedback and decreasing overall statistics which demotivates the players in turn. Resistance training with weights lack accuracy due to the absence of physical weights, exercises in lying down postures are still not detected by the application and is mostly focused on cardio, legs and shoulder exercises.

Fig 11. Your Shape: Fitness evolved for Xbox 360

These existing applications have exhaustive features to cater to the needs of people interested in maintaining a healthy lifestyle. They are commercially successful and widely used in household scenarios. For people having limited range of motion, however, these applications might not suffice. Some features could definitely prove useful for both the groups and could be explored further. Certain features that had worked previously for similar applications could be refurbished and used in the solution for AS patients discussed in details in section [5].

4. Primary Research

The initial motivation was to understand the disease to empathise with a close acquaintance suffering from AS. Accompanying her to multiple rheumatologists for pain management revealed insights such as the doctors' low threshold for prescribing medicines and patients looking for an alternative form of remedy to avoid side effects of the medicines prescribed. The first contextual inquiry was done six months before the project was initiated. It helped in understanding the importance of exercising as an alternate to early clinical intervention.The side effects of the drugs were understood to empathise with the patient. The patient being an anaesthetist herself had an elaborate understanding of the different phases of the disease and side effects of the drugs suggested by the doctors. In spite of drugs being prescribed unanimously by all the consulted doctors, she preferred to adhere to exercises and diet. She mentioned that lack of time and her rigid work schedule unmotivated her. She found it difficult to abide by the daily exercise regime because of her work load. However, it was observed that the patient engaged in lighter forms of entertainment inspite of alleging time as the constraint. Hence, lack of motivation was considered as a possible issue.

The gathered insights had to be generalised and validated through interviewing other patients, physiotherapists and doctors. The different stakeholders identified were :

1. Patient
2. Physiotherapist
3. Doctor
   a. Rheumatologist
   b. Anaesthetist
   c. Psychiatrist

4.1 Patients :

The physical and psychological conditions of patients vary considerably depending on the severity of the disease. Three types of patients were targeted :

1. Extreme Severity
2. Moderate Severity
3. Low Severity

Two patients with extreme severity and one patient each with moderate and low severity were interviewed. One of the patients interviewed was the founder of 'Ankylosing Spondylitis India', a social media forum for patients to seek help and discuss their problems with each other. The objective of the interview was to understand the necessity of an exercise application for AS patients. The questions framed were aimed at understanding at what time during the course of the disease he felt exercise was important. The interview included his experience as well as what he had observed while interacting with other patients from across the country. He acknowledged the importance of exercises, but accepted that he did not have access to necessary information to curb the course of the disease.

"Had no idea that it (Ankylosing Spondylitis) will change my life mentally, physically and financially…"

Age 43, Engineer, patient since 2003, founder of Ankylosing Spondylitis Facebook group for India.

- "If I had known that this would happen to him, he would have acted upon it from the beginning." — User Statement (US)
- "Knowledge is there, study is not available, limited access to information." — US
- Neck fused completely (5 degrees of radial movement possible). — Observation (OB)
- "There was no one to guide me at the onset of the disease, hence the condition aggravated." — US
- "I had to close business after it turned severe, decided not to get married." — US
- "Completely bedridden till October, 2015 after which I hired a physiotherapist for 3 months." — US
- Regular exercise and strict diet enabled him to walk once again. — Insight (IN)
- "I need help to do daily activities, take 10 minutes just to turn from one side to the other on bed." - US
- "My bed placed near wall, and I need to clutch the mattress to slide or get up (the mattress has holes as a result)." — US
- Opened a social media group so that people get access to information regarding this disease, something that he did not get during his initial phase. — IN
- He was proud to announce that a well known rheumatologists had recently joined the group, accepted the benefit of exercise and diet. — OB
- Suffers from depression, frustrated about conjugal life, very limited number of close friends. — OB
- "You cannot do anything to make our lives better, I have tried everything." — US
- "Never thought of having an exercise application as a solution, it has the potential to solve my current problem. I pay 600 rupees per day to the physiotherapist." — US

"I keep on walking till I feel like if I take one more step, I will die of pain…"

Age 29, Photographer, patient since 2008.

- Doctors had mentioned that he would be paralysed by 29, got demotivated. — OB
- "I had to take mild doses of chemo to combat the pain." — US
- "Started swimming and it improved his condition substantially. But recently got shifted to a place where there are no swimming pools around." — US
- During morning stiffness, he stays active on Facebook to divert himself from the pain. — IN
- Patients share a lot of problems with each other over Facebook which they do not share with their family members. — OB
- The pain increases if patients take rest, so he does not like to lie down. The only exceptions are Sundays. — OB
- Walks a lot as a substitute for full body exercise. — OB
- Started yoga for active lifestyle. — IN
- "I feel sleepy during working hours." — US
- Feels that lack of awareness and empathy among patients and non-patients is a major problem. — IN

"I do not want to live after 40…"

Age 32, Doctor, patient since 2012.

- Does not want to take disease modifying drugs, scared of the side effects. — OB
- Got extremely demotivated by two rheumatologists as they suggested immunosuppressants as the only remedy. — OB
- Exercises and plans to exercise regularly only when the pain aggravates. — OB
- Not motivated to exercise, falls asleep while doing exercises which requires her to lie down. — OB
- "Cannot maintain completely starch free diet being a vegetarian." — US
- Lives alone, hence there is no one to help her during morning stiffness or extremely painful conditions. — OB
- "I don't have time to exercise because of my work schedule." — US
- Gets tired after 5 to 7 minutes of exercise. — OB
- Cannot withstand vibration and jerks since it aggravates the pain. — OB
- Outspoken and jovial but admitted that she suffers from hidden depression. — OB

4.2 Doctor :

Three types of doctors were interviewed, a rheumatologist and anaesthetist for pain management, a psychiatrist. The rheumatologist and anaesthetist were interviewed to understand the different types of drugs available, their side effects and chances of drug abuse by the patient. The psychiatrist was interviewed to understand the typical psychological issues faced by ankylosing spondylitis patients.

"All medicines have side effects. Doctors do not stop prescribing medicines because of that."

- Rheumatologists prescribe drugs during acute exacerbation followed by disease modifying drugs on a regular basis. Inclined towards pain management and low threshold of prescribing these drugs. — OB
- Rheumatologists tend to ignore long time side effects associated with disease modifying drugs. — OB
- Rheumatologists are unconvinced of the benefits of exercising and low starch diet and try to convince patients that medicine is the only option to combat AS. — OB
- "Patients can become victims of drug abuse to get remedy from excruciating pain." — US
- "Patients have reduced conjugal activities due to physical limitations, depression and emotional state." — US
- "Patients getting divorced, patients deciding to be single due to AS." — US

4.3 Physiotherapist :

Physiotherapists play a key role in improving condition of patients. However, the amount of time invested per patient is compromised because of their busy schedule. The patients need to dedicate a particular time of the day for the physiotherapist, making the daily exercise regime rigid and short spanned. They change the pattern of exercises regularly, so it gets difficult for patients to remember the sequence and practice on their own.

"Exercises should not be restricted to affected joints…"

- Exercises should follow the FITT (Frequency, Intensity, Time, Type) principle.
- Maintaining posture is very important apart from exercising.
- The exercises should be in the order of Posture, Flexibility, Respiratory, Aerobic and Strengthening
- 30 minutes of daily exercise are prescribed, 10 minutes for each phase, 3 times a day.
- Same exercise can be done in different postures (Example : lying down can be replaced by crawling.)
- Patients come up with trick movements.
- Patients need to avoid contact sports, jerks.
- Patients need to be careful about brittle bones in advanced stages.

4.4 Insights :

Collective insights were derived from the interviews of both doctors and patients. These insights were directly used to develop the design ideas.

- There seems to be lack of motivation to exercise among patients, especially when they are at an early stage of the disease.
- Range of motion decreases with increasing severity.
- Joints affected can vary from one patient to the other.
- Keeping all the joints active is important.
- The exercise session should be moderated so that patients do not get bored or over work themselves.
- Exercises need to be repeated and should include maximum number of joints in any session.
- Exercises should not involve jerks and should consider decreased range of motion for affected joints.
- Patients have little knowledge about disease and its remedies.
- Patients are psychologically affected that lowers their self confidence.
- They are comfortable to talk to unknown people suffering from the same disease.
- Inducing repeat play mechanics in the system as the exercises need to be done throughout.

Exercising is indispensable for AS patients and needs to be done on a regular basis. The concerns regarding the psychological condition of the patients and disease awareness which could be taken into consideration while exercising. Hence, identifying a complete set of exercises was important at this stage. A physiotherapist was consulted to identify exercises involving affected, vulnerable and non-affected joints to enhance full body joint mobility. The focus was kept on making patients exercise regularly. Exergames were thought of as a potential exercising solution. The design ideas evolved around gamifying the exercise experience.

4. Exercises

The exercises to be included in the system were identified with the help of a physiotherapist. Emphasis was put on keeping all joint active. Tracking user movements could be a concern for the sensor. For exercises with overlapping joints, tracking might get difficult when the patient faces the sensor but could be tracked if the patient stand perpendicular to the screen. The order of importance (Fig. 11) while selecting the exercises were:

1. Posture maintaining exercises.
2. Flexibility exercises.
3. Respiratory or breathing exercises.
4. Aerobics.
5. Muscle strengthening exercises.

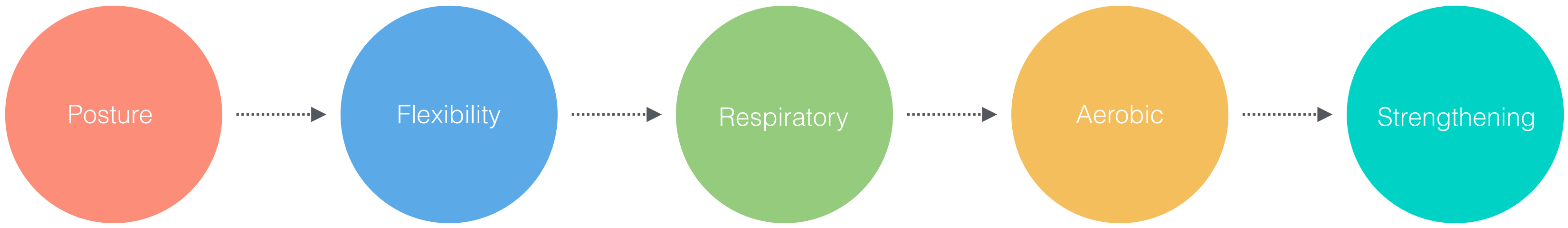


Fig 12. Sequence of type of exercises

Categorisation of Exercises :

The different classification of exercise variations possible are as follows:

1. **Position** - Standing, Crawling, Lying down.
2. **Number of joints** - Single joint, Multiple joints.
3. **Gravity** - Against gravity, along gravity.

The exercises assigned to AS patients mostly have position and number of joint variations. The exercises suggested by the physiotherapist were as follows:

- Neck movements in sitting/standing — forward-backward (Fig. 13), sideways (Fig. 14), and rotations (Fig. 15).
- Trunk movements standing with feet apart — forward, backward, sideways and rotations (Fig. 18).
- Breathing exercises with shoulder movements (Fig. 16).
- Bridging while standing, wall or chair as support. (Fig. 17)
- Cat-camel exercises (Fig. 19) in quadruped (crawling position).
- Hip rotations while lying on back — knees have to be bent for this exercise.
- Lying on stomach and lift each hand up from the shoulder and each leg up from hip.

The first five exercises were selected for the development of a prototype, exercises in lying down position were not included.

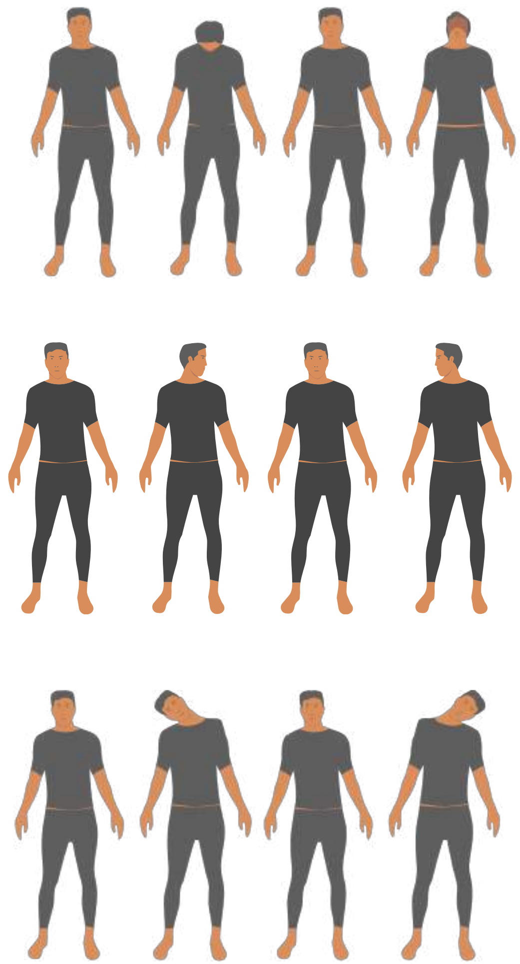


Fig 13, 14, 15 (From Top). Neck Exercises

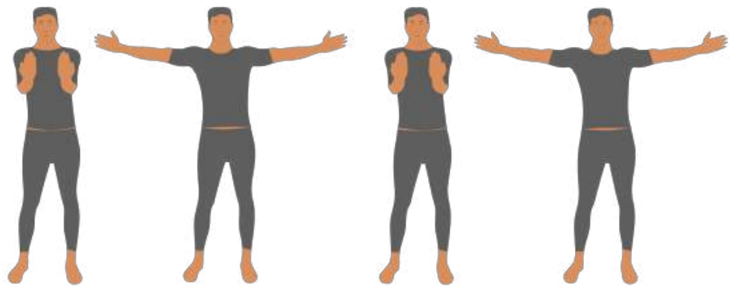


Fig 16. Breathing exercises

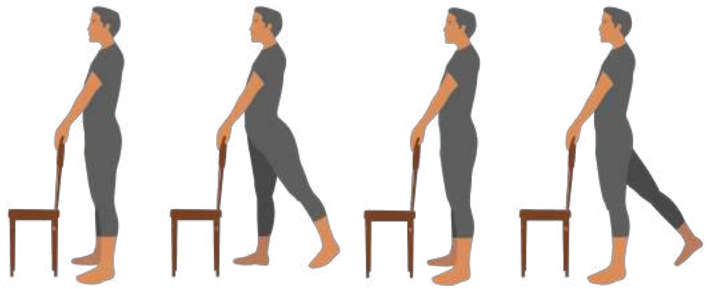


Fig 17. Bridging in standing position

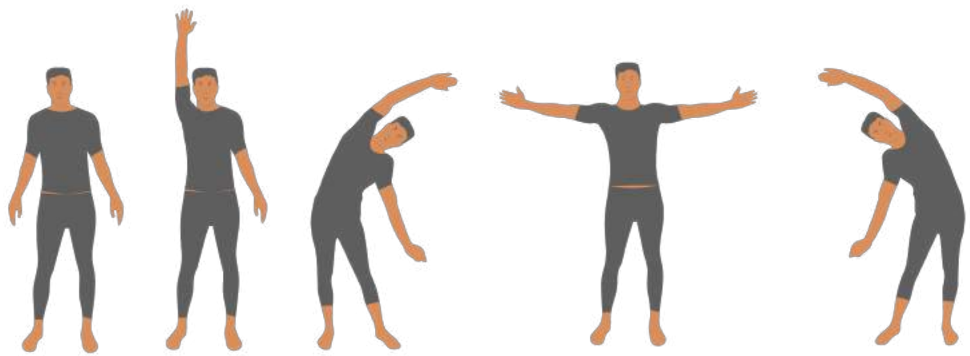


Fig 18. Trunk exercises

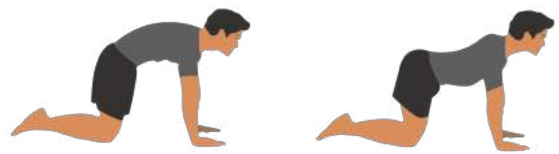


Fig 19. Cat-camel in quadruped position

5. Design Ideas I:

Tracking the patient while exercising and giving them appropriate feedback was the core objective of the exercise experience. Persuasive technologies and gamification were explored. The initial design ideas focused mainly on embedding exercises within games were as follows :

- Early success should be given to motivate patients to complete the session.
- Strong narrative in form of preamble should be provided to engage users.
- Complex exercises can be placed in higher difficulty levels. The order of postures in different levels can be standing, crawling, lying down in the increasing order of difficulty.
- Could start with postural exercises (easier in standing position for low and moderate severity patients).
- Exercises can be made either social or individual. For social games, the players need to participate from remote locations.
- Repetition of exercises should be embedded in the gameplay.
- Repetitions to be embedded in non consecutive steps to increase the gaming experience of patients.
- Illustrations of exuberant manifestation of the disease can be included to induce pain motivation among patients.
- Each session should not be more than seven to ten minutes to avoid dropouts.
- Inducing unpredictability by devising different ways to do the same exercise.
- Strategic breaks for breathing exercises.

- Embedding disease related information (diet habits and aqua therapy).
- Virtual reality environment to camouflage content. Cameras and IR sensors in Kinect can be leveraged to map joints.

5.1 Design Idea 1:

The patients align themselves with some highlighted points on the screen and complete an activity while maintaining that posture. The initial level could start with posture correction followed by tasks like killing a bug, breaking a wall which would ensure repetitions within the activity. Depth sensors like kinect could be used to track user movement and provide necessary feedback through scores. The exercises were mapped as micro-tasks to retain the interest of the patients.

One of the major challenges was to map the identified exercises on a gameplay. The chances of ambiguous interactions increase with the abstraction of exercises in form of a game. Moreover, providing extrinsic motivation such as badges and points might fall short eventually and might lead to disinterest in continuing with the regime.

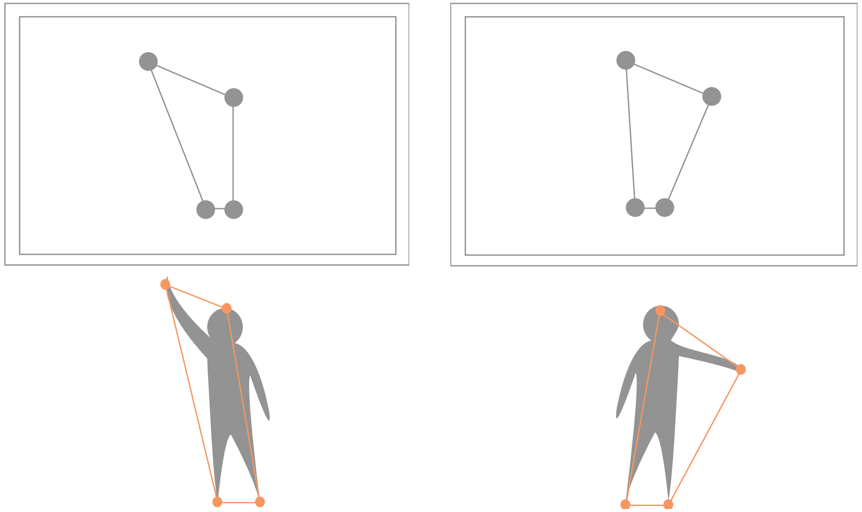


Fig 20. Dot matching, geometric abstraction

5.2 Design Idea 2:

This design idea was based on a narrative in which a convict, played by the patient, attempts to escape a prison. Game elements like traps, laser scanners, security, bats and wild animals pose a threat which the convict needs to save himself or herself from. Advancing through the game would require marching, crawling (in advanced levels) and stretching exercises. Strategic breathing breaks were kept to increase the health of the convict and thereby embedding breathing exercises. Bonuses and power boosts catered to motivation aspects. Repetitions were designed to be embedded by inducing the game elements multiple times within the escape journey. The idea was to engage the patient through a captive narrative.

However, repeat play aspects were still a cause of concern. Possibility of ambiguous interactions, intentional or accidental trick movements and hardware dependency to perform daily exercises were major drawbacks of this design idea.

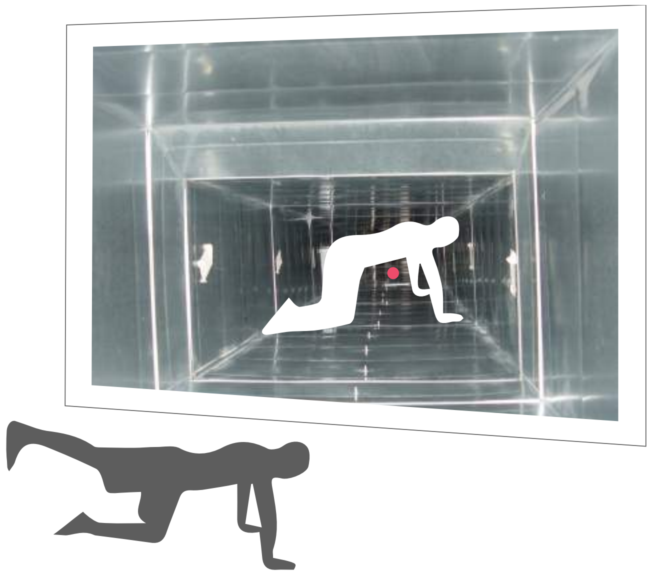


Fig 21. Crawling to advance within a tunnel

Game as a solution was surfacing as a less potent medium due to ambiguous interactions, repeat play and abstraction issues. If access to hardware is severed on a temporary or permanent basis, no knowledge of underlying exercises can prevent patients from performing the exercises. Moreover, games as a medium might be a embellishment for motivated patients. The questions that emerged were as follows:

- Will all patients play games to exercise?
- What problems are games solving?
- Will motivated patients be interested in playing games?

In an attempt to understand user requirements at a greater depth and find answers to these questions, a participatory design process was followed by involving patients at an early stage. The initial design ideas were explained to obtain feedback and understand the efficacy of game as a medium for AS patients.

5.3 Patient Feedback:

Multiple other issues surfaced in addition to lack of motivation while talking to patients. In metro cities, patients need to pay a around five hundred rupees to the physiotherapists for them to get a daily consultation. The logistics involved in the consultant travelling to the patient's residence or the patient visiting to a clinic is often a cause of concern for either of the stakeholders. Rigidity in exercise schedule and affordability issues force patients to discontinue their daily exercise regime once the pain subsides. In suburbs and villages, getting access to well trained physiotherapists is a challenge in itself. Patients do not have access to important information which might improve their condition. Thus, lack of disease knowledge about AS among patients and their family members add to the accessibility factor. The issues identified along with lack of motivation were as follows:

- **Accessibility** - lack of physiotherapists in suburbs and villages do not allow the patients have a regular exercise regime.
- **Affordability** - daily physiotherapist supervision is a costly service and is not affordable for patients with lower socio-economic status.
- **Motivation** - mundane exercises need to be done throughout and patients drop out after the exacerbation period is over.
- **Flexibility** - time of the day, duration of exercises, aligning with the schedule of physiotherapist becomes a problem for patients.

The existing design ideas could not cater to all these issues directly. Hence it was necessary to modify them taking into consideration the above mentioned issues. A modified set of design solutions were ideated which are discussed in detail in section 6.

Device	Price	Controller	Usage
Kinect (Xbox 360)	7000	No separate console	Can be used as a standalone sensor
Sony Playstation eye (PS3)	1,498 with playstation (16,200)	Separate controller with accelerometer, gyroscope	No depth in playstation eye, cannot be used without Playstation console.
Nintendo Wii	19,890	nunchuck with accelerometer, gyroscope	Plugins need to be bought separately to use it as a standalone device

Fig 22. Hardware Comparison

6. Design Ideas II:

The design ideas were modified and iterated using the feedback received from patients. The drawbacks of using games were already identified. In such cases, an affordable exercise application with remote supervision and feedback might cater to the needs of both motivated and unmotivated patients. Exercise charts in these scenarios have clear shortcomings of not being adaptive and lack feedback mechanisms for both patients and supervisors. However, the possibility of using games or gamifying exercises was not completely ruled out as motivation was still an issue with a substantial number of patients.

An application with sandboxed features of exercising and playing games was devised to address the identified issues in Section 5.3. In order to finalise on motion sensing hardware to track patient movements, the options explored were PlayStation, Wii Sport and Kinect (Fig. 22). While PlayStation and Wii require the patients to hold a controller, Kinect is handsfree and cost effective compared to the other options. Hence, Kinect was chosen as the tracking sensor over its commercial substitutes. The sensor was controlled through Unity 3D.

The initial iterations were designed to understand the hardware and gestures to advance in the application. Initially (Fig 23), it was assumed that 'click' would be the most intuitive gesture to select an option from the application screen. A click option took around 2.5 seconds to register as a gesture which turned out to be extremely difficult for non-patients as well.

The clicks were later replaced with gestures (Fig. 24a). The selected gestures were: swipe right, left, up and down. It did not have any pre-decided preference for each option. The layout was then tested out with a patient to understand the intuitiveness of the selected gestures.

Fig 23. Iteration with click gesture

Fig 24a. Clicks replaced with gestures

From the test feedback received, it was understood that patients might find swipe up gesture difficult due to limited range of motion. Hence, it became important to categorise gestures according to its intuitiveness, tracking ease and ability of the patients to perform that gesture. The possible classifications could be patient or sensor based:

- Patient — easy and difficult (ability/disease), intuitive and non-intuitive.
- Sensor — easily trackable and difficult to track.

The gestures were classified primarily based on their intuitiveness. The secondary classification was done based on ease of tracking by the sensor.

Intuitive Gestures:

- Raise Left Hand
- Raise Right Hand
- Wave
- T pose
- Psi pose
- Swipe (D)
- Swipe (U)

Non Intuitive Gestures:

- Swipe (L, R)
- Zoom in
- Zoom out
- Wheel
- Stop

Swipe Up was difficult for patients with back pain in spite of being intuitive. This categorisation was directly applied in the next iteration (Fig. 24b). The dashboard option was included for the patients to keep a track of health. There were still a few issues pertaining to the position of the options and instructions. It required the patient to look at the instruction placed in the middle and back to the options placed at different sides of the screen(Fitt's Law violation). This problem was rectified in Fig 25.

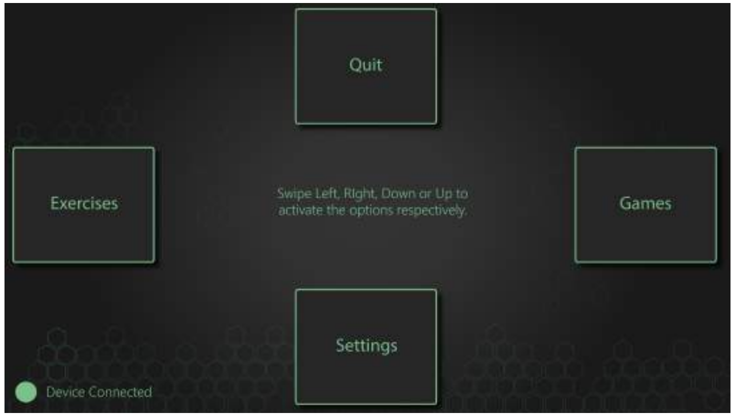


Fig 24b. With gesture categorisation

Fig 25. Fitts law rectification

6.1 **Daily Exercise Regime:**

The screen flow of exercise regime was designed to demonstrate each exercise to the patients followed by tracking movements of patients. Once the exercise was complete, the system would provide them feedback for each joint involved in the exercise. Voice over of the instructor was also added. A detailed introduction by the instructor was eliminated to reduce the amount of time required to start the regime.

The exercise demo (Fig. 26) continued to play until the patient raised his or her hand after taking appropriate position as suggested by the instructor. The next screen (Fig. 27) showed a silhouette of the tracked patient on the right side and the instructor demo on the left, in case the patient needed to refer to the demo for complex exercises.

The feedback was elaborated and designed at a later stage and is discussed in detail in section 6.3.1 .

Fig 26. Exercise demonstration

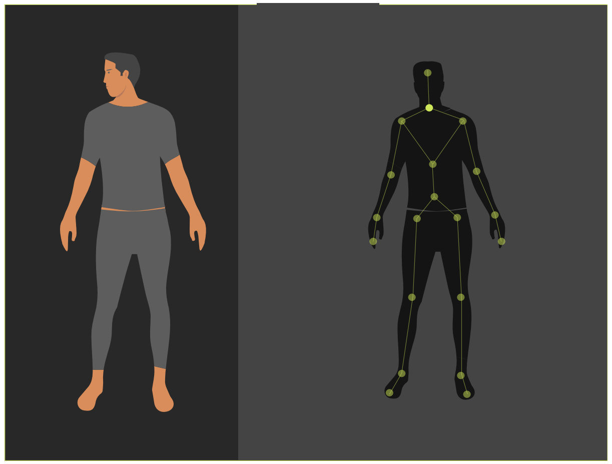


Fig 27. Tracking of exercise

6.2 Games:

The ideas for games were explored keeping in mind the following factors:

- Control over game duration to prevent overdoing of exercises through games.
- Minimum rules and game elements in the gameplay to reduce learning curve of patients.
- Demonstration of exercises embedded within the game for the patients to be able to practice.
- Mini rounds can be kept for practice sessions.
- Posture feedback as a part of the game.

Instead of long games with elaborate narratives, mini games with infinite runner genre were selected to have a control over rules, number of game elements and game duration. Demonstration of exercises was considered to be an important aspect. It was understood that not all game mechanics would allow the patients to filter out the exercise demonstration during the play.

6.2.1 Shape Up

In this game, different postures appear on the screen gradually. The patient needs to identify and replicate these postures. If the posture projected on the screen match with the patient's posture, the patient get positive feedback (Fig. 28, 29). The speed at which the postures appear could be moderated. The speed being adaptive to the user performance, the exercises would subtly demonstrate through these postures. This would enable them to perform in absence of the hardware as well. The features of the game were as follows:

- Posture demonstration through silhouette on screen.
- Gradual increase in speed depending on user performance.
- Auto Repeat of exercises if not done correctly.
- Mini rounds for practice within the game.
- Hints to achieve difficult shapes.
- Posture feedback through colour code and points.
- Difficult postures in higher levels.

Regulating the speed would be an important aspect in the game. The changes in postures should not result in giving unwanted jerks to the joint. Also, the game lacked ways to guide the patients through the exercise.

Fig 28. Perfectly matched posture

Fig 29. Moderately matched posture

6.2.2 Aster-Attack:

In this game, the player on the screen would be placed in a pod travelling through space. Asteroids of different strengths would be generated at specific time intervals and would hit the pod, thereby decreasing the oxygen level within the pod. The patient would have to touch these cracks and heal the pod. Each crack would be associated with a timer which would be its healing time. The patient would be eventually forced to use multiple joints as the number of cracks increase. The game was also of infinite runner genre. One clear advantage with this game was that the number of trick or ambiguous movements could be reduced by deliberately spawning cracks in pre-calculated locations. The features of this game included mini rounds for practice, gradual increase in speed and spawning multiple cracks in higher levels.

The idea of having exercises and games as sandboxed features within the application lacked coherence and failed to exploit the combined power of both the exercise and game applications. The possibilities of merging the two disjoint mediums to make people exercise was explored through system design approach.

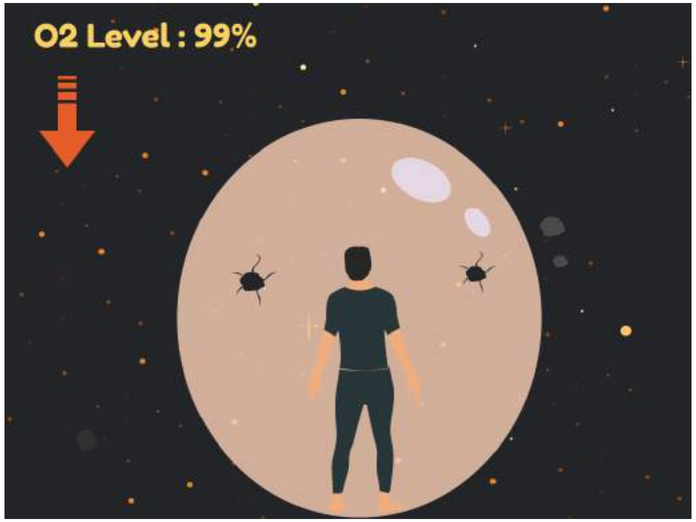


Fig 30. Spawned cracks with decreased oxygen level

Fig 31. Spawned cracks healing to increase oxygen level

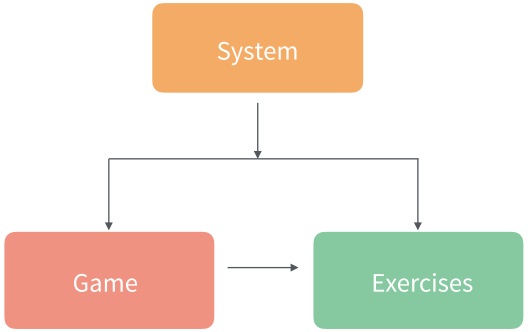


Fig 32. The proposed system

Hierarchy of benefits in Exercise and Games:

Exercises:
demonstration + tracking + feedback + motivation

Games:
motivation + feedback + tracking + demonstration

6.3 System Design:

A system design approach was taken to cater to both motivated and unmotivated patients. The system comprised of two options:

1. Normal exercise regime.
2. Games.

Design ideas for both the options were developed. The major question that could arise was why would the patients exercise in front of an application.

Exercising with the system offered multiple benefits like:

- Feedback and tracking.
- Repeat and redo.
- Remote supervision.
- Embedding disease knowledge.
- Intrinsic motivation and gamifying exercises.
- Switch between exercise and games.

Motivated patients might prefer to follow the normal exercise regime. The system could always 'nudge' them to play a game (Fig. 32) in case they find a session lengthy or monotonous. Similarly, a unmotivated patient could be nudged to practice a particular exercise in order to play a level better. Incorporating mini rounds for practice within the game can also be derived from the exercise sub-application.

The above mentioned benefits were explored to enrich the exercise regime through feedback, tracking, motivation and embedding disease knowledge.

6.3.1 Feedback and Tracking :

Patient tracking and feedback was categorised into four levels:

1. Joint Tracking
2. Repetition Tracking
3. Exercise Tracking
4. Session Tracking

For any exercise, the joints involved need to be identified along with its plane of movement. The joints could be assigned weightage (Fig. 34) to indicate joint feedback against its calibrated range of motion. The weightage would denote the hierarchy of importance of joints for a particular exercise. The joint feedback can be followed by exercise feedback (n = 10 rounds complete one exercise) and session feedback (n1 = 7 exercises complete one session) (Fig. 33).

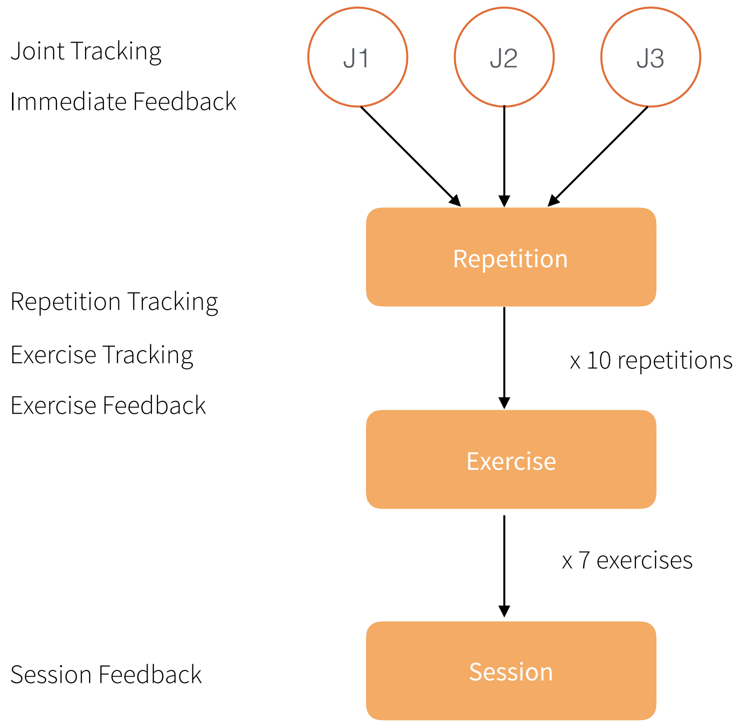


Fig 33. Different types of feedback

$$r = \frac{\sum_{i=1}^{n} w_i j_i}{\sum_{i=1}^{n} w_i}$$

$$e = \frac{\sum_{i=1}^{n} r_i}{n}$$

$$s = \frac{\sum_{i=1}^{n_1} e_i}{n_1}$$

Fig 34. Calculating round, exercise and session accuracy

r - repetition accuracy.
w - weightage assign to each joint by the therapist.
j - joint accuracy.
e - exercise accuracy.
s - session accuracy.
n - number of repetitions.
n1 - number of exercises in the session.

A few causes of concern in case of immediate feedback are as follows:

- Immediate feedback can be too intrusive.
- Poor performance can demotivate patients.
- Repetition feedback can distract patients.

Audio feedback could act as substitute to cater to these issue, For any particular exercise, the joints involved should be highlighted (Fig. 35) for the patient to focus more on them explicitly. The feedback given to the patients should be lucid enough for them to interpret the progress. The physiotherapist feedback should include as range of motion in different planes. The session feedback could be compared with recent history and an overall report could be generated at the backend for remote supervision.

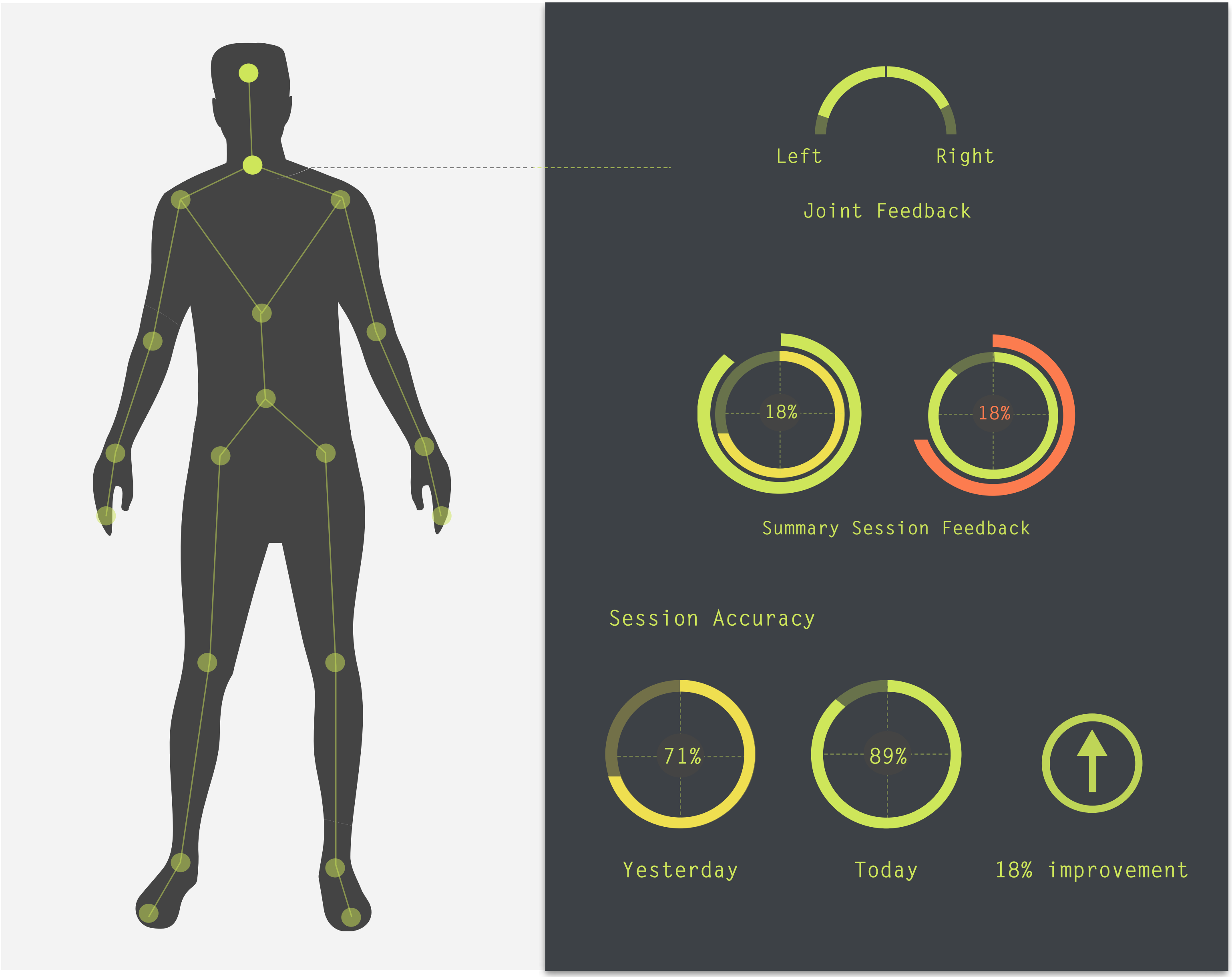


Fig 35. Highlighted joint and feedback

6.3.2 Repeat and redo:

The patient could be asked to repeat particular exercises if the performance deteriorates (Fig. 36). Depending on the amount of time taken to complete the exercise, decreased range of motion, past performances, history of stiffness of a particular joint etc. Empathising with the patient was considered to be an essential component and it was important to embed skip options in case of exacerbation of pain. Identifying and distinguishing between exacerbation and stiffness could also be challenging for patients. A skip option (Fig. 37) if availed should be notified to the physiotherapist for immediate action.

Fig 36. Repeating exercises if the performance deteriorates

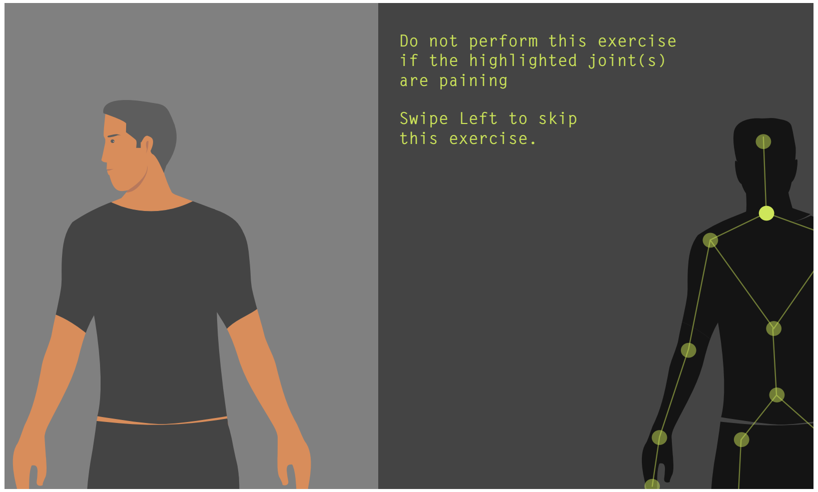


Fig 37. Warning and skip option

6.3.3 Motivation and Switch:

Intrinsic motivation can prompt patients to keep up with the daily regime. Increased range of motion (Fig. 38) across different planes can motivate the patients to continue with the scheduled set of exercises. Taking cues from the observation made during primary research, sharing improvement status on social media groups can help the patients gain self confidence. Social media shares can motivate other patients registered in the group. Posture and range of motion are identified as the two most important concerns. For patients with limited range of motion, performing difficult exercises also acts as an intrinsic motivation. The application should also explicitly mention the upgrade in exercises, if any.

Switching between exercise and games (Fig. 39) can also be suggested by the system depending on the idle time or time taken to complete a round or exercise. It can also be triggered to prevent patients quitting in between sessions.

Fig 38. Improved range of motion message

Fig 39. Nudge to switch between games and exercises

6.3.4 Embedding Disease Knowledge:

Lack of disease knowledge can lead to fatal consequences for AS patients. Facts pertaining to low or no starch diet (Fig. 39), clinical treatment options, side effects of medication and symptoms of the disease could be embedded within the system. The facts could be put while the system takes time to load the next level, on the home screen or along with the session feedback. Experiences of other patients could also be included as feed from different social media sites. The major categories of disease knowledge that can be integrated within the system are as follows :

a. Disease progression among female and male patients
b. Diet options, vegan no-starch food options
c. Clinical treatment options in the order of their order of effectiveness, side-effects and prices.

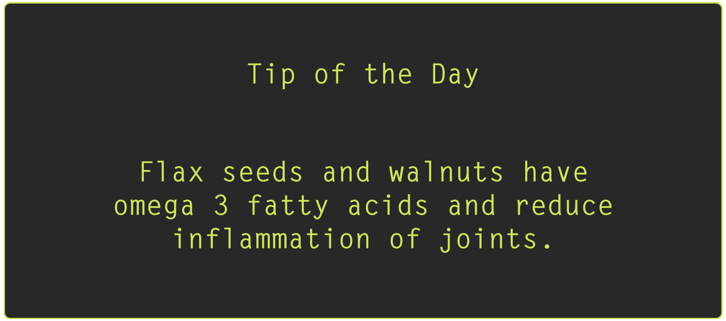


Fig 39. Diet knowledge

6.3.5 Remote Supervision

Remote supervision by therapists was an integral part of the application. The exercise regime of a moderate or high severity patient needs to be closely moderated by a therapist. The application does not try to eliminate therapists and automate the process, it acts a medium which connects patients and therapists taking into consideration affordability, accessibility and flexibility issues. Remote supervision is a feature where patients assigned a therapist who tracks their progress and actively modifies and customises the exercise regime. This feature is discussed in details in section 8.

6.4 Pilot Implementation:

Exercise Regime :

The pilot was evaluated by one patient each for the exercise regime and the games respectively (motivated and unmotivated respectively). The overall feedback was positive. A few improvements were suggested. The patient was of the opinion that distinguishing between joint and muscle pain (stiffness) is not difficult for patients. The problem lies in expressing them in a certain lingual form. The physiotherapist being experienced understands the difference and suggests exercise restrictions accordingly. Giving an option to patients to skip an exercise might not be the best way to address exacerbation. Another insight was to visually guide the patient to perform the exercises apart from the demo. This will enable the patient to understand the speed at which the exercise needs to be done.

Game :

The game ideas were approved by an unmotivated patient. A major concern was to prevent jerks and moderate the speed of exercising. Striking a balance between a captive gameplay and exercise specifications surfaced as a challenge. ShapeUp was pilot tested with one patient by showing her the postures (standing and crawling positions) on cardboards one after the other and asking to perform the posture that comes up. It was observed that the patient was focused during the process and diligently followed the rules in spite of feedback and extrinsic motivation parameters such as scores, sound and visual feedback being absent. After an interval of fifteen minutes, the patient was asked about the postures that were shown. She could remember most of the postures. But considering that she was a doctor herself, this was not sufficient to prove the efficacy of the system outright. The feedback given was to make the game multiplayer so as to have a competitive edge.

Fig 40 Pilot testing of ShapeUp

7. Core Flow

7.1 Exercise Regime

The insights gathered from the pilot implementations were used to add features into the system to enhance the exercise experience. Some of the major observations were as follows:

- A physiotherapist controls the speed of the joint movements.
- Controlling the speed is important to prevent the joints from getting jerks.
- A patient can distinguish between muscle stiffness and exacerbation pain. The patient is generally not in a state to exercise during exacerbation.
- There are colloquial terms to express health conditions, for example, stiffness can be expressed by patients differently. The physiotherapist needs to come to a conclusion after analysing the patient.
- Textual or on-screen feedback might hinder the exercise flow.
- The user participation in physiotherapist is passive. The user does not need to put in a lot of cognitive effort during an exercise session with the physiotherapist.

While designing, striking a balance between audio and visual feedback was a challenge. Although a visual guide would be more affirmative, there are exercises that need to be done with the user standing parallel to the screen. The visual guide (Fig. 41) would essentially start from the rest position and move towards the final position at a particular speed. It was important to maintain the speed without forcing the patient to look at the screen throughout the regime. Modulating audio to control the speed was a potential solution. A combination of audio and visual guide was finally selected where the visual guide could be used by the patients initially to understand the pace and the movements. Once the user adapts to the exercise pace with both the audio and visual guide, the audio guide would maintain the speed even when the patient is not looking at the screen.

In the initial design, patients were given an option to skip exercises. However, during exacerbation, they would not be in a state to exercise. The skip option would not be needed in that case as it might be exploited by less motivated patients to skip exercises. The option was eliminated in the final concept (Fig. 45).

The medical conditions could be explained through symptoms to reduce confusion. The visual and audio guides not only help the patients to maintain the speed but also decrease their cognitive load to understand the exercises. The visuals of the gestures were improved, the images were modified to give patients a better understanding of gestures (Fig. 43).

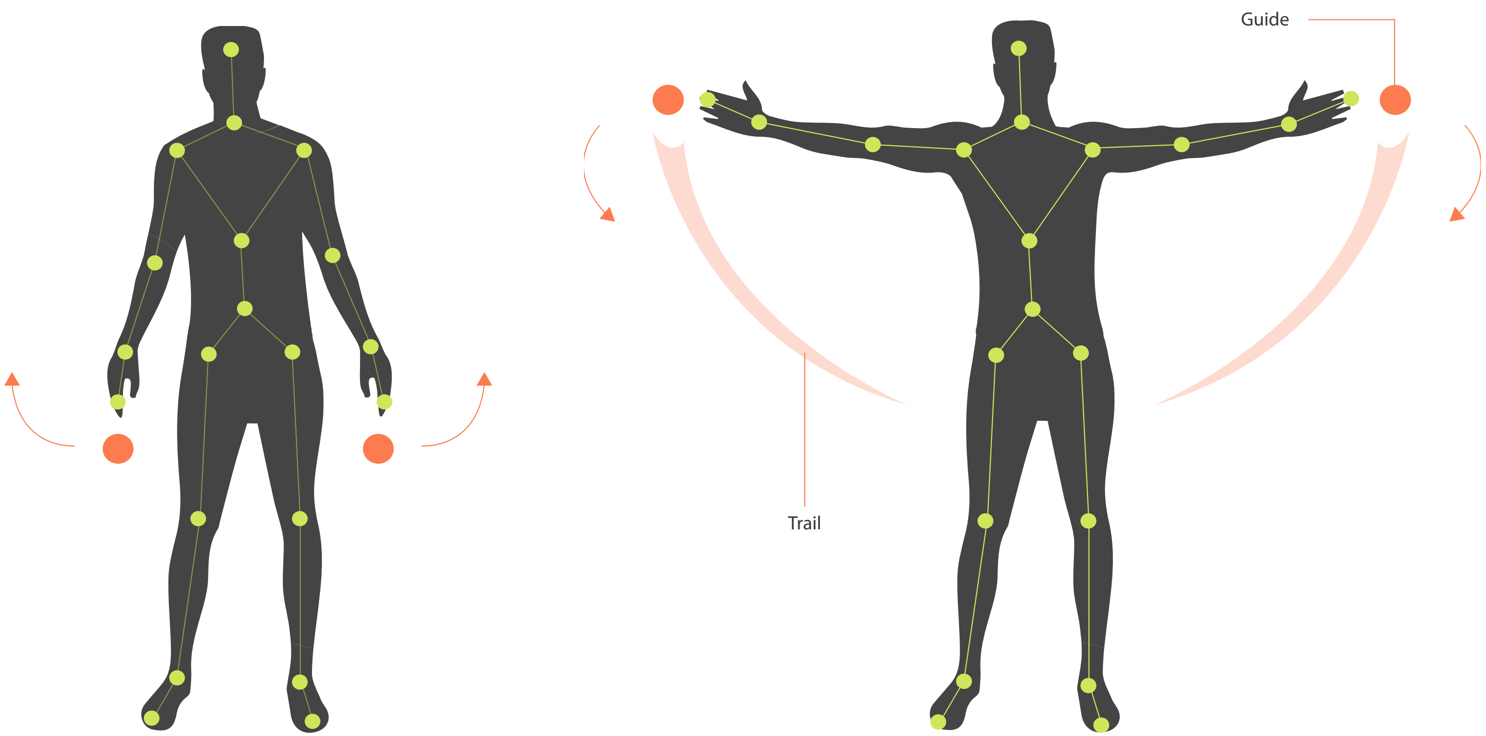


Fig 41. Visual Guide

7. 1.1 Screen Flow :

First time users have an option to personalise their account by adding profile pictures (Fig. 42). Patients do not need to get the joints scanned as a first time user. The system being adaptive in nature would update the range of motion for each joint each time the user completes a session. The user is taken to the start page immediately after the initial screen.

The overall exercise feedback (Fig. 46) is calculated from the formula in Fig. 34. After each exercise, the overall exercise feedback is displayed along with feedback of joints involved that exercise. The user can initiate the next exercise though a T-pose gesture (Fig. 46). Repeating exercises pop-up would appear once the user does the T-pose gesture if a deterioration in performance is detected.

Fig 42. Personalising user accounts

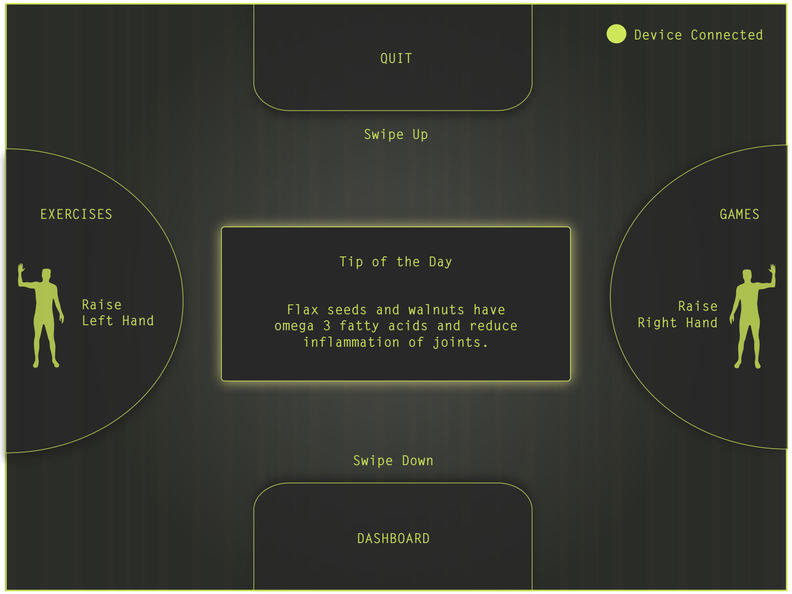


Fig 43. Improved gesture visuals

Fig 44. Exercise Demo

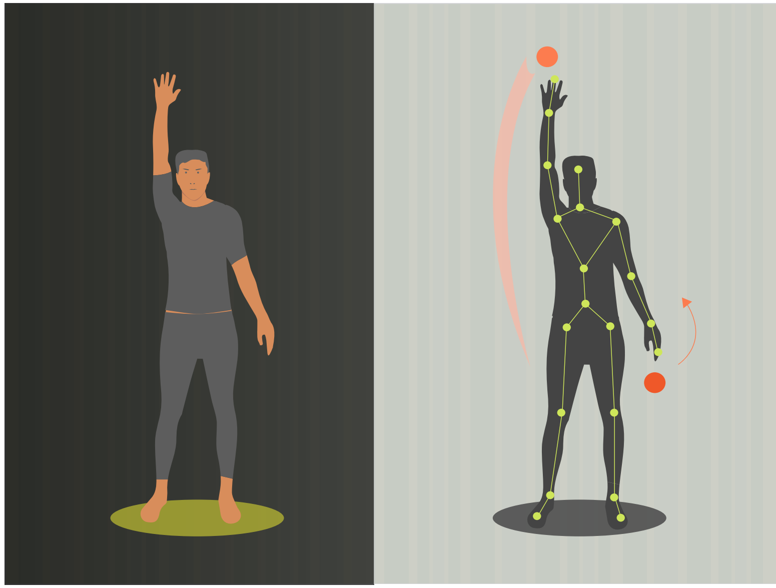


Fig 45. Demo and tracking with tracking and speed regulating guides

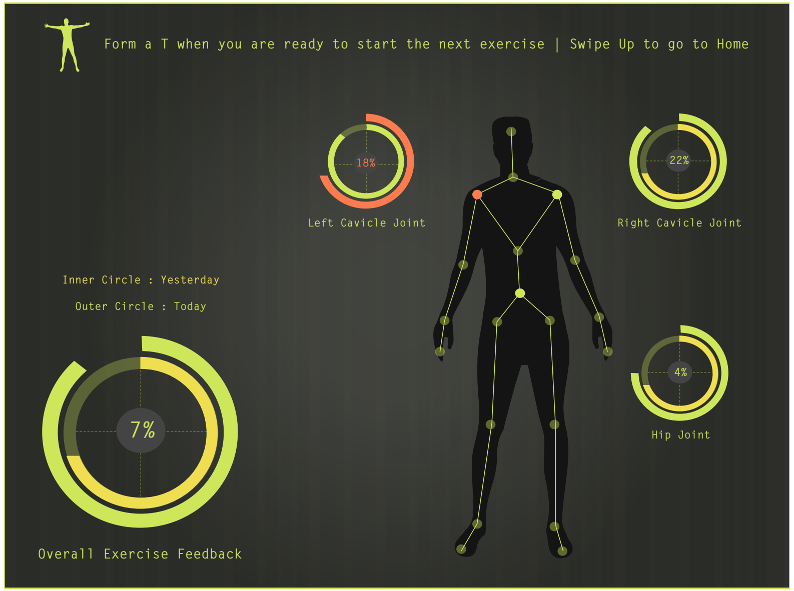


Fig 46. Exercise Feedback

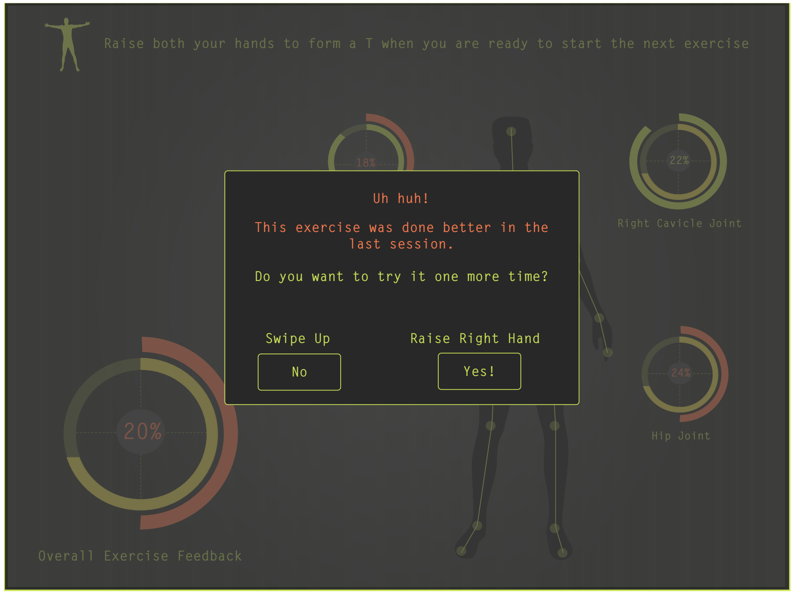


Fig 47. Exercise Repeat and Re-do options

Quit options are provided only at the starting screen and after each exercise is complete. Gesture is disabled in the tracking scene (Fig. 45) to avoid the system from triggering events while the exercises are performed. The screen changes to the feedback screen (Fig. 46) automatically once all the rounds for that exercise is completed. A hand cursor (Fig. 47) is given in the overall session feedback screen and the user can hover over each joint to check individual joint feedback. The session feedback is the default view for the dashboard. Weekly and monthly reports can be further explored by swiping right.

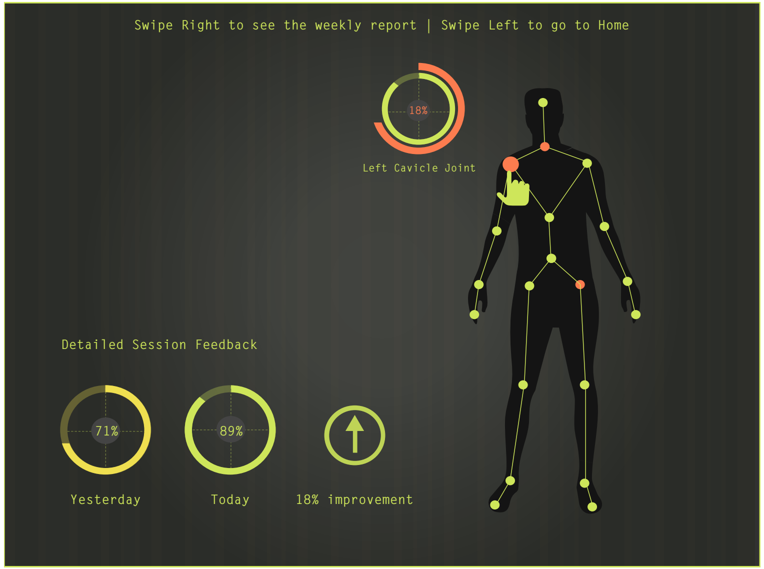


Fig 48. Session Feedback, also the dashboard

7.1.2 Therapist Feedback :

A therapist expert testing and feedback session was conducted before testing the prototype with the patients. Some of the major feedback given by the therapist were incorporated before evaluating the application with the patients.

During exercise sessions, the therapists check three parameters:

1. The pain level before and after the session. The feedback is taken in form of a Visual Analog Scale (VAS), on a scale of 0 to 10, 0 being no pain and 10 being extreme pain. The scale is subjective to the patient's tolerance level and is a well practiced method by doctors and therapists. The pain level help therapists decide upon exercises for that session and effectiveness of performed exercises in reducing pain.

2. The session time and number of repetitions are recorded by the therapists to measure the improvement with a given set of exercises. It gives them an idea when and by how much to upgrade the difficulty of the exercises in terms of speed, number of joints involved and positions.

3. The exercise speed are mapped to metronome beats and the average beats per minute for a moderate severity AS patient would be 35-40. The beats are decreased during exacerbation.

It was observed that the therapist was finding it difficult to follow the instruction on screen while navigating through the system. The textual information was not conducive to be interpreted from at a distance specially when viewed from a laptop.

An improved set of visuals and screen flow were designed taking into considering the therapist feedback as discussed in the following section.

7.1.3 Improved Screen Flow and Visuals :

Visual Design :

A dark theme was selected since the application was content driven [12] with gesture instructions and exercise demonstrations. The font sizes were increased from 24 pt to 48 pt for important call to actions. The other instructions were kept to 36pt to create a visual order within the onscreen instructions. The font was changed from a monospaced font (Letter Gothic Bold) to Copper Hewitt having a larger x-height to increase legibility [13]. The font colour was kept bright against the dark background and the instructions were given in all caps to reduce focus on the screen text [14] while following the exercise demonstration or performing the exercises. The environment was replaced by a three dimensional space replacing the flat two dimensional illustrations to add depth to the visual room.

Font sizes : 48 pt, 36 pt.
Font Family : Letter Gothic, Bold.
Colours : #CEE65A (text and icons), #2B2B2B (background).
Overlay opacity : 80%

Screen Flow :

Landing Screen :

A landing screen (Fig. 49) was introduced to make the patients aware of the prerequisites of the exercises. Personalising user account was removed from the flow and was added at an earlier stage when the user downloads the application. The instructions were kept elaborate and animated gifs were introduced to eliminate ambiguity in operating the application. The instructions were shortened gradually across the screens as the users get accustomed to the gesture operated system.

Gesture options :

'Raise Right Hand' to **Proceed.**

'Swipe Up' to **Quit.**

Pain level Screen :

The patients would need to input their current pain level (Fig. 50) on a visual analog scale of 0 to 10. Some of initial design ideas were to take the pain level as a voice input or finger gestures but were discarded keeping in mind the poor detection accuracy in existing applications using these input methods. The other gestures explored were push and click for selecting a particular pain level. The gestures were tested with experts and click was identified to be more intuitive while selecting an onscreen option. The onscreen cursor deflection was still a concern, hence the click detection threshold was decreased from 2.5 seconds to 1.5 seconds. The screen transition was triggered automatically once the input was registered by the system.

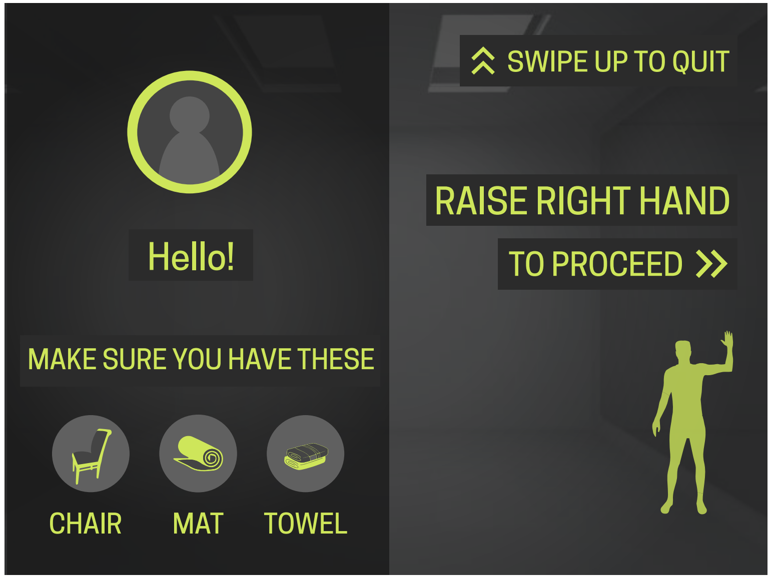


Fig 49. Screen 1 – Landing screen with equipment list.

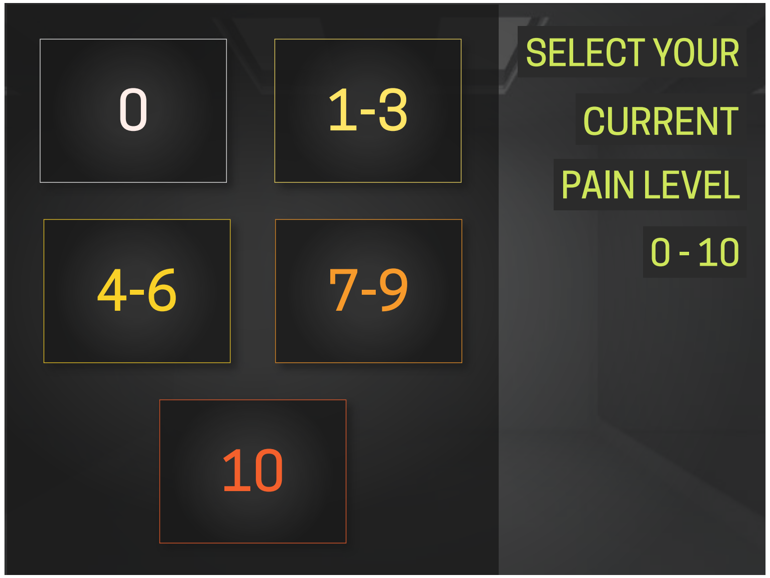


Fig 50. Screen 2 – Pain level screen.

Interim Screen :

The interim screens were added to embed disease knowledge. It was observed that screen transitions take adequate amount of time (15 - 20 seconds) and hence very short tips were embedded (Fig. 51) along with a progress bar to keep users engaged during screen transition. Gestures are disabled for interim screens. The embedded information aimed at creating awareness among the patients as most of the interviewed patients felt lack of knowledge and guidance aggravated the disease severity.

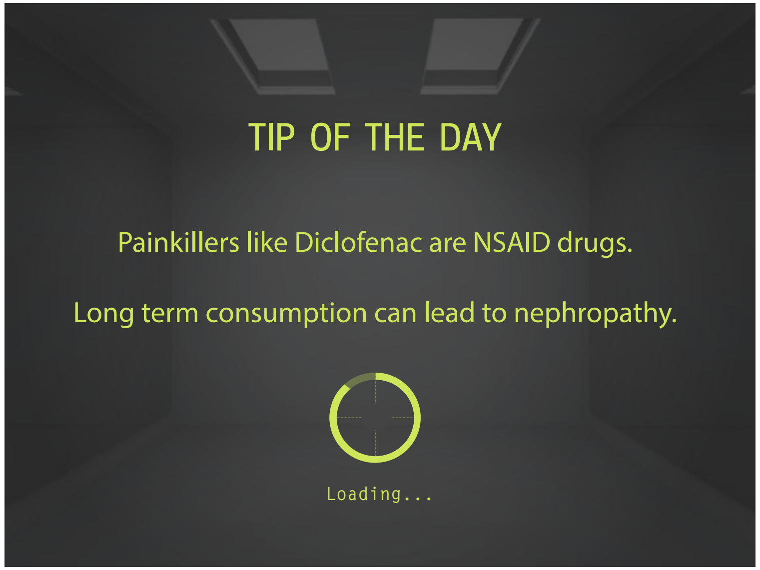


Fig 51. Screen 3 – Loading (interim) screen.

Menu Screen :

The menu options were not changed. The real estate of the screen was better utilised as the disease knowledge information was moved to interim screens. Technical terms such as 'Dashboard' were replaced with generic terms like 'History'. The instructions had audio support.

Gesture options :

'Raise Right Hand' to **Play Games**.

'Raise Left Hand' to **Do Exercises**.

'Swipe Up' to **Quit**.

'Swipe Down' to **View History**.

Fig 52. Screen 4 – Menu screen.

Demo Screen :

The background of the demo screen (Fig. 53) was replaced with a three dimensional space. Visual guides were added for the instructor to initiate the conceptual model of following the guide while performing the exercise. The demo screen did not allow the user to go back or quit to prevent patients from skipping exercises. Walking out from the field of sensor would put a pause to the demonstration and would commence again if the user is detected again. The demo screen had audio support.

Gesture options :

'Raise Right Hand' to **Proceed**.

Tracking Screen :

Exercise time and number of repetitions were added in the tracking screen (Fig. 54). The visual guide was supported and synced by 40 beats per minute metronome audio guide. Perfect repetitions were appreciated through audio feedback. The user position was marked on the screen for optimal tracking. Real time projections were displayed on screen instead of using avatars to prevent motion translation lag. The joints getting tracked were highlighted in the silhouette casted by the user. Gestures are disabled for this screen. The patients need to complete the specified number of repetitions and the screen transition is triggered once all the repetitions are completed. If the patients do not perform the exercises, the system calculates idle time and if it exceeds 20 seconds, the screen transition is triggered.

Fig 53. Screen 5 - Demo screen.

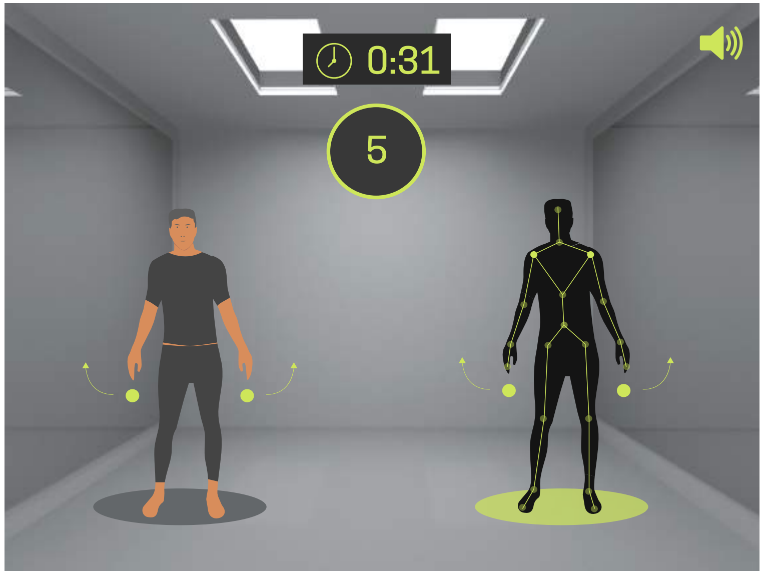


Fig 54. Screen 6 - Tracking screen.

Exercise Feedback Screen :

The exercise feedback was given immediately after each exercise was completed. The feedback comprised of detected range of motion for consecutive two days in a visual form and its comparison with the day before mentioned in percentage. It highlighted whether the range of motion had improved or deteriorated in the current session. An overall exercise performance feedback was provided and if the deterioration difference was more than 5%, the patient was given an option to repeat the exercise. The information is placed on the screen sequentially to help the patient focus on one feedback at a time. 'T-Pose' gesture to advance to the next exercise was replaced with 'Raise Right Hand' gesture to make the controls coherent across the application.

Gesture options :

'Raise Right Hand' to **Go to Next Exercise**.

'Swipe Up' to **Go to Menu**.

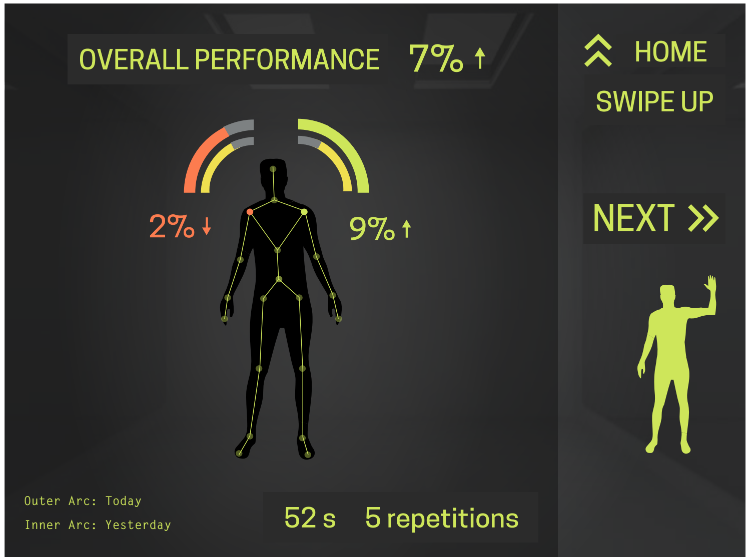


Fig 55. Screen 7 – Exercise feedback screen.

Session Feedback Screen :

The pain level screen (Fig. 50) was shown once more for the patients to enter post session pain level once all the exercises were performed. Once the pain level was registered by the system, the session feedback screen was auto triggered. The static visualisations in the session feedback screen were replaced with animated visualisations for affected joints in different planes. It compared range of motions with the ideal if the current performance was better than the previous performance. If the current performance deteriorated, the comparison was made between the current and last performance. The animated visualisation would autoplay for all the affected joints.

Gesture options :

'Raise Right Hand' to **Go to History** (Performance statistics).

'Swipe Up' to **Go to Menu**.

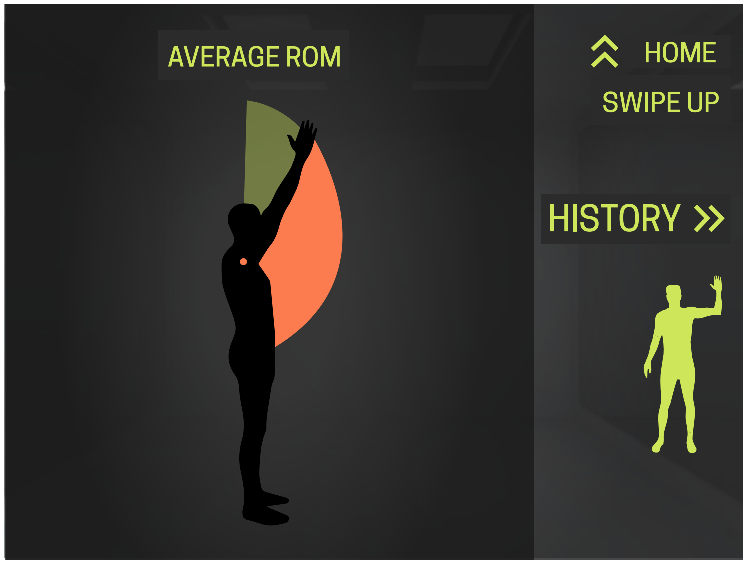


Fig 56. Screen 8 – Session feedback screen.

7.2 Game :

ShapeUp :

The ShapeUp game was modified to enhance the gameplay keeping in mind the disadvantages of abstracting the postures once the hardware is removed. The static postures were in form of a silhouette (Fig. 58) which when matched by the player changes to the next posture. Scores and sound feedback was added as extrinsic motivation. Each time a gesture was matched, the player was awarded 10 points. If a gesture was not matched, it led to point deduction by 2 marks. The difficulty level of postures were increased gradually. However, if a patient took multiple attempts to perform a gesture, easier postures were spawned to increase the player's confidence.

The posture remained on the screen until it was matched. This iteration accepted only perfectly matched gestures in order to proceed in an attempt to reduce ambiguous interactions.The gradual increase in time was eliminated keeping in mind that physiotherapists move the joints at a particular pace. Increasing the speed might result in unwanted jerks, damaging the joints further. The player needed to wave to start the game (Fig. 57) and walk out of the sensor range to quit. The possibilities of two player version of the same game were explored taking cues from the pilot feedback. The two player option would be auto triggered if the sensor detects two human figures.

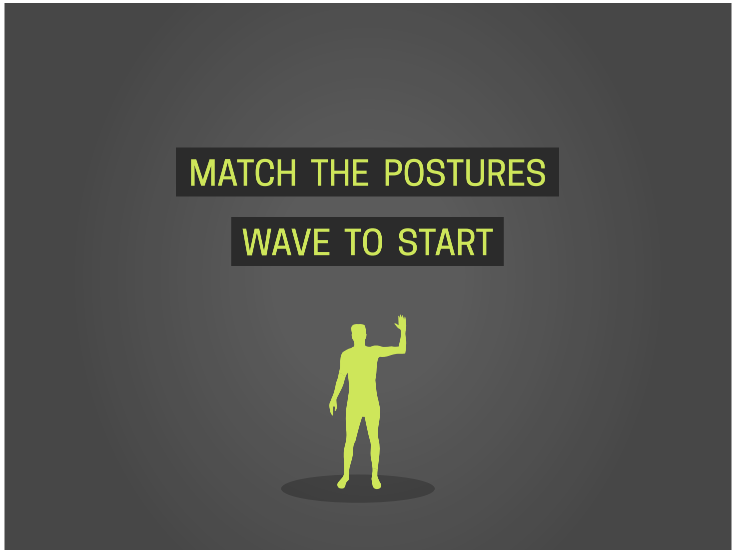


Fig 57. ShapeUp – Wave to start.

Fig 58. ShapeUp – Posture matching.

7.3 Expert Feedback :

The expert feedback was focused on enhancing the visuals for both the exercise regime and game. A lighter theme was suggested to uplift the mood of the patients. A longitudinal understanding and visualisation of the core flow was also suggested. Detailing of different difficulty levels of games and enhancing the gameplay were recommended.

Possible business models encompassing the application were explored to shape up an end to end solution. The major questions that surfaced were as follows :

- How do patients get introduced to the application?
- How do they procure the necessary hardware?
- What would be the level of engagement of therapists?
- How are the therapists going to benefit from the system?
- How is a patient mapped to a particular therapist?
- What feedback would the patients receive after a week long regime?

A holistic approach was taken to identify and connect all the major stakeholders and their role in the entire user journey embarked by a patient. The flow has been discussed in details in the next chapter.

8. User Journey

AS patients would generally seek a medical advise from a specialised doctor at the onset of acute pain. Doctors consulted are either from Orthopaedics or Rheumatology specialisation. The doctors are increasingly accepting the benefits of exercise and diet on slowing the joint fusion process. An initiative by AS patients promoting non-clinical remedies have already started getting doctors on board. These groups are highly active on social media and proactively spread disease awareness.

The initial touchpoint for patients newly diagnosed with AS would be a doctor. The role of the doctor would be to hand over an envelope to the patient. The envelopes are to be distributed by the existing patient groups to the doctors willing to sign up.

The envelope (Appendix 1.1) consists of a letter (Appendix 1.2) with contact details of a therapist and patients, instruction manual to operate the application and a badge (Appendix 1.3) to create disease awareness. These patients are active members of existing initiatives and can guide the new patients. Vendor details are also provided from where patients can either purchase or procure hardware on a rental scheme. The patients are informed about an exercising application which can be downloaded from a link or by scanning a QR code mentioned in the letter. The link and the code directs the patient to a short form. The form consists of disease severity, exacerbation frequency and demographic details. Once the patient submits the form, an unique patient code is generated, linked to the application and the executable file is automatically downloaded. The application does not need any installation process.

For patients who are already diagnosed and part of the social media groups can also access the link posted on these groups by the administrator.

Stakeholders of the Application :

The two major stakeholders of the applications are :

- Physiotherapists
- Patients

Each patient would be mapped to a physiotherapist when they register by submitting the form. The allocation is proximity based. The system is a network where both patients and therapists sign up. The ratio of patient to therapist would be decided based on the number of therapists available in the network. The renumeration of the therapists could be associated with the rental scheme. In case the patient buys the hardware, a monthly payment scheme could be initiated. The renumeration would depend on the disease severity of the patient and experience of the therapist. The amount could be moderated by the existing patient initiatives.

Physiotherapist :

The therapist registers by downloading a mobile application and filling up a short form mentioning their location, experience, specialisation if any. The physiotherapist is notified mentioning the age and severity of the patient allocated. If the therapist accepts the allocation, the patient details are shared. The supervision is asynchronous in nature. The physiotherapist can operate and make changes to an existing regime at any point. The system automatically synchronises next time the patient starts the regime. The application would be preloaded with a set of exercises tagged with joint, plane and movement information. For any particular joint for a given plane, physiotherapists can select and assign different joint combinations and position variation exercises. The therapists can also suggest addition of exercises in the system. Their contribution can be acknowledged through a royalty model. These exercises are included into the system during version upgrade.

The different modes of supervision are as follows :

- Auto mode
- Semi-Auto mode
- Manual mode

Auto mode only asks for speed and number of repetitions from the therapist. This mode starts with single joint movement exercises followed by independent and dependent joint combinations and position variation exercises. The auto mode is suitable for low severity patients where joint flexibility is more important. The semi-auto mode allows the therapists to assign special exercises for particular joints. The semi-auto mode is auto populated with affected joints. The therapists have an option to add other joints that might need a special regime along with the affected joints. For other joints, speed and number of repetitions can be set as a batch assignment.The manual mode is completely populated by the therapists. Exercises assigned by the therapists are only pushed to the patient's system. Other joints are not assigned any exercises. Manual modes are targeted for high severity patients where the therapists need to have complete control. These modes can be associated with spans after which the regime would be updated. These update spans are as follows :

- Daily
- Biweekly
- Weekly

The therapists can view all the joint information once a patient is selected. Exercises can be assigned by selecting a mode of supervision or directly from a joint statistics screen. Therapists can also set custom exercises for exacerbation periods specifying the pain level for each regime. The sequence of exercises can also be determined by the therapists. The default sequence is the auto mode sequence if no joints are affected. For patients with affected joints, the sequence starts with affected joint and movement specific exercises. Therapists are given an option to discontinue with a patient at any point of time. The patient is released along with a release note visible only to other therapists. Similarly, patients can request a change of therapist and attach a note for other patients to view.

Patient :

Day 1 :

The first day of the regime is a calibration session. The patient is introduced to the day one session as a warm up round. The equipments required as an aid are mentioned before starting the regime. Patients can select their onscreen instructor and mention the current pain level. Single joint exercises across multiple plane are demonstrated and the patients are asked to repeat the exercises thrice. The best range of motion (ROM) out of the three repetitions is assigned as the current range of motion for each of the joints. Exercise feedback is not provided during the calibration session. These ROMs are compared against the ideal values by the system. By the end of the session the patient is made aware of joints that have limited ROM. The post session pain level is also recorded. The session feedback consists of an animated visualisation of the actual and current ROMs for the affected joints. The session feedback highlights the most affected joint and informs the patient about a special regime to address the condition from the next session. This acts as a motivator for the patients to come back for the next session.

The session performance details appear in the patient dashboard and the physiotherapist is notified about the completion. The physiotherapist looks into the data and decides on a mode of supervision. For low severity patients, auto and semi-auto mode can be ideal. The exercises along with repetitions and speed are decided by the physiotherapist which in turn is fed to the patient system.

Day 2 to Day 6 :

Day 2 starts with the previous session feedback. This gives the patient a sense of continuity. The session feedback leads to selecting the pain level. The number of screens needed to start the exercise regime is reduced by eliminating the instructor selection screen. The exercise regime starts with the most affected joint. The regime also includes exercises for all non-affected joints in the axial skeleton and surrounding regions (knee and elbow). The core loop described in section 7.1 starts from day 2. The patient gets feedback after each exercise is completed. Information displayed in exercise feedback are the joints involved in that exercise, average and maximum ROM for each of the involved joints, ideal ROM, exercise time, repetitions and overall performance (for overall performance calculation example, refer to Appendix 1.4). Day 2 exercise feedback does not give any percent improvement data for each of the joints and the session. Henceforth, from day 3, all previously performed exercises and session feedback consists of improvement or deterioration information and is compared with the previous session. The physiotherapist has an updated performance statistics after each session. The physiotherapist can override the current mode and update span depending on the statistics or effect of certain exercises. For example, in a weekly update semi automated regime, if the pain level increases after session completion for two consecutive sessions, the therapist might change the exercises before the next expected update cycle.

Day 7 :

Overall improvement or deterioration (calculated by the formula in Fig. 34) as compared to the previous session is given after each session for the next 7 days. After each week, the patient would be given a detailed summary of the different parameters recorded throughout the week. The measured parameters are difference in pain levels before and after each session, exacerbations if any, session time, average and maximum ROM for each joint and overall performance after each session. New exercises can be introduced by the physiotherapist at any time depending on the progress of the patient. Newly introduced single joint exercises would not have a calibration session. Multiple dependent joint exercises would start with a 3 repetition calibration on the first day. The calibration information would help the physiotherapist decide whether to continue the exercise till the next update cycle.

Day 30 :

After each month, the patient would be given a detailed summary of the different parameters recorded throughout the month. The parameters are same as that of weekly feedback, the overall trends are observed over a wider longitudinal data.

Exacerbation Period :

During exacerbation, patients generally do not have the physical and mental condition to exercise. However, in some cases, if patients feel that exercising can improve their condition, the exercises given by the therapist is different from normal regime. The speed, repetition and type of exercises vary depending on the current pain level. The remote supervision, in the system is asynchronous in nature. The physiotherapist will be notified immediately in case the pain level is above 7. The therapist can modify the exercises in runtime or suggest a predefined exacerbation regime. This regime can be customised for each patient signed to the therapist. If the therapist does not have a predefined regime for exacerbation and runtime changes in the regime is not made, the system loads single joint exercises with a speed of 20 bpm. The number of repetitions are 5 by default. A warning is given to patients to stop performing an exercise in case the pain increases.

Offline Version :

The auto mode is saved in the patient system by default. This acts as an auto mode and is used if the patient has poor or no internet connectivity. The speed and the repetitions would be set to 40 bpm and 10 respectively. The mode is not recommended for patients. However, under circumstances mentioned above, the auto regime would help patients maintain their joint activity.

Special use cases :

Some special identified use cases that the patients might come across are as follows :

1. Patient starts having pain after two repetitions of an exercise.
2. Patient wants to quit after two exercises
3. Patient wants to play a game after a few repetitions
4. Patient wants to do half the regime in morning and half in evening
5. Patient walks out while exercising
6. Patient wants an upgrade in the exercise regime
7. ROM perfect for all joints
8. If the visual guide and patient movement fail to sync

The patients can stop doing the repetitions if they start having pain. The system calculates inactive time of 20 seconds and automatically triggers exercise feedback page. The patient would not be able to quit in between demo and tracking screens. Once the exercise feedback screen appears, the patient can go back t the menu screen. The menu screen has game and quit options. If the patient leaves halfway, the state would be saved till midnight and the patient would be prompted to open the application as left. Patients can accept or decline the prompt. Walking out of the sensor range will pause the application. It will start automatically once the user is detected again. Patients will be given an option to request for an upgrade at the end of each session. The therapist would be notified about the request. However, the upgrade would be left to the discretion of the therapist. If the patient does not have any affected joints, the patient would be informed about the status, but ask to come back the next day with a more challenging set of exercises. Visual guides just help patients in controlling the exercise speed. Once the metronome beat is fixed, each repetition is assigned a specific amount of time automatically. The visual guide would be adjusted to previous session's maximum range of motion for the joint under consideration. It's speed would be mapped to the calculated repetition time. It is understood that the patient might become out of sync due to limited range of motion or speed issues. The therapist would also be notified about the total time taken to complete each exercise. Modifying the speed for each exercise would be left to the discretion of therapists.

Games :

In ShapeUp, one of the major constraints was offline support. It was argued that the patient should be able to replicate the posture sequences without the hardware. The tradeoff was a compromised gameplay. One of the points raised by the therapist during a pilot session was that the patients should not be challenged from perception point of view. Their main challenge is to replicate the postures. Abstraction of shapes challenge a patient's perception skills, something which might demotivate the patients specially when their ability to perform the posture is limited. The perception challenge was removed from the game and tested it out with patients and experts. From the feedback it was understood that it was not identified as a game anymore. Based on the feedback received, the perception challenge was restored. However, the perception challenge was introduced at a later stage, i.e. when the ability of the patients was already tested (Fig.59). Three different game levels designed were as follows :

1. Posture Level
2. Abstract Level
3. Super Abstract Level

The posture level had clear demonstration of exercises which eventually reduced as the level changes to abstract. In super abstract level, possibilities of ambiguous interactions were increased. The interactions were rigid in the posture level and became more flexible and open-ended in the third level. The challenge in posture level tested the ability of patients to perform the exercise. As the level increased, the perception challenge was gradually introduced. The challenge lied in identifying and performing the posture in advanced levels.

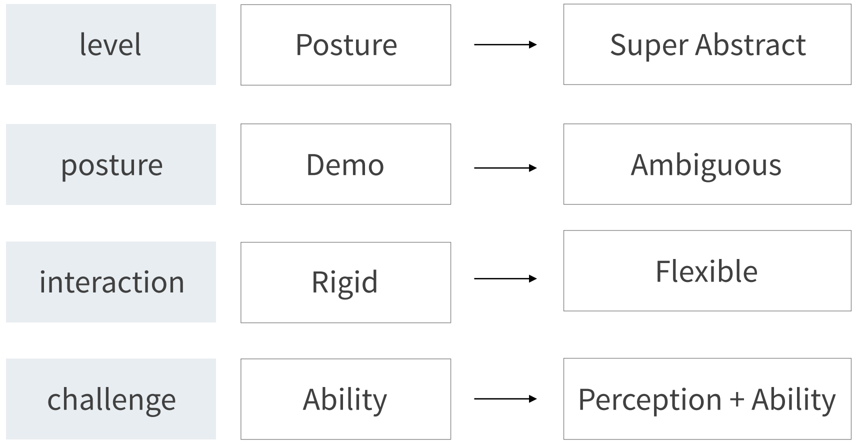


Fig 59. Game level comparison against different parameters.

Gameplay :

Across all the levels, the score calculation was kept the same. For each successful replication, the player would be awarded 10 points. If the posture is not matched 2 points would be deducted. The player would be given three consecutive changes to replicate the posture, failing which would lead to point deduction each time. If the posture was not matched after 3 turns, a new easier posture was generated. Partial matching of posture was not acknowledged. The posture detection threshold was increased at the backend to accommodate players with limited range of motion. The mode was infinite runner and the player needed to walk of of the sensor range to quit.

1. Posture Level :

The posture level had two sub rounds with easy and difficult postures respectively. The postures are realistic silhouettes appearing on the screen one after the other. Each posture would have minimum three non-consecutive repetitions. For difficult postures, hints are provided after the first turn is unsuccessful. The patients need to remember and replicate 10 postures from memory to unlock the abstract level.

2. Abstract Level

The silhouette becomes abstract and are stick figures with dots and lines. Some amount of perception challenge is introduced in this level. The scoring system is similar to the previous level and hints are provided after first unsuccessful attempt. Chances of ambiguous interactions increase in this level.

3. Super Abstract Level

In super abstract level, the postures are abstracted in the form of real life objects (Fig. 60). The perception challenge is highest in this round. For example, an antenna can be a T-pose, a bridge can be a camel posture in cat-camel exercise. The silhouette of the player would be casted on the screen and it needs to completely overlap with the abstracted posture.

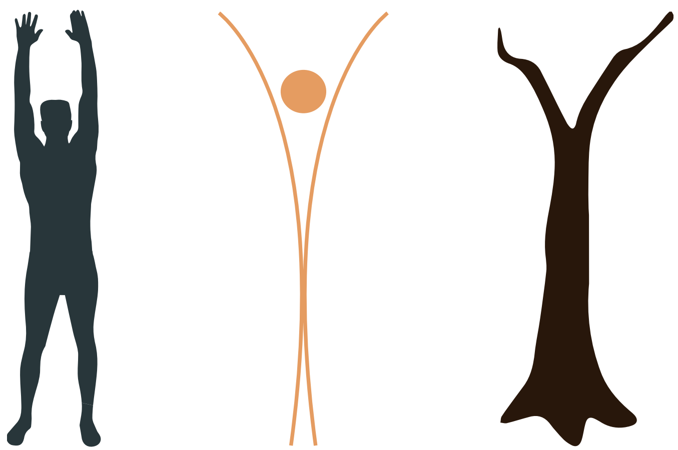


Fig 60 . Abstracting postures across different game levels.

Final Concept

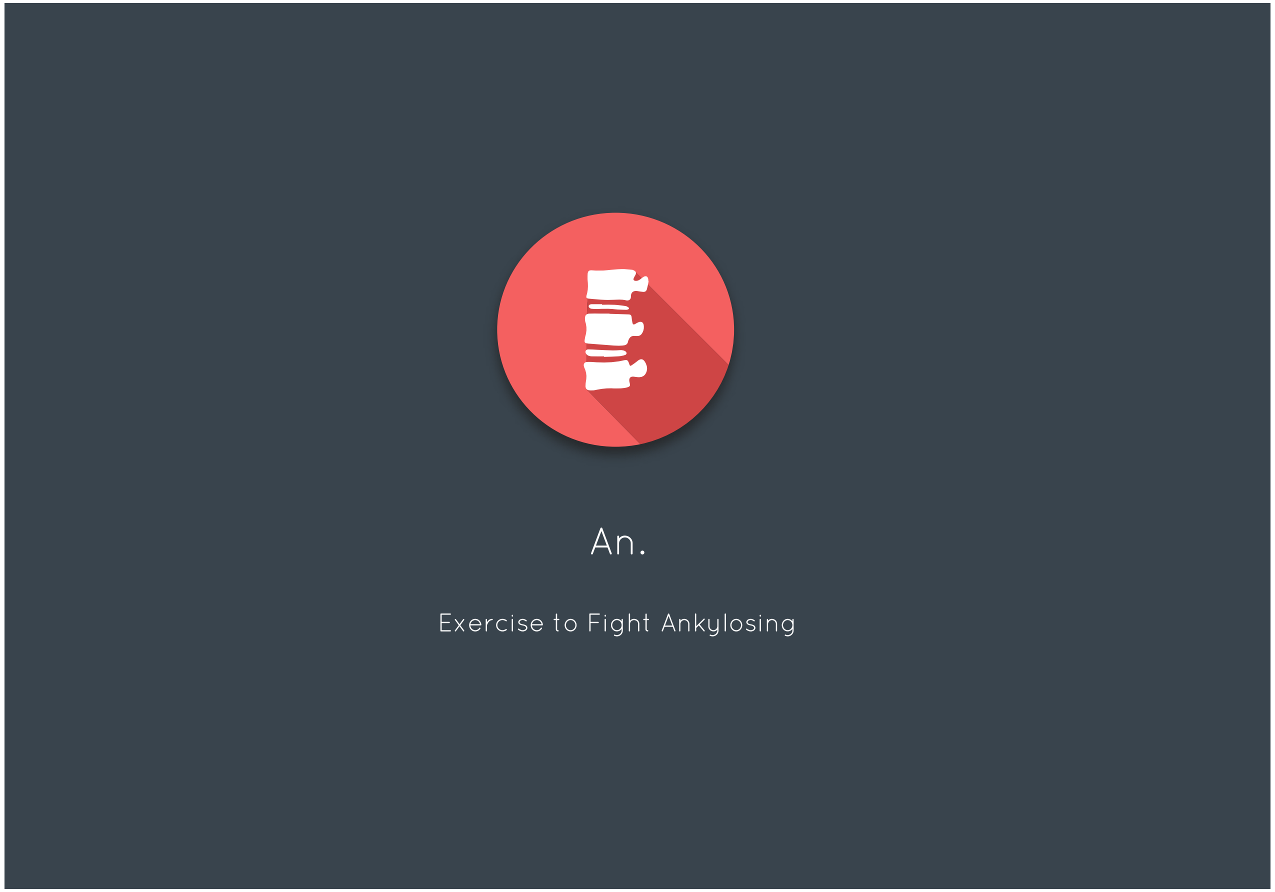


Fig 61. An – Exercise Application.

'An' is an exercise application that derive its name from the Sanskrit root suffix अन् which means to live or to breathe. The name also shares the initial letters of 'Ankylosing'.

Fig 62 Visual design - core flow and instructor selection.

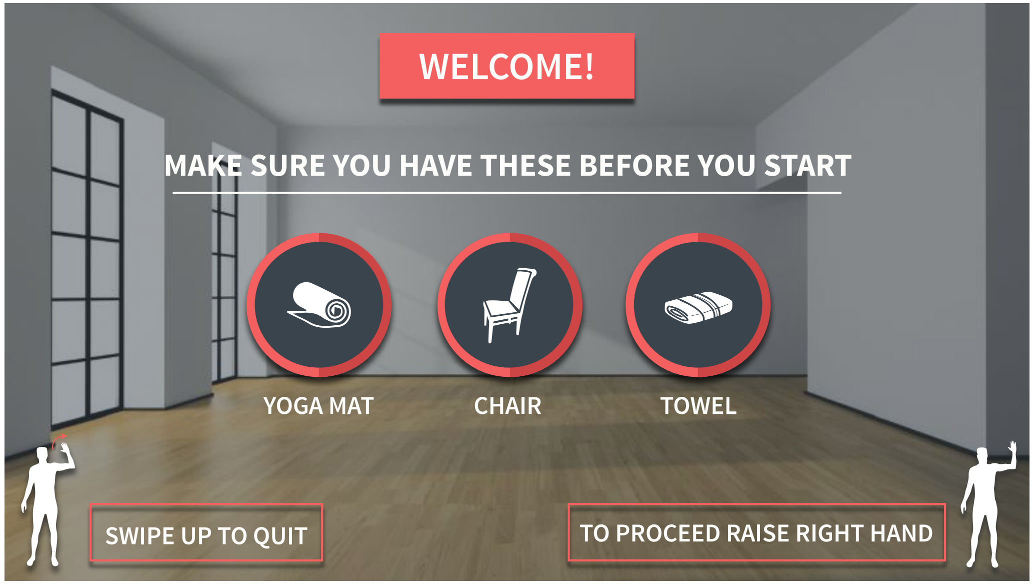


Fig 62a. Landing screen.

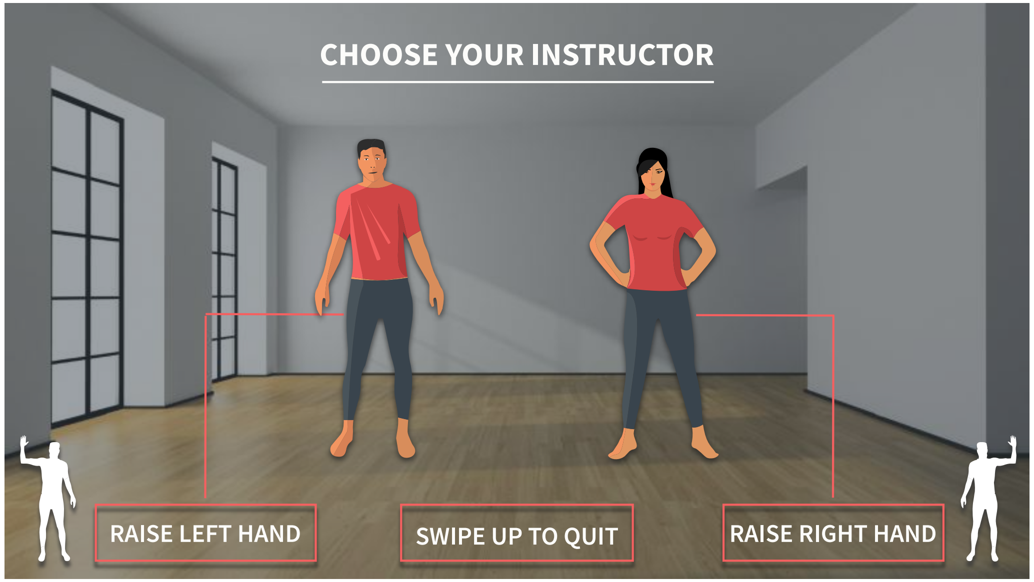


Fig 62b. Selecting instructor.

Fig 62c. Selecting the pain level.

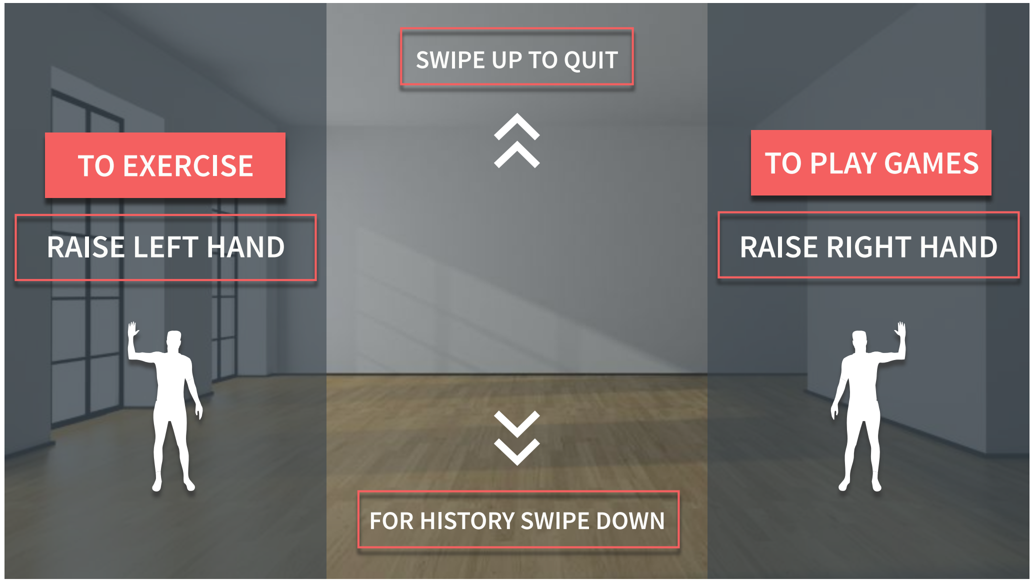


Fig 62d. Menu screen with exercise and game options.

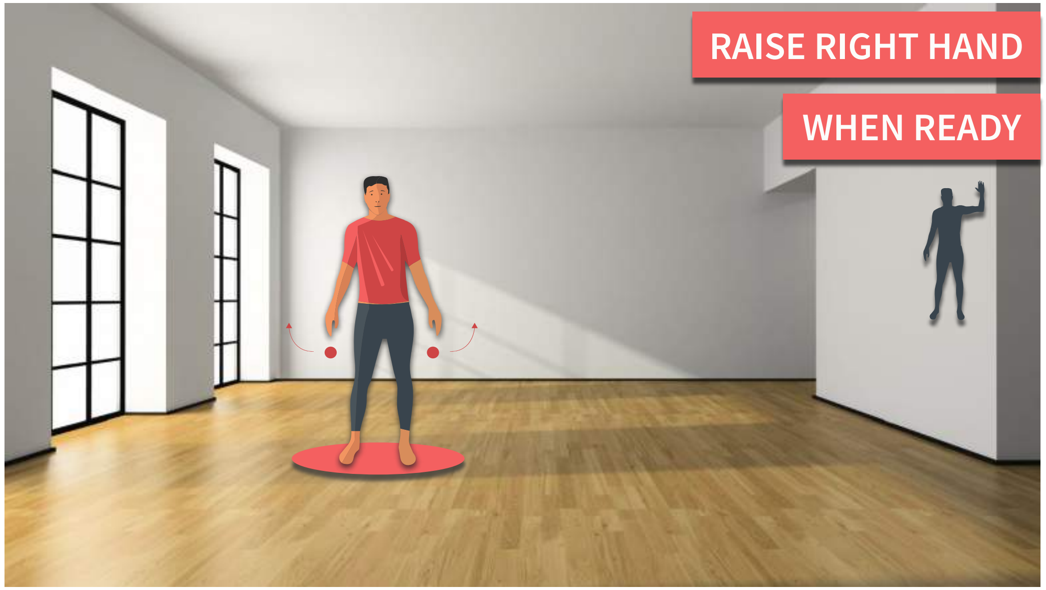


Fig 62e. Demo screen.

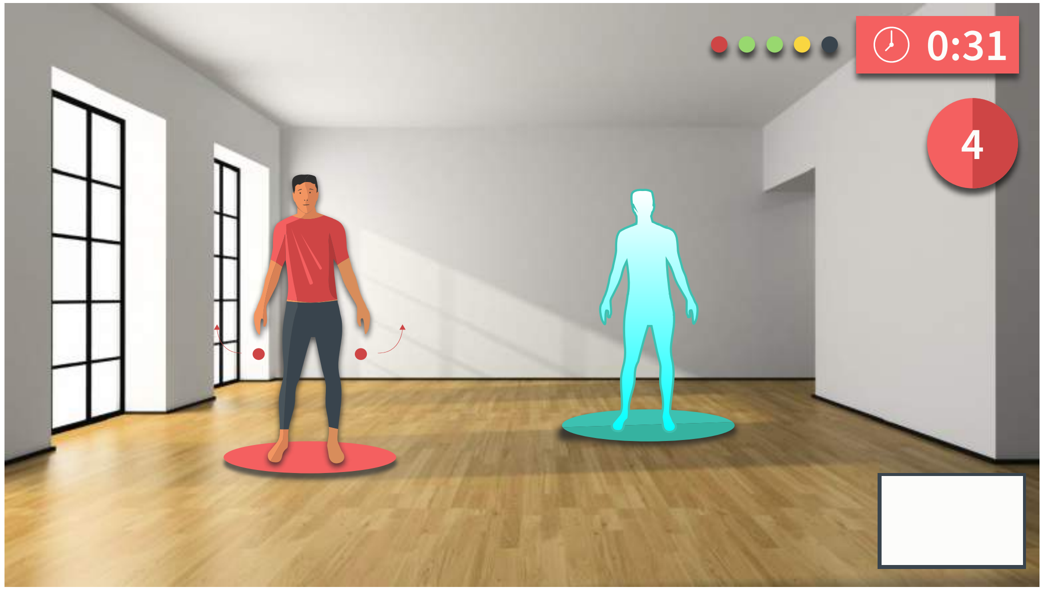


Fig 62f. Tracking screen with repetition feedback.

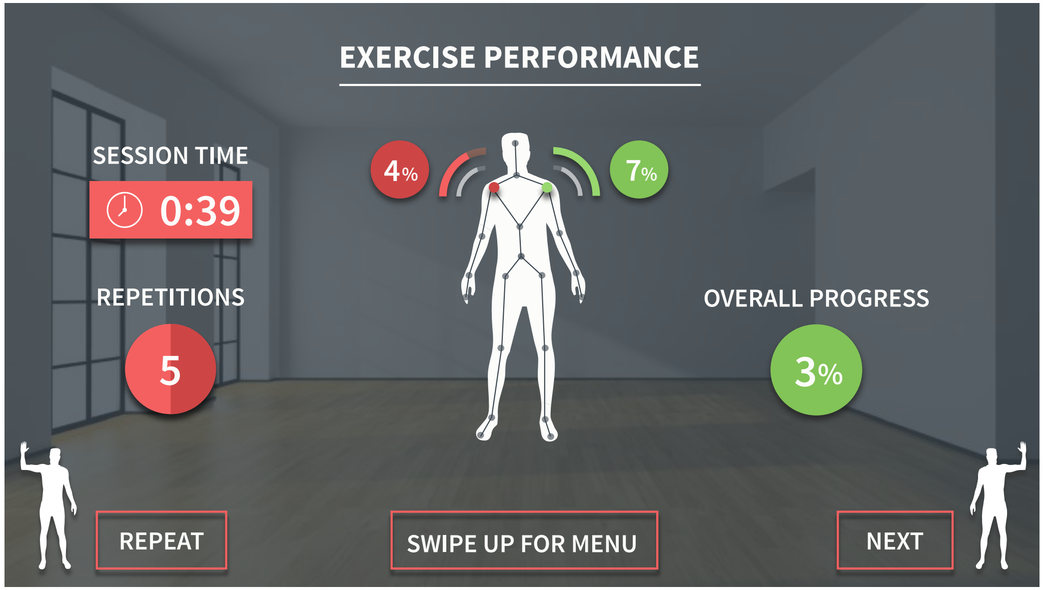


Fig 62e. Exercise feedback.

Fig 63 Mid Fidelity Prototype for remote supervision of therapist.

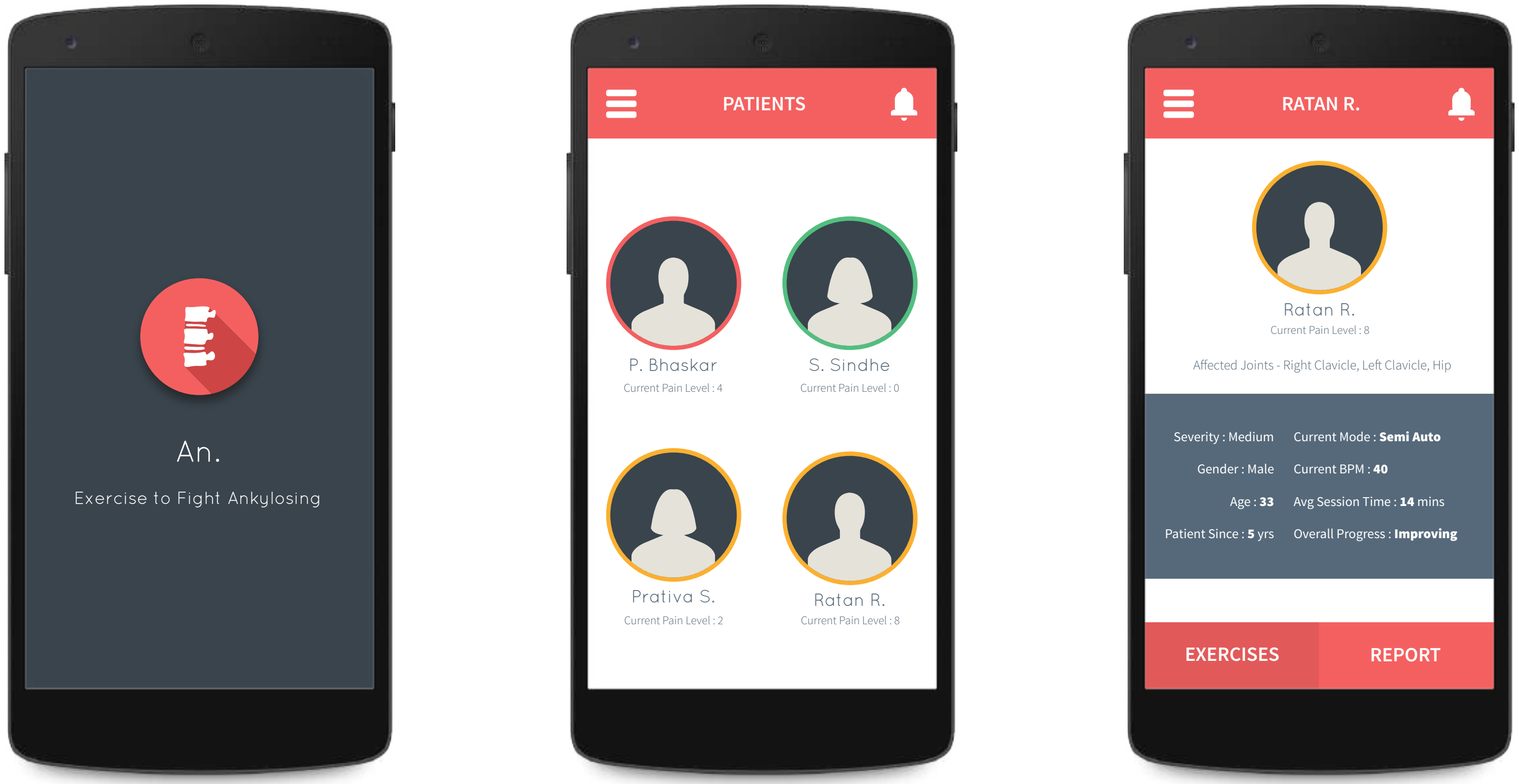


Fig. 63a 63b 63c (left to Right).

The therapist can select a patient and view the report and assign exercises.

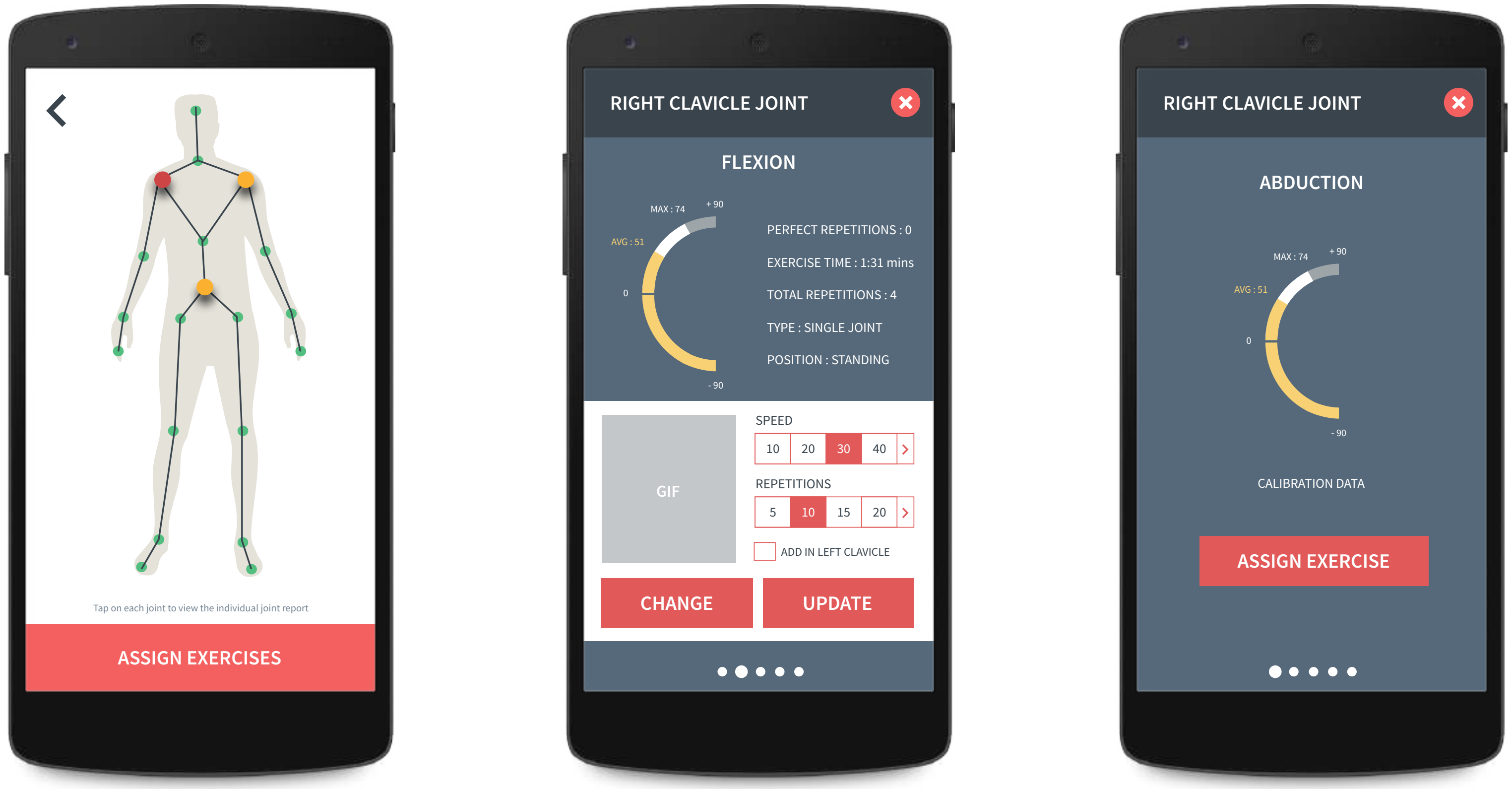


Fig. 63d 63e 63f (left to Right).

The therapist can select a joint and view the report and assign exercises, speed and number of repetitions.

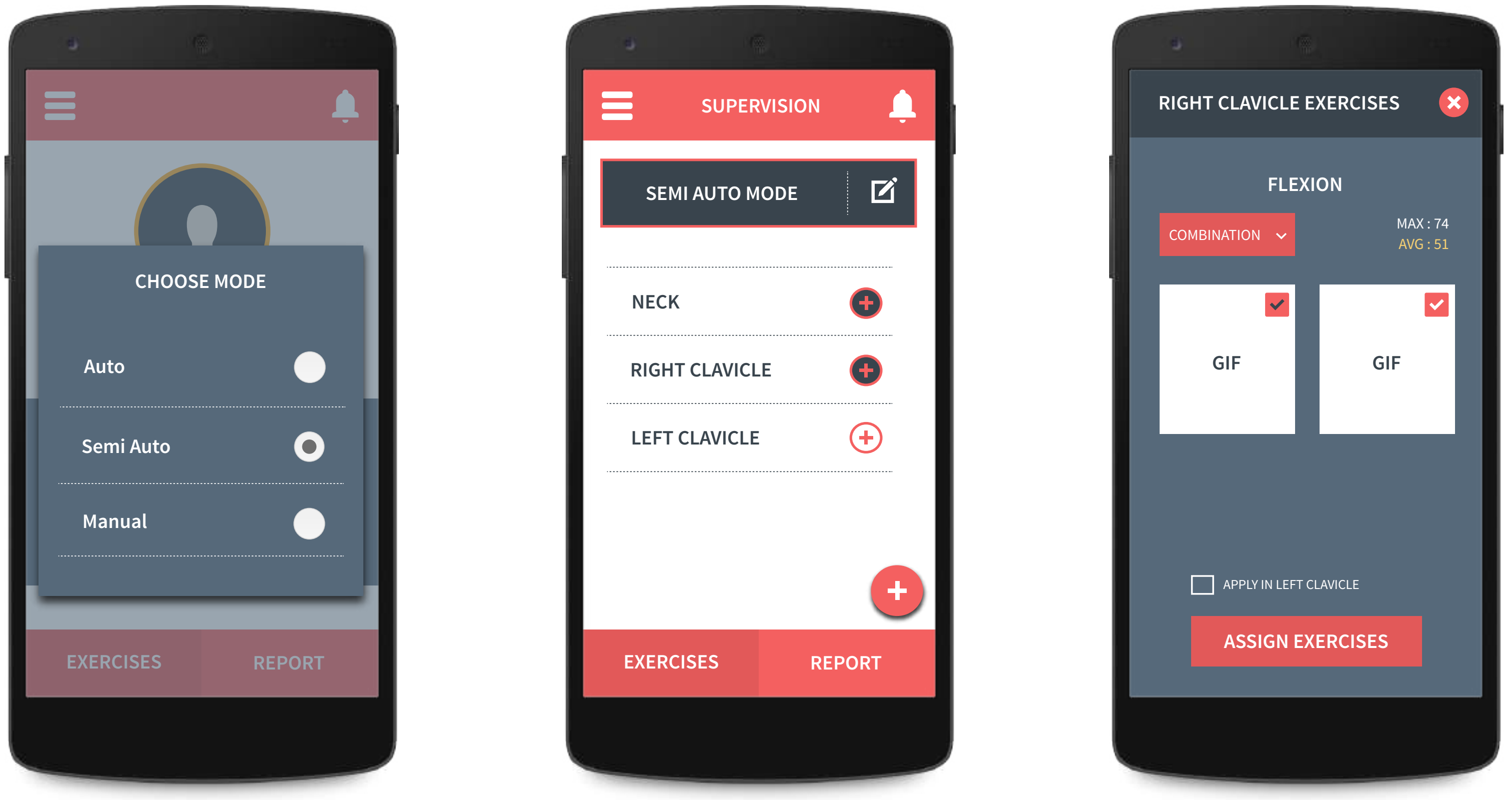


Fig. 63g 63h 63i (left to Right).

The therapist can select a supervision mode and assign exercises depending on the mode and update span.

10. Evaluation :

8.1 Evaluation Plan :

In order to understand the effectiveness of the core loop of the exercise regime and the posture level of the game, it was important to evaluate the application both quantitatively and qualitatively. The two components of the system were planned to be evaluated as follows :

8.1.1. Exercise Regime :

Conducting contextual interviews could be a way to evaluate where the user would be interviewed about their experience with the system. Summative evaluation to validate the following design parameters against specific goals :

A. Gesture : For UI control

- Intuitiveness
- Reliability
- Ability

The intuitiveness of the gestures were planned to be observed by the amount of time taken to identify the gesture asked to perform and whether the patient clarifies the gesture while interacting with the system. The reliability of the gesture would be measured by the number of times the gesture was performed by the user before it got recognised by the tracking device. The ability of gestures would be measured from the number of patients who are able to perform the gestures without pain (Visual Analogue Scale VAS 0-2) [11].

B. Exercise : Feedback and Tracking

- Mapping audio vs movement speed
- Mapping visual guide vs movement speed
- Feedback visualisation
- Tracking accuracy

The mapping of audio or visual and the movement were planned to be measured by the time taken by the patient to perform each round of exercise with the help of audio guide. This could be compared with the time taken by a physiotherapist to complete the same round. Qualitative feedback from the patient asking which guide was easier to follow while exercising could help in comparing the effectiveness of the audio and visual guides individually. The exercise feedback given by the system could be asked to be interpreted by the patient through think aloud. The tracking accuracy is a measure of the number of times the system failed to track the patient with a predefined threshold accuracy.

C. System Adaptability

Both qualitative and quantitative questions were framed to evaluate the adaptability of the exercise regime. Clocking the amount of time required by the patient to reach the tracking screen would be mapped to the adaptability of the system quantitatively. The patients could also be asked whether they faced any difficulties while operating the system. The patients were planned to be asked about their apprehension on a scale of one to five before and after their first experience with the system.

The patients were planned to be asked the following questions once the exercise regime was over :

1. Did you feel any pain while operating the system? If yes, what was the VAS level?
2. Did you find it difficult to follow the instructions while operating the system?
3. Which type of instruction could you focus on, audio or visual?
4. What could you interpret from the feedback you received after exercising?
5. How good are you with operating desktops and laptops?
6. Would you be comfortable operating this system alone next time?

Question 1 measures the efficacy of gestures used to control the system. Questions 2, 5 and 6 measure the system adaptability of the user. Questions 3 and 4 measure the understanding of the feedback provided by the system.

8.1.2. Games :

a. Patient engagement

b. Psychological benefits

c. Extracting exercises from games.

The patients was asked the following questions once the game is over :

1. How long you think you played the game?
2. Did you face any confusions faced while playing the game?
3. Were you eager to know what silhouette would be given in the next turn?
4. Did you look at the kinect while playing the game?
5. What was the instructor doing while you were playing?
6. Could you identify any exercise while playing the game?
7. Can you replicate a sequence that was shown in the game?

Questions 1-5 measure the effectiveness of game as a medium while questions 6 and 7 measure the effectiveness of the game elements in making patients remember the exercises and their ability to perform the exercises if the hardware is removed.

8.2 Evaluation Results :

The exercise regime and the game was tested out with 3 patients, 1 therapist and multiple experts. The hierarchy of testing was as follows :

- Experts
- Therapist
- Patients

Each iteration was first tested out with experts. Difficulties and features were understood through observation and expert feedback. The changes were incorporated and evaluated with the therapist. The patients were tested with the application once all the suggestions were incorporated.

8.2.1 Exercise Regime :

A. Gesture : For UI control

- Although therapist mentioned click to be more difficult in comparison to push, the click gesture to input pain level was performed with ease by patients.

- Patients did not find it difficult to understand and replicate the gestures. They could control the system from the instructions given.

B. Exercise : Feedback and Tracking

- Visual guide was more intuitive than the audio guide.

- Metronome guides might get annoying after sometime. Dynamic beats matching the tempo would be a better replacement.

- Feedback could be interpreted. ROM for joint movements were identified in different planes. Exercise feedback for neck abduction and shoulder flexion was shown to the patients.

- The repetitions were tracked properly, 5 repetitions were done after which the exercise feedback screen was loaded.

C. System Adaptability

- Patients were shown the connections to join the hardware with a laptop and they were confident about handling the system alone.

Observations :

- The patients were not interested in viewing feedback of all joints.
- They have an idea of the joints that were affected and showed interest in viewing the range of motion for only the affected joints.
- Patients had concerns regarding the accuracy of the system.
- The improvement in ROM feedback was found to be most useful by the patients.
- Most of the patients were comfortable in doing the exercises alone. They felt awkward to exercise in front of the system when other people were around.

Fig . Exercise regime (top) and ShapeUp (bottom) testing.

8.2.2 Game :

The posture level of ShapeUp was tested out with the patients. The postures include only cardio exercises.

- Patients thought they played for 2-3 minutes or less.
- Patients were oblivious about the what the instructor was doing.
- Did not think about what posture would come next.
- Did not look at the tracking device.
- One patient could replicate chest rigidity sequence.
- All patients could mention at least one sequence of postures.
- Patients trying to match postures exactly.
- T-pose recognition difficult, patients tried matching leg orientations.
- A report at the end of the session main motivator, should be included in games as well.

Exercise Regime or Game :

The intrinsic motivation was much more effective than extrinsic motivation in form of scores and positive feedback. Demotivated patients also wanted a consolidated joint feedback at the end of the game. Switching to games was not considered as an useful option. Games were identified to be faster than the exercise regime. According to the patients, if the game was not to show range of motion improvement information, exercise regime would be a better option in spite of it being slower than its gasified counterpart.

11. Conclusion

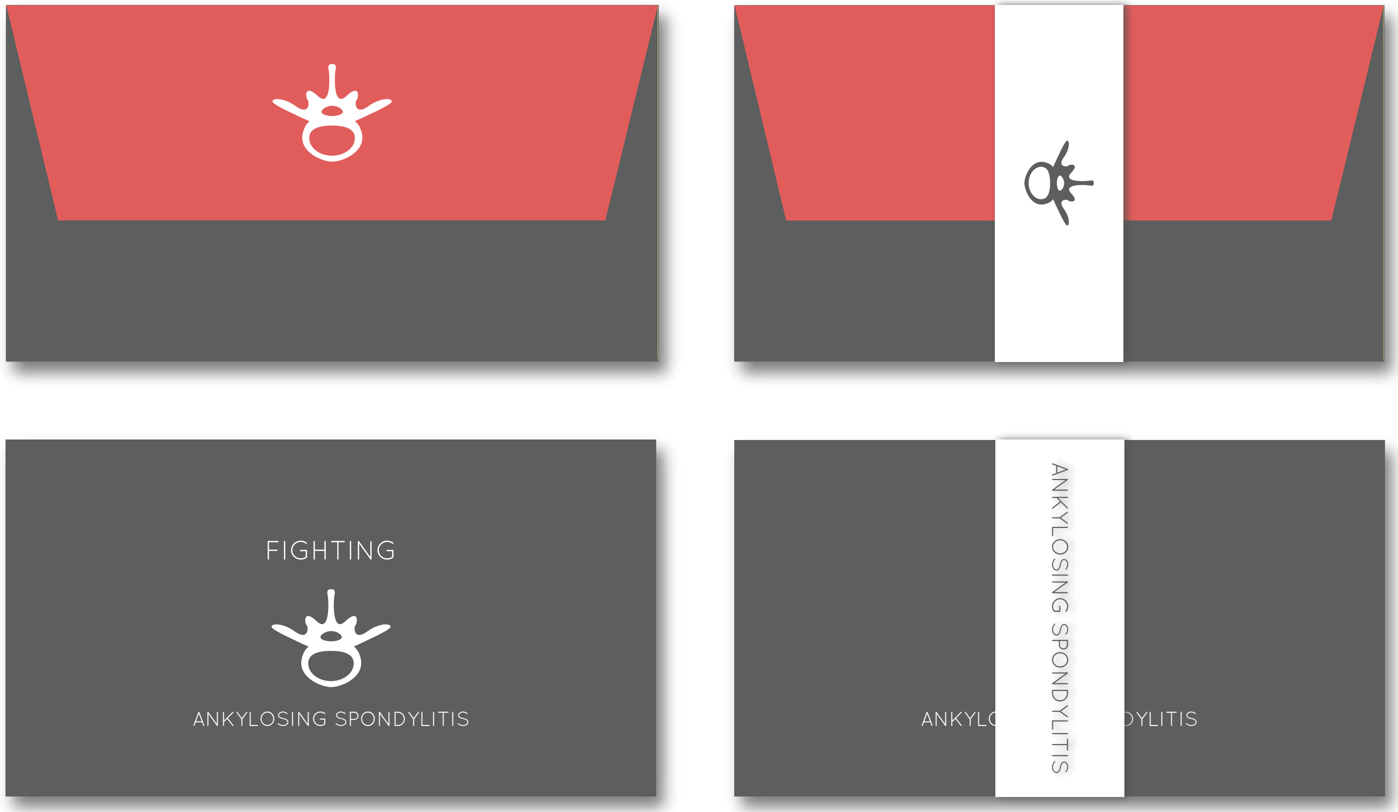
The exercise regime and the mini games were designed working in collaboration with the patients closely and looping them for feedback and suggestions at every step of the process. The core loop of the exercise regime and the posture level were developed and tested out with experts, a therapist and patients. The patients found the concept and the prototype unique from existing solutions. The solution has potential to solve accessibility, affordability and motivation issues.

The remote supervision integration was tested in form of a clickable prototype. The future scope lies in incorporating the suggested changes in the design and integrating the application with the mobile application for therapists.

The system also needs to evolve in terms of tracking accuracy. The prototype was built using Unity game engine and a third party open source kinect library. One of the major disadvantages of using the library was its incompatibility with Unity version 5 and above. These dependencies could be removed to make the system more robust. The hardware reliability can be enhanced with better joint mapping algorithms.

12. Appendix

Appendix 1.1 - Envelope



Appendix 1.2 - Letter

Dear Patient,

Exercising and maintaining low starch diet are the two most important things which can keep Ankylosing Spondylitis under control. If you are diagnosed as a moderate severity patient, we highly recommend you consult a physiotherapist. You can join Ankylosing Spondylitis - India group on Facebook, get your doubts clarified from other patients. You can also get in touch with the following people for more details :

1. Mr Gautam Dandekar Founder - Ankylosing Spondylitis India group (+91 986 725 5452)
2. Dr. Sudha Srinivasan Physiotherapist (+91 22 2414 7146)

We have an existing exercise application which you can download and use. It would give you all the necessary feedback on your range of motion of all the joints. The application would be synced with your physiotherapist who can modify your exercises and view your progress.

The application needs a sensor, a laptop or a television. You will get all the hardware details in the link or QR code shared below. In case you need help in procuring the hardware, you can get in touch with the following vendors:

1. Riddhi Siddhi Services (+ 22 2424 5666)
2. Santosh Electronics (+ 22 2414 4617)

Please scan the QR code mentioned below or go to www.jb.in/app. You will have to fill up a very short form which would generate an application with your unique ID. Download the application and follow the instruction manual (enclosed) to attach the hardware with the laptop and get started with your exercise regime.

Thank you!

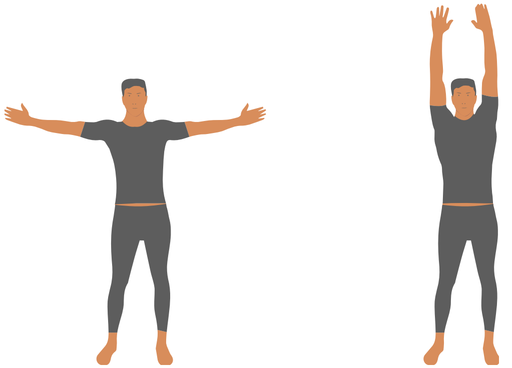
Regards,
Ankylosing Spondylitis India Team.

Appendix 1.3 - Badge

Colors based on severity of disease. White and grey for low severity, orange for mid severity, red for high severity.

Appendix 1.4 - Performance Formula Calculation

Angles are measured in degree. Exercise considered is shoulder flexion.



Joint	Max ROM	Current ROM
Right Clavicle	180	150
Left Clavicle	180	140

Joint accuracy (Right Clavicle) = (150 / 180) * 100% = 83.3%

Joint accuracy (Left Clavicle) = (140 / 180) * 100% = 77.7%

Assigned joint weightage for each joint w1 = w2 = 1.

Exercise Accuracy :

(1* 83.3 + 1*77.7) / (1+1) = 80.5

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