Using smartphone and sensor technology to facilitate non-pharmacological treatment in Rheumatology patients

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Submitted by: Bdour Al Lawzi

Declaration

This dissertation is submitted to the University of Bath in accordance with the requirements of the degree of Bachelor of Science in the Department of Computer Science. No portion of the work in this dissertation has been submitted in support of an application for any other degree or qualification of this or any other university or institution of learning. Except where specifically acknowledged, it is the work of the author.

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Abstract

People with chronic diseases do not only struggle with the physical aspect of the disease, but the emotional and mental one as well. Accordingly, the treatment model has now transformed to include both pharmacological and non-pharmacological aspects. This project focuses specifically on Ankylosing Spondylitis (AS), a chronic inflammatory condition that affects the connecting or supporting structures of the body. AS patients' pharmacological treatment is long-term and complex. Moreover, AS treatment highly encourages involving exercise as a non-pharmacological treatment to improve mobility. Yet adherence to either treatment is generally low due to many factors; particularly with AS patients, this is affected by people's emotions or their lack of understanding or appreciation of the impact exercise has on their condition. In recognising the chronicity of AS disease and its increasing prevalence, this project sets to identify and improve the factors that lead to treatment non-adherence. It aims to realise the tools and information necessary that will better help AS patients manage their overall health. This involves educating the patients about the disease and treatment process; building confidence and relieving fear. It also emphasises the importance of self-management strategies such as relaxation, goal setting, exercise, joint protection techniques and the appropriate use of exercise. The contributions of this project can be seen as identifying and stressing the need for consideration and innovation in the delivery of therapeutic treatments and content, and what form that should take.

This was delivered by designing appropriate technologies to address the challenges and findings in the field, by including a self-management prototype tailored to help and support AS patients to self-manage and adhere to treatments. This contributes to previous works on patient care as it additionally addresses the various non-pharmacological aspects of care.

Furthermore, the exercise recognition app uses smartphone and sensor technology to explore the impact of real-time feedback on exercise performance and adherence. This project has presented the successful implementation of real-time multimodal feedback as supported by user testing and system evaluation presenting a short recovery time. The use of wearable sensors increases the user's awareness of their movement, allowing them to monitor their own progress based on the real-time feedback received.

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Chapter 1

Introduction

1.1 Problem Description

Rheumatic diseases (RD) are characterised by inflammation that affects the connecting or supporting structures of the body. Most rheumatic diseases affect bones and joints, but there are other diseases, such as lupus, that affect other systems in the body as well.

In the UK today, rheumatic disorders cover over 200 different diseases, are extremely common, and affect over eight million people of all ages, with this number, is rising each year. Over three million adults are physically disabled, and one in every thousand children have arthritis. At a personal level, arthritis is devastating, particularly for young people in their 20s and 30s. Around 50% of people of working age diagnosed with rheumatoid arthritis cannot work due to chronic pain and fatigue, depriving them of their independence and self-esteem (*About rheumatic disease | Nuffield Foundation* 2019).

Such treatments incur a large impact on economic and social care systems, and the health-care system needs assistance. Dr Raj Sengupta, a Consultant Rheumatologist, emphasises this during a talk on the future of diagnosis and management; mentioning the strain and lack of support to RD patients throughout the year, as they mainly see RD patients once a year (Sengupta 2019).

NHS has also been encouraging and working with about 350 developers to build mobile apps offering patients advice, self-care and signposts to health services. In July 2018, the NHS celebrated reaching 70 apps in the NHS Apps library in honour of their 70th birthday (*NHS Apps Library | NHS Digital* 2019).

Patients suffering from chronic diseases often struggle with the unpredictability and chronicity of the disease. Not only that, but their treatment plan is complex, requiring high levels of adherence. However, treatment non-compliance is present across all chronic conditions, with 50% non-adherence across RD patients (DiMatteo et al. 2007). This can be a result of several factors, of which include a patient's behaviour, different economic and cultural backgrounds, and a lack of understanding of the importance of maintaining treatment, managing several treatment plans as well as possible issues between the patient and the health provider (Bugni et al. 2012, Elliott 2008).

Commonly, adherence is addressed through measures of monitoring and accountability.

However, as alluded to before, adherence can be affected by emotional and behavioural states. Self-management and self-efficiency are critical factors in addressing these factors to improve adherence (Hammond & Freeman 2004).

Self-management is vital as the participant needs to be engaged and involved in their treatment. However, adherence rates still range between 18% and 57% (Hammond & Freeman 2004). Additionally, incorporating education and self-efficacy is critical, such that the patient is aware and believes that the treatment will yield progress and help relieve pain. This knowledge and appreciation can encourage long-term adherence and improve patient outcomes (Marks 2001). The following presents a number of non-pharmacological treatments to be adopted by patients.

Furthermore, exercise has been highlighted in various treatments as it improves the overall quality of life, relieves pain, and improves mobility and function. However, patient compliance with exercise remains low. This is especially true for ankylosing spondylitis (AS), a type of RD known for causing spinal pain and stiffness. For the course of this project AS will be the focus, due to time limitation as well as considering AS treatment's high inclusion of exercise and physical activity, which has proven to reduce pain and stiffness.

Opportunities and advancements in persuasive and interactive technologies can provide a platform to address adherence, self-management and education. Specifically, smartphone technologies are used due to their ability to be personalised, intuitive, user-friendly, connected, portable and sensor-rich. Sensor technology is incorporated as it can provide real-time feedback based on movements; ensuring exercises are performed safely and correctly. By providing AS patients with such technological support, the impact of non-pharmacological treatment in improving patient outcomes and relieving pain can be realised.

1.2 Structure

The structure of the dissertation is as follows:

Chapter 1 - Introduction

This chapter introduces the problem to be tackled, outlines the aims and contributions of the project.

Chapter 2 - Literature and Technology Survey

This chapter explores state of the art starting with exploring areas around rheumatology, the challenges, and treatments. Based on these findings and specific needs of AS patients, similar works and technological applications are explored to identify possible delivery methods.

Chapter 3 - Requirements

This chapter details the process of requirement capture and identifying based on the literature, similar works and persuasive design principles from the previous chapter. This chapter formulates the key requirements and the techniques, approach and tools to be used. Concluding with implementation challenges and scoping justification where required.

Chapter 4 - Design
This chapter starts by giving an overview of the proposed solution supported by system models presenting a high-level overview. Followed by identifying the mobile best practices to aid in the design. The chapter then concludes with the creation of designs based on requirements and discusses feedback received on designs.

Chapter 5 - Implementation and further design
This chapter details the development of the app as rationalised in the previous chapters. The implementation is approached in two parts: (1) self-management prototype (2) exercise recognition system. The implementation is evaluated against the requirements defined in Chapter 3.

Chapter 6 - User testing and evaluation
This chapter details the user evaluation and testing approach, to assess the success and potential of the implementations. The testing is divided into two parts: (1) the usability of the self-assessment and goal setting interface to maintain treatment adherence (2) conducting exercises using the wearable sensors to validate the classification and review the impacts of the real-time feedback on behaviour and performance.

Chapter 7 - Discussion and Conclusion
The final chapter looks back at the project as a whole. It starts by drawing findings from the user testing and evaluation, relating it to the literature and similar works, analysing the work conducted. Concluding with identification of the project achievements, problems overcome, and lessons learnt. Future works present extensions of work to support adherence and non-pharmacological treatments further.

Chapter 2

Literature Survey

This literature review will cover areas surrounding the challenges of individuals with rheumatic diseases (RD). This is highlighted by describing the treatments and rehabilitation techniques. Treatment adherence is low within patients; patients need to be an active part of their treatment. As such, the focus will be towards pain-management and self-management such that patients are aware of and can deal with the unpredictability and strain of chronic diseases.

Exercise has been highlighted in various treatments as it improves the overall quality of life, relieves pain, and improves mobility and function. As such, this project will look into opportunities to incorporate self-management techniques, exercise and technology addressed the limitations identified in the studies highlighted in sections 2.1-2.5.

2.1 Rheumatology treatment and rehabilitation

Rheumatology is the study of musculoskeletal conditions to diagnose, support and treat patients. Classification of musculoskeletal conditions to RD is often hazy due to unknown aetiology and heterogeneity in their clinical presentation (Sangha 2000). RD varies over 100 different conditions affecting joint tendons, ligaments, bones, muscles and soft tissues with varied symptoms, signs, pathophysiology and duration time. Some examples of rheumatic diseases; rheumatoid arthritis, osteoarthritis, spondyloarthritis, including autoimmune diseases; systemic lupus erythematosus and scleroderma, osteoporosis, back pain, gout, fibromyalgia, and tendonitis (Azevedo et al. 2015).

Musculoskeletal conditions account for a significant segment of disability and morbidity, putting a strain on social and economic care systems; leading to substantial costs on health-care systems as well as the effect on individuals results in decreased quality of life, occupational burden, and high unemployment rates (Sangha 2000). In the UK today, rheumatic disorders cover over 200 different diseases and affect over eight million people of all ages, and the numbers are rising each year. Over three million adults are physically disabled, and one in every thousand children suffer from arthritis (*About rheumatic disease | Nuffield Foundation* 2019).

As such, rheumatic diseases treatment is multi-disciplinary, requiring continuous treatment involving balance and attention to pharmacological treatments and all-around rehabilitation (Gloag 1985). The spread of various rehabilitation approaches and services are individualised based on a patients case and state. Non-pharmacological interventions may include strategies such as education, occupational therapy, employment counselling, joint protection, maintenance of muscle strength and exercise (Goldenberg et al. 2011). There is not one standard that can be followed for rehabilitation and chronic pain management.

2.2 Ankylosing spondylitis

Note: Due to the time limitation for this project, AS will be focused on as a form of rheuamtic diseases. AS was specified as non-pharmacological treatments are key to relieving pain and stiffness. The literature below will give a brief overview on AS, and present the

Ankylosing spondylitis (AS) is a chronic inflammatory condition, primarily affecting joints in the spine, resulting in pain and progressive spinal stiffness; significantly impacting the overall quality of life (King et al. 2013).

The onset of AS occurs in the late teens or 20s, affecting men more often than women. Noticeable symptoms begin as a result of sacroiliitis, which causes persistent low back or buttock pain that may radiate throughout the thighs. Such symptoms are alternating; affecting one side for up to several months then affecting the other. Nonetheless, these symptoms can be improved by exercise as back pain and stiffness often worsen after inactivity. It is important to note that care should be taken while increasing activities as prolonged standing may aggravate sacroiliac pain (Keat 2010).

Spinal deformity is not unusual amongst those severely affected and flexed posture may be aggravated by hip involvement with flexion deformities. Deformity often leads to personal isolation as well as practical difficulties (Keat 2010).

Other noticeable and disabling symptoms of AS include fatigue and stiffness. Together with the constant pain, people with AS struggle during everyday life; resulting in low scores on the quality of life measures, such as the SF-36 and ASQoL (Zochling 2011), and on health utility measures such as the EQ-5D (Zochling 2011). These numbers are further exacerbated by complications in severe AS, such as spinal and flexion deformities, as they may lead to personal isolation and increase the difficulty of managing everyday tasks (Keat 2010).

The debilitating consequences of AS are far reaching; contributing to societal costs as patients stop work before the retirement age, or reduce their work. Such costs substantially increase as the disease progresses and worsens the patient's function (Edavalath 2010).

AS treatment aims to improve the patient's well-being and function by reducing pain and stiffness, as well as by delaying further bone and joint damage. Regular exercise is key to increasing patient comfort, maintaining good spinal mobility, and minimising deformity or spinal joint restrictions (Edavalath 2010). No treatment has been proven to prevent bony progression, though this remains an important aim.

2.3 Pain Management

Rheumatic pain has been commonly associated with nociceptive, peripheral pain; tissue damage or inflammation (Borenstein et al. 2010). However, there has been journals and studies on pain pathophysiology and exploring pain mechanisms at a molecular level revealing a clear separation between the peripheral damage seen using radiographs and the pain and functional symptoms of an RD patient (Hannan et al. 2000, Creamer et al. 1997).

This disassociation/division raises several other factors rheumatic pain can be stemmed from involving neurological mechanisms as well as psychological state, environment, cultural background, previous pain experiences as well as an individual pain tolerance genetics (Clauw & Witter 2009, Fitzcharles et al. 2005).

These insights significantly impact the approach taken to develop a therapeutic plan and manage pain incorporating several pharmacological and non-pharmacological interventions. There is strong evidence that exercise and physical activity improve chronic rheumatic pain; studies have proved that exercise releases pain, improves function, movement and physical fitness as well as health quality of life (Gowans & deHueck 2004, Ettinger et al. 1997, Minor et al. 1989).

Education is another primary non-pharmacological treatment, ensuring that patients are well equipped to self-manage their progression and effectively manage their pain, mainly due to the unpredictability and chronicity of the disease. The focus is on equipping and educating individuals with the information and skills to manage their own health (Cooper et al. 2003). This involves informing the patients about the disease and the treatment process, to build confidence and relieve fear, as well as emphasising on the importance of self-management strategies such as relaxation, goal setting, exercise, joint protection techniques and the appropriate use of medications (Goldenberg et al. 2011).

2.4 Self Management

Delving deeper into self-management, the term itself was first mentioned in health education book on the rehabilitation of chronically ill children (Yule 1978). The term came to mean that the patient is an active participant in their own treatment. It is now more commonly used in conjunction with the education of patients with chronic diseases (Lorig et al. 1985). Self-management is prevalent in daily lives; engaging in work, exercise, healthy living style and a good quality of life. The need for self-management is heightened for those with chronic diseases to maintain healthy behaviour and disease management.

Corbin & Strauss (1985), studied home care for adults with chronic illnesses, developing a framework based on a set of tasks for self-management; medical and behavioural management, role management and emotional management. Medical and behavioural management refers to tasks involving maintaining medication and complying with all aspects of treatment and therapeutic plans such as maintaining a diet plan and physical activity. Role management takes into account maintaining daily activities, modifying tasks where adequate to ensure no strain or fatigue as well as undertaking new roles and behaviours to help ones own management. Finally, emotional management is vital at every step of managing chronic conditions from diagnoses. Various emotions such as anger, fear, frustration, and depression can accompany the realisation for the need to change and adapt ones view of the future.

These subjects are reflected in RD self-management interventions; educational and psychosocial interventions, lifestyle interventions and treatment interventions aimed to improve an individual's health quality of life, health-care utilisation, and perceived self-efficacy whereby an individual is more confident and in control of their condition believing they will be able to exercise (e.g. Lorig & Holman 2003, Goeppinger et al. 2007). The combination of these tools will enable independence, as well as knowing how to manage the psychological barriers of disease effectively (Lorig et al. 1985).

2.4.1 Educational and psychosocial interventions

As mentioned above, education is fundamental in the treatment of RD, and thus self-management in combination with psychosocial interventions are used to address behaviour and build self-confidence relieving any negative connotation associated with limited conceptions of one's ability (Foster et al. 2007, Dures & Hewlett 2012). Often when an individual is diagnosed or has reached a plateau in their progression, they are manifested with feelings of worry, anxiety, and helplessness. Individuals become demotivated and fear worse pain or further injury leading to poor compliance to rehabilitation plans and treatments; causing occupational burden and strain on health-care systems. Several studies have evaluated the effectiveness of educational and psychosocial interventions seen to prove health quality of life and perceived self-efficacy (e.g. Dures & Hewlett 2012, Yocum et al. 2000, Garnefski et al. 2013). Incorporating multiple disciplines such as education, behaviour and exercise have significantly changed individuals pain outcomes; as seen in a study by Yocum et al. (2000) by incorporating yoga, tai chi and musical therapy. As such, the focus on psychosocial intervention and self-efficacy development is critical in self-management.

2.4.2 Lifestyle interventions

Studies have explored the impact of a healthy lifestyle on the overall quality of life and behaviours (Foster et al. 2007, Conn et al. 2008). Lifestyle self-management strategies address to maintain a healthy diet, physical fitness, sleep and avoid any unhealthy behaviour such as smoking. Managing lifestyle has been seen to maintain and/or improve muscle tone, enhance joint movement and protection, relieve pain, promote confidence and stay motivated to progress (Foster et al. 2007, Conn et al. 2008).

In a study to explore and describe the rehabilitation goals of patients with RD during rehabilitation stays, goal content change was examined from admission to discharge. Berdal et al. (2018), explored the rehabilitation goals of RD patients aiming for a healthier lifestyle. The participants generated a total of 779 goals ranging on nine general classifications; adaptation, disease management, healthy lifestyle, inner life, knowledge, life fulfilment, manage everyday life, social life, and symptoms. Maintaining a healthy lifestyle was a goal topic for all participants in the study, of which 98% frequency identified physical fitness and exercise showing the patients determination and motivation to exercise.

Followed by a healthy lifestyle, disease management was also a common goal with most participants (75%). The focus was on managing their condition by adhering to a treatment plan, seeking support by health-care professionals and resources as well as applying self-management techniques, monitoring symptoms and developments to preventing therapeutic regression and further deterioration. An aspect of disease management is maintaining a healthy lifestyle and exercises, with the implementation of the diseases management aspect through utilising technology.

With that, 52% of participants had goals regarding social interaction with others, contributing and carrying out social activities.

From this study, we can see individuals do have a general idea of what they need to do. They need guidance and pushing applying self-management interventions to their goals.

2.4.3 Treatment interventions

Treatment non-compliance is present across all chronic conditions, with 50% non-adherence across RD patients (DiMatteo et al. 2007).This can be affected by a patients behaviours, different economic and cultural backgrounds and lack of understanding on the importance of maintaining treatment, managing several treatment plans as well as possible issues between the patient and health provider (Bugni et al. 2012, Elliott 2008). Some patients cautiously and intentionally do not adhere to their treatment, such as not taking medication as prescribed. While that will cause adverse negative drug reaction, it reflects the individual's emotional and behavioural state, such as a belief that the pharmacological treatments are not relieving pain or symptoms (Elliott 2008). Meanwhile, others intending to take medication forgot to do so. Failing to follow a therapeutic plan will result in setbacks, possible deterioration, and therapy failure, an increase in the number of hospital visits and high costs on the health-care system (Elliott 2008).

Therefore, treatment interventions and monitoring need to be carried out regularly to maintain drug effectiveness, and best possible treatment plan as well as minimise cost on health-care systems.

2.5 Exercise and exercise adherence

As we defined educational, psychosocial, lifestyle and treatment interventions in self-management, we can see the same translation in goals set by RD patients in aiming for a healthy lifestyle; gain more awareness on disease management as well as interacting with others. Exercise is mentioned as a mechanism for treatment and management of RD, and as such delved into deeper.

Exercise is another form of non-pharmacological intervention of RD. Not only does exercise produce endorphins thus improving mental health and well-being, but it also generates morphine-like-effects by inducing the production of endogenous opioids. Therefore, with regular exercise, patients will be better capable of managing chronic pain (Fitzcharles et al. 2005).

There has been multiple studies and self-management programs evaluating the use of exercise as alternative therapy; systematic reviews on strengthening and aerobic exercises for individuals with rheumatoid arthritis concludes great progress in movement, function and improving muscle tone. Preventing deterioration as well as improved self-efficacy and overall well-being (Stenstrm & Minor 2003, Van Den Ende et al. 2000). Nonetheless, both studies above seemed to find a lack of clear, concrete outcomes on the effects of long-term exercise adherence, requiring further exploration and development.

A study by de Jong et al. (2003) addresses long-term adherence by focusing and targeting on the need for behavioural-based exercise education; conducting a study over two years of regular vigorous exercise such that individuals can maintain and increase physical activity over time to see progress and improve functionality.

Self-management and self-efficiency are critical factors for adherence. While self-management is vital as the participant needs to be engaged and involved in their treatment, adherence rates are still typically between 18% and 57% (Hammond & Freeman 2004). Incorporating education and self-efficacy such that the patient is aware and believes that the treatment will yield progress and help relieve pain can encourage long-term adherence and outcome (Marks 2001). As such, motivational strategies have to be applied to the patients' lifestyle to promote compliance.

Studies on patient education have concluded the implementation of group cognitive-behavioural approaches to be effective in improving adherence with self-management over the use of traditional educational methods constrained by time and feedback (Riemsma et al. 2003). Applying several strategies in conjunction, carrying out group exercise can be seen as motivator and encouragement improving self-efficacy across several individuals.

A journal on interventions for enhancing adherence with physiotherapy treatment highlighted that there were only positive results in the case where there was a feedback loop in the form of diary completion. However, it is not real-time compliant leading to questioning the validity of the data (McLean et al. 2010). A journal is not a real-time complaint as the data is not recorded while the exercises are being conducted. This could result in data invalidity, as a user will write in the journal based on their own recollection of the events, and if forgotten about could potentially be invalid data. Meanwhile, several studies on home-based exercise in osteoarthritis have yielded positive results. A controlled trial of hospital versus home exercises on physiotherapy in osteoarthrosis of the knees was carried out, with only two exercises and three induction sessions (Chamberlain et al. 1982). The results showed that home exercise could be just as beneficial as outpatient physiotherapy, but was unsuccessful without an incentive of assessment follow-up visits and diary completion to record progress (Chamberlain et al. 1982).

This was further explored by Thomas et al. (2002) on behalf of the Community Osteoarthritis Research Group, conducted a randomised home controlled study whereby participants were divided into 4 groups: physiotherapy and monthly telephone contact with a therapist, physiotherapy and regular telephone contact with a therapist, physiotherapy, no intervention along with a placebo health food tablet and lastly physiotherapy, no intervention, and no food tablet. While the programme reported a significant reduction of knee pain, the focus for this literature is that there was no difference in results between patients who had contact with therapists versus no intervention; which would possibly signify disassociation to psychosocial aspects of having a therapist to contact.

Sangle et al. (2015) investigates the impact of sleep on fatigue and exercise in RD. Sleep is fundamental to the immune system for restoration and maintenance. Lack of sleep and fatigue is a common symptom with RD, affecting an individual's health, overall well-being and the capabilities to exercise (Sangle et al. 2015). Additionally, McKenna et al. (2017) study the impact of exercise on sleep for people with rheumatoid arthritis, identifying a correlation between the level of physical activity and duration of sleep. Physically active people tend to sleep for longer. However, further support and studies are required. Combining interventions such as education and exercise ensuring real-time feedback and progress review could lead to effective self-care as well as improving adherence and commitment.

We can see across the multiple interventions, the need for adherence and motivation to maintain a good and healthy quality of life. Exercise and physical activity are standard throughout all the interventions as a treatment and a self-management intervention. There is a need for education on the benefits of maintaining a healthy lifestyle, reassurance to relieve fear and anxiety as well as the need for compliance, monitoring, and accountability to encourage exercise adherence.

The literature thus far has identified the need to educate patients such that they are involved in their treatment, and able to self-manage pain. However, only 50% of patients' adhere to their treatment. Thus, this project aims to build on these findings from the literature by exploring opportunities in technology to incorporate self-management techniques and motivate users. Exercising is the treatment of choice as studies have identified improvement in health quality of life as well as releasing pain, and improving movement.

2.6 Opportunities in technology

Revisiting what has been discussed previously, self-management, exercising and education aim to help improve an individuals quality of life. Although, various issues negatively impact the process; non-compliance and non-adherence to treatment as well as social and economic implications to health-care systems. Incorporation of emerging technologies such as mobile health (mHealth) can be used to address the limitations we face with exercise adherence for RD patients. mHealth is defined, by the World Health Organisation, as the application of health and medicine using portable devices such as mobile phones, patient monitoring devices, personal digital assistants, and other wireless devices (Martnez-Prez et al. 2013). The use of mHealth as a remote platform has changed how we interact with health-systems and how we receive our health-care (Kumar et al. 2013, EJ et al. 2015).

Persuasive and interactive technology to promote physical activity and health has been a booming topic in Human-Computer Interaction (HCI), due to its ability to be tailored, intuitive, user-friendly, connected, portable and sensor-rich (Patrick et al. 2008).

Applying these advancements with consideration and research has the potential to change a patient's behaviour and engagement in their treatment process targeting several purposes and contexts as it is a socially and economically practical solution (Silva et al. 2015).

2.7 Self-management technological applications

As mentioned previously, literature and studies have encouraged self-management interventions as part of a patient's treatment plan. However, there are several constraints to self-management plans; maintaining communication between the patient and the multidisciplinary team, and limitations evaluating success as a result of incomplete knowledge and accessibility to the activities undertaken throughout the course (Kendall et al. 2011, Glasgow et al. 2008, della Volpe et al. 2006).

The potential of emerging technology has been recognised applying self-management, using websites, mobile applications and social networks (Lorig & Holman 2003, Yamada et al. 2012, Shinohara et al. 2013). There are several prototypes and studies implementing applications for RD tracking, monitoring, and recording of symptoms. A study reports the development of an application that records a life-log' of a rheumatoid arthritis patient's condition day to day and disease activity, sharing it with health professionals. Although, the system was only evaluated in terms of usability and feasibility, reporting high engagement and usage. The health professionals point of view was not considered in the study and how the data will be evaluated (Shinohara et al. 2013). Nonetheless, this does give us insight into an individuals willingness to self-manage and be engaged in their treatment.

Some other studies look at gait patterns using sensors and self-assessment (Yocum et al. 2000), which has been seen as an assessment tool for RD patients although it does not take into account the unpredictability and the pain management aspects associated with the condition.

Referring back to the literature on the areas of rheumatology, management and education emphasised throughout. Education is vital such that a patient can effectively manage their pain and are equipped to self-manage. If we are going to enable technology such that individuals can self-manage we need to provide the patients with a mechanism in which they can learn, engage, be held accountable for their actions and provide real-time feedback. Self-management technologies must go beyond tracking and recording activities; patients' needs must be translated evaluated and reflected in the design requirements. Design and user needs will be assessed further in Section 2.9.

2.8 Persuasive technology

Persuasive technology is used to understand drivers of human behaviour, and as such learn to automate change of users' behaviours through the use of technology channels and interactive information technology (Fogg 2009, Oinas-Kukkonen & Harjumaa 2008). Applications of persuasive design can be seen in technologies promoting healthy lifestyle (e.g. Consolvo et al. 2009), e-commerce shopping experiences (e.g. Saari et al. 2004) and social networks (e.g. Fogg & Iizawa 2008) in addition to many others. Health care applications may be developed to motivate people towards health behaviour, and ease the economic situation in public health care (Intille 2004).

However, computers do not have intentions of their own; those who create, distribute or adopt the technology are the ones who have the intention to affect someone's attitudes. The Fogg Behavioural Model (FBM) is a psychological model that identifies and defines three factors that control whether a target behaviour is performed(Fogg 2009).

Mostly a person must have sufficient motivation, sufficient ability, and an effective trigger, present at the same instant for the behaviour to occur. A trade-off between ability and motivation is needed; motivation no matter how high may not be able to perform a behaviour if people do not have the ability. Additionally, the types of trigger and timing are essential to a successful, otherwise could annoy and develop a negative associated with the target behaviour.

Evaluating the situation of AS and RD individuals against the FBM model is fundamental to identify elements that could potentially move a user to a higher position in the FBM landscape. In Figure 2.1, three core motivators are identified. Pleasure/pain can be applied to AS patients as a motivator; exercising releases pain for AS patients. The response to this motivator is immediate to what is happening at the moment, and this will be based on the patient's knowledge of how to handle pain. Similarly, hope/fear would be a result of the same cause of pain. However, it is characterised by anticipation of an outcome, so patients would exercise of fear from pain and hope it will improve function and release pain. Finally, social acceptance/rejection can be a motivator adding a social dimension to it, but there have not been studies exploring it for motivating chronic disease treatment adherence.

The next major factor that has a significant impact on behavioural changes in AS patients is ability. Physical effort is the most dominant simplicity factor; exercising for AS patients are quite hard when pain is experienced; however, motivation would be higher as they are experiencing pain. Additionally, non-routine plays a factor. If the patients adhere to their treatment plan and maintain it, they find these behaviours simpler as they are routine.

The third factor, as seen in Figure 2.1, is triggers; telling a person to perform a behaviour now. Triggers can take a form of prompts, cues, calls to action. There are different types of triggers: sparks, facilitators and signals. Sparks is a trigger most often used when a person lacks motivation and as such designed in tandem with a motivational element such as goals or rewards. Facilitator is a trigger appropriate when a user has the motivation but lacks the ability, and as such trying to trigger the behaviour. This can be seen in AS patients as education, reminding the user that while exercising takes physical effort, it does release the pain. A signal serves as a reminder as the person would have both the motivation and the ability. A simple example of a signal is a traffic light that indicates when behaviour is appropriate.

Persuasive technology to motivate healthy behaviour is a growing area within HCI and ubiquitous computing. Fritz et al. (2014) explores the emergence of personal information systems that offer wearable sensors for automated tracking of personal information, physical activities, and sleep representing persuasive technology. The findings identify

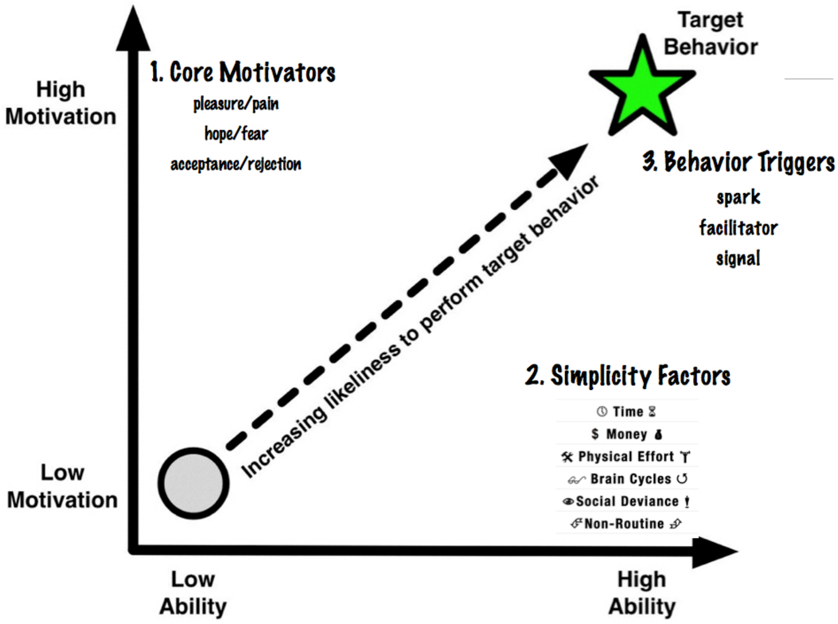

Figure 2.1: Fogg Behavioural Model has three factors - motivation, ability, and triggers - and sub-components (Fogg 2009).

the population of wearers drives value and motivation from the technologies in the short-term and long-term by the use of metrics, data sharing, and rewards as persuasive design principles.

It was observed among the participants of the study that strong emphasis was placed on the numerical feedback, "*accountability*", acting as an immediate objective that in some cases overshadows the underlying motivation behind the persuasive system; to be active or fit. This is further re-enforced where people still wanted to receive system rewards even if they were inaccurate representations - such as over-calculated steps. However, long-term participants had to extend their reward system on their own accord by incorporating real-world rewards or other tools. As such, Fritz et al. (2014) identify the need for further support for increasingly sophisticated fitness priorities, changes in activity and metrics as well as the evolution of rewards.

2.9 User needs and requirements

We have seen that there are aspects of motivation and reflection in existing literature and related works. However, post-exercise reflection and progress visualisation is not enough for self-management. There are some works with real-time feedback (Rosser & Eccleston 2011), such as LumoFit (Aamoth 2014) and iPosture(n.d.). Although, these do not address the emotional strain individuals with chronic musculoskeletal conditions face concerning physical activity. Individuals often lack confidence and have negative misconceptions fearing physical activity could cause injury and pain (Leeuw et al. 2007) making it difficult to maintain and build towards long-term activity goals (Singh et al. 2014). RD patients, unknowingly, develop these behaviour changes as protective instincts to prevent further pain. However, this could cause further deterioration, limiting the range of movement, and everyday mobility (della Volpe et al. 2006).

Thus, an understanding of the physical and psychological factors of the users must be reflected in the technology applied as their needs vary to physical activity applications of the general population. Technological applications must advance from providing monitoring and tracking to incorporating self-management and pain-management strategies to support, encourage and build confidence and awareness in ones capabilities.

Based on studies and interview conducted by University College London researchers, Swann-Sternberg et al. (2012), five main themes emerged aimed to focus on the needs of patients with chronic diseases; reassurance, personalisation, exercise adherence, supportive functions, and visual representations (Swann-Sternberg et al. 2012).

The following sections 2.9.1-2.9.5 describe the common themes identified by Swann-Sternberg et al. (2012) along with possible technological applications.

2.9.1 Reassurance vs warning

RD patients often fear participating in physical activity and exercising, especially when unmonitored at home, to cause further injury and pain (Singh et al. 2017). While patients think they must perfect posture to benefit from completing exercises, physiotherapists stress that physical activity is encouraged to facilitate movement and flow. Repetitive corrective feedback can signal negative misconceptions leading to thoughts of pain and danger of injury. To avoid this, another exercise should be suggested rather than repetitive correction.

With that, participants of the study highlighted that knowledge of the correct exercise movement is desired as comfort and reassurance that they are safe and progress can be seen over time. A balance between warning and reassurance is needed to build confidence and relieve fear while building up progress and movement for the users. To add an element of reassurance, accountability and providing real-time feedback, sensors to detect movements along with careful design considerations would allow us to explore the balance providing corrective real-time feedback and reassurance.

2.9.2 Personalisation

As each RD patients' case and capabilities are different, participants of the study highlighted their need for personalisation; being able to adjust pain level, express their physical ability, identifying areas of progress as well as setting goals. The importance of goal setting has been identified in self-management interventions and translated into supporting technology such that a user is directly involved in their progress, adding the element role and emotional self-management.

Goal setting for individuals with chronic conditions can vary quite a lot of from the general population. Goals should be adjustable and provide feedback on the progress made, while other goals may be directly related to physical activity rather psychological or social goals such as assertiveness which can be seen to impact regular exercise. As we have discussed, in Section 2.4.2, on lifestyle and rehabilitation goals, goal setting aspects can vary due to the unpredictability of the condition and may incorporate psychological, occupational or physical goals such as assertiveness.

2.9.3 Exercise adherence

The main key to adhering to long-term exercise is enabling the user to set appropriate daily and long-term expectations to maintain regularity and stay motivated. However, due to the nature of chronic conditions capabilities and pain may vary every day. Two aspects are to be highlighted here; an individual should be able to adjust their expectations and goals as well as give an indication of their state that day. In turn, the app would need to employ self- management techniques to help guide and educate the user for the best way to manage their current state and cautiously explore positive feedback strategies to show progress and give reassurance keeping the user motivate to carry out exercises. This could be addressed by suggesting low impact exercises, relaxation and behavioural therapy techniques providing further encouragement and possibly add more reassurance aspects.

The integration of self-management interventions and exercise with technology has been seen as a motivator being a social expectation in daily tasks. Furthermore, the use of technology allows for different mediums of feedback whereby a user can see progress thereby staying motivated; feedback strategies will be discussed further in the sections to come on users needs.

2.9.4 Supportive functions

The studies show that participants highly valued personalisation of the exercises suggested for a given user based on their own physical needs and capabilities; taking into account type of pain, abilities, pacing and functional goals can be integrated into their everyday lives such as walking, shopping and taking the bus.

Monitoring, tracking, and feedback of physical activities were prevalent in all conducted interviews. While we have seen examples and related works on monitoring and tracking (Jansen-Kosterink et al. 2013, Lam et al. 2016), the participants expressed particular interest in multimodal and real-time feedback strategies to build body awareness and be proactive during the exercise sessions.

The use of technology in this area has enabled many different strategies. The display of an avatar demonstrating the ideal movements identifying the areas of focus for the specific exercise, to guide and motivate the user. In combination with the use of accelerometer wearable sensors, exercise recognition and repetition count can be tracked obtaining the form and movement of the patient highlighting areas of improvement.

While there are several physical activity tracking applications for the general population, the participants in this study were more interested in tracking so they can understand and become aware of the fluctuations of their daily activity; mapping their daily and physical performance to review their long-term and short-term progress, goals, and achievements.

Education on pain-management was raised as a concern by participants when looking to translate users needs during physical activity. The combination of reassurance techniques, wearable sensors, and supportive functions to demonstrate and guide users through exercises is the first step in exploration that can be further developed through iterations and testing.

This study highlights the above as feature and user needs. Further studies explore various other multimodal feedback strategies in exercise and physical fitness system. The combination of textual, aural, and visual cues has been beneficial guiding exercise movements and encouraging performance (Jansen-Kosterink et al. 2013, Lam et al. 2016). Participants, in the study by Swann-Sternberg et al. (2012), have identified visual representation as a supportive function; this often used when designing for tethered and in-situ systems with large displays, further thought needs to be taken into account when creating a portable app with relatively smaller screens. Vibrations are used in fitness applications such as signalling duration lapse (Bark et al. 2015). This mode of feedback can be used for signalling such as time-lapse, over implementing continuous feedback (Bark et al. 2015, Wall 2010).

Auditory feedback and sonification, mapping movement to auditory feedback, has been explored for facilitating exercise by instructing and guiding movements in motor function rehabilitation (e.g. Vogt et al. 2010, Rosati et al. 2013). There has been studies analysing 3D movements using electromyography data (Pauletto & Hunt 2006) to correct exercise movement and/or posture (Vogt et al. 2010) as well as facilitating awareness of body movement and capabilities (Ghez et al. 2000, Singh et al. 2016).

A sonification framework, Go-with-the-Flow (Singh et al. 2016), develops a prototype, to help motor function, focusing on psychological support aimed at individuals with RD and chronic pain. The study was facilitated by working physiotherapists and individuals with RD and chronic pain. A prototype was implemented based on the framework using wearable sensing technologies tracking sonified body movements and breathing patterns. Users were able to adjust the sonification conditions based on the movements. The results concluded a strong preference to sonification and sound feedback over no sound feedback at all, showing an increase in movement awareness, performance, confidence, and relaxation.

2.9.5 Visual Representation

The visual appearance of an avatar seemed to have raised some concerns throughout the study depending on the participant's mood. The use of a young, fit avatar was seen as unrealistic and demotivating. However, even the use of a slightly overweight and middle-aged still seemed to discourage others, preferring more abstract representation. A visual representation can be addressed as an adjustable feature by the user and explored further throughout the next stages of the project.

2.9.6 Related Work

Figure 2.2, from the study (Swann-Sternberg et al. 2012), evaluates a number of relevant studies' technology prototypes and technologies against the user needs, we have discussed above.

Target Users			Healthy							Acute Injury	Chronic Musculoskeletal Pain	
Technology and Study			Wii Fit	Kinect	Consolvo et al. , 2008	Ijsselsteijn et al., 2006	Buttussi, Chittaro and Nadalutti, 2006	Eyck et al., 2006	Ruttkay and Welbergen, 2008	O'Huiginn et al., 2009	Rosser et al., 2011	Schonauer et al., 2011
Users Needs	Before Exercise	Provides flexible goal setting		P	P						✓	P
		Facilitates self-assessment									✓	
		Facilitates adjusting session goals/setting expectations									✓	
		Provides encouragement and reassurance										
	During Exercise	Provides exercises tailored to users needs		P						✓*		✓*
		Demonstrates exercises	✓	✓			✓		✓			
		Provides option for non-ideal virtual coach							D			
		Show user's movements		✓								✓
		Provides avatar choices including standardised options	✓		P							
		Correct movements if desired		✓					✓			
		Provides feedback on exercise progression and performance		✓		✓	✓	✓	✓	✓		
		Provides encouragement and positive feedback	✓	✓		✓	✓	✓	✓	✓		
	After Exercise	Display tracked information	P	P	✓				D	✓*	✓	✓
		Allows user to select what information to track	P		P						P	
		Provides options for different goal and progress visualisation										
	General	Adjusts guidance and feedback to user's current state							D		✓	
		Facilitates use of cognitive behavioural therapy										
		Promotes engagement	✓	✓	✓			✓		✓		✓

Figure 2.2: Related works (Swann-Sternberg et al. 2012)

✓: requirements fully met P: requirements partially met

D: proposed development *: function performed/assessed by physiotherapist

The study highlights the use of infrastructure-based systems using the Kinect or Wii and a television. While these devices can allow for customisation and various modes of feedback, numerous other studies have received negative feedback on the complexity of setting up and maintaining the technology (Axelrod et al. 2009) as well as a preference to portability over having equipment in the living room (Axelrod et al. 2009, Balaam et al. 2011).

Wearable sensor technologies target the limitations above, being portable and possibly more accessible to set-up, maintain and configure still offering similar functionality measuring exercise movements without the need for interference from the user if implemented correctly.

There have been several technological advancements in the field of physical fitness and activity for the general population, as seen in the green labelled section of 2.2. While these applications have applied monitoring and feedback strategies to promote self-efficacy, assumptions are made regarding the users own belief in their capabilities.

Although there have been studies (Schnauer et al. 2011, Rosser et al. 2011) developed targeting the individuals with RD to address their physical activity, none of these designs addresses the different needs of these patients. Currently, serious games implemented focus on engaging and pacing (Rosser et al. 2011) the patient in the physical activity, but fail to meet the patients cognitive and emotional needs (Schnauer et al. 2011). In summary, various tools look at movement and tracking progress as well as exploring ways to engage users through games. These are all critical aspects to engage the user. However, RD users aim in regards to exercise is to be able to maintain and self-manage to improve their overall quality of life and prevent deterioration. Careful consideration is needed in this area, giving guidance and encouragement to users even when faced with setbacks or pain, providing reassurance and motivation highlighting the progress made.

2.10 Data

As new technologies are developed, data transfer becomes increasingly important, especially when considering how data derived from mHealth devices integrate into clinical workflows. While the focus is on developing an application that can support RD patients to be able to main regular exercise, rheumatologists' point of view still plays a huge role. For this section, we will be looking at data collection without going into details clinical data interpretation and visualisation.

The data collected from apps and wearable technologies should be analysed taking to account two aspects. As we have mentioned previously, progress and feedback visualisation based on data should be tailored to specific user needs; taking into account possible barriers and setbacks faced that can be collected through self-assessment. Meanwhile, the data health-care professionals needs can vary requiring more extensive assessment and detail the user is not aware of such that they can conduct data analysis and modelling. The following area raises questions, in regards to, if a user would like the data to be shared with rheumatologists or physicians? Would data collected for the clinical needs be shared and discussed with users?

While home rehabilitation and exercise has many benefits, no supervision and data are indicating the performance of individuals. It is then difficult for health-care professionals to review and identify progress to be able to recommend modifications to treatment. Furthermore, if no improvement is seen trying to determine the cause (e.g. non-adherence or ineffectiveness of exercises) and thus identify the best course of treatment could prove to be difficult (Sluijs et al. 1993). Physical therapists (PTs) consider the following to make informed decisions; frequency and duration of exercise sessions, pace, and range of movement of the exercise completed and if any symptoms were exhibited prior or post-exercise such as pain or dizziness. The use of a wearable sensor and mobile platform is a way of achieving collecting the data. A study on a Technology Probe of Wearable In-home Computer-assisted Physical Therapy (Huang et al. 2014) carries out interviews with physical therapists to get an understanding of data metrics needed. The sections to follow will go into details of the data to be collected on exercise compliance and training as well as exercise performance and symptom levels.

2.10.1 Exercise Compliance and Timing

Related works have collected data on exercise repetition and session duration, such as counting daily hand exercise repetitions for stroke patients (Balaam et al. 2011). PTs pointed out other metrics to gathered could be affecting exercise performance and effectiveness but not visible to the user such as time of day exercise is performed and the order in which the exercises are met.

2.10.2 Exercise Performance and Symptom Levels

Exercise movements and extensions metric such as velocity, range of motion, frequency (repetitions per second) have been identified and used to measure performance by related work in technologies for individuals with limited mobility as well as the general population (e.g. Chen et al. 2012, Taylor et al. 2010). As we have mentioned before and is further supported by PTs in this study, symptoms and psychological factors are as crucial to performance and recommendation of exercise to be performed in the session. In some case, symptom levels before and after exercise can be indicative of the effectiveness. For example, dizziness can be used as a measure of stimuli, if an increase is seen after exercise that shows neural strengthening.

Symptom levels should be collected and used in applications to support management and progression. This can be achieved by creating the means for a user to record their symptom levels pre and post exercise and analysed to show progress and trends for each session and across a period. Enabling a user to see the improvement and trends over time will allow them to be more aware, take caution and better manage while carrying out physical activity.

2.11 Challenges of technological application in health

Although we have seen literature investigating and exploring the technical implementation of home rehabilitation and self-management for RD patients, the study above shows the different perspective a human mediator can have. There is a need for more outcomes and a clear direction on how to effectively adapt therapy conducted with human presence to a technological platform. We are still unsure if applications such as these can be solely independent of human intervention, as there have been studies suggesting high non-compliance and drop-off as a result of less face to face therapy (Rosser et al. 2011).

Throughout the literature, we have developed on the premise that technology is an emerging platform that can be utilised to interact with the health-care system relieving economic and new limitations and inequalities. Careful consideration should be taken when designing and testing usability making sure it is adequate for all age-groups, varying skills as well as the infrastructure of different locations such as network connectivity.

Furthermore, as technology is dependent on the data gathered, concerns have been raised regarding data privacy, monitoring, and storage especially in the field of health. With the increase in the integration of health and technology, more guidance, support, policy, and investigation are needed to ensure privacy and control access (Landau et al. 2010).

We can see there is a lot of potential incorporating technology and health to benefit patients and health-care professionals. Nonetheless, we need to stay focused ensuring that the systems solve the user needs, without getting lost in the excitement of new emerging technologies.

2.12 Analysis of existing studies' approach and design

Throughout the literature, we have discussed several technological related works in self-management, pain management, home rehabilitation and how these are applied to the specific needs of users with chronic musculoskeletal conditions. In this section, we will review the approach and design taken by similar works. This will identify areas of focus and limitations studies have faced such that we can use their findings in the requirements and design aspects of the project.

2.12.1 Home rehabilitation studies

A study, Physio@Home (Tang et al. 2014), developed a prototype that guides patients through exercise movements using visual representation overlaid on top of a mirror-view of the patient on a wall-mounted display. The study evaluates important design aspects and results that could aid in our design and approach.

The study is building on the base of interviews with physiotherapists on the course of treatment, how they guide and teach patients through exercises to derive design requirements. The study highlights several aspects that further support user needs, identified in Section 2.9; feedback and feed-forward guidance is to be used in conjunction to help guide direction and instruction to the user. The use of mirrors was mentioned as a way to teach exercises to help understand how to do it correctly giving the sense of self-assessment and contextualisation of the movement. There are other platforms and modes discussed throughout this literature utilising wearable sensors and multimodal real-time feedback to explore similar measures.

The interview further identified the need for simplicity; the way in which direction is given is vital when addressing users. Exercise instructions should be easy and quick to interpret, without cluttering the screen. The pace of a user is another factor in design as each user would have their own pace completing an exercise, that can vary day to day depending on the state of pain during the exercise.

Further design elements and improvements were identified in the second phase of the study to gain information richness while maintaining simplicity; arrows were used to guide and trace conducted movements. Euclidean distance between joints and angles of limbs on anatomical planes was used to identify user's movements. By recording and comparing a users exercise movements to the expected exercise and apply scaling and transformations to account for different body sizes and position, they were able to measure a user's deviation from an exercise. Finally, illustrating depth was an ongoing issue throughout the iterations that was explored using 2D and 3D elements in the design. The illustration of depth to demonstrate movement was one of the main challenges in this study, which will be further explored throughout the design phase.

There have been some studies for post-operation and post-stroke home rehabilitation. While it is not aimed at RD patients, we will be looking at the design and considerations. Ayoade & Baillie's (2014), study aimed at home rehabilitation for individuals after having knee replacement surgery, build a system and evaluates its usability and feasibility.

The system is designed with a remote control, laptop, and wearable sensors. Several design aspects could be helpful in this study. Avatars were used displaying the ideal movement alongside the patient's movement such that they can be compared. As part of the usability study with patients, the ideal movements were modified and displayed as a smaller portion of the screen as to help guide the patient but not force the patient to match it. The movements were highlighted using a fan-like signal in the direction of movement along with a gradient if colours from red to green, where green represents the idea movement have been achieved, light green indicates that the patient is almost there, while yellow and red show a lower range. Signalling certain colours was seen to motivate a user to progress and get a green light. Calibrating the right levels can be seen as a challenge as it is to be modified per exercise based on an individual's own goals and progress over time. This approach could be further explored as a feedback strategy in prototyping and design phases. A counter displays the target number of repetitions to be achieved for each exercise, seen to encourage and keep the patients moving as the counter went down. Finally, progress was highlighted as an essential design recommendation, while in the case study the measure was based on a range of motion, applying the following to RD patients progress has to be approached differently (Ayoade & Baillie 2014).

While these technologies are aimed at patients with impaired mobility, they are not focused on patients with RD taking into consideration the unpredictability and their needs. With that, there has to be balance taking into account both the patients and the health professionals perspective from their experience and knowledge of the condition.

2.12.2 Technology studies

myHealthAssistant (Seeger et al. 2011) uses three accelerometers placed on the hand, arm, and leg to identify exercise. A Bayesian classifier was trained on the mean and variance of 13 exercises on each accelerometer axis, reporting 92% accuracy. Repetition counting was evaluated by looking at one of the accelerometer axes, counting the peaks with consideration of an exercise period estimation.

Chang et al. (2007), with a similar approach, uses two accelerometers placed on the hand and waist. Exercise recognition was addressed using a Hidden Markov Model (HMM) and a Bayes Classifier to train the model. The study tested a variation of training the model using subject-specific training and subject-independent training reporting 95% and 85% accuracy, respectively. Repetition counting was evaluated using an HMM and matched filter, a linear filter to maximise the signal to noise ratio reducing any background noise.

Finally, we will be going into further detail on a system RecoFit (Morris et al. 2014) focused on automatically recognising and tracking repetitive movements, providing real-time and post-exercise feedback. The study evaluates the system against 114 participants achieving precision and recall greater than 95% in identifying exercise periods, recognition of 99%, 98%, and 96% on circuits of 4, 7, and 13 exercises respectively, and counting that is accurate to 1 repetition 93% of the time. We will be evaluating the challenges associated with exercise analysis, motivating a large-scale training data set exhibiting real-world behavioural variability as well as how segmentation of continuous is addressed without user intervention, not studied by the related works mentioned above.

The dominant elements of the system can be categorised by gesture spotting and auto-correlation and periodicity. Gesture spotting is the isolation and identification of precise movements. HMMs are frequently used in combination with filter methods for noise reduction. The auto-correlation function was the key to identifying similar movements such that the system can achieve repetition count. The idea was taken from similar periodic concepts such as speech recognition analysing voice patterns, distinguishing speech from non-speech. Similar limitations are also applied in this area, identifying exercise from non-exercise connective movements between exercises such as rest, stretch or drinking water. Periodicity comes into play, as exercises are more repetitive than non-exercises whereby identification can be made.

An area addressed, in this study, that is heightened when applied to RD patients is the variability of posture and form of different individuals and how that will impact the recognition of exercises. The study stated the possibility of addressing this issue with large- scale training data collection. Although, this study is aimed at the general population with a large variety of movements and exercises such as press-ups, squats, and row. Exercises for RD patients will differ, as such exploration of variation will be addressed when prototyping and testing with specific exercise for RD patients and possibly varying the number of accelerometers used as well as placement of the accelerometers. Finally, the study addresses segmentation whereby recognising the different exercises and when the user is not exercising in a given period inferring exercise periods based on the accelerometer data. In summary, this was achieved by calculating the auto-correlation of each signal, normalise the value and calculate the prominent and weak peaks, the maximum correlation value and the height of the first correlation peak after none-peak. Along with auto-correlation calculating, the root mean square, mean, standard deviation, variance, and power bands (i.e. the magnitude of the power spectrum in 10 bands specified linearly from 0.1-25 Hz.) were also computed.

Expanding on the previous mention of the use of multiple sensors and on-body device localisation. Vahdatpour et al.'s (2011) study explores ways to identify the placement of sensors on the human body to ensure precise and accurate measurements in health monitoring technologies. The basic concept behind the exploration is to analyse data from accelerometer sensors, for walking. However, this can create very variable results as it will be dependent on users' performance. The approach implemented uses support vector machine (SVM) to analyse patterns and identify the placement of the sensor on the body.

Results were able to classify the localisation of the chin area receiving high impact while walking; however, the head leads to the least accurate data as it directly imitates upper body movements. Neglecting the importance of placement of the accelerometer or disregarding the instructions given for a particular exercise could lead to misclassification or unidentified changes.

A study, TademTrack (Smolyak et al. 2018), explored the idea of using smart speakers and voice interaction through Alexa in combination with a mobile app to provide visual cues if necessary. However, the system is targeted to healthy individuals, with no recognition capabilities as such, not providing the reassurance needed for individuals with chronic pain. We will be evaluating gaps the study is trying to address to apply the considerations to the project requirements.

To provide exercise guidance, an auditory trainer was implemented to guide the user through the exercise session, using a timer and audio signal promoting a change of exercise or to rest.

Figure 2.3, shows an example of possible voice interaction. TademTrack suggests using the visual representation through the app if the voice interaction is not convenient (i.e. too much noise, other people around) to guide a user through an exercise; however; as we have discussed previously on supportive functions the combination and coordination between different modes can be efficient to encourage the user. The trainer can also facilitate functionality to set the days and the corresponding time of day be reminded to exercise by voice interaction through the Alex skill. However, this can be a limitation as a user might not be present around the Alexa device requiring further support from the mobile app. The aspect of facilitating daily routine reminders and notification has been seen to motivate a user to complete a workout.

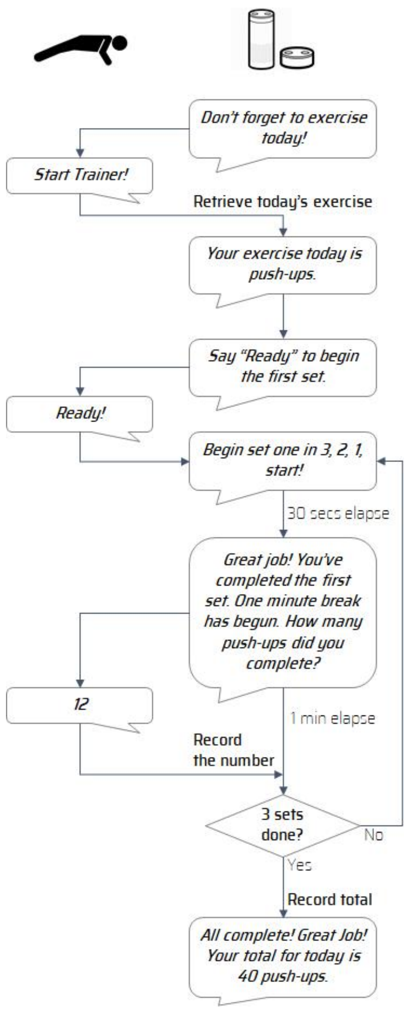

Figure 2.3: Example daily interaction with the Tandem Alexa skill.

The incorporating with the Alexa skills also support data capture, asking the user about the number of sets/repetitions completed as a way to keep the user engaged and aware of the exercise they are achieving while reducing the time between sets, it would manually take to record. Using wearable technologies to recognise and count movements removes the need for a users interference. However, a good point is raised concerning the engagement of a user throughout the exercise if there is no need for direct interaction with the system, further asserting the need for providing real-time feedback and progress updates. Further exploration will be needed in the design and prototyping phase to evaluate the best way to keep users engaged.

TademTrack displays progress over time for different periods (i.e. daily, weekly, monthly), giving details of the exercise and frequency of the sessions. Maintained frequency is shown on a calendar connecting the series of days forming chains. The use of Alexa enables other features whereby a user can ask on the longest streak of continuous workout days or how long a user exercised for the day. While visual representation of progress is beneficial, other modes of interactive post-exercise feedback need to be further explored to keep the user captivated.

2.13 Summary

This chapter gives an introduction to the area and audience for this project. Rheumatology is the study of musculoskeletal conditions to diagnose, support and treat conditions. It varies over 200 different conditions limiting mobility. Its treatment is multi-disciplinary, requiring balance and attention to pharmacological and non-pharmacological treatments. However, only 50% of RD patients adhere to treatment. Therefore, focus needs to be placed on Self Management and Pain Management were patients are an active part in their treatment. Exercise has been called-out as the treatment of choice as studies have identified improvement in health quality of life as well as releasing pain, and improving movement. Afterwards, exploring opportunities in technology and similar works on exercise, self-management and 'life-log' to address the findings. k

Chapter 3

Requirements Analysis and Specification

In the next chapter, literature and similar works will be explored further and translated into requirements of the system employing further literature, technical documentation, and similar works. This involved three cyclic stages: requirements elicitation, analysis, and specification. The focus in the chapter will be on setting out what the system should do, its implementation and define constraints. This involves an understanding of the application, identifying the sources of requirements, analysing the stakeholders, selecting the techniques, approaches, and tools through which identifying key requirements and constraints.

3.1 Understanding the application domain

3.1.1 Application domain

The application domain is covered in the Literature Survey chapter above. The main findings that define and drive the domain are:

- **Education**: fundamental for rheumatology patients to be able to self-manage pain and progression. Such that patients are active participants in their treatment.
- **Exercise**: releases pain, improves function, movement, and physical fitness as well as health quality of life.
- **Compliance**: needs to be addressed as about 50% of RD patients adhere to treatment.
- **Social care systems**: effect on individuals dealing with the unpredictability, and chronicity of the condition.
- **Economic care systems**: large costs on health care systems as RD is ubiquitous and affects over eight million people of all ages and the numbers are rising each year (*About rheumatic disease | Nuffield Foundation* 2019).

3.1.2 A user story for the system

Jack is a 29-year-old male who works as a customer facing consultant in London, UK. He has been suffering from back pain and stiffness, waking up regularly during the night because of the pain. It gets worse in the morning and at night. He tried resting and staying home to relieve the pain. However, he realised that the pain gets better when he has many client meetings and has been walking around and exercising regularly.

He decided to go to a GP which then referred him to a Rheumatologist, where he was diagnosed with AS. A course of treatment was agreed upon, including physiotherapy once bi-weekly and home exercises. However, Jack's fear of injury from unmonitored home exercises and his frustration from the treatment complex regime caused his treatment adherence to decrease.

The PT suggests a new app, myAS. Jack and the PT do the initial setup of the app. Firstly, they set up the user profile; including self-assessment of pain, symptoms, mood, and sleep. Then, based on Jack's specific needs and self-assessment, they tailor workouts targeting particular areas from a list of exercises from the NASS Back to Action programme.

The app can give real-time feedback on how to complete the exercises and as such relieve fear of injury. As well as addressing adherence by enabling a mechanism to hold Jack accountable through goal setting and notifications.

This user-story highlights the problem and the use-case leading the app recommendation. After which, defines the initial assumptions of profile and exercise set-up carried out by the RD patient and the appropriate PT or health-care professional. The data collected from the app on exercise, goals, and self-assessment could be shared with the health-care professional, and the mechanism to do so will be discussed as future work.

3.2 Identifying stakeholders and recognising multiple viewpoints

Several stakeholders help define and shape the project at an early stage. Stakeholders can have varying levels of influence and/or interest in its outcome, as they would not be affected by it in the same way.

This raises questions to be addressed about the stakeholders: what financial or emotional interest do they have in the outcome? Is it positive or negative? Motivations for involvement and interest in the project? Opinions on the objectives and direction of the project? If there are blockers and critics, how will these be addressed? Is there bias and influenced options across the stakeholders?

Figure 3.1 analyses the stakeholders, to prioritise and scope the project and identify blockers, guiding the requirement elicitation.

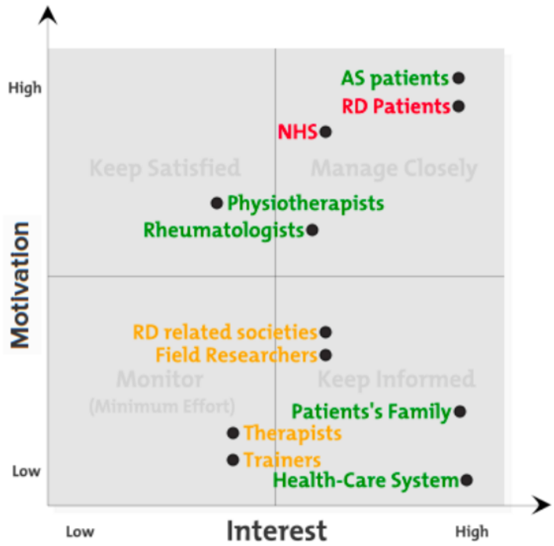

Figure 3.1: Stakeholder Map for prioritisation and scoping

Blockers and limitations

Neutral

Supporters and advocates

As the project is targeted to rheumatology patients, there is an emotional interest and motivation to their involvement as well, as expressed in Figure 3.1. Their involvement would have a high influence on the requirements gathering and testing. Ideally, this would involve RD patients themselves. However, it would require HTA and NHS REC approval. The approval process is lengthy, presenting a limitation to the access to stakeholders within the project time-frame, as such presented as a blocker.

Analysing the stakeholders presented a wide variety of requirements and objectives. Due to the time constraint of the project, the focus is placed on facilitating the patients with a mechanism to manage and carry out exercises. Initially targeting all rheumatic diseases, this presented a blocker due to the time constraint as RD varies over 200 conditions. Rather, the project is scoped to focus on exercise for AS patients, as exercise is fundamental to their treatment. Health-care professionals point of view will be taken into account with a focus on self-management and exercise. Future work, to be discussed in Section 7.2.3, could incorporate other functions desired by stakeholders such as facilitating communication and data sharing between the user - RD patient - and their responsible health-care professional.

3.3 Sources of requirements

Eliciting and understanding stakeholders requirements, discussed in Section 3.2 above, identified some blockers to requirements discovery; direct interaction with some stakeholders would not be possible due to time constraints. As such, initial requirements discovery will be based on literature and technology survey findings and similar works.

Throughout the process of requirements gathering, design and implementation will involve users of different age groups and pain experiences - not necessarily RD diseases. Input from health care professionals and subject matter experts will mainly be based on literature.

The following sections discuss the key functional requirements that are to be prioritised to meet the system objectives and user needs.

3.3.1 Literature and technology survey

Chapter 2 exposes state of the art identifying the application domain. Findings from the literature and technology survey identify RD patients' needs and therefore acts as a primary source of requirements. Table 3.1 reflects on the main findings from Chapter 2, translating it to requirements:

Table 3.1: Requirement discovery from literature and technology survey findings

Domain	Requirements	Literature Finding
(LR 1) Self-Management	Must facilitate mechanisms to: • help user comply with treatment through ways of accountability and notifications. • express pain level and mood, to be able to cope appropriately. • identify and review progress, to be reviewed and used in times of emotional stress.	Corbin & Strauss (1985)'s self-management framework set of tasks translates well into the needs of a RD patient: • *medical and behavioural management*; maintain medication and complying with all aspects of treatment and that includes exercise especially for AS patients. • *role management*; modifying tasks where appropriate to ensure no strain or fatigue. • *emotional management*; important at every step as emotions such as fear, anger, frustration, and depression often arise due to the unpredictability and chronicity of the condition.

Continued on next page

Table 3.1 – continued from previous page

<table>
<tr><th>Domain</th><th>Requirements</th><th>Literature Finding</th></tr>
<tr><td>(LR 2) Education</td><td>Must facilitate mechanisms to:
regularly reminding the user of the importance of exercise.
keep the user informed on their progress.
clarify benefits of exercise/s.
tips on completing exercises.</td><td>Focus is on equipping and educating individuals with the information and skills to manage their own health (Cooper et al. 2003, Goldenberg et al. 2011):
involves informing the patients about the disease and the treatment process, to build confidence and relieve fear.
emphasising the importance of self-management strategies, specifically exercise in this case.</td></tr>
<tr><td>(LR 3) Exercise</td><td>Must facilitate mechanisms to:
select from a range of home exercises.
show user's exercise movements.
provide corrective movements for reassurance.
assist user through exercise.</td><td>Exercise is a non-pharmacological treatment Keat (2010):
that produces endorphins to improve mental health and well-being as well as morphine-like-effects.
if regular, patients will be better capable of managing chronic pain as well as improve function and movement.</td></tr>
<tr><td colspan="3" align="right">Continued on next page</td></tr>
</table>

Table 3.1 – continued from previous page

<table>
<tr><th>Domain</th><th>Requirements</th><th>Literature Finding</th></tr>
<tr><td>(LR 4) Adherence and Compliance</td><td>Must facilitate mechanisms to:
• set flexible exercise schedule.
• set goals and milestones.
• set reminders.
• take notes.
• provide motivational messaging and encouragement throughout exercises.</td><td>Self-management and self-efficiency are key factors to adherence.
• Incorporating education and self-efficacy such that the patient is aware and believes that the treatment will yield progress encouraging long-term adherence and outcomes (Dures & Hewlett 2012).
• Motivational strategies to encourage compliance.
• McLean et al. (2010) highlighted that there were only positive results with regards to compliance when there was a feedback loop such that patients are held accountable.</td></tr>
<tr><td>(OR 1) Social Support</td><td colspan="2">• In Section 2.4.2, 52% of participants had goals regarding social interaction with others, contributing to and carrying out social activities. The incorporation of adherence through goal setting with a social aspect to the technological system in RD such as exercising together, sharing milestones and achievements to feed motivation and encouragement. (Berdal et al. 2018).
• Incorporating a social aspect to the technological system in RD by exercising together, sharing milestones and achievements can provide greater impact to adherence and motivation as it acts as persuasive design principles, as discussed in Section 2.8.
• However, it is defined as out-of-scope due to the time constraint of the project. To be further discussed in future work (refer to Section 7.2.3).</td></tr>
</table>

3.3.2 Similar works

As part of requirement discovery, analysing similar works and extending the findings from the basis of the literature of the specific needs for RD patients as they vary over the general population requiring a need from more personalisation and tailoring a user's specific condition and capabilities. Table 3.2 reflects on the common themes emerged from similar works that have lead to specification of the following key functional requirements.

Table 3.2: Requirements from similar works

Common Theme	Requirements	Link to RD patients' needs
(SR 1) Personalisation	• Adjusting exercise based on physical needs and capabilities. • Goals and milestones setting is flexible, not just specifically exercising. • Streaks for goals and milestones; set a specific period in which a goal has to be complete regularly. • Set daily and long-term expectations.	This is supported by similar studies and implementation by Swann-Sternberg et al. (2012) and Rosser et al. (2011):The flexibility of types of goals to be set provides a mechanism for a user to self manage and thus be able to track. The flexibility of the period accounts for the unpredictability of the condition and still provides a mechanism for holding the user accountable and staying motivated. Expectations are set, but not necessarily have to adhere to all the time. It is an extension of the goals to maintain regularity and stay motivated.

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Table 3.2 – continued from previous page

Common Theme	Requirements	Link to RD patients' needs
(SR 2) Tracking and monitoring	Track: • frequent exercises • goals and milestones • moods • sleep • pain level and symptoms	• As the physical and physiological state of a user can vary at certain periods, several factors need to be taken into consideration when tracking. • Appropriately educate and guide a user on how to best manage their current state, based on tracking information (Fritz et al. 2014). • Understand and become aware of fluctuations of activity. • Taking into account possible barriers and setbacks faced collected through self-assessment (Rosser et al. 2011).

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Table 3.2 – continued from previous page

Common Theme	Requirements	Link to RD patients' needs
(SR 3) Feedback	• Multi-modal and real-time feedback strategies; audio and visual cues, motion detection (Seeger et al. 2011). • Strike balance - in giving feedback - between warning and reassurance (Swann-Sternberg et al. 2012). • Demonstrate activity over time, especially with regards to the user set goals and milestones (Berdal et al. 2018). • Avatar demonstrating the ideal movements, identifying areas of focus to the specific exercise (Tang et al. 2014).	• Real-time feedback builds body awareness and allows the users to be proactive during the exercise sessions. • Balance between warning and reassurance, to build confidence and relieve fear while building up progress and movement for the user. • As the physical and physiological state of a user can vary at certain periods. Frequency and duration of exercise are not always good indicators for RD patient.
(OR 2) Data	• Health-care professional needs can vary, requiring more extensive assessment and research. Data integration into clinical work-flows and evaluation is set to be *out-of-scope*. • The project will cover the data collection for progress and feedback visualisation presented directly to the users; for exercise recognition and tracking. As stated above in tracking and monitoring. • Sharing this data with the appropriate health-care professionals could be possible. However, it set to be *out-of-scope* as it raises concerns around privacy and, later discussed as future work in Section 7.2.3.	

3.3.3 Persuasive design principles

Section 2.8 identifies a persuasive system possibly resulting in reinforcement, change or shaping of attitudes and/or behaviours. Persuasive design principles identified by Oinas-

Kukkonen & Harjumaa (2008) are to be applied to the system to support further the requirements defined above, to motivate and main regular exercises as identified as one of the main challenges to be addressed throughout this project.

The design principles can be categorised based on varying levels of support: primary task, dialogue and social. The primary task involves design principles to support a user to carry out the primary tasks. Dialogue support helps a user to move towards their goal or target behaviour. Finally, social support describes how the system can be designed to motivate users by leveraging social influence. This involves principles on social learning, cooperation, comparison, competition, and recognition. While this can be seen to provide further motivation and persuasion it has been set of scope for the duration of this project, further discussed in Section 7.2.3.

Table 3.3: Requirements based on persuasive design principles (Oinas-Kukkonen & Harjumaa 2008)

Principle	Requirements	Possible implementation
Primary Task Support		
Reduction: Reduces complex behaviour into simple tasks helps the user perform target behaviour and it may increase the benefit/cost ratio of the behaviour.	(PR 1) System should reduce the effort for users to create goals. Also, similarly reduce the effort needed to start an exercise.	Providing a quick way to complete the self-assessment based on the previous log.
Tunnelling: Guide users through a process or experience provided opportunities to persuade along.	(PR 2) System should guide the users in the attitude change process of delivering a simple step by step means of completing the self-assessment logs, bringing the user closer to carrying out exercises.	After a self-assessment, the system displays the exercises and benefits of exercising to release pain.

Continued on next page

Table 3.3 – continued from previous page

Principle	Requirements	Possible implementation
Tailoring: Information is more persuasive if tailored to individuals needs, interests, personality or usage context.	(PR 3) The system should provide tailored information based on the profile and workouts set up by the patient and their health-care professional. Similar requirements have been discussed in table3.2 on personalisation, the addition of these principles help guide the design of these requirements.	Based on the preference set up, the system will display different content and especially when in experiencing more pain.
Self-monitoring: track one's performance or status supports in achieving goals.	(PR 4) System should provide the means for users to track the exercises and logs completed. Additionally, using motion sensors, the user should be able to track their movement and function, for the exercises completed. Requirements on monitoring and tracking have been defined in table 3.2 complementing the other requirements identified.	The system will present the real-time feedback on exercises being completed. Self-assessment history will be displayed and presented, to form a mental of exercising behaviour relative to pain levels.
Dialogue Support		

Continued on next page

Table 3.3 – continued from previous page

Principle	Requirements	Possible implementation
Praise: Offering praise and reinforcement of target behaviours can make a user more open to persuasion.	(PR 5) The system provides positive reinforcement immediately after the behaviour. Additionally, use praise via words, images, or sounds to give positive feedback.	Praising through notifications on goal completion. Positive reinforcement and praise throughout the exercise using audio cues based on sensor detection to guide and motivate users to keep going. Requirements on the type of multi-model feedback are defined in 3.2. Implementing these principles along with different feedback enable more persuasive strategies.
Rewards: System that reward target behaviour may have great persuasive powers.	(PR 6) Provide virtual rewards for target behaviour achieved, exercising and goals achieved. More caution will have to be taken here as it can be difficult to quantify exercises for AS patients.	Virtual rewards are given when a certain number of logs have been completed. The user will set milestones on long term goals to be achieved and rewarded against over time.
Reminders: If a system reminds the user of their target behaviour, the users will be more likely to achieve their goals.	(PR 7) System should remind users of their target behaviours; self-assessment, goal setting and exercising - during the use of the system.	
However, caution has to be placed when implementing reminders, as discussed in section 2.8 Fogg (2009), as a trigger can be annoying as they seek to motivate users to do something they did not intend to. For a successful trigger, a user should notice it, associated with the target behaviour and the trigger should occur when the user is both motivated and able to perform the behaviour. Leading nicely into the next principle suggestion.		

Continued on next page

Table 3.3 – continued from previous page

Principle	Requirements	Possible implementation
Suggestion: System offering suggestions at opportune moments will have greater power of persuasion.	(PR 8) System should suggest users certain behaviours during the system use process.	Addressing as users ability; suggesting exercising in the morning rather than the evening as it is the opportune moment for AS patients. Similarly, giving tips and benefits if a user has logged fatigue and little sleep.

3.4 Non-functional Requirements

Non-functional requirements are not directly concerned with the specific services delivered by the system to its users. However, these do specify or constraint characteristics of the system as a whole (Sommerville 2016).

Product requirements of efficiency, reliability, security, and dependability are not of particular concern as this project is developing a prototype to explore mechanisms to facilitate exercise adherence for rheumatology patients. However, these points are mentioned throughout the literature on data in this field, refer to Section 2.10, as it could raise privacy and security concerns.

Meanwhile, usability requirements are to be addressed throughout the design of the system. To determine "usability", user studies will be conducted watching the users interact with the system and answering the following questions (Constantine 1993):

- Is the system usable without continual help or instruction
- Do the rules of interaction help a knowledgeable user to work efficiently?
- Do interaction mechanisms become more flexible as users become more knowledgeable?
- Is the user aware of the state of the system? Does the user know where she is at all times?
- Is the interface structured logically and consistently?
- Are interaction mechanisms, icons, and procedures consistent across the interface?
- Is the interaction simple?

Similarly, with organisational requirements, operational policies and procedures would need to be set out when implemented such as system in the "real world" rather than a prototype due to the sensitivity of health information. The time constraint of the project acts as organisational requirements and as such resulting in the scoping and prioritisation of certain features, to be further discussed in Section 3.6.

External requirements have already presented a blocker as expressed in Section 3.2. There is a regulatory requirement to get ethical approval from the NHS to involve rheumatology patients for user studies and experiments. Addressing this challenge will be discussed in Section 3.6. Additionally, ethical requirements that ensure that the system will be acceptable to its users and the general public is also presented as a challenge as there are no direct access rheumatology patients. However, literature and previous works have studied similar systems identifying data secrecy and privacy (Section 2.10, identified and scoped out of this project, refer to Section 3.6 for more detail on the approach taken.

3.5 Selecting the techniques, approaches, and tools

The sections above literature and technology survey and similar works define key user requirements. Approaches and techniques to be used will enable further definition and application of system requirements. This section discusses the techniques and approaches used and why they were chosen.

3.5.1 Exercise selection

As previously mentioned, specific exercises are to be displayed and available for the user to perform. As exercise is heavily involved in the treatment of ankylosing spondylitis, there are specific programmes that are tailored and created by subject matter experts and health care professionals. The National Ankylosing Spondylitis Society (NASS) Back to Action exercise programme is to be used for this project. As it is created by physiotherapists and exercise therapists working with NASS and uses up to date know-how from the fields of physiotherapy and sports medicine (*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019). The programme includes detailed exercise descriptions with steps, notes and tips (refer to Appendix 8.1 - Figure 8.5 - for more detail). These can be translated and used for the content implementation of the system. This programme stands out as it also includes tips and information for exercise personnel that can be mimicked by the system to support and motivate the user (refer to Appendix 8.1 - Figure 8.6 - for more detail).

3.5.2 Mobile App

Approaching the delivery of the project, we have seen opportunities in technology for health applications. The use of mobile with assisted technologies addresses the compliance and adherence domain requirements, due to its portability and tailor-ability. Implementing the system using a mobile app, over other delivery methods such as a website, supports functions for notifications - push messages - and reminders. With that, an app enables more personalisation with profile setting and the ability to retain data for progress review and self-assessment. Combining these features encourages regularity of exercise performance and motivation to do so. Mobile app design and considerations will be further expanded upon in Section 4.2:Mobile Design Best Practices.

A functional prototype of the system will be implemented in Android, as I have had more experience with Java and Android development.

3.5.3 Inertial measurement unit sensors

An area raised in literature and similar works is the need for feedback to build confidence, relieve fear and capture the user to remain proactive throughout the session. We saw this in literature and similar works through multi-model and real-time feedback. Motion recognition is seen to capture and support the user. This can be implemented by various motion sensing input devices such as Microsoft Kinect, mobile-integrated sensors and inertial measurement unit (IMU) sensors.

IMU wireless sensors are the method of choice. Firstly, the portability of the sensors is an advantage over technologies such as Microsoft Kinect, as it would have to be mounted on a wall or display and needs empty surrounding space such that the user can be recognised. Additionally, IMU wireless sensors are easily wearable over mobile-integrated sensors, supporting the use of multiple sensors for more specific exercise recognition. However, there could be an incurred cost of buying the sensors, requiring both mobile and sensors. Again, there is a chance some users would not have a phone with integrated sensors. The project acts under certain assumptions that the user has been diagnosed, has a rheumatologist and/or physiotherapist to start this journey with to personalise the application, a mobile phone and the sensors needed.

There are various makes and types of IMU sensors. For this implementation, MetaMotionR (MMR) from Mbientlab will be used. It was selected for multiple reasons: ultra lightweight at just 0.2oz/5.7g, wireless and rechargeable with long battery life, and low power consumption sleep mode adequate and easy to use by varying age groups. In terms of functionality, it includes a triple-axis gyroscope and accelerometer needed to facilitate motion capture and implement exercise recognition. Other motion and environment sensor data are available, but not used for the scope of this project.

MMR sensors support real-time data streaming via Bluetooth as well as recording 2 hours-48 hours of data on internal memory. Most importantly it also supports multiple sensors simultaneously with a synchronised time-stamp enabling better classification and recognition of exercise for different body part motion movements.

User development tools are also available. A MetaBase app is available from MbientLab with functions to configure the sensors and log or stream data. This app is to be used for initial exploration and prototyping as well as throughout development and design for further prototyping and debugging. Having the MetaBase app also helps address the time constraint of the project; enabling the iterative development of the user experience and interface independent to some of the recognition functions, that can be prototype-ed and tested separately.

Finally, there are open-source APIs that allow app development with features such as noise filtering and sensor fusion especially calibration and Kalman filter fusion to provide distortion-free and refined orientation vectors. There are technical specifications that would be imposed using the MMR sensors, such as calibrating and connecting the sensors to the device over Bluetooth, informing the user when the battery is running low.

3.6 Scope management and areas of particular challenge

So much can be done in this area, the main challenge here is to deliver a functional prototype, that can facilitate a mechanism to motivate and encourage regular exercise, within the time-frame of the project. The key is to scope and prioritise the requirements needed.

Scoping and areas of conflict have been discussed throughout the body of the sections 3.1 - 3.5 above. This section will summarise the challenges and conflicts that may arise; as a single point of reference throughout the course of the project.

Conflicting requirements can come from various stakeholders. RD patients are the direct users of the system. They would want to simple quick process such that they can do it regularly without taking too much time. Meanwhile, a health care professional would want as much data and self-assessment if the data is to be shared with them (considered as future work). This was addressed in 2 parts; the scope of the project covers facilitating exercise adherence through self-management. As such the user was to be aware of patterns in their state, i.e. what time of day is best to exercise, the correlation between sleep and mood and so on. This data will be captured. Other data that is required and discussed in Section 2.10, will be addressed as an extension of the project.

Another main challenge is the time constraint of the project. As discussed previously, NHS approval is needed to involve NHS RD patients, but this will not be possible. As such requirements and design will be based on literature and similar works. Afterwards testing and validation will be carried out against users of different age and painful experiences. Further scoping is required as the NASS Back to Action programme varies over 30 exercises. As such, the system will be implemented along with the recognition mechanism for 2 or 3 exercises to prototype the intended functionality and how the app can help encourage and motivate.

Exercise classification could be a pose a challenge if the exercises are similar in movement as expressed in Chang et al. (2007). Due to the scoping defined above focusing on 2 or 3 exercises, this might not be a challenge but would be when implementing the whole system, not the prototype.

Providing feedback to help the user while conducting exercises is one of the essential requirements as discussed in tables 3.1 and 3.2. Particular attention needs to be stricken between reassurance and warning of feedback, as repetitive corrective feedback can lead to hesitation and fear of injury. This can be a challenge as different people would respond differently to feedback. This could be addressed by suggesting another exercise rather than repetitive correction.

Additionally, AS patients' would have different function and movement. Some people might not have the same range and extension of specific muscles. When implementing exercise recognition, there is a chance that some cases might not be accounted for.

3.7 Summary

This chapter looks at the requirements needed to deliver the objectives of the system. The key requirements highlighted in this chapter are enabling a mechanism for exercise with multi-modal feedback strategies using visual and audio queues as well as the use of wearable sensors for exercise recognition. To encourage and maintain adherence to the exercise treatment, goal setting and progress review is to be implemented. With that user education on their current state is needed such that they are accordingly able to manage, facilitated by providing tips and notes based on self-assessment of pain, mood and sleep carried out through the system.

Chapter 4

Design

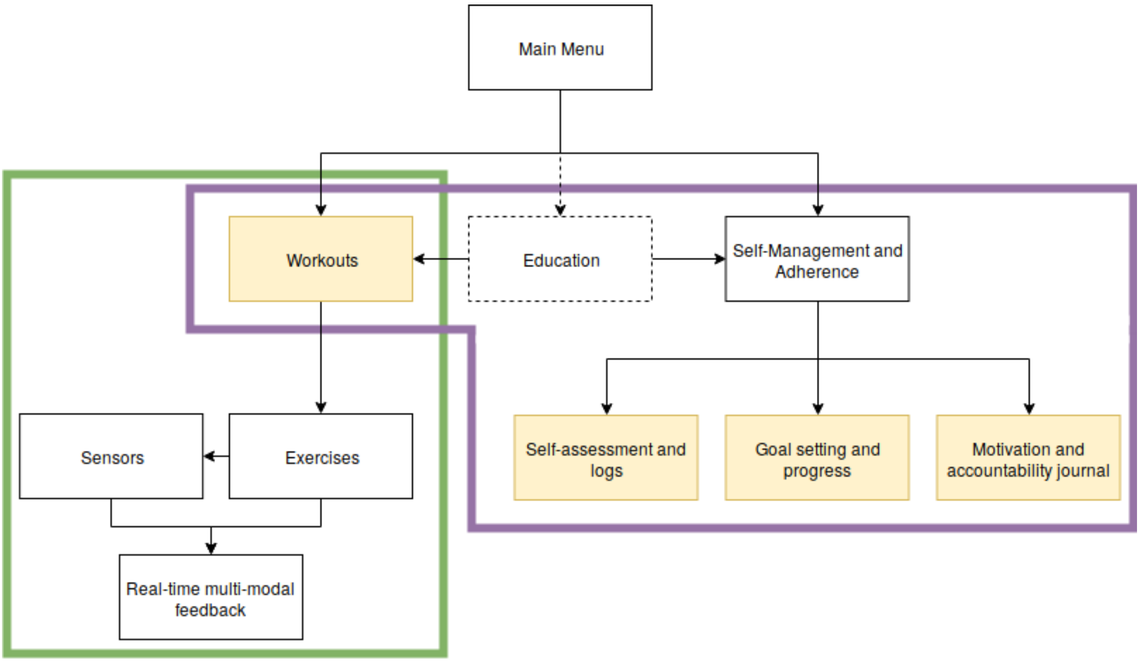
The previous chapters have exposed the state of the art, defining the problem and extracting root causes to be addressed. The findings and objectives are then applied to set out the requirements and what the system should do. This section transfers and enforces the requirements, defined in Section 3, to design a potential solution. The focus of this chapter is on product design addressing the interaction between the system components and the users; as we the project aims to specifically explore ways in which the use of sensor-based and persuasive technologies can be applied to support AS. Chapter 5: Implementation and Further Design will delve into the internal structure and class design where applicable.

4.1 Overview proposed solution and system modelling

The system can be broken down into two high-level concepts: exercises and self-management. Exercises will involve exercise recognition using the MetaWear sensors and APIs, and facilitating real-time feedback while exercising. Self-management will include self-assessment by logging pain, symptoms, mood, and sleep as well as goals setting to review progress. These concepts can be broken down into smaller components to model the system. Figure 4.1 represents the key components needed for the system to support non-pharmacological treatments especially exercise.

4.2 Mobile Design Best Practices

There are several guidelines for developing mobile apps as well as platform-specific guidelines. Mandel (1997) identifies 3 golden rules for interface design: place the user in control, reduce the user's memory load, make the interface consistent (Pressman 2015).



Exercise Recognition implementation   Self Management implementation

Bottom navigation bar components presented in both so the users can make a connection how the system will work as a while when incorporated

Figure 4.1: High level system architecture presenting the components identified in the Design Chapter. The implementation is then subdivided into 2 implementations.

Table 4.1: Golden rules for interface design

Design Principles	**Implementation in design**
Golden rule 1: Place user in control	
Define interaction modes in a way that does not force a user into unnecessary or undesired actions.	An interaction mode is the current state of the interface; translated into the design. A tutorial and tips on using the system are to be provided tailoring to the audience however is not forced. With that, self-assessment could also be skipped if the user wants to exercise straight away.

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Table 4.1 – continued from previous page

Design Principles	Implementation in design
Provide for flexible interaction.	Different users have different interaction preferences. A choice should be provided in design through touch screen as well as voice recognition. However, this is set as a low priority in the design as the objective is to deliver a prototype.
Streamline interaction as skill levels advance and allow the interaction to be customised.	As the nature of the system is to be used regularly, the users would often perform the same action and sequences of interaction repeatedly. This design principle is addressed in the prototype designed in Table 4.3; design addresses this by breaking up some interaction of self-assessment into multiple pages, versus a faster single page assessment.
Hide technical internals from the casual user.	The user interface should move the user into the virtual world of the application. This design principle is essential when they are interacting with the sensors and is considered in the design in Table 4.3.
Golden rule 2: Reduce the user's memory load	
Reduce demand on short-term memory.	Interface to be designed to reduce the requirement to remember past actions, inputs, and results. This specification is clear in design by showing progress, exercise completed and previous self-assessment logs. Self-assessment logs are also pre-populated with the previous entry as to make it easier and faster when completing a new log.
Establish meaningful defaults	Defaults are hard to set as AS patients' cases can vary quite a lot. Address this by one of the assumptions specified previously, that the initial set-up would be carried out by the user and an appropriate health-care professional.
Define intuitive shortcuts.	This is addressed for mobile by designing a custom navigation for easy and intuitive user flow, as presented in the designs of Table 4.3. With that, a shortcut is defined in design by setting workouts of existing exercises to guide the user through the exercises, not requiring page hopping.

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Table 4.1 – continued from previous page

Design Principles	Implementation in design
Progressively disclose information.	This will be translated into many aspects of design. Firstly, in a step by step tour of the app (although set as a low priority). Can also be seen in the self-assessment going through pain, mood and sleep logs progressively. Workouts and are exercises organised hierarchically. The workouts are presented at a high level, and then more detail is presented as the user selects the workout and starts the exercises displaying the movements and tips.
Golden rule 3: Make the interface design consistent	
Allow the user to put the current task into a meaningful context.	Providing indicators that enable the user to know the context of the behaviour at the moment; this is designed by clear headings and custom tab navigation with icons.
Maintain mobile user interface pattern consistency.	Use of popovers to present message and information that arises in real-time or as a consequence of a user action. Popovers will be used during self-assessment to give tips in cases when a user is experiencing extreme pain or has not slept well. Popovers assisted by audio feedback will also be used during exercise if a sudden movement is experienced that could be a user fell. Emergency contact will be addressed if the dialogue or popover is not addressed for a long time after an apparent incident. Custom tab navigation is vital in the design to represent the different content objects with the ability to select those easily. The objects would include workouts, goals and self-assessment logs and profile.

Other guidelines (Schumacher 2010) identify mobile app best practices include identifying the audience which we have done throughout the course of this written work. The application must be written with the expectations and backgrounds of the users in mind; AS patients are of varied experiences, as such some hand-holding approach will be needed as identified in Table 4.1 on providing flexible interaction. Additionally, mobile design needs to consider support for personalisation. It is important to indicate to users what features can be personalised and how users can personalise them. Special consideration is to be placed as AS patients' cases vary, thereby enabling individualised profiles, workouts, and goals. Under the assumptions that the user will initially set those up with the appropriate health-care professional. Further personalisation; adding goals and exercises can be enabled further.

4.3 Key aspects of design

The key aspects of design as highlighted in the requirements is through supporting users and incorporating multi-modal feedback through wearable sensors and recognition as well as demonstration and visualisation of progress.

The key aspects of design are identified and addressed by creating UI design prototypes, based on literature, similar works and requirements identified. The designs are reviewed against the system models and best practices defined above. User input on the designs is essential to get multiple perspectives.

4.3.1 User Feedback

User feedback was conducted throughout the initial design stage to get insights on the usability and understanding the different icons and abstractions of the design. User feedback was conducted with 10 participants between the age of 21-26, 2 of which are pharmacy students with knowledge on rheumatic diseases and their treatment as to give feedback from the health-related design perspective. The demographic is represented in Table 4.2.

Participants were given a brief description of the problem present in the project proposal (Appendix 8.3). After which, the low fidelity designs presented in Table 4.3 and asked to evaluate usability and highlight areas of improvement.

More specific design feedback will be mentioned throughout the justifications of the design and if changes are to be taken on in the following Section 5 common issues raised for the self-assessment revolved around the crowding and clustering of the overview page. The description of the pain levels was expressed as useful by 100% of the participants. However, the feedback on the exercises was on separating the pages as to make sure the goal of each page is clear rather than needed to carry out separate functions on the same page to progress.

Table 4.2: Table presenting the demographic pf participants involved in the design stage feedback

	Participants	Gender	Age
Yasmeen	P1	F	22
Toby	P2	F	22
Jasmine	P3	F	21
Francisco	P4	M	24
Hana	P5	F	21
Waleed	P6	M	20
Kareem	P7	M	20
Zaid	P8	M	20
Thea	P9	F	21
Faisal	P10	M	22
Summary	Number of Participants 10	Female: Male 5:5	Age Mean: 21.30 SD: 1.25 Mode: 22

Table 4.3: Translating key aspects of design

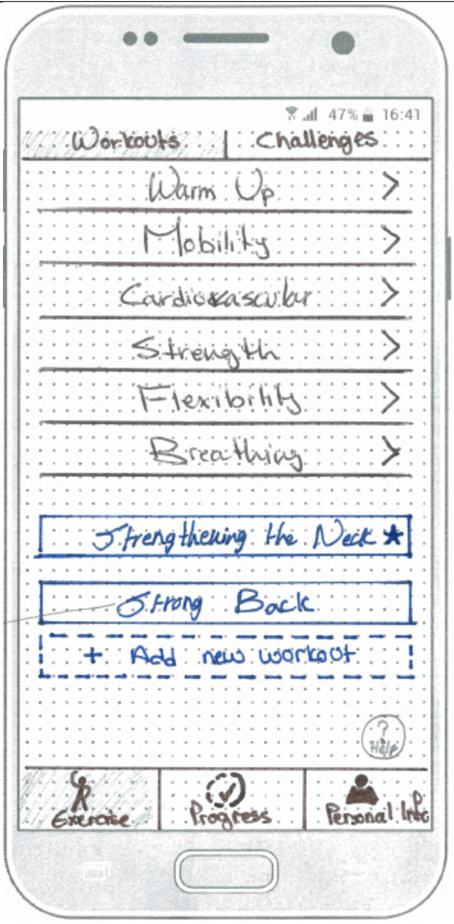
Design	Justification
 **Figure 4.2:** Design: Workout fragment	• Exercises are categorised based on the NASS Back to Action Programme. • Workouts target specific pain and areas that need to be addressed, allowing for personalisation based on the individual's case. • The blue sections are workouts identified in the initial set-up with the physiotherapist. Workouts can be added and modified based on future physiotherapy sessions. • During user feedback, concern was raised with allowing users to set their workouts. Reviewing literature and similar works; during the first use of the app, it will list safety recommendations. Following, when the user is creating a new workout from the exercise list, the app will give recommendations on safety and when it is needed to see an appropriate health-care professional. This behaviour is similar to the NASS Back to Action programme safety (refer to appendix 8.1:Figure 8.3 for more detail). The exercises are all taken from the NASS Back to Action programme which is created by physiotherapists and exercise therapists. • Challenges are a separate tab. These would be additional exercises or self-care promoting tactics. It can facilitate further encouragement for the user going beyond the exercises, motivating them to challenge themselves continuously. This feature is set as a low priority requirement, to be implemented if there is time. Otherwise, having suggested goals can help facilitate adherence, discussed further sections.

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Table 4.3 – continued from previous page

<table>
<tr><th>Design</th><th>Justification</th></tr>
<tr><td>

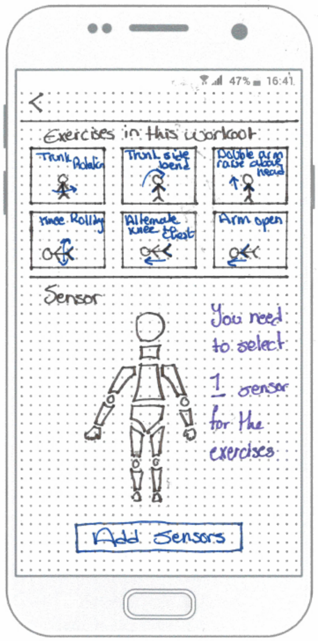

Figure 4.3: Design: Exercise

</td><td>

- On selecting a workout to complete, the exercises are displayed along.
- As the exercises facilitate real-time feedback using wearable motion sensors, the placement of the sensors for all the exercises is displayed. The sensor placement is designed at this step, such that the users do not have to change/add sensors throughout the workout if multiple are needed.
- Clicking on adding the sensors will go to the design below.
- Once all the sensors have been calibrated and positioned, then will be allowed to start the workout. This design ensures it is tailored to the vast audience, providing extra guidance for those who need and otherwise just quickly set it up.
- From feedback, it was suggested to separate the pages as to make the intention of each page clear.

</td></tr>
<tr><td>

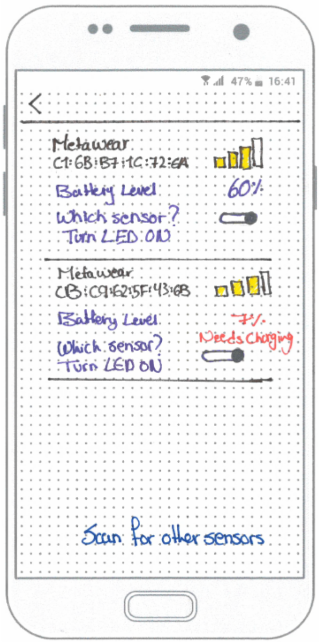

Figure 4.4: Design: Sensor

</td><td>

- This design is based on the MetaWear sample app, as it enables re-use of open-source code.
- Additions are made to account for the audience. Switch to turn the LED on/off as to identify the specific sensor, in cases where they do not know the MAC address. Clear battery level status.
- Bluetooth can be quite glitchy. A *scan for other sensors* is added to the design to scan for other sensors again, if not found.
- The number of sensors for the exercises - at the previous step - is to be selected to continue exercises.

</td></tr>
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Table 4.3 – continued from previous page

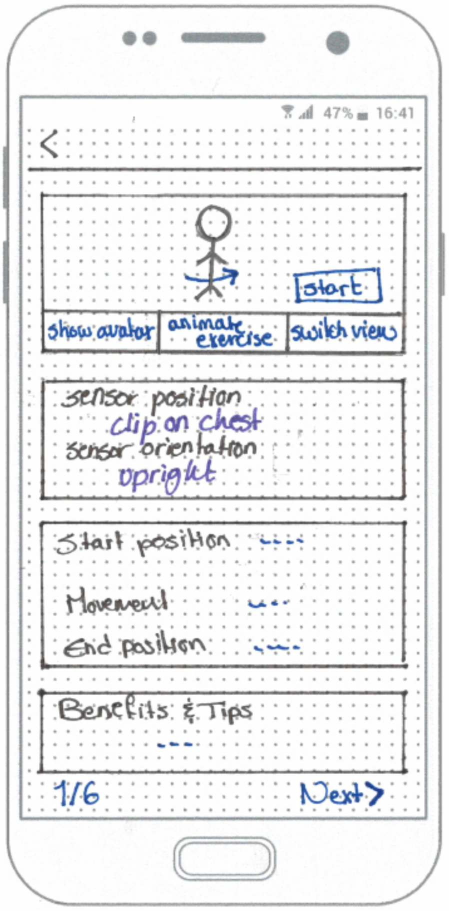
Design	**Justification**
 **Figure 4.5:** Design: Start Exercise	• An animation of the exercise is displayed so the user can mimic the movement. Realism is an essential factor here such as the pace of movement and choice of visual representation of the avatar. • The sensor information is still listed here to be able to identify if the connection is lost or if the orientation of the sensor is no longer correct. • Tips and benefits are vital to guide users through exercise and how to deal with pain or dizziness experienced. • Clicking on start/perform the sensors will start the recognition system. Based on which a timer will display how long the user has been exercising and provides audio cues to enhance movements based on sensor information as well as audio feedback to encourage the user such as ”10 seconds left keep going.” • In this design, the best practices discussed in Section 4.2 are applied. The information on this exercise is on the same page based on the preference of scrolling. • Users expressed the need for the picture to always be animated or use a video as not to have to interrupt an exercise to click a button to review the conducted movement. • Users were confused about the function of the buttons below the animation: change the perspective of the animation and show avatar. When explained, the switch view was expressed as being very useful to understand movements clearly; however, the avatar as not necessary. • User feedback also indicated for the need for a more apparent start button.

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Table 4.3 – continued from previous page

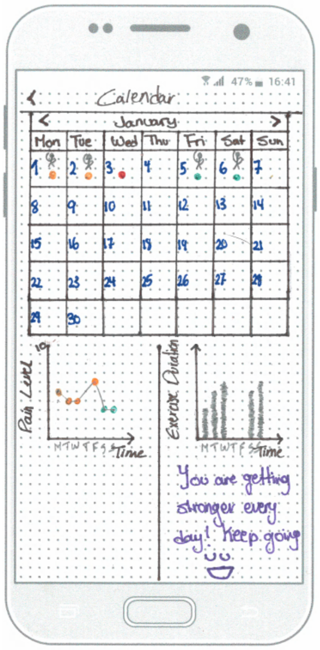
Design	Justification
 **Figure 4.6:** Design: Calendar	• This design mimics similar works from fitness apps. However, due to the nature of the app tailored to AS patients, quantifying how often and the duration of the exercises is not suitable. • A design needs to address self-assessment pain, mood and sleep logs completed over time, with correlation to exercises performed if applicable. • This design was disregarded, and more details on goal setting can be seen in the next designs. • Another view will be added to review all goals over time, categorised based on self-assessment and exercises as to indicate progress over time.
 **Figure 4.7:** Design: Goal	• The main form of accountability will come from goal settings, which will include suggested goals such as exercise, drinking water, pain, and sleep logging. • The benefit of using goals is the flexibility of adding a range of different goals concerning exercise and self-care to encourage a healthy quality of life. • Goals completed will demonstrate progress and adherence. Notifications on specific goals can be set, to push users to be determined and comply with treatment. • Goals can be set with the physiotherapist from their meetings and discussions.

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Table 4.3 – continued from previous page

<table>
<tr><th>Design</th><th>Justification</th></tr>
<tr><td>

Figure 4.8: Design: New Goal</td><td>

- Goals can take several forms to address exercise and adherence.
- Goals can be set for a period, and then to be repeated regularly.
- A *streak* is set as a way to encourage a user to maintain regularity and as such adhering to treatment. For example, if logging pain level and symptoms every day is a goal, a streak would be the number of days a user has done so.
- Reminders are to be set to notify the users to complete the actions associated with their goals. However, reminders are not mandatory as they can result in negative triggers as identified in table 3.3 on persuasive design principles.
- Feedback was given here to categorise the goals and giving guidance on goal setting with examples.

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Table 4.3 – continued from previous page

<table>
<tr><th>Design</th><th>Justification</th></tr>
<tr><td>

Figure 4.9: Design: Overall pain

</td><td>

- To complete the self-assessment for the first time, a user would go through a page by page walk-through.
- The first page is to select the overall pain level. The numbers represent buttons; a pain level is selected displaying assisting text on the pain being experienced: noticeable, constant but not too limiting, controls my attention. Refer to appendix 8.2 for more detail.
- This is based on literature and similar works to devise the descriptions.
- Users liked the description of the different pain levels as to be able to have a constant scale when regularly logging pain levels.

</td></tr>
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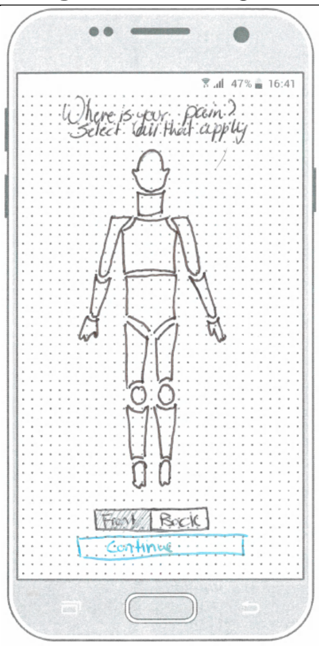

Figure 4.10: Design: Pain Location

</td><td>

- Selecting parts where the pain is experienced along with the symptoms associated.
- The pain can be varied for each of the different parts on a scale of 1 to 10, as in the page before.
- Areas of front or back can be selected.
- This was an initial design. Special anatomy for AS segmentation, Margolis, will be used for further design and implementation.
- The users expressed an option to skip the following as it can often be quite hard to point out specific pain areas.

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Table 4.3 – continued from previous page

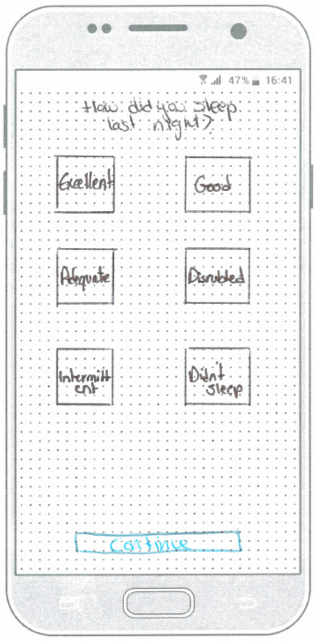
Design	Justification
 tr **Figure 4.11:** Design: Sleep	• Literature discussed earlier, (Sangle et al. 2015, e.g.) where physically active people tend to sleep for longer. Lack of sleep and fatigue is a common symptom with AS, affecting an individual's health, overall well-being and the capabilities to exercise. • This is therefore translated in the design. • User feedback suggested this can be quite subjective; adding a general indication on average hours of sleep and the number of times woken up by pain. Literature and similar works further support this.
 **Figure 4.12:** Design: Mood	• Users various emotions such as anger, fear, frustration, and depression can accompany the realisation for the need to change and adapt ones view of the future. • The unpredictability of the condition causes a user's emotions to fluctuate depending on the factors above such as sleep and pain. • The self-assessment helps the user become more aware of their situation whereby being able to manage appropriately. • Guidance and tips are given to the user - in the form of pop-ups. Such as in cases of severe pain to contact the appropriate health-care professional and when frustrated encouraging exercise.

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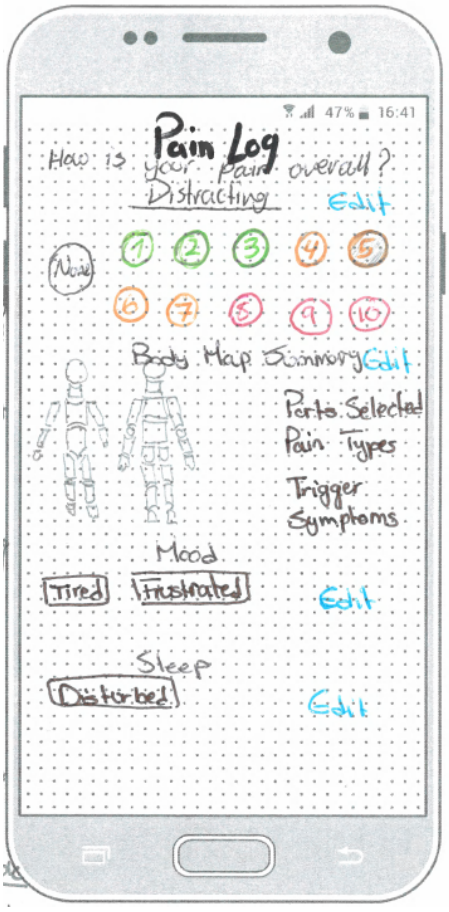
Table 4.3 – continued from previous page

Design	Justification
 **Figure 4.13:** Design: Pain overview	• Pre-populated details from the last log will be filled, making it easier to log pain, mood, and sleep regularly. • Based on user feedback, the layout was addressed as to make sure it is not too clustered. • User feedback suggested the use of a slider instead of buttons for the overall pain, as it is commonly recognised in mobile apps. • User feedback also suggests there should be more focus on the pain triggers, symptoms, pain types and the time of day pain is experienced.

4.4 Summary

The design chapter draws from requirements specified in Chapter 3 and learning from similar works, mobile best practices and re-using existing code for the sensor behaviour to define key aspects of design. User feedback is conducted on the initial design to feedback into further designs and implementation discussed in the coming implementation Chapter 5.

Chapter 5

Implementation and Further Design

Software design and implementation are interleaved activities. The level of detail in the design depends on the type of system being developed (Sommerville 2016, p.222). This chapter focuses on further transforming the requirements identified in Chapter 3.

5.1 Implementation approach and techniques

As previously discussed in Chapter 4, the system can be broken down into two high-level concepts: (1) self-management (2) exercise and its recognition. To be able to address all the findings and requirements elicited, different implementation approaches are carried out.

Due to the inaccessibility to AS-diagnosed patients, there would be no 'real' data from self-assessments that can be fed into a functional system. As such, a high-fidelity interactive prototype will be implemented to present the functionality and features needed to facilitate self-management and encourage users to maintain exercise. The implementation is carried out based on the literature and similar works explored in Chapter 2. Chapters 3 and 4 on requirements and design have identified persuasive design principles and features that need to be implemented. Based on which, Section 5.2 delves into critical aspects of implementation for the self-management implementation justifying the decisions taken. User evaluation and testing are conducted in the next chapters to assess the potential and contribution of the system.

Exercising is initially explored as part of the self-management strategies on the importance of home exercises . The literature identified the importance and willingness for AS patients to exercise (Berdal et al. 2018). However, Tang et al. (2014) and Thomas et al. (2002) report on low compliance to home exercises, whereby the addition of accountability and feedback strategies were shown to improve adherence. Therefore, as discussed previously in Chapter 4: Design, smartphone and sensor technology are used to implement the exercise recognition prototype. Exercises recognition and additional feedback strategies will be further explored implementing a functional prototype on Android using Java and using the MetaWear Android SDK (*mbientlab/MetaWear-SDK-Android* 2019) to access the sensor APIs, as discussed in the approach and tools of the Chapter 3, Section 3.5.3. The implementation is further discussed in Section 5.3.

The system can naturally be sub-divided as the system components are of object-oriented structure. Figure 4.1 presents the key components needed for a system to support non-pharmacological treatments and encourage self-management to achieve and adhere to the treatments. The division is noted in Figure 4.1. The self-management prototype addresses the fundamental aspects: self-assessment and pain logs, goal setting and progress, and motivation and accountability journal.

The exercise recognition system involves the exercises, sensor connection and classification based on which feedback is presented. Education is a fundamental part of self-management strategies and treatments and as such present in all components of the implementation. It plays a hand to clarify the importance of exercise and self-management for AS patients to better handle their condition.

5.2 Self-Management implementation

The implementation first started with the focus on addressing self-management for AS patients such that they can manage the chronicity and unpredictability of the disease. The chapters above (2, 3, 4), are used to guide and justify the decisions taken during implementation.

The self-management implementation is approached by building a high-fidelity mobile app prototype justified and support by the literature and technology survey and further explored in the requirements and design. Persuasive design principles are additionally implemented to promote motivation and behavioural changes. This has extended on similar works by incorporating several non-pharmacological treatments, for exampling journaling, goal setting, education and exercise.

As mentioned previously, a high-fidelity prototype is used to approach this to focus on user interaction and experiences, as there would be no data from AS patients to be fed into the app. Furthermore, having a prototype allows me to do conduct user tests and more easily modify the implementation at each iteration, enabling review and result of the changes made.

The prototype is implemented using an online software Proto.io (*Proto.io* 2019). This tool was selected as it has a range of features and library elements. Additionally, it can be incorporated with another software called Validately (*Validately: Powerful User Research* 2019), enabling remote user testing reaching a wider audience or ranging ages rather than being restricted to university students. Features include screen and video recording, enabling the use of the think-aloud protocol for user testing. This will be discussed further in Chapter 6.

Note: the high fidelity prototype has been added as an HTML to the submission zip file.

Focus is placed on the essential aspects of the requirements and design in previous chapters and expands on them to present and justify the implementation.

Based on the literature and tech survey findings on needs of AS patients requirements are identified in Chapter 3 - Table 3.1, and Table 3.2.

Delving deeper, persuasive designs have been reported in the literature (Section 2.8) and then explored further in the requirements, Table 3.3; a set of persuasive design principles and requirements are identified to encourage behavioural change. The behavioural changes we want to see from the user are taking on exercise, understanding the importance of disease management and how to handle it. Implementation of the design principles is highlighted in the tables below.

5.2.1 Self-Management features

Self-management strategies are fundamental for AS patients as constant pain, stiffness and fatigue would substantially affect their overall quality of life. The treatment of such spinal diseases most involves non-pharmacological treatments (Keat 2010). The need for self-management is heightened in this case such that patients can maintain health behaviour and diseases management to reduce pain and stiffness, increasing well-being and functions through exercise.

Corbin & Strauss (1985)'s self-management framework identifies the need for:

- Medical and behavioural management; maintain medication and complying with all aspects of treatment and that includes exercise especially for AS patients.
- Role management: modifying tasks where appropriate to ensure no strain or fatigue as fatigue is a common and disabling symptom with AS (Edavalath 2010)
- Emotional management: important at every step as emotions such as fear, anger, frustration, and depression often arise due to the unpredictability and chronicity of the condition.

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Table 5.1: Implementation based on Self-Management (LR1) requirements from literature and technology, presented in Table 3.1

Implementation	**Justification**
Requirement (LR1.1): Express pain level and mood to be able to cope appropriately	
Screen 1: Pain Logs	
 **Figure 5.1:** LR1.1 - Screen 1: Pain Logs	Completing a pain log can be a complex task. Introducing persuasive design principles reduces the behaviour into simpler tasks that do not require manual input, only selection reduces the complexity as seen the screens 2-5 below. Tracking performance and status is implemented by goal review. As well as tracking exercises and self--assessment logs completed. This is supported by literature on RD patients as well as to users need to understand and become aware of fluctuations of activity (Foster et al. 2007). Reviewing their previous logs also allows the user to take into account possible barriers and setback, understanding the balance between rest and exercise. Understanding one's own situation encourages motivation and progression.
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Table 5.1 – continued from previous page

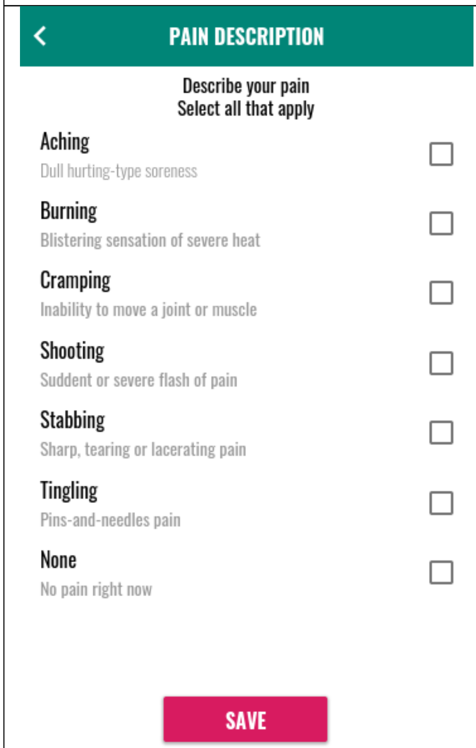
Implementation	Justification
Screen 2: Log Pain Description	
 **Figure 5.2:** LR1.1 - Screen 2: Pain Log Description	Several measures need to be taken to form an idea of your current state. The guidance was taken from the ASQoL Survey to ask questions from those and thus can be further applied by health care professionals (Zochling 2011).
	Continued on next page

Table 5.1 – continued from previous page

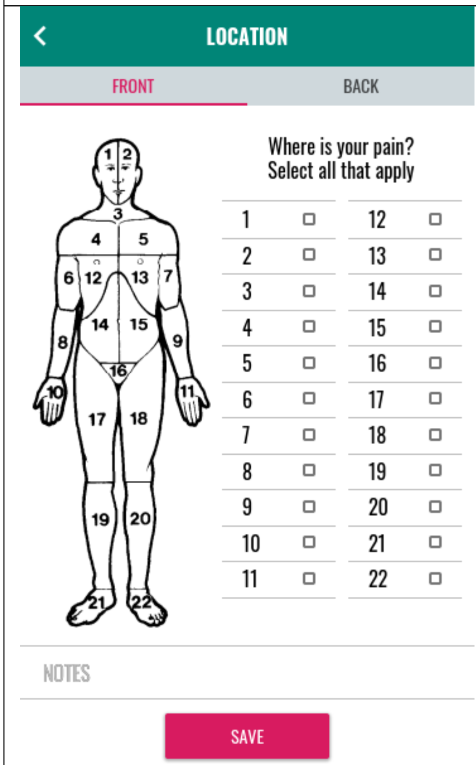
<table>
<tr><th>Implementation</th><th>Justification</th></tr>
<tr><td colspan="2">Screen 3: Log Pain Location</td></tr>
<tr><td>


Figure 5.3: LR1.1 - Screen 3: Pain Location
</td><td>The pain location is a fundamental aspect to the self-assessment as the more users would understand where there main is the better they can choose the exercise that suite their state based on their learning from the app. The Margolis pain map (Margolis et al. 1986) is used, defining a rating system for use with patient pain drawings. Further work can be done here to add a pain level to each area as different pain levels can be experienced. With this advancement, further research needs to go into then appropriately providing the best exercise to stretch and improve function.</td></tr>
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Table 5.1 – continued from previous page

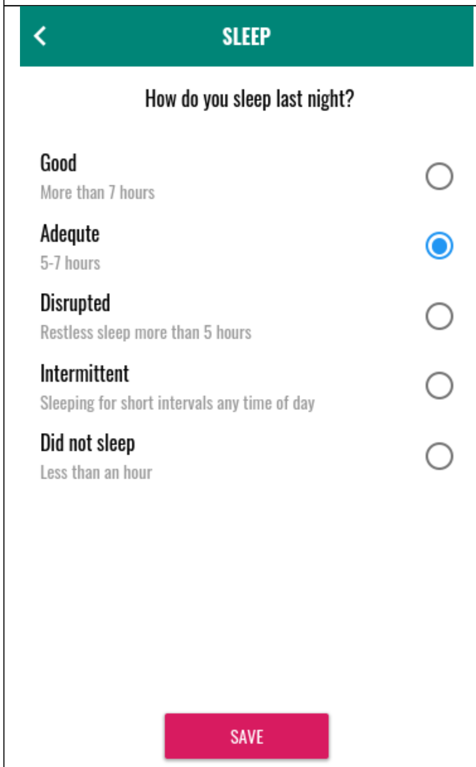
Implementation	Justification
Screen 4: Log Sleep	
 **Figure 5.4:** LR1.1 - Screen 4: Pain Sleep	Sleep and fatigue are often associated with AS patients. It is one of the questions on the ASQoL survey that needs to be appropriately translated (Zochling 2011). AS patients often struggle with sleep and are waken up several times through the night from the pain. Based on the self-assessment, strategies and learning material on what to it should be presented.

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Table 5.1 – continued from previous page

Implementation	**Justification**
Screen 5: Log Mood	
 **Figure 5.5:** LR1.1 - Screen 5: Pain mood	Logging mood is often a reflection of one's capability and attitude towards handling the condition. Logging mood makes a user more self--aware. Use of mood as a measure to present means to boost mood and positivity.

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Table 5.1 – continued from previous page

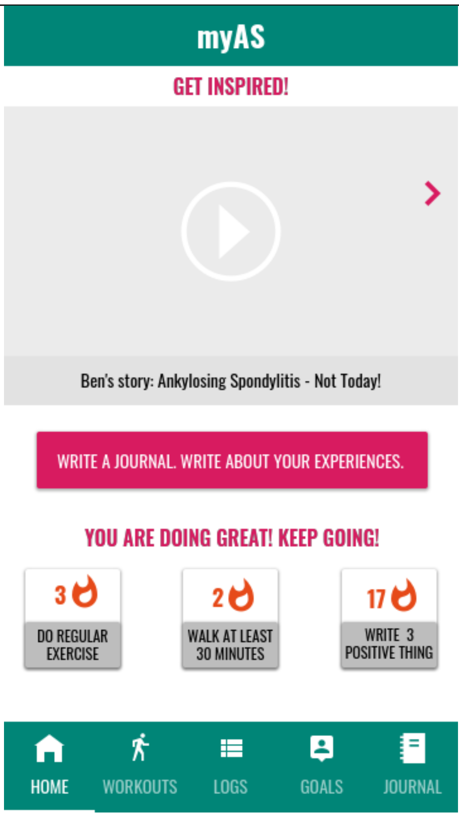
<table>
<tr><th>Implementation</th><th>Justification</th></tr>
<tr><td colspan="2">Requirement (LR1.2): Identify and review progress, to be reviewed and used at times of emotional stress</td></tr>
<tr><td colspan="2">Screen 6: Home page</td></tr>
<tr><td>

Figure 5.6: LR1.2 - Screen 6: Home Page</td><td>Progress view of the goals as to present current state is on the home page. Implemented to show the user their progress and achievements when they first open the app. Receiving praise and reward on the maintenance of a streak encourages and boosts a users mood and drive. Additionally, if a user is not feeling good, a journal entry option is presented to make sure there is a way to facilitate emotional release. This makes use of persuasive design principles guiding a user through the app as well as presenting praise and reward.</td></tr>
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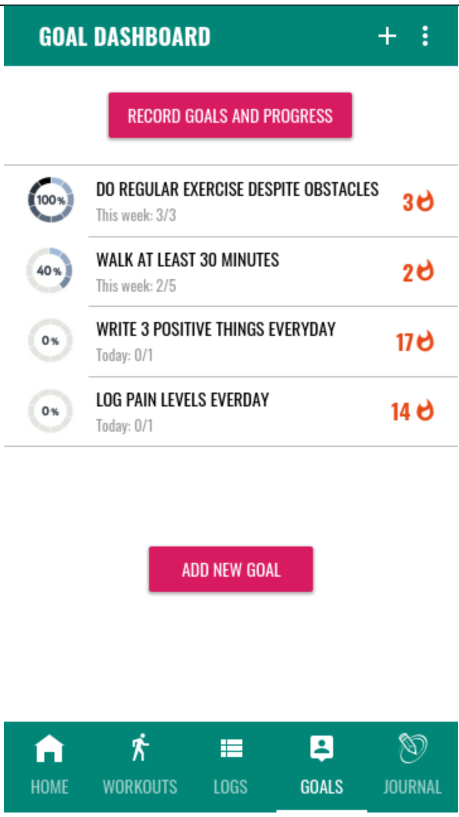
Implementation	**Justification**
Screen 7: Goals page	
 **Figure 5.7:** LR1.2 - Screen 7: Goal Dashboard	Opening the goal dashboard provides further encouragement to maintain adherence to goals and treatment by reviewing progress made. Again, the presentation of the goal streak (the number of times this goal has been achieved in a row) presents a reward system. Aided by the use of quantitative percentage to present what still needs to be done.

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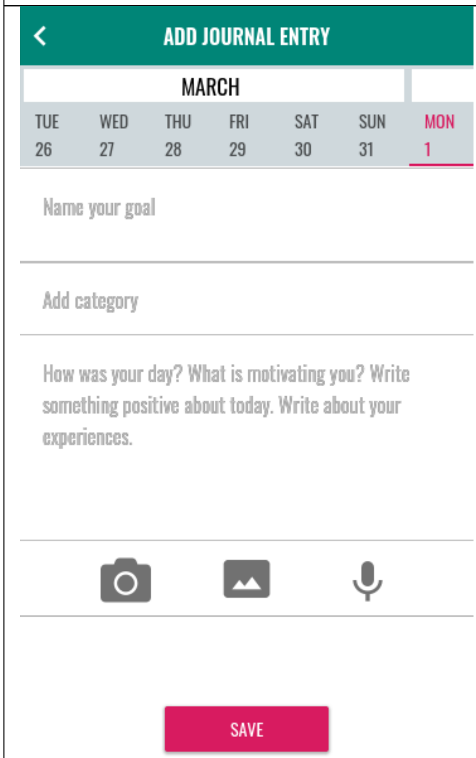
Implementation	Justification
Screen 8: Journal Entry	
 **Figure 5.8:** LR1.2 - Screen 8: Journal Entry	The use of the journal entry allows for emotional release as it is often quite hard to talk to people about the condition (Goldenberg et al. 2011). Reviewing past experiences and motivations would help a user recover from a bad day through previous coping mechanisms used.
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Table 5.1 – continued from previous page

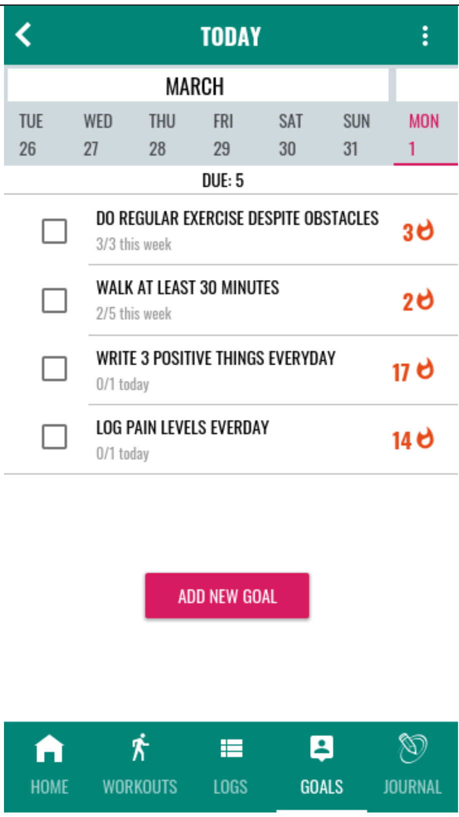
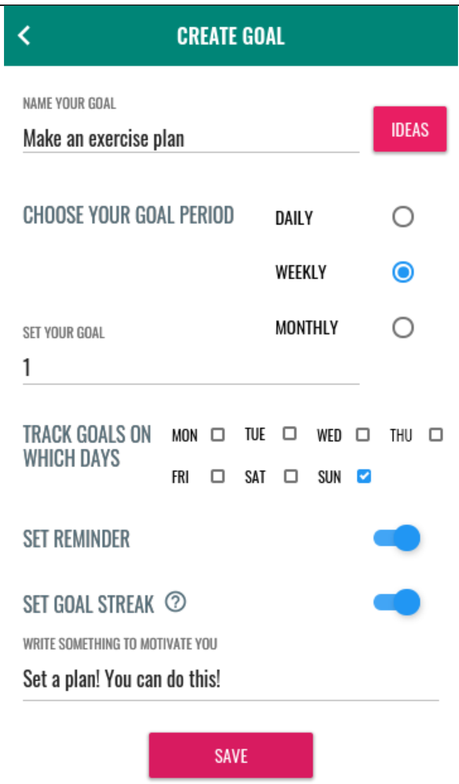
Implementation	Justification
Requirement (LR1.3): Help user comply with treatment by means of accountability and notifications	
Screen 9: Logging goals	
 **Figure 5.9:** LR1.2 - Screen 9: Logging Goals	Compliance and adherence to treatment and goals requires an understanding of why it is important to do so, to better the quality of life. The use of goals and notification on these goals is a form of accountability and is translated by persuasive deign principles needing an effective trigger as to make the user act on the behaviour.
	Continued on next page

Table 5.1 – continued from previous page

Implementation	Justification
Screen 10: Create goals	
 **Figure 5.10:** LR1.2 - Screen 10: Create Goal	As discussed in the literature (refer to section 2.8) on the FBM model, ability, motivation and an effective trigger is needed to result in adoption of new behaviours and adhere to them. As AS patients needs and capabilities often quite vary, the importance of flexible goals setting it fundamental and present in this implementation.

5.2.2 Education features

Education is a critical non-pharmacological treatment, to ensure that patients are equipped to self-manage their progression and effectively manage their pain. This would involve knowledge of understanding and managing flares and fatigue (Cooper et al. 2003, Goldenberg et al. 2011). Importance is placed on informing the patient about the diseases and the treatment process, to develop the self-efficacy to take action to better their health and overall quality of life. Emphasis is also placed as to encourage adoption of self-management strategies, particularly exercise for AS Keat (2010).

Table 5.2: Implementation based on Education (LR2) requirements from literature and technology, presented in Table 3.1

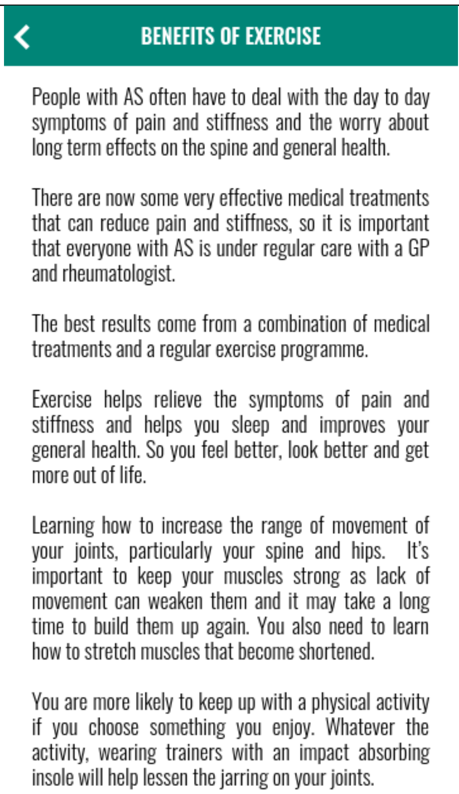
Implementation	Justification
Requirement (LR2.1): Clarify benefits of exercise	
Screen 1: Exercise Benefits	
 **Figure 5.11:** LR2.1 - Screen 1: Exercise Benefits	The importance of exercise at to remind why exercises is being carried out.
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Table 5.2 – continued from previous page

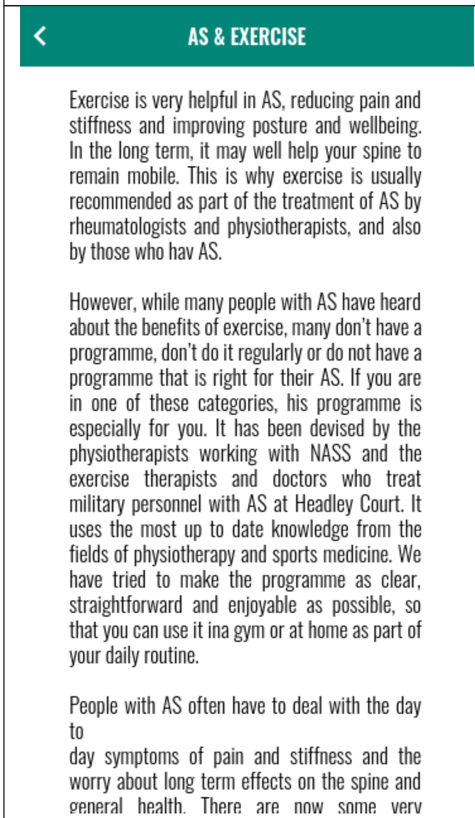
<table>
<tr><th>Implementation</th><th>Justification</th></tr>
<tr><td colspan="2">Screen 2: AS and Exercise</td></tr>
<tr><td>


Figure 5.12: LR2.1 - Screen 2: AS and Exercise Benefits
</td><td>Similarly, exercise plays a big role in managing and relieving pain for AS patient. Making it clear for user will improve adoption.</td></tr>
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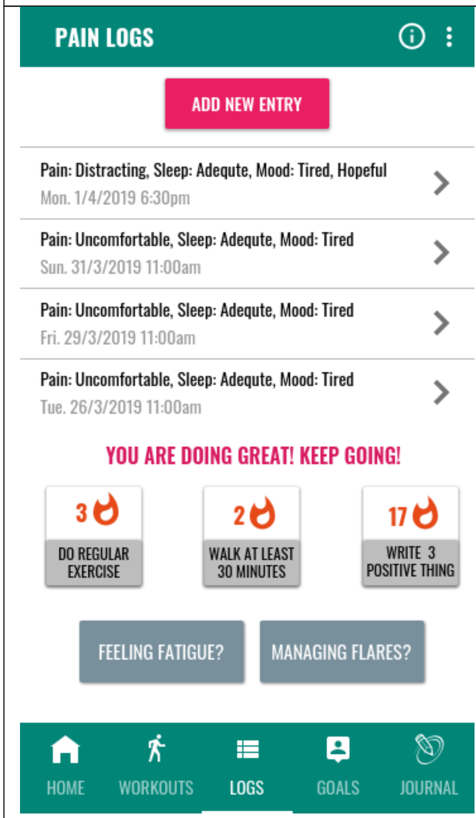
Implementation	Justification
Requirement (LR2.2): Regularly reminding the user of the importance of exercise	
Screen 3: Pain Logs	
 **Figure 5.13:** LR2.2 - Screen 3: Pain Log history	On self-assessment completion the main goals a user is currently undertaking are presented. The use of tunnelling encourages and persuades users to conduct exercises and similar goals educating and reminding them of the importance of non-pharmacological treatments.
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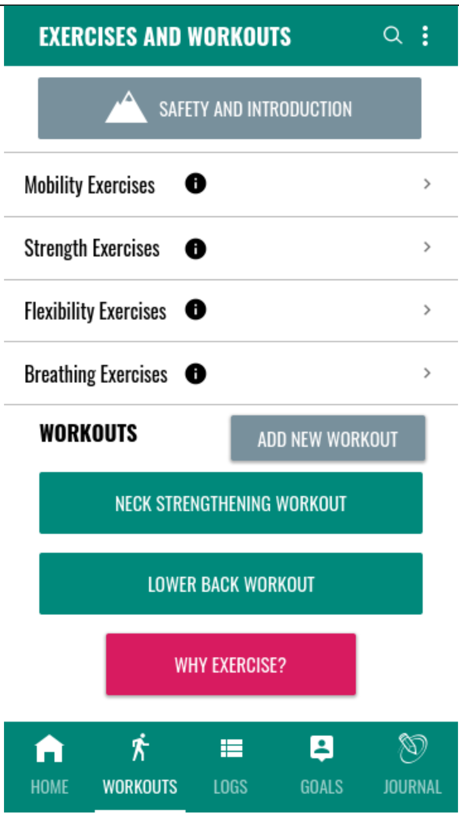
Table 5.2 – continued from previous page

Implementation	Justification
Screen 4: Why Exercise	
 **Figure 5.14:** LR2.2 - Screen 4: Why exercise	Presenting why exercise appropriately on the same page as completing exercises, promotes the user to explore the app and find out more about the benefits of exercise. Understanding the benefits of exercising, specially for AS patients, further encourages the user to comply to regular exercise.

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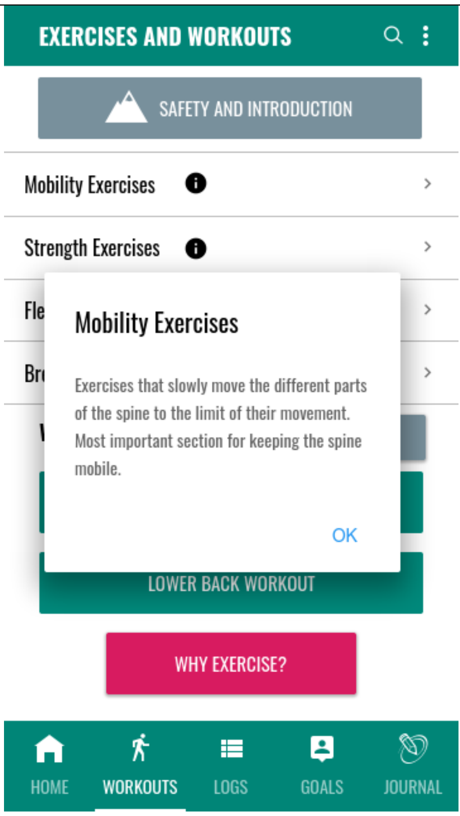
<table>
<tr><th>Implementation</th><th>Justification</th></tr>
<tr><td colspan="2">Requirement (LR2.3): Tips on completing exercises</td></tr>
<tr><td colspan="2">Screen 5: Exercise Information</td></tr>
<tr><td>


Figure 5.15: LR2.3 - Screen 5: Exercise Information
</td><td>The importance of presenting the benefits of each exercise is essential to guide the user through the app. This enforces the balance of different types of exercises to be able to maintain and increase mobility and function. Additionally, breaking up educational aspects makes it more appealing. Tips and benefits of each exercise are presented throughout the workout by audio cues. This is presented in Section 5.3.</td></tr>
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Table 5.2 – continued from previous page

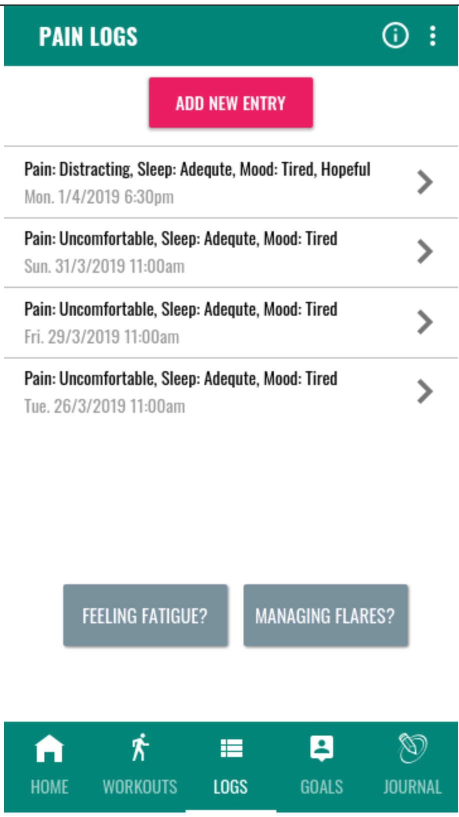
Implementation	Justification
Requirement (LR2.4): Importance of logging pain levels, self-management and self-efficacy	
Screen 6: Logging benefits	
 **Figure 5.16:** LR2.4 - Screen 6: Logging Benefits	The importance of logging and monitoring is supported by literature on RD patients as well as to users need to understand and become aware of fluctuations of activity (McLean et al. 2010). Being aware of one's state the user enables the use of the educational features of the app and take the appropriate steps to manage their pain. Furthermore, understanding one's situation encourages motivation and progression.
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Table 5.2 – continued from previous page

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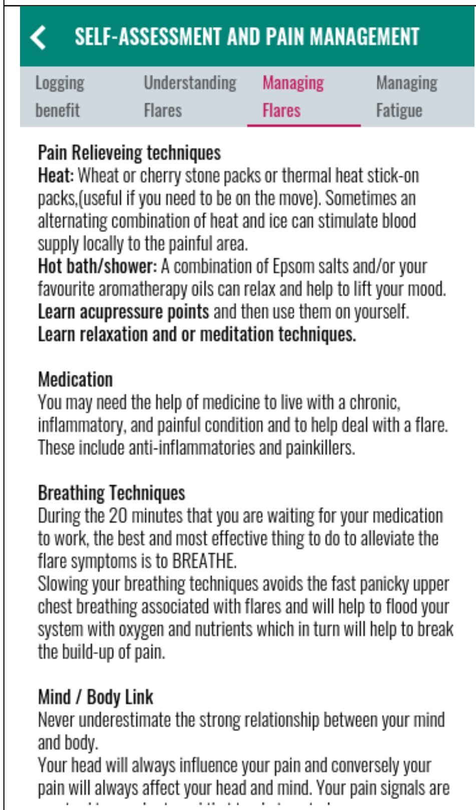
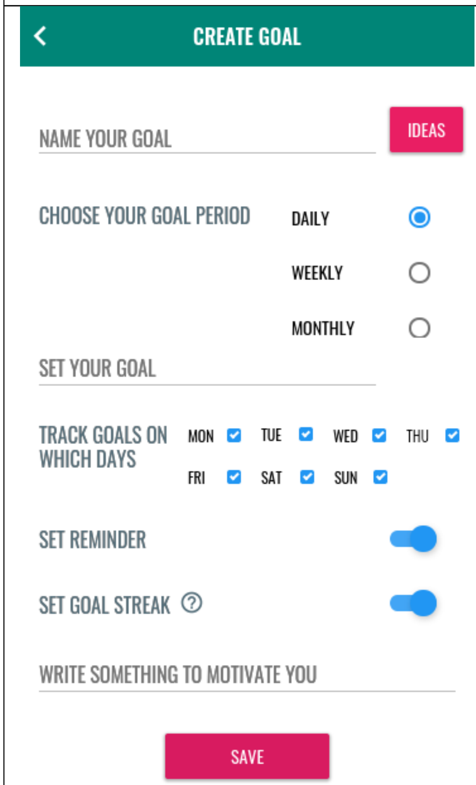
<tr><th>Implementation</th><th>Justification</th></tr>
<tr><td colspan="2">Screen 7: Managing flares</td></tr>
<tr><td>


Figure 5.17: LR2.4 - Screen 7: Managing flares
</td><td>Finally, several educational pages are presented from the pain log page on managing flares and understanding why they occur. These are presented on the log-history and on completion of a pain log. The use of tunnelling here positions the information such that the user can make a relation between the pain experiences and possible ways to manage it.</td></tr>
</table>

5.2.3 Adherence and compliance features

Adherence to treatment is quite low amongst AS patients. Self-management and self-efficiency are critical factors for adherence. Hammond (2004) study the adherence rate adopting self-management strategies, in which adherence rates are still typically between 18% and 57%. Incorporating education and self-efficacy such that the patient is aware and believes that the treatment will yield progress and help relieve pain can encourage long-term adherence and outcome (Marks 2001). As such, motivational strategies have to be applied to the patients' lifestyle to promote compliance. Persuasive design principles are highlighted throughout as to present features of promoting behavioural change.

Table 5.3: Implementation based on Adherence and Compliance (LR3) requirements from literature and technology, presented in Table 3.1

Implementation	Justification
Requirement (LR3.1): Set goals and milestones	
Screen 1: Goal setting	
 **Figure 5.18:** LR3.1 - Screen 1: Goal setting	Ability to set flexible goals such that it meets the varying AS patients needs. A streak is defined as a measure of the frequency of which a goal has been achieved repeatedly and consecutlively. Reminders and streak both act as a form of *persuasive design principles* presenting rewards in form of streaks for goals achieved encouraging constant maintenance of the goals. A user is able to set their motivational message that will be used when notified. This re-enforced by the persuasive design principles defined in Table 3.3 as it is tailored and personal. Although not visible in this screenshot, the goal period can be scrolled where it also presents monthly and yearly. This could allow a user to set a milestone that can be a collection of many smaller goals.

Continued on next page

Table 5.3 – continued from previous page

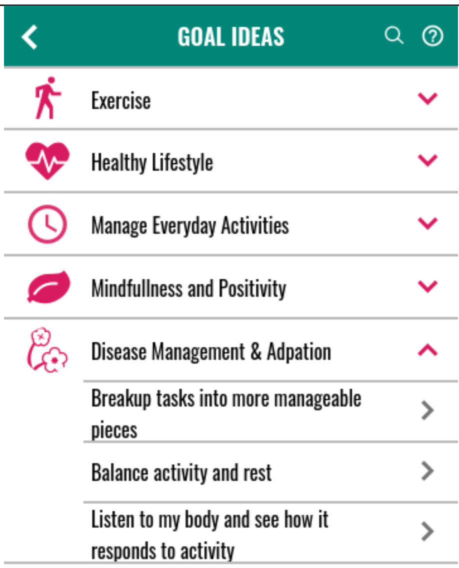
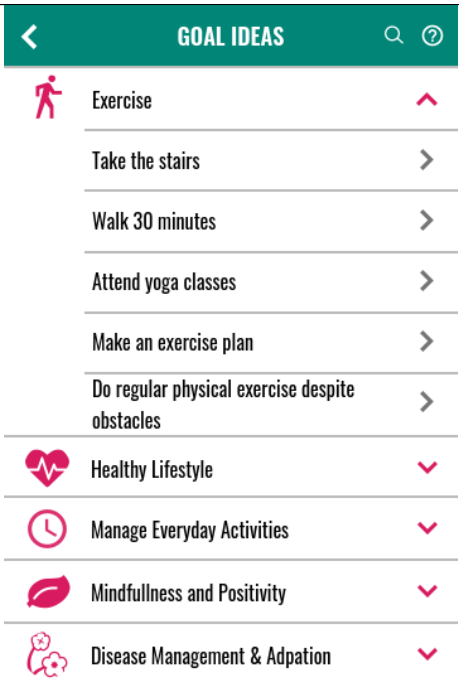
<table>
<tr><th>Implementation</th><th>Justification</th></tr>
<tr><td colspan="2">Screen 2: Goal ideas</td></tr>
<tr><td>

Figure 5.19: LR3.1 - Screen 2: Goal idea</td><td>The goal ideas is extended from the create goal as seen in Figure 5.18 above. It presents possible goals. This is based on literature by Berdal et al. (2018) taking inspiration from the categories and goals set by the RD patient themselves. The goal ideas help guide the goal creation and provides a subtle way of education the users on what type of goals they should look to achieve. Implementation of goal ideas that fills the fields based on selection. This based on persuasive design principles, by means of reduction making it easier for users to set a goals as it fills the goal creation and still allows modification.</td></tr>
<tr><td colspan="2" align="right">Continued on next page</td></tr>
</table>

Table 5.3 – continued from previous page

Implementation	Justification
Requirement (LR3.2): Set flexible exercise schedule	
Screen 3: Exercise frequency	
 **Figure 5.20:** LR3.2 - Screen 3: Exercise frequency	Setting an exercise schedule can be a hard task due to the unpredictability of the disease. The way in which to quantify aspects of treatments presents one of the challenges in this implementation as discussed in Sections 5.2.4 and 7.1.1. Nonetheless, this is addressed by the implementation of goal ideas to facilitate a way to remind the users on the frequency of completing exercises, the different types of exercises they can be completing and the need to plan. On selection, the fields are pre-filled thus enabling tailoring for individual cases. Notification and tracking encourages the adopting of exercise plans and other goals.

Continued on next page

Table 5.3 – continued from previous page

Implementation	Justification
Requirement (LR3.3): Taking notes	
Screen 5: Pain Logs	
 **Figure 5.21:** LR3.3 - Screen 5: Pain Logs	Taking notes is enabled in several features of the app. In the pain log, notes are enables on the overall pain, and the pain location pages so a user is able to further express their current situation. Users are then able to refer back to pain log history and review the pain experiences and any emotions associated with it. Additionally, journaling is introduced as a way for self-expression and note-taking. This is a new addition from the design stage as to emphasise the importance of emotional management (Corbin & Strauss 1985).

Continued on next page

Table 5.3 – continued from previous page

<table>
<tr><th>Implementation</th><th>Justification</th></tr>
<tr><td colspan="2">Requirement (LR3.4): Providing motivational messaging and encouragement throughout exercises</td></tr>
<tr><td colspan="2">Screen 6: Exercise Information</td></tr>
<tr><td>

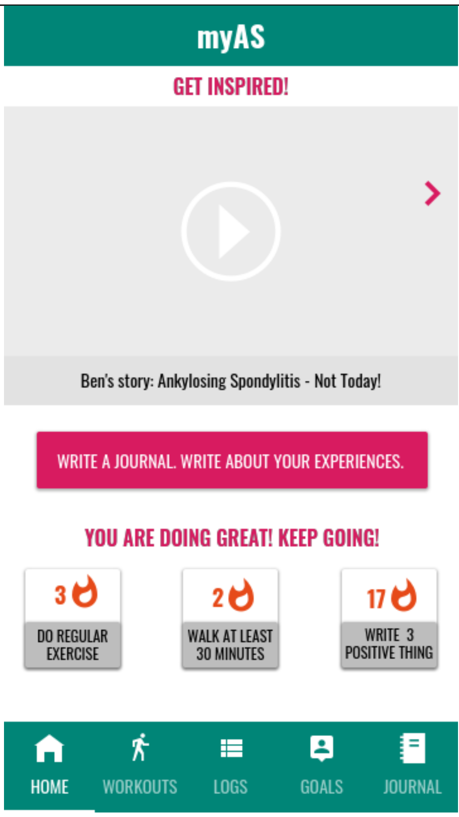


Figure 5.22: LR3.4 - Screen 6: Exercise Information

</td><td>Motivational messaging is present all throughout the app. This is present on the home page by presenting personal stories of other people, how to manage flares, news on AS, as well as information from health-care professionals on the carousel as to get inspired. Praise and dialog support are design principles to prompt actions. This is then followed by presenting an action to add a journal to express emotions and feelings as it is often quite hard to talk when in pain. Writing in the journals on what motivates and helps you stay positive and mindful acts as a reassurance for one's self Swann-Sternberg et al. (2012). Finally, the goals top goals are presented as to encourage the user to keep going. The streak identifies the frequency at which the goal is completed and lost when a goal is missed. Maintain this streak acts as great motivation as presented by the reward persuasive design principle.</td></tr>
<tr><td colspan="2">The implementation expressed does not highlight motivational messaging throughout the exercises. This will be further discussed in section 5.3.</td></tr>
</table>

5.2.4 Implementation Challenges

The following section presents the areas of challenge while implementing the self-management high fidelity prototype.

As seen in Table 5.2, education is implemented in the application by presenting benefits and understanding. This is beneficial for recently diagnosed AS patients and acts as a reminder or reference guide when needed. However, implementing progressive education that would update based on users need would be better suited but would be quite tough.

To present dynamic news and information, a data model of users' activity must be formed based on their mood, pain levels, fluctuations, exercise and goals as to present the best fit. After-which, an algorithm would be developed, such that it can collect data from different sources and match it the users' activities.

Taking ideas from apps in the market such as Facebook and Instagram, a dynamic carousel is added to the home page (as seen in Figure 5.21. There is potential to dynamically update the carousel information based on past pain levels, mood and goals as to present what is the best fit for the user. Potentially, a solution could introduce levels; beginner, intermediate, advanced or if they have recently been diagnosed versus if they have had the condition for a while with the knowledge to manage it better. However, this can be quite hard to quantify as it would depend on users own willingness and attitude toward their diseases such that if they are already taking an active part in it. Additionally, adding what type of content the user would like to see: AS stories, new information on AS, how to manage flares, new exercises, mindfulness and positively.

5.3 Exercise recognition implementation

The functional prototype focuses on the exercises and how adding exercise recognition, and feedback components can support AS patients. This section starts with an overview of the app and how the sensor components fit in. The sensor implementation and real-time feedback pose the key aspects of the implementation as such explored further.

5.3.1 System overview

The following section describes the typical user interaction for one exercise using the system. This is supported by a storyboard of the android screens presented in Table 5.4 and a sequence diagram Figure 5.32; highlighting sensor and classification components at a high level.

A similar look and feel is taken from the self-management prototype and implemented in the Android implementation, as seen in Figure 5.24 and 5.25. Presenting the bottom navigation in the Android app gives the context of how the exercise recognition system fits in the context of the entire system. The focus for this implementation is not necessarily on the user design. It is more focus on the user story and how they would feel while using it and if it supports them.

On starting the exercise, visual and audio feedback is cued. Time and repetition countdown is presented visually as to aid the user throughout the exercise if needed (Figure

5.29). Along with motivational supportive text as presented in Figure 5.30. However, exercises required would need a posture and position to be maintained, having to look at your phone to check on the current state would result in incorrect movements with respected to exercise recognition. Therefore, audio feedback is also presented to support the user while they are completing the exercise. The app instructs the user on repetition change, side change (right or left side) if applicable. Additionally, it provides encouragement and tips throughout the exercise to make sure the correct movement is being performed.

To further support this, based on the exercise recognition, the user is instructed when a wrong movement is detected, with tips on how to recover or modify the movement.

The exercise recognition is implemented using the MetaWear APIs requiring classification, as presented in Figure 5.32 with the blue box. The use of blue as an identifier across Figures 5.32, 5.33 and 5.41 highlights the different viewpoints for the exercise classification. Figure 5.32 represents the users' point of view. The user does not directly see interact with it, rather, receives feedback cues on how to perform exercises based on the classifications. Figure 5.33 is from the viewpoint of the programmer, representing the steps that need to be taken to distinguish incorrect movements. Figure 5.33 delves deeper to explore the use of the MetaWear SDK to implement the feature extraction to data processing modules.

The next sections go into more detail on the exercise recognition, and the appropriate real-time feedback response as these represent the key aspects of the implementation.

Note: A zip file is uploaded on Moodle contains a video of how the entire system works with audio and sensor LED feedback.

Figure 5.23: Bridge exercise

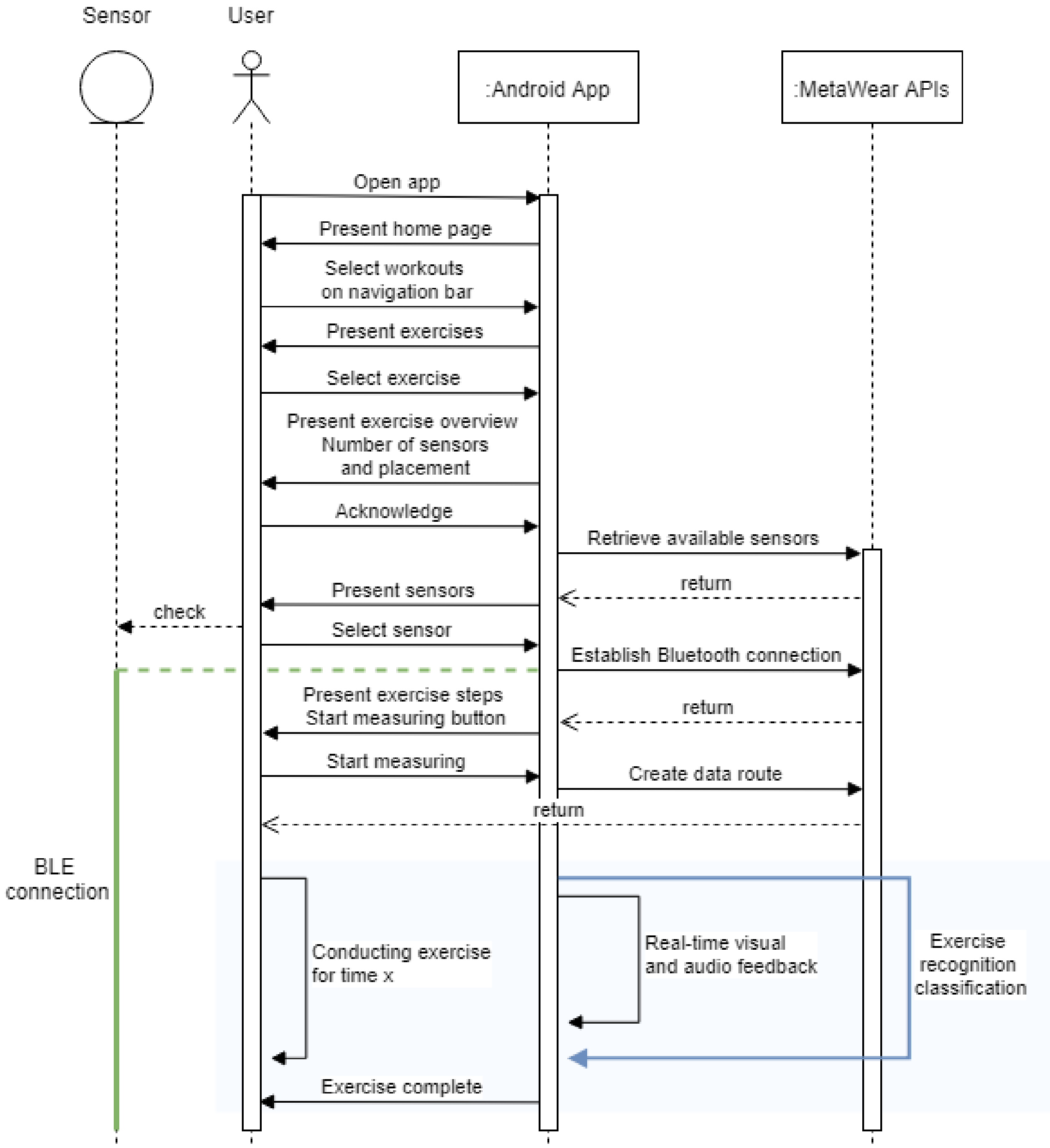


Figure 5.32: Sequence diagram presenting the interaction between the user and the system

As described in Section 5.3.1, the use of the blue highlighting across the Figures 5.32, 5.33, 5.41 is to identity the different viewpoints for the exercise classification; user, programmer, sensor interface.

Table 5.4: Storyboard of the android app for a typical user interaction

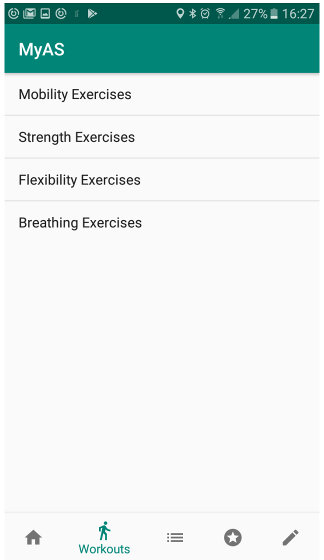


Figure 5.24: Home Page

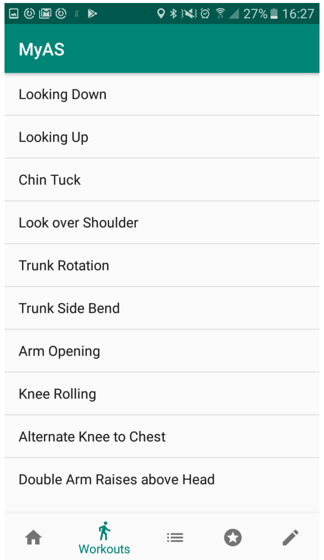


Figure 5.25: Mobility Exercises

Figure 5.26: Sensor Placement

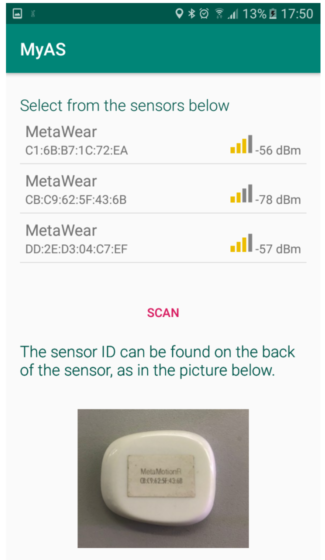


Figure 5.27: Connecting the sensor

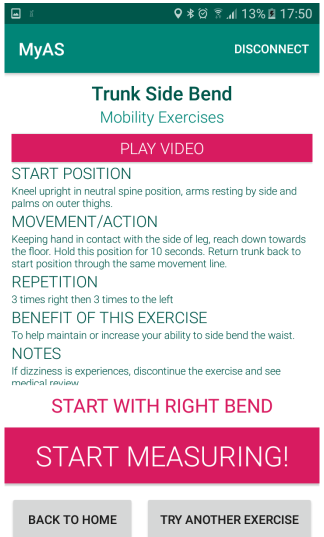


Figure 5.28: Trunk side bend exercise

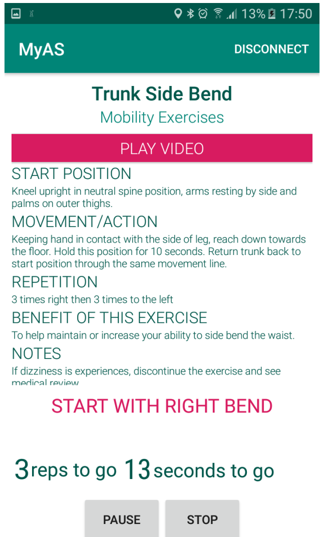


Figure 5.29: Visual, audio and LED feedback

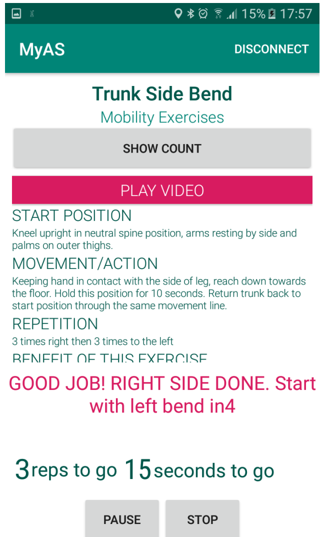


Figure 5.30: Encouragement and educational tips

Figure 5.31: Exercise completed

5.3.2 Steps to classify exercises

As discussed previously, classifications need to be made to identify if an exercise is being performed correctly. To implement this and present a prototype of how this could be implemented in a system to support AS patients, classification for this project refers to pre-programmed exercises rather than machine learning. A high level representation of the steps taken to achieve this is seen in Figure 5.33; (1) **Pre-processing**: using the MetaMotionR sensor to complete the exercise multiple times and log the data (2) **Segmentation**: break down the data to identify how the data values look like when the exercise is performed incorrectly (3) **Feature extraction**: based on the data breakdown, extract the features that make a specific exercise recognisable (4) **Classification**: implement the following using the MetaWear APIs.

5.3.3 Inertial measurement unit and exercise selection

As identified in the approach and tools of the Requirements Chapter, Section 3.5.3, the MetaWearR Mbientlab IMU sensors are used for this project. This section goes into a bit more detail to understand the different measurement units and their limitations. Exercises are selected to explore the capabilities of IMU sensors.

Defining measurements

IMUs are used for multiple measurements incorporating accelerometer, gyroscope, magnetometer, temperature and so on. Each of which can be used as measurement units on their own but have limitations on what it can detect. Accelerometer and gyroscope measurements will be discussed as they related to motion for exercise recognition.

Accelerometers are used to sense motion, static (e.g. gravity) and dynamic (e.g. sudden starts/stops) acceleration. For example, an accelerometer in Nintendo's WiiMote can be used to sense emulated forehands and backhands of a tennis racket or rolls of a bowling ball (*Accelerometer, Gyro and IMU Buying Guide - SparkFun Electronics* 2019).

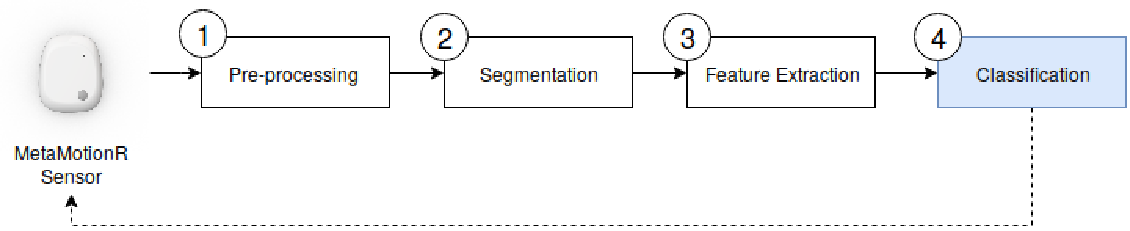


Figure 5.33: Steps involved in the development of the IMU-based exercise classification system

As described in Section 5.3.1, the use of the blue highlighting across the Figures 5.32, 5.33, 5.41 is to identity the different viewpoints for the exercise classification; user, programmer, sensor interface.

Gyroscopes measure angular velocity, how fast something is spinning about an axis. It can be used to monitor the orientation of an object in motion. An accelerometer may not give enough information to know precisely how it is oriented. Angular velocity would be represented in units of rotations per minute (RPM), or degrees per second (/s). The three axes of rotation are either referenced as x, y, and z, or roll, pitch, and yaw (*Accelerometer, Gyro and IMU Buying Guide - SparkFun Electronics* 2019).

In the past, gyroscopes have been used for space navigation, missile control, underwater guidance, and flight guidance. Now they are starting to be used alongside accelerometers for applications like motion-capture and vehicle navigation (*Accelerometer, Gyro and IMU Buying Guide - SparkFun Electronics* 2019). Gyroscopes and accelerometers each have the capability to sense motion. Each alone would not give enough information to obtain the orientation, position, and velocity of an IMU sensor.

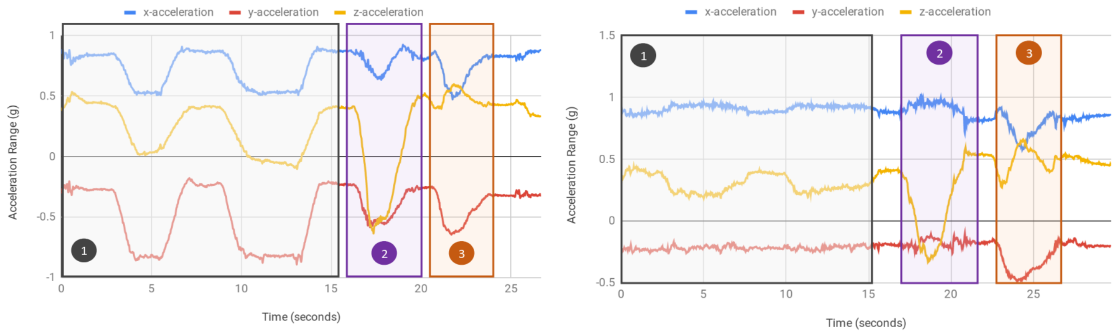
Exercise selection

The use of the different measurement units depend on the exercises implemented; whether it is dependent on motion and/or rotation. An example like that can be seen with certain exercises such as trunk side bend and trunk rotation. A trunk side bend is an exercise taken from the NASS back to action program (Figure 5.35): kneeling upright in neutral spine position, arms resting by side and palms on outer thighs, reaching down towards the floor and holding. The acceleration data for trunk side bend seem to form a specific pattern for the movement as seen in Figure 5.34a, box 1. For trunk rotation (Figure 5.36); kneeling upright, with arms across chest and neutral spine position, turn trunk from the waist as far round as you can. When the exercise is performed correctly, there is slight to no acceleration data detected (Figure 5.34b, box 1). However, it can be seen quite using the gyroscope as seen in Figure 5.40 .To explore the use of accelerometer and gyroscope measurements for exercise recognition, trunk side bend and trunk rotation are chosen and implemented in the android app. More exploration into the accelerometer data presented in Figure 5.34 will follow in Section 5.3.4.

Additionally, bridge exercise was chosen as the third exercise to explore how different orientation and position can yield different measures of acceleration and gyroscope. Bridge is an exercise in which lie on your back, knees bent up and feet flat on the floor at hip distance apart. Arms resting by side, palms down. Lifting buttocks and lower back off the floor into a bridging position and hold. The movement for the bridge exercise is mainly along the x-axis, as such specific deviations from the correct movement can be identified (refer to 5.5 for more details) and accordingly feedback can be presented to the user specific to the wrong movement identified. The use of specific feedback to help the user is further discussed in Section 5.3.5.

Sensor limitations

Beange (2019) studied the validation of wearable sensor performance and placement for MetaMotionR sensors specifically. The works assessed the performance of the MetaMotionR IMUs relative to a 7-camera optoelectronic motion capture system (Vicon 2019) in



(a) Accelerometer data for trunk side bend (Figure 5.35)

(b) Accelerometer data for trunk rotation (Figure 5.36)

(1) Executed corrected (2) and (3) Incorrect movements

Figure 5.34: Comparison of accelerometer data for trunk side bend and trunk rotation

Figure 5.35: Trunk side bend exercise

Figure 5.36: Trunk rotation exercise

both controlled and uncontrolled environments with the main goal of assessing spine movement quality in people with lower back pain. It raised that is MetaMotionR IMUS can be regarded as acceptable for clinical use. Overall, it was revealed that the sensors perform very well in the first movement direction and one secondary axis; however, correlation in the third axis is sub-optimal for orientation estimation and motion tracking. However, refinement of the IMU post-processing algorithms is necessary for overall validation of the sensors for clinical use.

Beange (2019) provided further insight on the IMU accuracy being highly dependent on orientation (Vicon 2019). There is often an inherent human error during sensor placement, and this is especially important when measuring the accuracy of the instrument. There is currently working being done to explore the reliability of sensor placement, as well as combinations of sensors and orientations, in congruence with corrective computational algorithms to attempt to improve on these potential errors. However, this still expresses a limitation that has to be carefully considered especially with home rehabilitation exercises.

More complexity is introduced for specific exercises that would require multiple sensors. MetaWear provides an interface to merge multiple sensors called sensor fusion. The benefit of using this is that already merges accelerometer and gyro, additionally utilising Kalman-based fusion. Kalman filters are commonly accepted as a foundation for orientation algorithms (Madgwick et al. 2011). They filter out statistical noise, gyroscopic drift, and other potential inaccuracies in measurements over time, by using probabilistic determination to predict what the system does next (e.g., position and trajectory of body segments) (Madgwick et al. 2011). The widespread use of Kalman-based solutions demonstrate their level of accuracy; however, the linear regression iterations utilised require high sampling rates that may exceed the sampling bandwidth and demand large computational resources (Madgwick et al. 2011), which may not be ideal for real-time use with mobile applications.

However, the implementation of the Kalman filters in sensor fusion of MetaMotionR acts as a "black box" as there is limited access to the corrective computational algorithm making it hard to identify processing errors. Nonetheless, MetaMotionR IMUs are equipped with on-board sensor fusion and are capable of outputting either Euler or Quaternion orientation. Obtaining Quaternion orientation eliminates the issues of singularity and gimbal lock (Marin et al. 2017); however, it is not as easily interpretable as Euler orientation. Fusion techniques by Madgwick and colleagues are available to implement and customise if required (Madgwick et al. 2011), and are, therefore, possibly another method of exploration for sensor fusion.

For the exercises chosen, there is no need for multiple sensors and would introduce an extra layer of complexity for the user interaction in which it would introduce more limitation in regards to orientation and positions and which sensor is belonging to a particular classification. The use of multiple sensors and exploration of sensor fusion capabilities presents future work.

5.3.4 Exercise MetaWear SDK classification

Now that we have an idea of how the acceleration data looks like. We will be looking at a specific example of how the data can be segmented defining features that make incorrect movements identifiable and implementing the logic using the MetaWear SDK.

We will be starting with the bridge exercise (Figure 5.23), described previously in Section 5.3.3.

Table 5.5: Accelerometer and gyroscope data representing a bridge exercise, divided to represent the ideal movement, and incorrect movements.

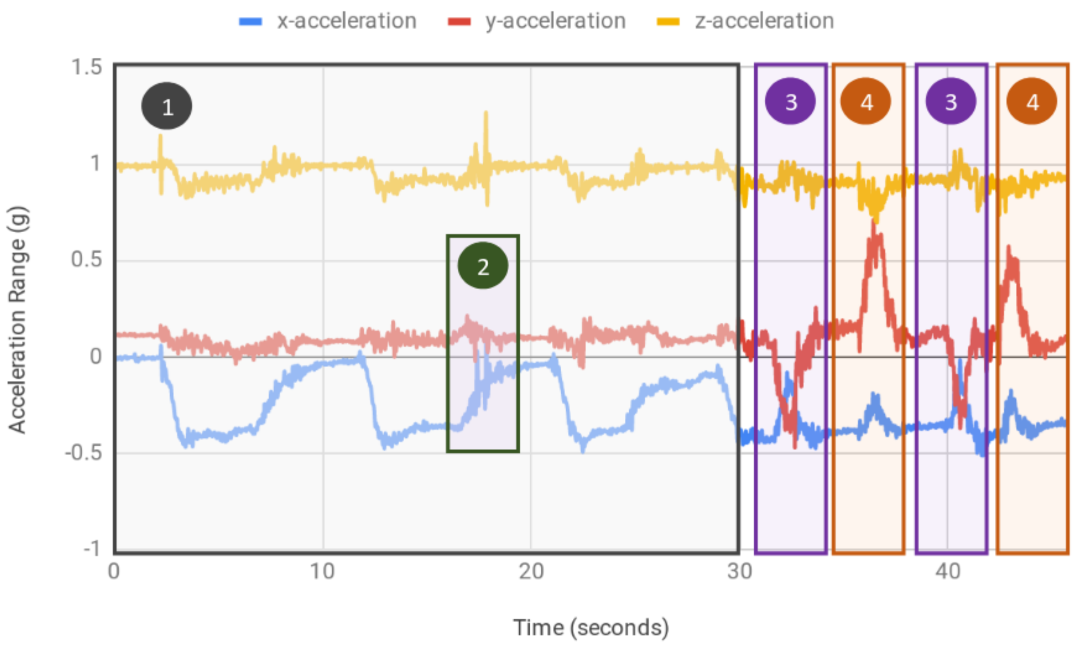


Figure 5.37: Bridge classification and translation

(1) Bridge exercise executed correctly

(2) Arched back or sudden decent

(3) Right side hip dip or slip

(4) Left side hip dip or slip

Referring to Figure 5.37 above, we can see that the movement is axis based in which most of the movement is in the x-acceleration. There are slight movements range of +/- 0.1g from the starting position for the y- and z-acceleration. When incorrect movements are carried out, acceleration is experienced in the other axes of acceleration. The MetaWear SDK is used to manipulate data on-board before passing it to the user. Processors can be chained together to combine multiple operations in one route and so identify the incorrect movements. An example of logic behind the classification is presented below along with the code implemented in the Android app.

Continued on next page

Table 5.5 – continued from previous page

<table>
<tr><th>Data feature extraction</th><th>Exercise recognition implementation</th></tr>
<tr><td>Create data route defining how data flows from a producer to different endpoints. After which, the multicast component creates branches in the route where the same data can pass to different components to be able to detect several incorrect movements.</td><td>Listing 5.1: Creating acceleration data route
<pre>accelerometer.acceleration().
     addRouteAsync(source
         ->
     source.multicast()</pre></td></tr>
<tr><td>A live stream of data to the android device is created to collect the total count for data collection and testing results. The use can be seen in Section 6.4.2, Table 6.6.</td><td>Listing 5.2: Collecting count of the total count for data collection and testing
<pre>.to().count().stream((Subscriber)
    (data, env) -> {
     whileExercising.streamCountTotal
         (data.value(Integer.class));
})</pre></td></tr>
<tr><td colspan="2" align="right">Continued on next page</td></tr>
</table>

Table 5.5 – continued from previous page

Data feature extraction	Exercise recognition implementation

Referring to Figure 5.37, the steady starting position of a bridge lying on the flow starts at around 0. The pause between the repetitions of the exercise should stay at around zero. There could be slight movement of the sensor itself that can yield different results. Identifying an arched back or a sudden movement on decent can be identified when the x acceleration is above 0. Box 2 of the figure shows this, when an slight arched back is carried out.
Implementing this logic, the data is split to obtain the individual x values in acceleration data (index=0). The filter then removes the data whose value does not satisfy the comparison operation. The count tallies the number of data samples received used for data collection and testing. This is then passed subscriber where feedback strategy methods are called. Feedback strategies using audio cues and LED light will be further discussed in Section 5.3.5.
	Listing 5.3: Detecting arching back
	`.to().split().index(0).`
	`    filter(Comparison.GT,`
	`        0.1).count()`
	`    .stream((Subscriber)`
	`        (data, env) -> {`
	`    wrongmoveLED();`
	`    playAudio(12, 7);`
	`    whileExercising.backarched`
	`        (data.value(Integer.class));`
	`})`

Continued on next page

Table 5.5 – continued from previous page

Data feature extraction	**Exercise recognition implementation**

Referring to Figure 5.37, when the exercise is performed correctly, the y-acceleration does not fluctuate much (+/-0.1g). Incorrect movements carried out shifting towards the right or left can be detected along the y values in the acceleration data. Box 3 shows a right hip dip or slipping in which the y acceleration falls 0.5g from the starting base line.
Data processing is implemented similar to before, breaking down the combined data, to get the individual y values acceleration data (index=1). If the data satisfies the comparison operation (y-acceleration¡0), the number of data samples is streamed and passed to the subscribed based on which the feedback strategy methods will be carried out.
	Listing 5.4: Detecting right side incorrect movements
	`.to().split().index(1).`
	`    filter(Comparison.LT,`
	`        0).count()`
	`    .stream((Subscriber)`
	`        (data, env) -> {`
	`    wrongmoveLED();`
	`    playAudio(14, 11);`
	`    whileExercising.righthipdip`
	`        (data.value(Integer.class));`
	`})`

Similarly to the movement before, incorrect movements on the left side can be identified by changes in the y-acceleration. Referring to Figure 5.37, box 4 shows an increase of about 0.5g from the starting base line when movements such as left hip dip, shift or slipping is carried out. The data processing implementation mimics the one above, changing the comparison operation. The right and left side filter was implemented so more precise feedback can be given to the user on how the exercise is performed incorrectly and how to modify it. A similar approach is taken for the other exercises; trunk side bend and trunk rotation.	**Listing 5.5:** Detecting left side incorrect movements
	`.to().split().index(1).`
	`    filter(Comparison.GT,`
	`        0.5).count()`
	`    .stream((Subscriber)`
	`        (data, env) -> {`
	`    wrongmoveLED();`
	`    playAudio(13, 11);`
	`    whileExercising.lefthipdip`
	`        (data.value(Integer.class));`
	`})`

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Table 5.5 – continued from previous page

Data feature extraction	Exercise recognition implementation

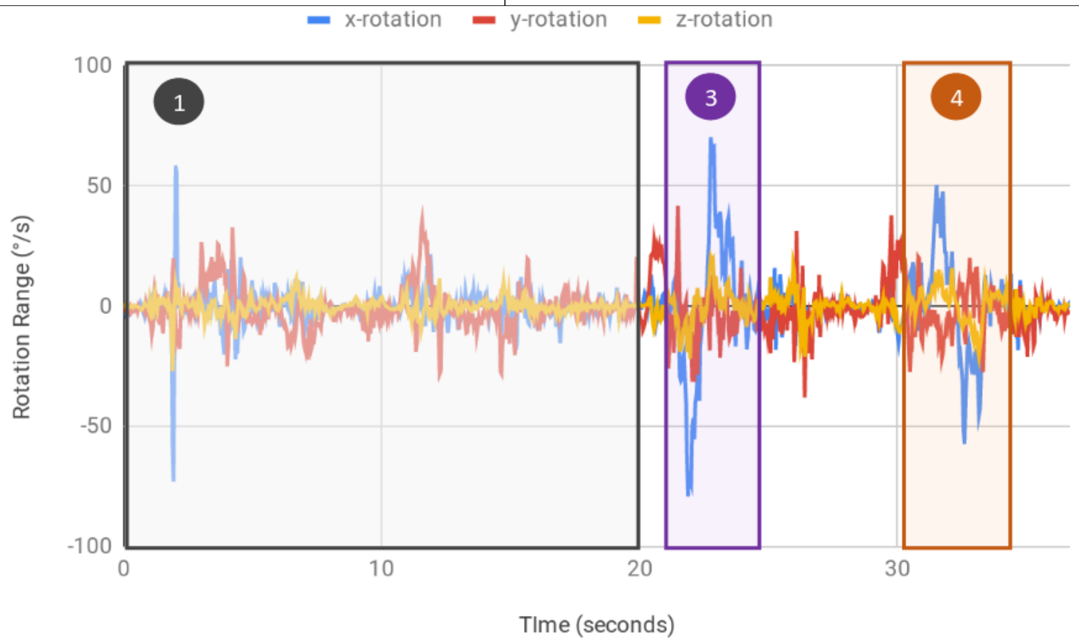

Figure 5.38: Gyroscope Bridge classification and translation

(1) Bridge exercise executed correctly

(2) Arched back or sudden decent

(3) Right side hip dip or slip

(4) Left side hip dip or slip

Referring to Figure 5.38 above, the gyroscope rotation range can not be used to identify a movement. Rather it detects angular acceleration of a movement. Box 3 and 4 show a right and left hip dip respectively, as there is an acceleration about the axis, there is an x-rotation change. The gyroscope can not be used as a single identifier of an exercise. Meanwhile, acceleration could be used as a measurement classifier as a pattern can be recognised with clear features to identify shifts. Nonetheless, a better classification and accuracy would be obtained using both the acceleration and gyroscope.

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Table 5.5 – continued from previous page

Data feature extraction	Exercise recognition implementation

A very similar approach is taken with the gyroscope, creating a data route, forming branches, breaking down the data and carrying out filter comparisons on the data. The data route creation is presented in the adjacent listing. The filter operation implementation use the same methods with different inputs for comparison (less than or greater than 40).	**Listing 5.6:** Creating gyroscope data route
	`gyro.angularVelocity()`
	`.addRouteAsync(source`
	`->`
	`source.multicast()`

For the bridge exercise, we can see that the classification is mainly based on acceleration data. Using gyroscope does add another measure to make sure there is no rotation about the axes. To further explore the possible classifications using the gyroscope, the trunk rotation exercise is evaluated in Table 5.6 extracting defining features of the movement. Less detail on implementation using the MetaWear SDK is presented as a similar approach is followed using filter methods and mapping functions. A similar conclusion is drawn; the rotation along the axis is more defined and thus able to identify when an incorrect movement is performed. However, gyroscope data values cannot be used to identify the exercise being.

In summary, acceleration acts as the main identifier of an exercise where deviation can be extracted. Acceleration is based on the position of the sensor on the body, and thus the start point is one possible identifier of an exercise. Looking at the acceleration data values along the axes present the motion presenting a trend of an exercise that can be extracted. If we look at the acceleration values in box 1 of Figures 5.37 and 5.39 we can clearly see how the acceleration values differ. Meanwhile, look at Figures 5.38 and 5.40, we can see that there is a rotation about certain axes, however, could not be used to distinguish exercises.

Table 5.6: Further expanding on Table 5.5 to trunk rotation based classification.

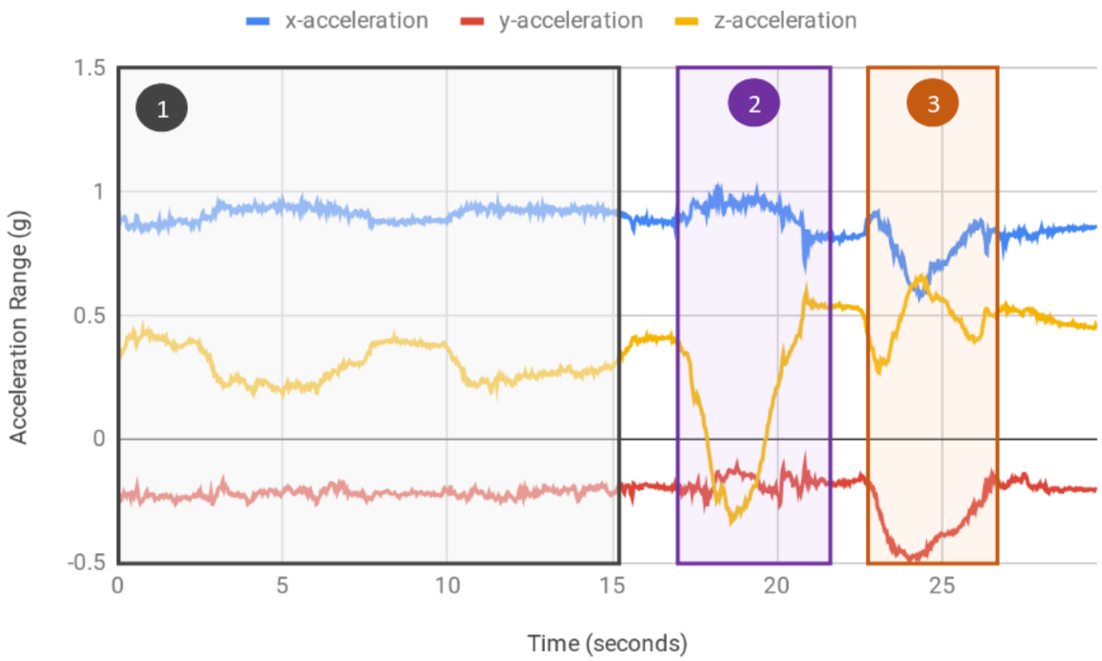

Figure 5.39: Trunk rotation acceleration data values and segmentation

(1) Trunk rotation exercise executed correctly

(2) Bend/tilt forward

(3) Bend/tilt forward

As discussed previously, trunk rotation was chosen as an exercise as to explore the how gyroscope can be used to extract classification features. As seen in Figure 5.39, box 1 represent when the exercise is performed correctly, where the acceleration is relatively steady. There is a small pulse along the z-axis.

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Table 5.6 – continued from previous page

Feature extraction	Exercise recognition implementation

When the exercise is performed incorrectly bending forward or backward during movement as seen in box 2 and 3 respectively, acceleration is experienced along the other axes. Similarly to the implementation process presented in Table 5.5. The identifying factor in the boxes above is the intersection of the axes. As such the map function of the MetaWear SDK is used to mapper subtract the values and based on which make a comparison.	**Listing 5.7:** Data forwarding
	`.to().split().index(0).delay((byte) 1)`
	`.map(Function2.SUBTRACT, accelerometer.acceleration()`
	`.zAxisName()).filter(Comparison.LT, 0).`
	`count().stream((Subscriber) (data, env) -> {`
	`    //tilt back`
	`    wrongmoveLED();`
	`    playAudio(1, 8);`
	`    whileExercising.tiltBackwardFeedback(data.value(Integer.class));`
	`})`

Continued on next page	

Table 5.6 – continued from previous page

<table>
<tr><th>Feature extraction</th><th>Exercise recognition implementation</th></tr>
<tr><td colspan="2">

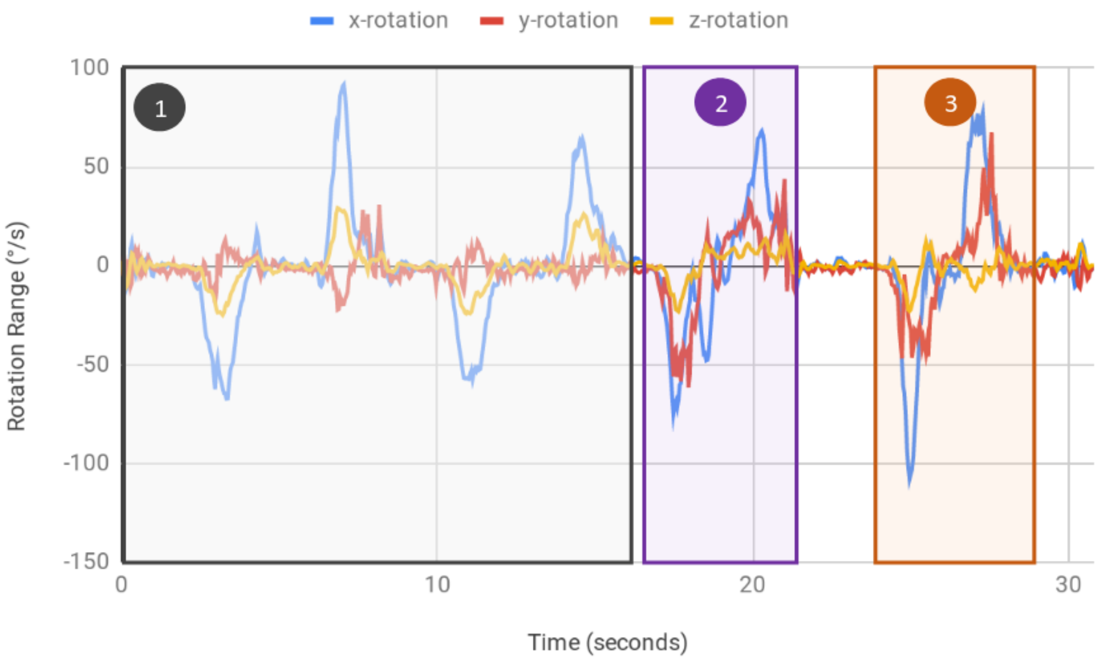


Figure 5.40: Trunk rotation gyroscope data values and segmentation

(1) Trunk rotation exercise executed correctly

(2) Bend/tilt forward (3) Bend/tilt forward

</td></tr>
<tr><td colspan="2">The gyroscope data values present as clear pulse about the x-axis. While this can be used to support that an exercise is being performed correctly by having a pulse. Additionally, there should be small rotation on the y- and z-rotation in which the exercise is performed correctly. Gyroscope data can be used for this exercise to identify that a user has rotated about the correct axes. However, other exercises could present similar trends and as such can be the sole identifier of an exercise.
The implementation of the gyroscope classification for this exercise is similar to the explanation in Table 5.5.</td></tr>
</table>

Figure 5.41 presents an overview of the approach taken to implement the exercise recognition using the MetaWear motion sensors.

5.3.5 Feedback strategies

Feedback strategies are introduced in the system to support users during the exercise. Looking back at literature, feedback strategies, monitoring and accountability act as motivators to adherence and performance. This is translated into the app by the use of audio and visual feedback cues.

Visual cues act as extra support as seen in Figures 5.28 - 5.31. However, it is the dominant form of feedback as it would interrupt the exercise movement and result in tallying of incorrect movements.

Audio feedback ranges in providing guidance on the stage in which the user is at, encouragement and movement correction. This is presented in Figure 5.42 with ex maples of some of the specific audio cues. There are 3 types of audio cues: (1) corrective, (2) recovery and tips, and (3) current state. Correct audio cues are based on the incorrect movements recognised by the system. It informs the user on what is currently being performed incorrectly (if identified correctly). The use of words such as "detect" reminds the user that they are monitored and held accountable, and thus more aware of movements.

The corrective feedback would follow by audio cues on how to modify the movement and/or provide tips on how to do so. The current state audio cues guide the user through the exercises informing them of rep count as well as word of encouragement throughout to keep going. Throughout the exercise further information is given on the benefits of the exercise being performed. As well as safety reminders in case of fatigue or dizziness.

LED was initially set up to urn the green light on when the service is connected. Then to be able to test and observe users, the use of the LED was extended to light RED when a wrong move is detected. The LED red sensor can provide as further support by people around you in which they can signal or let you know when you are completing the exercise incorrectly.

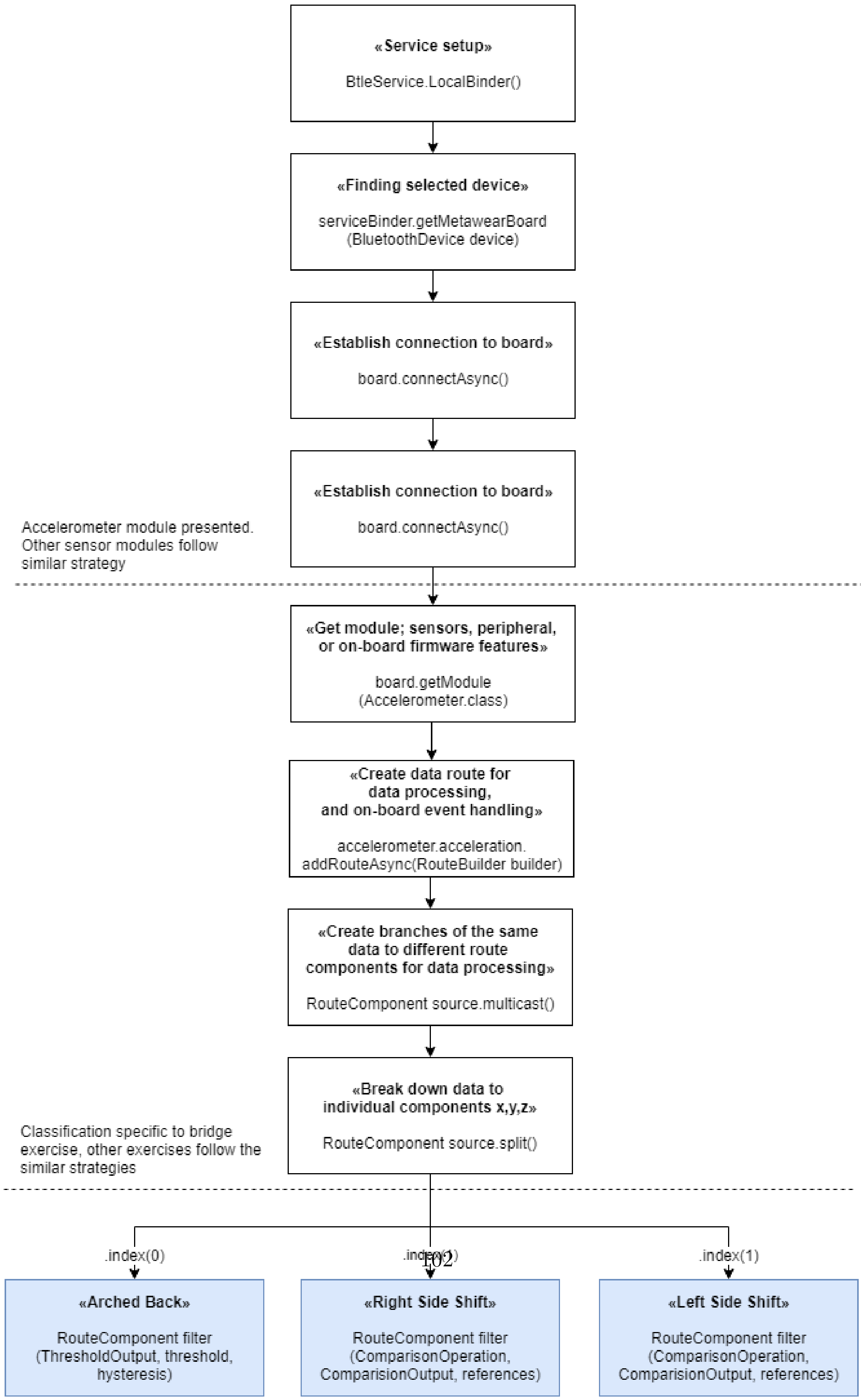


Figure 5.41: Overview of MetaWear sensor connection

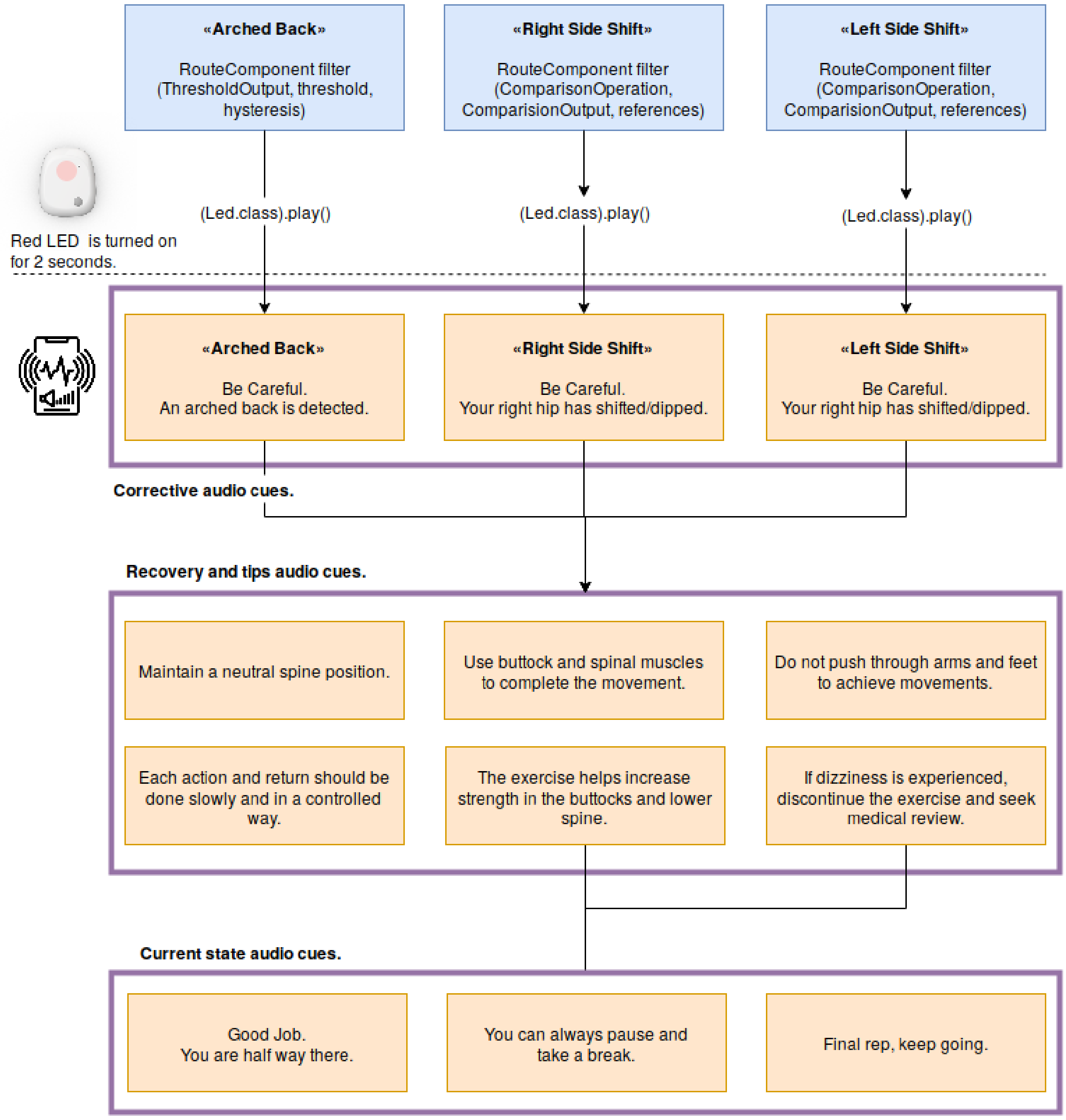


Figure 5.42: Feedback in the exercise recognition implementation

Chapter 6

System User Evaluation and Testing

The previous chapter discussed the strategy of implementation and the decisions taken to address the key factors to support AS patients and promote adherence; self-management, education and exercise. This section will evaluate and test the implementation, and further discussion will be presented to measure if the intended objectives have been met. A user test and evaluation plan will be developed for the self-assessment high-fidelity prototype and the exercise recognition separately, similarly to how the implementation was presented.

6.1 Self-management implementation

Key concepts have been identified throughout the project to determine how to deliver mechanisms for encouraging treatment adherence. For AS patients, education and self-awareness are fundamental, so they are well equipped to self-manage their progression and effectively manage their pain (Cooper et al. 2003).

As presented in Section 5.2, persuasive design principles are used to encourage and motivate behavioural changes by means of self-monitoring, rewards, praise, reduction of complex tasks as well as tunnelling to guide users from one task to another.

This section will expand on the previous chapter to present user tests and evaluate the extent to which the implemented features promote adherence, self-management and usability of the prototype by user evaluation and testing.

6.1.1 User Evaluation Plan

The main challenge here, as mentioned throughout the body of the project, is that there is no access to AS patients to be involved in the testing. To address this an explanation on AS will be given along with a use case in which a user has to act upon for the duration of the user testing, refer to Appendix 8.4 for the transcript.

To evaluate the aims and objectives of the prototype a think aloud protocol will be conducted, followed by an questionnaire. The think aloud protocol examines the usability of a product. It is designed to see whether or not a new user can easily carry out tasks within a given system understanding participants thoughts as they occur and attempt to complete the tasks.

Conducting a task-specific approach for testing targets the specific system components presented in Figure 4.1. The users are instructed to think aloud expressing their thoughts, impression, noticeable features, areas of confusion. Additionally, users are instructed to provide the reasoning behind the task performed keeping in mind the AS use case presented in the beginning of the study. This is fundamental in the test as to identify if an AS patient can also find reasoning and educational content that encourage and clarify why they should use the app and how it can help them.

To further evaluate the implementation, questions specific to AS patients needs, identified in previous chapters, will be raised on completion of a task for the user to express their thoughts on. This is similar to probing asking follow up questions on thoughts and actions as the results could be better linked and evaluated against literature and previous works. Tasks will be presented one at a time as to raise questions appropriately based on each task.

Table 6.1 presents the tasks, along with the guiding questions to follow the tasks, and reasoning to why these specific questions are raised linking to literature and requirements. The questions present a guide and might be answered if a user is speaking aloud as an AS patient.

Simultaneously to the think aloud protocol presented, the assessor will make observations based on a set of guiding questions to evaluate usability. Blackmon et al. (2002) set four guiding questions to be adopted by the assessor:

- Will the user try and achieve the right outcome?
- Will the user notice that the correct action is available to them?Will the user associate the correct action with the outcome they expect to achieve?
- If the correct action is performed; will the user see that progress is being made towards their intended outcome?

Table 6.1: Think aloud tasks along with respective AS patient need reasoning

Task	Guiding Questions	Expectations/Reasoning
Open app. Spend a few minutes on the home page.	What was your first impression of the app? What are your thoughts? What do you think are some noticeable features here?	This is presented as the home page has to be motivational and encouraging especially for an AS patient. There are some educational features here that should be noticeable. This would be desired as an outcome of the tests.
Complete a journal about your experiences today. Spend a minute on the journal page.	What are your thoughts? What do you think are some noticeable features here? Do you think its important to mention the benefits of journaling to the user?	Based on the response on noticeable features would guide the questions. Journaling is a good way for patients to become aware and build self-efficacy over time that needs to recognised. Additionally, on this page tunnelling is used as highlighted in the implementation chapter, to guide a user to completing a self-assessment log.
Enter a new pain log (presenting a the details to be filled in).	Do you think the pain log adequately describes potential pain points? Remember the use case and refer to it again if needed.	A reference to the use case is needed as a user will adjust this every day depending on the mood.
You just completed a pain log. This is one of your daily goals. Go record and check this achievement in your goals.		Goals are presented after the log to guide a user and encourage them to complete their goals as a tunnelling persuasive technique. This is presented to show goals are to recorded. This reward system here is to be highlighted as a user completes a pain log daily a streak will be maintained.

Continued on next page

Table 6.1 – continued from previous page

Task	Guiding Questions	Expectations/Reasoning
After updating your goal progress, add a new goal. Let the goal ideas guide you. Spend a minute on the goal idea page, scrolling through the different options to explore the ideas. Choose and click on Make an exercise plan from the exercise option. Save your goal.	Is the importance of setting goals clear? Do you think its important to mention the benefits of journaling to the user?	Flexibility of goal setting is desired as AS patients needs can vary. The goal ideas should also represent the needs of AS patients and also present recommendations indirectly education the users on what type of goals to set and what to do.
Head back to goal dashboard. Spend a minute on this page.	What are your thoughts? What do you think are some noticeable features here? Is it enough to quantify progress and set personal expectations.	Again here the self-monitoring, accountability and rewards are expected keywords for the following task.
Finally, go to workouts. Spend a minute going over the page, clicking through the options.	Does the page educate you on why exercise is beneficial for AS patients.	Exercise is fundamental to AS. The information should be representative of that. Information should present tips, benefits and further encouragement. These areas should be highlighted by the participant.
The tasks are done. Feel free to play with the app.	Speak aloud on your thoughts on the positives, and if there are any areas of improvement. Is the app user friendly, easy to manoeuvre? Were there any areas of confusion?	As this is an interrupted think aloud this gives a chance of uninterrupted use.

While, think-aloud protocols are a dominant method in usability testing, there are limitations to using concurrent think aloud assisted by probing and questioning. Concurrent think aloud does interfere with usability metrics such as accuracy and time on task. However, these are not important factors for this evaluation. Rather the focus is on obtaining real-time feedback and emotional responses while using the system.

Another limitation of using think-aloud is that it can be biased as the assessor is guiding it rather than relying simply on the tasks. To address this, a questionnaire is conducted following the think aloud protocol as a way to provide impartial feedback. The questionnaire covers basic usability questions on look and feel, recommend to a friend, areas of improvement (refer to Appendix 8.4 for the full questionnaire). The questionnaire again addresses the aspect tailoring to AS patients presenting specific questions on if the app and rating(scale) on if it; provides reassurance, promotes engagement, translates a feeling of personalisation as well as AS-specific supportive functions.

Similarly to the concurrent think aloud protocol presented above, extensions to testing to conduct a retrospective think aloud could be adopted. This is where a testing session is videotaped and reviewed after with the user, asking the them to describe and justify the actions taken. This can be useful in regard to raise questions while watching the video as to not interrupt with a participants thought process. However, the questions raised concurrently while using the prototype are focused on how an AS patient would respond to the tasks which can be hard to recollect. Additionally, it does increase the session length which would discourage participants.

6.1.2 User test plan and procedure

The user evaluation discussed above included 15 participants, majority of which are from a university background as this was the surrounding demographic. Four pharmacy students are sought out as they have better and more clinical understanding of autoimmune and musculoskeletal conditions, therefore presenting as an advantage in this study. Computer Science students are also targeted in order to obtain a more extensive view on the usability and persuasive design principles.

Participant recruitment mainly occurred through personal contacts due to the demographics of the environment. Nonetheless, a variety of different participants were recruited, some of which were sought out due to having specific sets of skills and knowledge. For example, recruiting users with knowledge of rheumatic diseases and their treatments, such as pharmacists. As well as recruiting personal trainers and instructors, so as to provide insight into the appropriateness of the exercises and the motivational aspects. Finally, to ensure the test results are representative of a wider audience, two participants were included within the age of forty to fifty one years old.

The platform used to develop the prototype is integrated with a user testing platform, Validately (*Validately: Powerful User Research* 2019). This enables remote moderated and unmoderated user testing. Tasks can be set along with follow-up questions that are presented based on the screen a participant is currently on. Using this platform is more time consuming and requires more planning, however it enables a wider demographic; targeting participants ranging from thirty to forty years of age.

The purpose of the test is to evaluate the usability and user interaction, as well as raise questions as presented in Table 6.1.

Each session would last around 15 minutes for the self-management think aloud protocol (all participants proceeded to complete the exercise recognition android app testing). The sessions mostly took place in university booked rooms.

Upon arrival, the participants are required to sign a consent form. It is clarified that no compensation will be received. The AS use case (refer to Appendix 8.4) is then presented to them, following which they have a few minutes to ask any questions. Then the self-management prototype is presented on a mobile phone. The same phone is used for all participants to control the usability feedback received. The tasks are given one-by-one on cue-cards, and follow-up questions are asked accordingly. The tasks are defined above in Table 6.1.

On completion, the participants are free to answer the questionnaire provided anonymously, in order to reduce the possible bias.

Face-to-face participants then continue on to test the exercise recognition implementation further discussed in Section 6.3.

6.2 Self-management prototype results

6.2.1 Participant Demographic

Table 6.2: Table presenting the user demographic for testing

	Number of participants	Female:Male	Age		
			Mean	SD	Mode
Self Management Prototype	15	8:7	25.36	8.21	22
Exercise Recongition Prototype	10	5:5	25.90	9.41	22

The user testing strategy discussed in Section 6.1.1 above was conducted with 15 participants. The test plan was carried out, 10 of which were conducted face-to-face and 5 on the Validately platform. Table 6.2 presents the demographic representation.

6.2.2 Evaluation Results

Positive feedback was received on the usability and interactivity of the prototype. The use of the the navigation bar was expressed as intuitive and gives an overall idea of what is expected from the app; "immediately you see the point the app is trying to tackle; working out, logging, setting goals and journaling. It is clearly labelled, which helps you realise exactly how to navigate it and what to expect when using it."(p12) General usability comments were good; nice icons, informative and motivating use of videos (Figure 5.6), easy to read font, eye catching colour schemes, positive placement of streak next to goals (Figure 5.7), interactive response of the pain description slider (Figure 5.1). However, the colour of the safety and workout button was criticised as it does not stand out, change of colour would encourage action upon it.

The home page was expressed by all participants as motivational and encouraging - "Good encouraging word and mottos"(p2). Through the think aloud protocol participants expressed their expectations if it was a functional app and most of those met the expected answers discussed in Table 6.1. A participant expressed that the videos would be new everyday which acts as a would encourage her to open the app in which the motivational messages and streaks would promote achieving these goals.

From the home page, all users went to complete a journal and then a pain log after. The use of these persuasive techniques was recognised by participants without the need for prompt questions discussed in Table 6.1; participants expressed the positive presentation of the past pain log, and weekly logs for journals on the same page as reminder to do the pain logs. Additionally, three participants liked the comparison between the journal being "expressive" versus the pain log which is more "subjective". On pain log competition presenting the goals as a remind was confusing to some participants.

Idea suggestions (Figure 5.19) in goals were expressed as "good because they are simple and achievable, people will not feel discouraged to use" and "support the AS use case as they can be personalised and suited to my needs"(p6). Additionally it was expressed that "filling out the goals and choosing them it becomes more personal with the motivation to follow through."(p10) However, it took participants a few seconds to find the idea button, modifications are to be made for more prominent placement.

The description of sleep in the self-assessment (refer to Figure 5.4) was mentioned as to confuse some people because what is normal for one may not be normal for others.

One of the challenges expressed in Section 5.2.4 was further highlighted by some participants as the use of some quantitative data was expressed to track average journal entry per week or per month for example, and similarly to exercise. The use of quantitative for the general population does act as a beneficial persuasive technique. This was addressed in the prototype by the maintaining streak count as it counts the progress at the pace at which an individual sets it.

The educational aspects were highlighted as beneficial, clear and provides good content especially the "Why exercise" (Figure 5.14). The workout categories were specifically expressed as beneficial as it "focuses on specific areas AS patients struggle with" giving a sense of personalisation. However, the presentation needs to be addressed as it was "not easy to follow and people will be discouraged to read through it"(p1).

The information on each exercise (refer to Figure 5.15) was expressed as "very useful because people forget and disregard the importance of basic exercises"(p2). The positive reaction to the following suggests further addition of the educational aspects by embedding it into the app presented as the patients would use the app. This is implemented in the exercise recognition prototype to be further discussed in Section 5.3.

Table 6.4: Table representing the responses questionnaire to the post think-aloud protocol on the self-assessment prototype. Refer to this with Table 6.3

	Q1	Q2	Q3	Q4	Q5	Q6
P1	5	5	5	5	5	5
P2	4	4	4	4	5	5
P3	5	5	4	4	5	5
P4	4	5	4	4	5	5
P5	5	4	3	4	5	4

Table 6.4 continued from previous page

P6	5	5	4	4	4	4
P7	5	5	4	4	5	5
P8	5	4	4	5	5	5
P9	5	4	4	5	5	5
P10	5	5	3	4	4	5
P11	4	4	4	5	5	4
P12	5	4	4	5	5	4
P13	4	4	4	4	5	5
P14	5	4	4	3	4	4
P15	5	5	5	4	4	5
MEAN	4.73	4.47	4.00	4.27	4.73	4.67
MODE	5	4	4	4	5	5
SD	0.46	0.52	0.53	0.59	0.46	0.49

The post think aloud questionnaire reflected the similar results to the think-aloud protocol. Participants were asked to rate features and characteristic on a scale of 1 to 5. The results are presented in Table 6.4. The average rating on all questions were between 4 and 5; supporting the incorporation of self-management factors such as education. Additionally, the results of from the think-aloud protocol highlight the motivational strategies, and is re-enforced by the questionnaire presented by (Q5) with a mean of (4.73). The standard deviations were not significant, thus signifying that the participants has similar experiences.

6.3 Exercise recognition implementation

The focus of the testing for the exercise recognition system is on evaluating and analysing the use of the system and how the use of sensors and real-time feedback can help users' self-efficacy and awareness of ones own movements that they become comfortable with maintaining regular home exercise.

Software and unit testing was not extensive for this prototype. Testing was conducted on the components of the system for the purpose of error prevention during user testing. This product will not be released to patients for clinical use yet, it is implemented for this study as a proof of concept.

Table 6.3: Table representing the questions to the post think-aloud protocol questionnaire on the self-assessment prototype. Refer to this with Table \ref{tab:pos-question}.

Q1	How likely is it that you would recommend the product to a friend or patient suffering from Ankylosing Spondylitis (AS)?
Q2	How well do you think the app meets the needs of the AS patient's use case, defined before the study?
Q3	How satisfied are you with the look and feel of this app?
Q4	To what extent is the app personalised to the user's needs?
Q5	To what extent does the app promote engagement?
Q6	To what extent does the app educate you on the importance of engaging in non-pharmacological treatments, especially exercise?

6.3.1 User evaluation plan

Classification test measures

Similarly to what has been discussed in the strategy for the self-assessment prototype (Section 6.1.1), there is no access to AS patients to evaluate the system and receive feedback. As such a brief will be given about AS along with a use case in which a user has to keep in mind for the duration of the user testing, refer to Appendix 8.3 for more detail.

The test strategy for the exercise recognition implementation will focus on analysing the accuracy of the system against the exercises completed. This approach will be less guided than the prototype as the functional app should stand alone. High-level tasks will be set in which participants will have to complete the exercises and appropriately respond to the instructions by the app to wear the sensors and start measuring.

The user testing will be carried out by volunteers that are not undergoing rehabilitation and with no current or recent musculoskeletal injury that would impair their exercise performance. Therefore, deliberate incorrect movements will be instructed while using the sensors as to measure the accuracy and get an appropriate feedback response to guide the user back to the correct movement and function. As described in Section 5.3.4, exercises are pre-programmed in which possible deviations from the correct form are identified and translated in the implementation using the MetaWear SDK.

Based on the movements, there are 4 measures of accuracy for the recognition of each move. True positive (TP) refers to movements that have been performed correctly and recognised as such by the system no incorrect movements were detected while a false negative (FN) represents movements that have been classified as incorrect though performed correctly. True negative (TN) is a movement that has been performed incorrectly and the system detected it as such. Whereas a false positive (FN) is where a movement was performed incorrectly yet the system failed to detect this and the movement was classified as correct. The classification of a move is determined per repetition of the exercise; if the movement was performed incorrectly and initially recognised as TN, then it will be counted as such, even if the user had corrected it and was given feedback that it was a TP.

To be able to tally the the indicators above during testing and make the appropriate observations, the LED light of the sensor will turn on when the system recognises and incorrect movement (as seen in Figure 6.3). The absence of an incorrect move is then specified as correct. Audio cues are also played when an incorrect action is detected for the user to respond.

To measure the quality of the exercise recognition, accuracy, sensitivity and specificity will be calculated. Accuracy is the number of correctly classified repetitions of all the exercises divided by the total number of repetitions completed. This is calculated as the sum of the TPs and TNs divided by the sum of the TPs, FPs, TNs, and FNs. Sensitivity measures the effectiveness of a classifier at identifying a desired label, whereas specificity measures the classifiers ability to detect negative labels. As the implementation is based on negative labels, the evaluation results will more closely look at the accuracy and specificity measures.

More details on the test plan and procedure to be carried out by the volunteers will follow in Section 6.3.2.

The total number of data samples of an exercise is recorded along with the number of incorrect data samples. The data is presented on exercise completion (Figure 6.1). This data can be analysed based on the number of incorrect movements carried out to get an average of duration of incorrect movement and recovery from the movement.

User interaction evaluation measures

As to evaluate the incorporation of real-time feedback using the sensors and appropriate feedback on observations will be made on the users reaction to the feedback and the response time in which the user will go back to the correct movement.

Additionally, after completing the exercises, an semi-structured interview will be completed to get insight on the user interaction and their thoughts while completing the exercise. (A think aloud protocol will not be asked of the participants as this would interrupt the real-time audio feedback flow.) The interview questions will address similar points raised in the self-assessment questionnaire as to evaluated the compatibility of the system to AS patients. The following guiding questions will be used:

- How did you feel while you were completing the workout?
- Was the feedback motivational and encouraging?

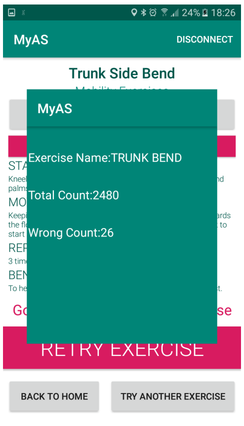


Figure 6.1: Screen showing the data sample count

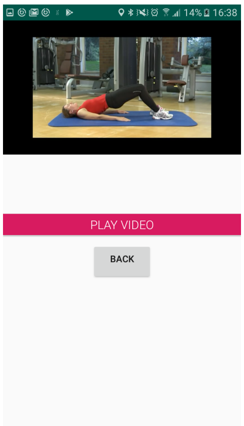


Figure 6.2: Screen showing YouTube video

Figure 6.3: Showing red LED light while testing

- Did you feel the system provided appropriate feedback relative to the sensor data and movement being conducted?
- Did the implementation using the sensor give you feel reassured? Was the feedback too repetitive (warning-like)?
- Did you feel the sensor supported you while performing the exercises helping you carry them out better?
- If you were experiencing back pain, would you be comfortable using this as regular home exercises without a physiotherapist to support you, given they have approved these exercises before hand.

6.3.2 User test plan and procedure

The participants are the same from that involved in the testing the self-assessment prototype in Section 6.1.2. The use case explaining what AS, the symptoms and what they look for in a system is presented to them again (refer to Appendix 8.3 for the use case). Upon which 2 sensors and a mobile phone is presented to them. The same equipment is used for all participants as to ensure the same usability. A few minutes are given to participant to navigate through the exercise recognition app and ask any questions. The app in itself should be explanatory on the set-up and use of the sensor and as such a tutorial is not presented.

A cue card presenting the 3 exercises to be completed are given to the user with instruction on the number of deliberate mistakes to be made.

- **Trunk side bend** (Figure 5.35): This exercise involves 6 repetitions of the movement where the participant would hold the move for 10 seconds. The participant is instructed to do 3 deliberate incorrect movements.

- **Trunk rotation** (Figure 5.36): This exercise involves 6 repetitions of the movement where the participant would hold the move for 10 seconds. The participant is instructed to do 3 deliberate incorrect movements.

- **Bridge** (Figure 5.23): This exercise involves 10 repetitions of the movement where the participant would hold the move for 5 seconds. The participant is instructed to do 4 deliberate incorrect movements.

Freedom is given to user in terms of when and how they will deliberately make the mistakes; this ensures objective results so that limitations of the classification can be recognised. No further guidance is given about the exercises or how to perform them as the app should support and guide the user through it. Based on which, the three metrics defined above - accuracy, sensitivity, and specificity - will be measured to assess the recognition quality of each participant for each of the 3 exercises.

Additionally, the following variable are to controlled for this test as to collect quantitative results:

- The orientation and location of the IMU must be consistent across all study participants.
- The IMU sampling rate and sensor range settings are identical across all IMU data when using multiple sensors.

6.4 Sensor-based app results

6.4.1 Participant Demographic

The participant demographic representation is presented in Table 6.2.

6.4.2 System evaluation results

Table 6.5 demonstrates the mean accuracy and specificity scores for all participants conducting the three exercises, as specified in the user test procedure (Section 6.3.2). As described in Section 6.3.2, a fixed number of deliberate mistakes is performed in each exercise, in order to measure the system's classification performance and accuracy.

The system was least accurate for bridges (71.00%) and most accurate for the trunk side bend (85.17%) across all participants. This may have been observed due to the complexity of the bridge exercise, which is prone to several different error labels that may have not been identified. Moreover, the accuracy did vary across individuals, as seen in the represented standard deviations (Table 6.5), which can be associated with the considerable standard deviation of the age of the participants (9.41) (Table 6.2); resulting in variable exercise execution performance.

For all the exercises, the sensitivity was higher than the specificity; the system was better at detecting either correct movements or those performed incorrectly but mis-classified as acceptable, than it was in detecting incorrect movements. Sensitivity and specificity

Table 6.5: Exercise recognition mean accuracy, sensitivity and specificity classification evaluation measures

Exercise	Accuracy, %		Sensitivity, %		Specificity, %	
	Mean	SD	Mean	SD	Mean	SD
Trunk Side Bend	90.71	13.11	93.33	14.05	88.33	15.32
Trunk Rotation	88.33	13.72	100.00	0.00	76.67	27.44
Bridge	87.00	13.37	96.67	7.03	72.50	24.86

should have similar results, such that there is no bias to either correct or incorrect classification while an exercise is performed. The current higher sensitivity is as a result of the implementation approach discussed previously, where the system only detects incorrect movements, therefore a correct movement is represented by the absence of the incorrect movement. Referring to a specific example, the trunk side bend has about a 7% chance that an acceptable repetition may be classified as incorrect, and about a 12% chance that an incorrect exercise may be classified as acceptable.

Table 6.6: Table presenting the

Exercise	Incorrect move data count, %		Incorrect data count per move, %	
	Mean	SD	Mean	SD
Trunk Side Bend	6.44	1.72	2.15	0.57
Trunk Rotation	5.31	0.76	1.77	0.25
Bridge	3.48	0.73	0.87	0.18

Table 6.6 shows the average number of data samples classified as incorrect against the total number of data samples for the exercise across all participants (the raw data can be found in Appendix, Table 8.3). The percentage represents the number of incorrect data samples detected for the whole session. This number is representative of the duration at which a wrong move is detected and the time it took to correct it (recovery time). To obtain a value representative of the time spent in an incorrect position and the recovery from it, the number of data samples is divided by the number of deliberate incorrect moves instructed during the session. Trunk side bend has the largest data sample count in an incorrect movement in comparison to the other exercise implemented, 6% of session was spent in a position detected as an incorrect move. However, this is still a small percentage of the session, implying that the feedback cues successfully guided the user to correct their form and complete the exercise correctly, in a timely manner.

Dividing the samples by the number of repetition according to exercise gives an average of how much time is spent on one incorrect movement. The smaller the data sample, the quicker the participant was able to recover. The results imply and further highlight that the feedback cues helped educate and encourage the user to correctly perform the exercise.

6.4.3 Observations and post-interview results

Observation were made throughout the session on the users reaction to feedback and their response to it. The main observation from the session was that when users realised that audio cues and feedback is given, the participants fully relied on it without looking at phone at all. This identifies the need for the audio feedback to fully guide a user through the exercise. Additionally, users could become too reliant on the use of the sensor to correct them and give them support throughout the workout that they are not able to exercise without it.

In the interviews following the exercise completion, users presented positive feedback on the system that it has guided them. All participants expressed that the audio cues are much easier to follow than text based. The immediate feedback when doing the feedback was positively received as participants were able to "fix the movement right away". The audio cues were easy to understand thus making the recovery quicker. Participants used words such as “encouraging” and “motivating” when describing the audio messages.

A participant emphasised the educational value the tips and benefits provided throughout the workout gave, as they were able to associate the moves and exercises with the feedback received. Reference to educational aspects were also presented by another participant, referencing that the exercise recognition system is a “learning tool” of the exercise presented.

Monitoring and performance were mentioned during the interviews: "Having real-time feedback that tells me if I am performing the move incorrectly, I want to prove to myself that I can complete the exercise without any incorrect moves detected." Several participants wanted to try conducting the test again without any deliberate mistakes as to see whether they are performing the moves correctly. This immediate reaction from the participants presents the potential that AS patients would similarly respond to it and maintain regular exercise.

Two of participants still expressed the need for some support by the physiotherapist as to prove the sensor is actually presenting correct feedback. A participants mentioned that home rehabilitation would have to be carried out for cases like these, the use of the sensors is a better alternative then nothing at all as it guides and supports you through the exercise.

Nonetheless, some concerns are raises as to how the exercise recognition can be adapted to more complex exercises using gym machines and equipment. Additionally, a participant expressed the need for training on the use of the sensors in case of trouble shooting; what to do if the sensor can not be found or are not connecting? Another participant raised a concern if the motion sensor was not working and the user is not aware of it. However, this issue should not occur as the exercise tracking would not initiate if a sensor connection has not been made. There could be cases in which a sensor would disconnect and then try re-connecting.

For the first participant some trouble was experienced when clipping the sensor on a top. If it were loose, then it would keep falling forward in which the classification of the exercise would be inaccurate. This was modified to ensure the sensor was stable and fixed by tying the shirt to tighten it, and instructing further participants to wear sports shirts. However, in a real-life setting, this could be an issue. Possible adaptation and extensions are discussed in the future works (Section 7.2.3). Sensitivity to orientation and placement is a large factor to the success of a classification.

Chapter 7

Discussion and Conclusion

7.1 Discussion

The reviewed literature identified that low adherence to treatment is a major barrier to achieving optimal treatment outcomes for AS patients. To overcome the barrier of low adherence, self-management and self-efficacy need to be introduced into a patient's everyday life. These key aspects are evident in the systems to support AS patients.

Testing was carried out to evaluate whether the requirements and problem description have been addressed. The results from user testing and evaluation support the requirements and design aspects that were identified as fundamental for AS patients. A discussion will be presented below to further evaluate the results in Sections 6.2 and 6.4.

7.1.1 Self-management prototype

We started the project with the initial problem we are aiming to address; AS patient often struggle with the unpredictability and chronicity of the disease. Not only that, but their treatment plan is complex, requiring high levels of adherence. However, treatment non-compliance is present across all chronic conditions, with 50% non-adherence across RD patients (DiMatteo et al. 2007). This can be affected by a patient's behaviour, different economic and cultural backgrounds, and a lack of understanding of the importance of maintaining treatment, managing several treatment plans as well as possible issues between the patient and the health provider (Bugni et al. 2012, Elliott 2008).

Commonly adherence is addressed through measures of monitoring and accountability. However, as alluded to before, adherence can be affected by emotional and behavioural states. Self-management and self-efficiency are critical factors in addressing these factors to improve adherence; as the patient is encouraged to be more involved in his/her treatment (Hammond & Freeman 2004). This is mainly achieved by incorporating education and self-efficacy such that the patient is aware and believes that the treatment will yield progress and help relieve pain; encouraging long-term adherence and improving treatment outcomes (Marks 2001). As such, motivational strategies have to be applied to the patients' lifestyle to promote compliance.

These key aspects have been translated in the requirements, design and implementation. User testing and evaluation in Sections 6.2 and 6.4 have presented positive results in these areas.

This is done through the implementation of a self-management app prototype and an exercise recognition android app. Whereby the self-management prototype incorporates self-assessment to log pain progression and mood, journaling to explore emotions especially ones associated with AS experiences and goal setting as a measure of accountability and monitoring. Educational aspects are added to each component to highlight its benefit and why the patient should continue to engaging with the app.

The first impression of the app by participants was about the clarity of its objectives, whereby the home page - supplemented by the AS use case - clearly define the features that the user should engage in, including physical exercise, logging, setting goals, and journal. Several motivational and encouraging aspects were also highlighted, such as the use of videos and motivational phrases that encourage people to use the app continuously. The presentation of goals on the home serves as a reminder and provides re-enforcement for the user that they have been achieving and can achieve their goals.

Remarks on motivation and encouragement were identified in the results. Participants expressed their liking towards having motivational aspects on the home page as it encourages people to further explore and use the app. Moreover, the fact that the goals paired streaks and motivational messages would encourage repeat use.

These motivational strategies further encourage self-assessment, journeying, and goal setting all of which are important for self-awareness.

The goal streaks and percentages were explicitly noted as motivational; users would feel competitive in achieving goals to ensure the streak continues. This is also a form of monitoring and accountability. Upon using the goals and the goal ideas, they recognised the importance of educating the user on what type of goals they should be trying to achieve. The goal ideas were described as "helpful suggestions if confused or overwhelmed. Offering guidance on what to do. It is wholesome, as it gives ideas and guidance to improve the overall quality of life."

Personalisation was constantly brought up during the think-aloud protocol: • the pain log was expressed by all participants as descriptive • the "addition of notes makes it more personal" • "when creating a goal the option to write something to motivate me is more encouraging than a generic motivation quote, it would definitely encourage more and personally remind me why I want to achieve this goal" • creating and modifying workouts specific to AS and what an individual would want to work on (Figure 5.12). This is additionally expressed in literature (Section 2.9.2) and requirements (Table 3.2, SR1).

The emotional and behavioural state of a patient is addressed by the implementation of self-assessment logs and journaling. A user can express themselves, as presented in the results. On the journal page, multiple participants scrolled through to previous days to review improvements and the progress of what they have been doing. A participant highlighted the importance of the journal title to be able to see improvements and compare them against the pain logs presented below; "People often do not realise if there is a reason you are emotionally feeling a particular way on one day. Seeing my pain log below the journal entries helps me correlate my feelings with my pain experience, to see if pain level and emotional well-being affect one another. ".

Several educational features were raised during testing to support the user and clarify the importance of why they are carrying out specific tasks. These were highlighted as beneficial, clear and provide useful content - especially the "Why exercise" (Figure 5.12). Participants highlighted the placement and colour choice making the "Why exercise" prominent. A participant added a remark on the phrasing whereby "reading the words puts it in mind; why should I exercise? I should be exercising." However, the presentation of the educational sections needs to be addressed as it was "not easy to follow and people will be discouraged to read through it"(p1). Presenting it as text would only attract users who are looking for the information, but would otherwise be discouraged. This goes back to literature on the Fogg Behavioural model 2.1 were it would require a high level of ability and motivation to achieve the task. Reducing the ability needed to complete the task by making it more appealing and interactive would address the issue.

Inclusion of education dynamically while completing tasks was better received such as the presentation of goal ideas as a way to indicate what kind of goals and changes a user should adopt. Additionally, participants using the exercise recognition system received real-time feedback on tips and benefits of specific exercises. Participants expressed that the correlation of the benefits of an exercise would relate to the movement conducted where they would remember it better.

As such, the incorporation of dynamic response and messages acts as an educational opportunity by relating it to user input. For example, when creating a goal based on exercise, the system can inform the user that it is best for AS patient to exercise in the morning. When a user is completing the self-assessment log, and the symptoms present that of a flare, the system should appropriately present information to the user on managing flares (Figure 5.17). Rosser et al. (2011) have additionally identified the need for dynamic and intelligent response to patient experience and behaviour, highlighting the need for more discussion and documentation of therapy adaption to technology-based delivery.

One of the challenges expressed in Section 5.2.4 was further highlighted by four participants as the use of some quantitative data was expressed to track average journal entry per week or month for example, and similarly to exercise. The use of quantitative for the general population does act as a beneficial persuasive technique. Individuals diagnosed with AS can vary quite often whereby it is difficult to set a generic data measures for evaluation.

This was addressed in the prototype by including a streak count, which is personalised to the individual's own goals and the pace at which they would like to achieve it. However, some patients might want more quantitative data as a measure of accountability and motivation. To be able to introduce quantitative measures a mechanism to input days in which flares and fatigue is fundamental as to present that there has been a setback, still, the user is self-aware and has taken the steps to manage and respond to flares. Potentially for this implementation, an option can be added to settings to enable quantitative data throughout the system. Nonetheless, further research and exploration will have to be looked into to define the quantitative measures of progress for people with chronic and unpredictable diseases.

The prototype is a starting point identifying the key factors needed to support AS patients such that they are self-aware and have the education to be able to take the appropriate step to manage their condition. The decision made had been drawn from literature and justified at every stage. The expectation set to each task of the user testing and evaluation in Table 6 have been raised by participants.

Next steps involve implementing the system and addressing the limitation described above; to present more dynamic messaging and responses such that education becomes part of the interaction rather than a point of reference. Additionally, more literature review and exploration need to be carried to identify quantitative measures of progress for people with chronic and unpredictable diseases.

7.1.2 Exercise recognition and motion sensors

Exercise has been called-out in various self-management interventions as it improves the overall quality of life, releases pain, and improves function . As such, this project addresses the use of smartphone and sensor technology to support adherence incorporating self-management, education, and exercise.

The workout and exercise section is presented in the self-management prototype as a non-pharmacological treatment to relieve pain and improve function (Figure 5.12). This is expanded upon to implement an exercise recognition app using MetaWear sensors and SDK to identify if exercises are performed correctly. Real-time corrective and encouraging feedback is presented to guide the user through the exercises.

The system evaluation (Table 6.5) shows a high accuracy for the exercises implemented. However, to get a more representative classification and reduce the bias towards correct classification, the systems need to additionally support correct movement recognition and/or further identify error labels of exercise deviations.

It is difficult to make comparisons to previous works as the implementation approach varies. Comparisons can be made to similar systems in terms of specificity measures as it best represents the classification of the system.

Rehabilitation systems using motion sensor vary in their approach. Some studies have introduced the use of multiple sensors to more preciously recognise movements (Fennema et al. 2019, e.g.). It can enable more precise feedback on incorrect movements and is better suited for complex exercises. However, for this implementation, economic factors are raised to relieve health care costs and burden on the health care professional. Though the IMU sensors are relatively cheap, they might not be attainable by all patients, let alone those requiring several. Additionally, the NASS back to action program present exercise as involving targeting and isolated movements. One sensor would be enough to recognise the move, an introduction of a second sensor could be used to ensure the stability of the other muscle groups.

The testing results present successful measures of recognition. Nonetheless, the evaluation focuses more on the use of motion sensors to provide feedback to help the users correct their movements. This is representative in the results by the short time spent in

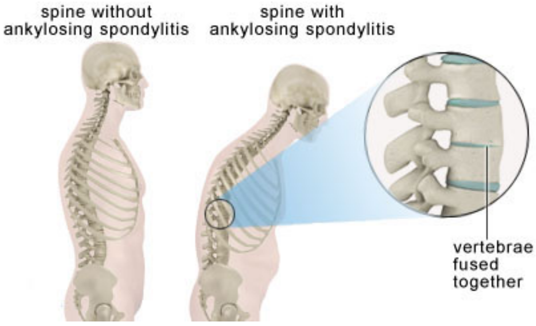


Figure 7.1: Advanced case of spine with ankylosing spondylitis

the incorrect form of an exercise; signifying that the feedback cues guide the user to the correct movement with quick recovery time, as presented in Table 8.3.

The feedback is positively received as there is a short recovery time for an incorrect movement throughout the exercises as presented in Table 8.3. Additionally, users gave positive feedback that the audio cues were encouraging and descriptive. Even the absence of corrective feedback at times throughout the exercise would provide them with the reassurance that they are completing the exercise correctly.

Therefore, a key benefit to using motion sensors is that it provides users with reassurance on the exercise performed by giving feedback on when it is performed incorrectly and how to modify it. This is further supported not only by the quantitative measures above but also by the post-interview conducted with participants who appreciated the implementation of the correction and recovery cues (Figure 5.42).

This system shows the app's potential in patient education, emphasised by the positive reaction participants have had to use of the motion sensors, and the sensor-rich data supplied to the app to give guidance. A participant called it a "learning tool" to correctly perform exercises and keep improving to increase mobility.

However, this raises an area for concern as some AS patients maybe not have the capability to conduct the exercise in the correct form. They would be instructed on completing exercises regularly to regain muscle memory and increase function of certain muscle groups. It can act as a learning tool to help guide the user to perform the exercise better. However, the feedback can become too repetitive and warning-like, where the participant would be discouraged to continue exercises as the app would keep saying that the movement is wrong. As derived from literature (Swann-Sternberg et al. 2012), there needs to be a balance between reassurance and warning. Some logic is implemented in the app such that if the incorrect movement count is too high, then the correction audio cues are no longer played (Figure 5.42). Nonetheless, there is still a range of incorrect movement data samples that may discomfort the user. The system could have an option to turn off the corrective cues, other tip and state audio feedback would still be given.

A similar issue is raised with the use of the sensors, as in advanced cases of AS the posture would be compromised (refer to Figure 7.1). Therefore, the performance of the exercise - though correct for the specific patient according to his/her capabilities - would be classified as incorrect according to the current implementation. The system would have to address this similarly to the discussion before, whereby logic needs to be added so as not to warn the user too often, and an option needs to be presented to turn off the corrective feedback. Another possible solution, in this case, would be to set a baseline for the classification of moves per user or advanced cases. This would involve a system in which a user's starting point is tailored to their posture according to each move; standing up, lying down, or kneeling. The classifications are then adjusted according to the posture and starting position the individual is capable of achieving. This would require system support for first-time use, which must be supported by the physiotherapist to set a correct initial baseline.

The exercise recognition system has been implemented for three exercises with positive feedback received on the incorporation of sensors to guide a user and allow self-monitoring of progression of mobility and function. This further supports that there is potential for such technologies to enter the market, as people are willing and excited to adopt them to further involve themselves in bettering their health. Nonetheless, it will need further development to add other NASS Back to Action exercises and address the limitations above as described.

Upon full implementation, rheumatologists would be able to review the self-assessment and journals carried out by the user. While the physiotherapist is comfortable that the patient is completing the exercises, supported by sensors; encouraging them to increase and maintain muscle movement and function.

7.1.3 Persuasive technology

The implementation requires behavioural changes to be carried out by the patient. As such persuasive design principles are adopted in the system.

For the self-management implementation, the concurrent think-aloud protocol explained the participant's reasoning behind the navigation through the app; re-enforcing the positive application of tunnelling as a design principle. Reduction was also introduced using a bottom navigation bar; participants positively expressed this as being clearly labelled thus encouraging and guiding AS patients to focus on achieving specific objectives. Moreover, as previously mentioned, the use of virtual rewards on completion of goals and logs presented by streaks (Figure 5.6) was highlighted as motivational, encouraging the user to maintain the streak number competitively.

Participants have also identified the use of persuasive design principles linking to the AS use case. Specifically, the tunnelling technique from journals to pain logs was identified. A participant expressed how when on the swiping through different days on the journal page 7.2, it allowed self-realisation of a trend and to realise if there is an association between how they were feeling as a result of or in relation to the pain experienced that day.

The use of smartphone technology for a patient to be able to carry out self-assessment has been identified by rheumatologists as expressed by Raj Sengupta, a Consultant Rheumatologist and Lead for Ankylosing Spondylitis at The Royal National Hospital for Rheumatic Diseases, during a talk on Inflammatory Arthritis Machine Learning and Digital Technologies(Sengupta 2019). He expressed the lack of such technology as they currently mostly

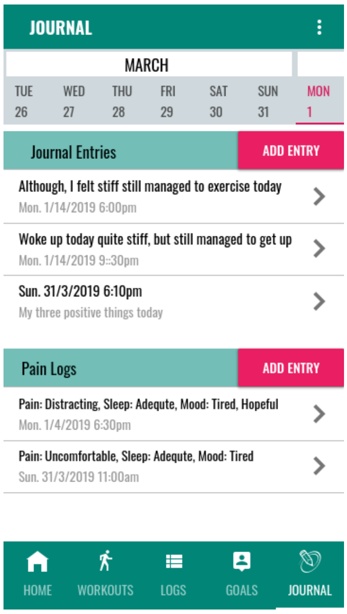


Figure 7.2: Journal page with pain logs presented below was a tunnelling technique

rely on the ASQoL survey for regular self-assessment (Zochling 2011). The ability for smartphone technology to be tailored and connected to other wearable technologies poses an opportunity and potential for self-monitoring and real-time feedback. The exercise recognition app presents this by tracking one's performance, which has been expressed by participants as beneficial to improve movement form and encourage the repeated use of the app so as to perfect movement based on the sensor feedback. There are several success measures of persuasive technologies promoting behavioural change presented in the results and discussion above.

However, several questions emerge on designing for long term support, by offering support of an individual's behavioural development over time. This prototype has been intentionally designed to support users of varied capabilities and dealing with unpredictability; through flexible goal setting, in which a user can set their milestones and challenges. However, there is still more to be done, as expressed in the results. Participants have raised the use of quantitative measures of progress as a possible persuasive strategy. However, literature has identified studies (Rosser et al. 2011) in which quantitative measures intimidate and worry AS patients that there has been little to no progress, regardless of all the effort put in.

Fritz et al. (2014) study the long-term use of activity sensing devices for fitness. The findings using point systems such as Fitbit alluded to not enough coverage of persuasive design; initially, devices helped foster engagement in fitness but later were unable to support increasingly sophisticated fitness priorities. Also, participants of Fritz et al. (2014)'s study had to extend their reward system on their own accord by incorporating real-world rewards or other tools. An example of a participant, using Striiv, who made donations to charities by completing fitness challenges. Such external rewards can be adopted by the system to donate towards AS causes, for example, the National Ankylosing Spondylitis Society.

7.2 Conclusions

7.2.1 Project Achievements

The project is targeted to address the prevalence of rheumatic disorder diagnosis, where it now affects over eight million people of all ages, with this number is increasing every year ((*About rheumatic disease | Nuffield Foundation* 2019)); largely and negatively impacting economic and social care systems. Initially, the project aimed to use technologies solely to facilitate exercise adherence to reduce burden and costs and encourage exercise as a non-pharmacological treatment.

However, during the research phase to deliver the literature and technology survey, the underlying problem was that there are several factors affecting a patients performance and adherence to treatment; such as patients behaviours, different economic and cultural backgrounds, possible issues between the patient and health-care provider, and a lack of understanding and appreciation of the importance of adhering to the agreed treatment (Bugni et al. 2012, Elliott 2008). To address these factors, studies identified the need for self-management and self-efficiency to improve adherence; as the patient is encouraged to be more involved in his/her treatment (Hammond & Freeman 2004).

In light of this, contribution has been made in identifying and stressing the need for consideration and innovation in the delivery of treatments and content, and what form that should take. These were derived from extensive use of literature and technology, presenting discussion and documentation on challenges RD patients face, as well as present strategies to address these through self-management, education and exercise. This was delivered by designing appropriate technologies to address the challenges and findings in the field.

The self-management prototype was developed based on the findings, tailored to help and support AS patients self-manage and adhere to treatments. This has extended on similar works by incorporating several non-pharmacological treatments, for exampling journaling and education. In comparison, Rosser et al. (2011) presented a system which can carry out self-assessment and set goals, while other (, e.g.) systems present the exercises to be carried out. The implemented system provides a platform for self-assessment and monitoring supported by educational aspects, resulting in increased awareness and better equips patients to handle their pain and progression.

Further contribution is drawn from literature by applying the Fogg Behavioural Model to identify persuasive design features explicitly needed for individuals with limited mobility and chronic diseases. This is successfully translated in the design of the self-management app as supported by the user testing and evaluation, as expanded on in the discussion (Section 7.1.3).

Additionally, the exercise recognition app uses smartphone and sensor technology to explore the impact of real-time feedback on exercise performance and adherence. This project has presented the successful implementation of real-time multimodal feedback as supported by the user testing and short recovery time elaborated upon in Sections 6.4.2 and 7.1.2. The use of wearable sensors makes the user more aware of their movement and can monitor their progress based on the real-time feedback received. Users will be encouraged to continue carrying out the exercises to develop further and/or maintain perfect form with no corrective feedback. This is also supplemented by the use of educational tips and benefits audio cues throughout the workout.

In summary, this project contributes a set of considerations and designs using smartphone and sensor technology to encourage adherence and support self-management for AS patients.

7.2.2 Problems overcome and lessons learnt

The tools, approaches and decision made throughout the course of the project have been justified by the Literature and technology survey and further supported by the results of user testing and evaluation. However, upon implementation, some obstacles were faced.

Having had limited experience with Android and motion sensor development, it took me a while to get up to speed and be able to start implementing the exercise recognition app. Obstacles were specifically faced when using the motion sensors app. Initially, I tried using the sensor fusion implementation of MetaWear to incorporate both acceleration and gyroscope in one measure. The application of sensor fusion in the MetaWear SDK is a black box; therefore, it was difficult to understand how it works. Additionally, there was not much documentation and sample apps to support my development. As discussed in Section 5.3, this was addressed by initialising separate time-stamped gyroscope and acceleration data routes.

Moreover, during testing and evaluation, the sensor sensitivity imposed a struggle. For the exercises in which the sensor was to be clipped on a top, if it were loose, then the classification of the exercise would be inaccurate. This was modified to ensure the sensor was stable and fixed by tying the shirt to tighten it, and instructing further participants to wear sports shirts. However, in a real-life setting, this could be an issue. Possible adaptation and extensions are discussed in Section 7.2.3 below.

Furthermore, during testing, I realised that incorporating new technologies requires time for the person to become comfortable and confident in using them, even if they are open to adopting new technologies. Therefore, tailoring the implementation to address a specific audience is fundamental when incorporating multiple technologies. Although the exercise recognition implementation does instruct the user on how to connect the sensor and the green LED light would turn on to signal a connection, instruction on troubleshooting the sensors were not considered.

It was essential to get a representative pool of participants for testing and evaluating. However, this was limited due to the demographics of the surrounding environment. I did manage to include some participants with knowledge of AS, including a certified fitness instructor, pre-registration pharmacists, and participants within the 40-50 age range (refer to Table 6.2). However, that resulted in a significant standard deviation (8.08) of the participants. More effort should have been placed to get a more representative participant pool.

The increasing number of diagnosed individuals and the strain of health and social care systems validate the imperative need for technological opportunities to support and encourage RD patients; through self-management and home exercise. However, I had overestimated the rate at which users would adopt new technologies over the more traditional ways. Adapting therapeutic practice from transitional face-to-face to technology-based delivery introduces other challenges for therapists, patients, and the health care professionals involved. Nonetheless, this system can act as an adjunct to the current treatment methods; adding value to therapeutic approaches rather than replacing it. It is used to make sure that patients take on an active role in their treatment and actively work to maintain a good quality of life.

7.2.3 Future Work

Limitation and feedback have been identified throughout the discussion above in Section 7. Extension and future works have been identified on these aspects respectively. Nonetheless, there is still more work that can be done.

Extending work

The implementations of the project present a prototype of ways to facilitate non-pharmacological treatment for AS patients using smartphone and sensor technology. This work has identified key factors and design principles for implementation. Extensions of the work would be to start implementing the prototypes incorporating the self-management prototype and the exercise recognition app into one system. The results have positively identified the potential for the system to help AS patients become more self-aware and encourage repeat use of the app, to maintain goals and receive real-time feedback on exercises completed using the sensors. However, due to the limitation of not having access to health care professionals and AS patients does mean there is still more to be done to evaluate the system's effectiveness further.

Data and social support are areas identified in the literature, but set out of scope for the duration of this project. Future work can be done to evaluate the potential of sharing the data from the implementation directly from the patient to the appropriate health-care professional. Studies have identified that the data needed by health-care professionals can vary from what is presented to patients, which have been hidden to not overwhelm them with quantitative data (Balaam et al. 2011, Huang et al. 2014). Providing such detailed information can assist health-care professionals in optimising a patient's treatment, as the data could indicate issues that need to be addressed. However, data integration into clinical-flows is quite limited due to privacy and security concerns attached to health-care, as presented in the literature. More studies and evaluation are encouraged.

Persuasive design principles identify social support as a mechanism for promoting behavioural change by leveraging social influence (Oinas-Kukkonen & Harjumaa 2008). Berdal et al. (2018)'s findings show that 52% of participants had goals regarding social interaction with others, contributing to and carrying out social activities. Future work could look into applying social support design principles such as social learning, cooperation, and, competitions tailored to RD patients specific needs. There is potential in extending this to provide further motivation and persuasion; participants highlighted the potential for outreach through the app by sharing videos and articles on the home page with others, thus forming community support.

Additionally, (Riemsma et al. 2003) concluded the implementation of group cognitive-behavioural approaches to be effective in improving adherence with self-management over the use of traditional educational methods constrained by time and feedback (Riemsma et al. 2003). Applying several strategies in conjunction, carrying out group exercise can be seen as motivator and encouragement improving self-efficacy across several individuals.

Section 5.3.3 has identified some limitations to the use of IMU sensors, whereby the classification is highly dependent on the placement and orientation of the sensors. Different strategies can be adopted to address this. Incorporation of sensors into caps or clothing is a possible solution, but it would reduce the versatility of the ability to place the sensors. Potentially, fusion and filtering techniques to determine placement and orientation can be explored. This is present in the MetaWear sensors but is limited as it acts as a black box. Madgwick et al. (2011) present fusion techniques that can be implemented with the MetaWear motion sensors.

Similarly to a study conducted by Beange (2019), the exercise recognition system could be validated against the University of Bath Camera Lab, to be able to evaluate further and achieve more accurate and supported classification measures; in order to identify the weakness of the classification and modify them.

Gap in literature

Throughout the course of this project, gaps in literature were identified to help support the implementation of self-management system for individuals facing chronic and unpredictable diseases.

As mentioned in Section 6.2, user evaluation liked the use of goals and streaks as a quantitative measure of progress and would like other quantitative measures. However, due to the unpredictability and chronicity of the diseases, setbacks and fluctuations are expected, and flares can quite often limit one's ability to carry out everyday tasks. Personalised and flexible goals are implemented to address the potential for quantitative measures of exercising to be discouraging when setbacks are experienced. However, further research and exploration to identify the quantitative measures of progress for people with chronic and unpredictable diseases is highly encouraged.

Additionally, more studies are required to evaluate the extent to which exercise can help relieve pain and stiffness. While individual cases differ, quantifying the impact of exercise can be used to enhance exercise adherence as well as give an indication to users when they should seek medical review in case of extreme pain.

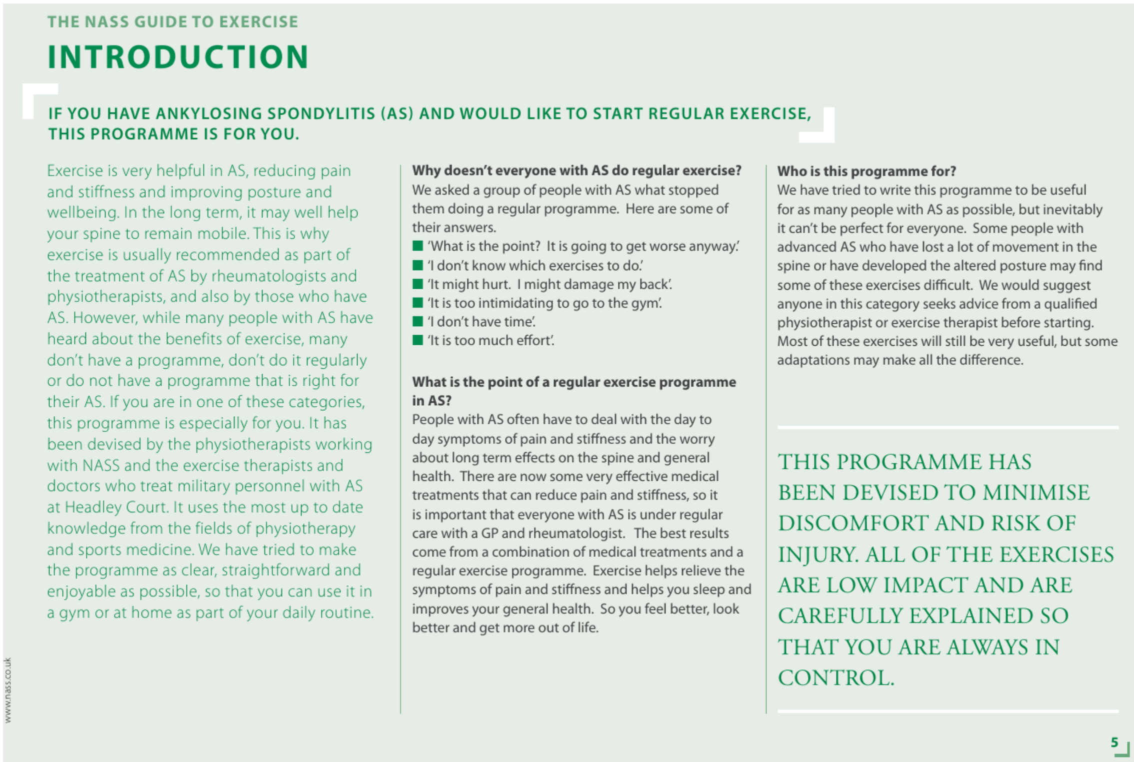
7.2.4 Project Summary

This project has achieved all that it initially set out to do, with the goal to facilitate non-pharmacological treatments through technical delivery. The project made extensive use of literature and technology, presenting discussion and documentation on challenges RD patients face and offering strategies to address these through self-management, education and exercise. The literature and technology survey presented helped better inform the requirements and design of the implementation and identify strategies and approaches of technical delivery. Based on the requirements, persuasive design principles and literature discussed in Chapters 2 and 3, a two-part implementation was carried out; (1) self-management prototype to present non-pharmacological treatments, assisted by educational aspects such that patients become more self-aware and persuasive design strategies to promote behavioural changes. (2) exercise recognition system using wearable sensor technology to facilitate real-time feedback encouraging better performance and repeat use. User testing and evaluation was conducted to assess areas of successful implementation and areas of improvement. Lastly, the report concludes with a discussion of the project as a whole, including what went well and what could have been done better, ending with possible future and extension of the work.

Chapter 8

Appendix

8.1 NASS Back to Action Programme



THE NASS GUIDE TO EXERCISE

INTRODUCTION

IF YOU HAVE ANKYLOSING SPONDYLITIS (AS) AND WOULD LIKE TO START REGULAR EXERCISE, THIS PROGRAMME IS FOR YOU.

Exercise is very helpful in AS, reducing pain and stiffness and improving posture and wellbeing. In the long term, it may well help your spine to remain mobile. This is why exercise is usually recommended as part of the treatment of AS by rheumatologists and physiotherapists, and also by those who have AS. However, while many people with AS have heard about the benefits of exercise, many don't have a programme, don't do it regularly or do not have a programme that is right for their AS. If you are in one of these categories, this programme is especially for you. It has been devised by the physiotherapists working with NASS and the exercise therapists and doctors who treat military personnel with AS at Headley Court. It uses the most up to date knowledge from the fields of physiotherapy and sports medicine. We have tried to make the programme as clear, straightforward and enjoyable as possible, so that you can use it in a gym or at home as part of your daily routine.

Why doesn't everyone with AS do regular exercise?

We asked a group of people with AS what stopped them doing a regular programme. Here are some of their answers.

- 'What is the point? It is going to get worse anyway.'
- 'I don't know which exercises to do.'
- 'It might hurt. I might damage my back.'
- 'It is too intimidating to go to the gym'.
- 'I don't have time'.
- 'It is too much effort'.

What is the point of a regular exercise programme in AS?

People with AS often have to deal with the day to day symptoms of pain and stiffness and the worry about long term effects on the spine and general health. There are now some very effective medical treatments that can reduce pain and stiffness, so it is important that everyone with AS is under regular care with a GP and rheumatologist. The best results come from a combination of medical treatments and a regular exercise programme. Exercise helps relieve the symptoms of pain and stiffness and helps you sleep and improves your general health. So you feel better, look better and get more out of life.

Who is this programme for?

We have tried to write this programme to be useful for as many people with AS as possible, but inevitably it can't be perfect for everyone. Some people with advanced AS who have lost a lot of movement in the spine or have developed the altered posture may find some of these exercises difficult. We would suggest anyone in this category seeks advice from a qualified physiotherapist or exercise therapist before starting. Most of these exercises will still be very useful, but some adaptations may make all the difference.

THIS PROGRAMME HAS BEEN DEVISED TO MINIMISE DISCOMFORT AND RISK OF INJURY. ALL OF THE EXERCISES ARE LOW IMPACT AND ARE CAREFULLY EXPLAINED SO THAT YOU ARE ALWAYS IN CONTROL.

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Figure 8.1: NASS Back to Action programme introduction
(*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019)

THE NASS GUIDE TO EXERCISE

THIS PROGRAMME WAS DESIGNED BY SPECIALISTS IN SPORTS AND EXERCISE PHYSIOLOGY. IF YOU USE THIS PROGRAMME, YOU WILL KNOW EXACTLY WHAT YOU ARE DOING AND WHY.

I don't know which exercises to do.
If you have AS, the priorities are to remain fit and healthy and also to promote good mobility of the spine and good posture. There is a huge range of exercise regimes on offer these days, designed to promote fitness or to improve sporting skills or simply to look good on the beach. They are usually good advice but not necessarily good for AS. This programme uses the most effective exercises for AS. The authors have years of experience prescribing exercise and have designed it so that it shouldn't take too long to get the full benefit.

It might hurt. I might damage my back.
This programme has been devised to minimise discomfort and risk of injury. All of the exercises are low impact and are carefully explained so that you are always in control. The programme starts with a warm up, followed by mobility, cardiovascular fitness and strength training with flexibility and breathing exercises at the end. You start with the basic programme and only progress when ready. It shouldn't hurt, but you will feel the stretching and probably feel pleasantly tired at the end of the cardiovascular section. You may notice some muscle soreness for a few days after doing the strength section. As with all medical conditions, you should check with your GP before starting the programme.

It is too intimidating to go to the gym.
Most people feel intimidated when they first go to a gym. They always seem to be full of super-fit people. In reality most people don't have much direction and many of the most eye catching exercises don't make you much fitter or stronger. This programme was designed by specialists in sports and exercise physiology. If you use this programme, you will know exactly what you are doing and why. This will be very obvious to the staff in the gym and to anyone there who is serious about fitness.

I don't have time.
Not having enough time is one of the commonest reasons for not exercising, so we have kept the programme as short as possible. The full programme has been designed to take 30 to 40 minutes, so it can be done in a lunch break or early evening. If you don't have that long, it can be broken down into shorter sections.

It is too much effort.
This is probably the most difficult objection to answer! You may believe that exercise is important and that the programme is effective, clear and easy. But if you never enjoyed exercise and now on top of that have developed the pain and stiffness of AS, it can seem a lot to ask. All we can say is that many people have found it enormously worthwhile; it really does help your symptoms and can be great fun and great for your confidence. So why not give the programme a serious try? Read the rest of the introduction, pick up some kit, earmark some time and get started.

Dr Tim Jones
Consultant in Rheumatology and Rehabilitation Medicine
Defence Medical Rehabilitation Centre,
Headley Court

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Figure 8.2: NASS Back to Action programme introduction - continuation (*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019)

THE NASS GUIDE TO EXERCISE

REMEMBER:

REMEMBER TO SEEK MEDICAL ADVICE if you become faint, short of breath, dizzy, unwell or experience unaccustomed chest pain during any exercise session.

SAFETY/POINTS TO REMEMBER

- **Some trained gym staff** may not have heard of ankylosing spondylitis and may not understand how it affects you. Take time to explain your condition and use this guide to help discuss what exercise you should be focusing on (see page 65).
- **Don't overdo it.** Keep within your limits. Some people overdo it when they first start.
- **Don't expect** all gym equipment to look the same. Often different makes of gym equipment are set up slightly differently, so ensure a trained member of staff has shown you how to use each piece of equipment safely before you start. Don't overdo it.
- **You will have good and bad days** where you are able to do a bit more or may need to do a little bit less.
- **Pick a good time of day** to exercise – most AS patients experience some stiffness and pain in their spine or joints in the morning, so this is probably not a good time to exercise.
- **Don't worry** if you have some mild aches or pains when you are exercising. This is normal for people with AS. The pains should ease off after the exercise session is completed. If you have anything more than mild aches or pains that do not ease after the exercises, stop and seek medical advice.
- **Focus on stretching** anterior muscle groups (muscles at the front of the body – abdominals, pectorals and biceps).
- **Focus on strengthening** extensor muscle groups (muscles at the back of the body – lower back, trunk, shoulder blades and buttocks).
- **Use a regime** that involves low weights and high repetitions – remember you are trying to stay mobile, strong and healthy. You are not training for a weight lifting competition.
- **Maintain a good posture** with all of your exercises. Neutral spine is an important part of this and is explained in the next section.
- **Stay motivated** – you may not notice big changes in your appearance but remember the exercises are to help you stay healthy, mobile and to help maintain a good posture.
- **Vary your exercises.** Remember that you need to do a mixture of strengthening, cardiovascular and stretching exercises.

The best programmes are individually tailored. This is our recommendation to get you started. It gives most of the benefits and shouldn't take too long. As you get fitter you may want to progress. For this, we would recommend that you consult an experienced exercise therapist or physiotherapist who knows about AS.

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Figure 8.3: NASS Back to Action programme safety tips (*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019)

THE NASS GUIDE TO EXERCISE

PROMOTING GOOD POSTURE-NEUTRAL SPINE

■ Looking from the side, the normal human spine at rest has three gentle curves: at the small of the back; between the shoulder blades; and at the neck.

■ During movement, these curves may flatten or increase, but the closer they stay to their original shape, the better, because this shape leads to less strain on the ligaments and joints and therefore less risk of pain or injury. This position of good posture is often called the neutral spine position.

■ Unfortunately, the pain and stiffness of AS encourages the spine to hunch forwards and over time, the spine may lose the ability to straighten back up.

■ Here is a checklist that you can use to educate your spine to keep in a good posture. We suggest that you do this as often as possible through the day and while doing these exercises.

Line drawing by Caroline Silver Lewis

STARTING POSITION:

Stand with the feet shoulder width apart and grip the pelvis between the fingers at the front and the thumbs at the rear. Starting at the top is the best way to visualise correcting your posture. Making a mental check list is a good way to help.

1 **Head position**
2 **Shoulder position**
3 **Hand position**
4 **Pelvis position**
5 **Knees**

1 Draw the chin in but keep the head vertical aiming to line up the ear lobe with the mid line of the shoulder. This will bring the head back towards the mid line of the body (figure 1). Another way of thinking of this is to imagine that you are holding a tennis ball under your chin.

2 Draw the shoulders downwards towards the feet and lengthen the collar bones so your shoulders are open but NOT pinched back. Try to utilise the muscles in the mid and lower back rather than those at the top of the back. This will draw the shoulders back so they are not rounded, opening the front of the chest.

3 If your shoulders are rounded then you will find your hands tend to rest on the front of your thighs. To correct this you need to draw your arms, shoulders and shoulder blades back so your hands are now resting on the outside of your thighs (palms resting on your trouser seam).

4 To understand figure 2, the correct position of the pelvis, imagine that you are holding a bucket of water. Tipping water out of the front of the bucket will tip the pelvis forwards and vice versa. Working only in a range of movement that is comfortable, tip water out of the front, then back of the bucket, several times. At this point, stop in the mid position. Then slowly tip the bucket forwards to gently dribble water from the front of the bucket (slightly anteriorly tilted).

5 Finally, fully straightened knees can contribute to bad posture. Therefore softening and slightly bending the knees will help.

PRACTISE THIS AS OFTEN AS YOU CAN

Figure 1

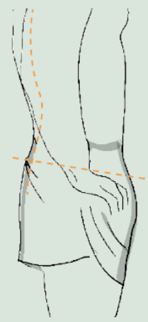

Figure 2

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Figure 8.4: NASS Back to Action programme posture tips
(*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019)

THE NASS GUIDE TO EXERCISE

WARM UP

- You should always warm up prior to any exercise session and especially before stretching.
- A warm up does exactly what it says it does and warms up your body by increasing the blood flow to the working muscles. This prepares your body for exercise and means the muscles are ready to exercise and are less prone to injury.

WARM UP IN THE GYM:

Static bike or cross trainer for 5-10 minutes on easy to moderate resistance. You should be able to hold a conversation throughout your warm up and not get out of breath. Remember even during your warm up you should be aware of your posture in sitting or standing and if using the cross trainer try not to let your chin poke forward.

WARM UP AT HOME:

March on the spot or use a bottom stair for step ups or else go for a walk for 5-10 minutes. You should be able to hold a conversation throughout your warm up and not get out of breath. Remember even during your warm up you should be aware of your posture in standing and if doing step ups try not to let your chin poke forward.

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Figure 8.5: NASS Back to Action programme before exercise warm-up (*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019)

THE NASS GUIDE TO EXERCISE

INFORMATION FOR EXERCISE PERSONNEL

REMEMBER, SOME TRAINED STAFF MAY NOT HAVE HEARD OF AS AND HOW IT AFFECTS YOU. YOU MAY NEED TO EXPLAIN WHAT THE CONDITION IS AND USE THE GUIDANCE POINTS ENCLOSED TO HELP THE TRAINER CONSTRUCT A SUITABLE GYM PROGRAMME FOR YOU. PLEASE SHOW THESE GUIDELINES TO YOUR INSTRUCTOR.

THIS PROGRAMME IS DESIGNED TO ENCOURAGE PEOPLE WHO HAVE ANKYLOSING SPONDYLITIS TO DO REGULAR EXERCISE.

ANKYLOSING SPONDYLITIS (AS) IS A RHEUMATOLOGICAL CONDITION THAT CAUSES INFLAMMATION IN THE JOINTS AND LIGAMENTS OF THE SPINE AND CHEST WALL. THIS INFLAMMATION CAN CAUSE SYMPTOMS OF PAIN AND STIFFNESS.

This programme is designed to encourage people who have ankylosing spondylitis to do regular exercise. Ankylosing spondylitis (AS) is a rheumatological condition that causes inflammation in the joints and ligaments of the spine and chest wall. This inflammation can cause symptoms of pain and stiffness and over time can lead to a loss of movement of the spine and a stooped posture. It usually starts between the ages of 20 and 40.

There are now some very effective treatments for AS. These include medical treatments that can reduce the symptoms and the inflammation in the spine. Consequently, anyone who has AS should be under the care of a rheumatologist who can advise on these. However, regular exercise which includes spinal mobility is one of the mainstays of treatment. It can improve the symptoms, as well as the mobility of the spine and promote general wellbeing. For this reason, the combination of medical treatments and exercises are widely recommended and can have a dramatic effect.

Unfortunately, many people with AS do not exercise regularly. This programme has been designed to make it as easy as possible for someone with AS to start exercising, even if that person has not had much experience of regular exercise or gyms before.

The programme brings together the previous evidence on exercise in AS with the most up to date guidelines on exercise prescription from the American College of Sports Medicine (ACSM) and our own experience. It is focused on maintaining spinal range of movement, good posture, and good general health.

A limitation of a published programme like this is that it cannot be tailored to each individual. This is why we believe that advice from a properly qualified exercise therapist is so useful. The following paragraphs explain some of the important points to be aware of in the assessment of a person with AS and some of the principles that are important in the exercise prescription.

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Figure 8.6: NASS Back to Action programme information for exercise personnel - part 1 (*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019)

THE NASS GUIDE TO EXERCISE

INSTRUCTOR ASSESSMENT

ASSESSMENT

- AS can occasionally lead to medical conditions that can affect the heart or lungs: examples include fibrosis (scarring) of the lungs, or aortic valve regurgitation in the heart. These conditions are usually mild, but some may be worsened by exercise. We therefore recommend that everyone with AS should see a doctor before starting this exercise programme and then do so annually. Of course, most people will already be under the care of a rheumatologist who will have made this assessment.
- It is still always worth checking for any of these medical conditions, which should be considered in anyone who develops undue shortness of breath, dizziness, palpitations, chest pain or loss of consciousness.
- Ask about medication. The non steroidal anti-inflammatory drugs (NSAIDs) in particular are often used and can have an effect on blood pressure.
- Check for swelling of the peripheral joints, particularly the knees and ankle. In some people with AS, the swelling can affect these joints and this will require different treatments.
- Remember that some people with AS can develop inflammation in the eye called iritis. This causes pain in the eye, redness and blurring of vision. If this happens, that person should go directly to a hospital casualty department.
- Suggest that anyone with AS is under the care of a rheumatologist, who can advise on the most effective medical treatments for the pain, stiffness and inflammation.
- Assess the shape of the spine. In AS, there is a tendency for the lumbar spine to flatten and lose its lordosis. The thoracic curvature can increase into a kyphosis and the cervical spine may straighten up.
- Assess the range of movement of each part of the spine. There is a tendency for all parts of the spine to lose range of movement. If you wish to make a recording of range of movement, flexion of the lumbar spine can be measured with the modified Schober test and overall movement can be assessed using the Bath Ankylosing Spondylitis Metrology Index (BASMI). For details and a copy please visit www.nass.co.uk
- Assess flexibility, particularly of the anterior muscles, including hip flexors, abdominals and pectorals.
- Assess strength, particularly of the extensor muscle groups including lower back, gluteal muscles and shoulder external rotators and retractors.
- Assess the overall level of cardiovascular fitness and conditioning.

NOTES ON THE EXERCISE PRESCRIPTION

- Consider the best time of day to exercise because the symptoms can vary a great deal through the day and may be particularly bad in the morning.

- The warm up is particularly important before a strength or cardiovascular session, because stiffness is such a major symptom of AS. However, a warm bath is good preparation for a stand-alone flexibility or mobility session and is convenient for the end of the day or the evening.

- Mobility exercises should take each part of the spine through the full range of movement in a gentle controlled way with a hold at the end of range. Pay particular attention to movements that are reduced, but remember that it will not be beneficial or possible to force the spine into a range that is uncomfortable. The emphasis is on promoting extension of the spine.

- Include mobility exercises of the chest wall and breathing to promote full expansion of the chest.

- Ensure that there is an excellent understanding of good posture and give a practical demonstration during the session. Remember that if the spine has lost range of movement, it may not be possible to get back to a neutral position.

- When considering flexibility, promote flexibility of the large anterior muscles such as the abdominals, pectorals and hip flexors that might pull the spine into flexion if they remain tight. The flexibility programme should probably not be done just before the strength or cardiovascular exercises because the stretching may inhibit the activity of those muscles.

- When considering the strength programme, promote the strength of extensor muscles such as gluteus maximus, lower back and latissimus dorsi as these will tend to pull the spine into an extensor pattern.

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Figure 8.7: NASS Back to Action programme information for exercise personnel - part 2 (*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019)

THE NASS GUIDE TO EXERCISE

NOTES ON THE EXERCISE PRESCRIPTION

- The strength component of this programme starts with two sets of low weight, high repetition movements. This can be progressed to three or four sets as the strength improves.

- There are no sit-ups, abdominal strengthening or core stability exercises in this programme, although there is a section on posture. The reason for this omission is that the focus of the programme is to encourage an upright posture and strong extensor muscles. When reviewing an individual's programme, the inclusion of some exercises to improve abdominal tone and core stability should be considered.

- When considering cardiovascular fitness, assess the current level of conditioning.

Some people with AS may not have been doing exercise recently and may be deconditioned. This programme recommends 30 minutes of cardiovascular exercise 5 times a week at a moderate intensity. This can be gradually progressed as appropriate.

- Most people with AS will find impact activities such as running on roads too painful and should do non-impact activities such as cycling, swimming or using the crosstrainer. Those who are able to run without pain can be reassured that it is fine to continue while they remain pain free. They should be given advice on good running technique including correct running shoes and a training regime that avoids excessive road running.

- Rowing is a very good aerobic exercise, but the stresses that this exercise puts through the thoracic spine makes it unlikely that many people with AS will be able to manage sustained exercise on a rowing machine. We have suggested that the time on a rowing machine is limited to 10 minutes. Demonstration of good technique is very important.

- Avoid sports that lead to forceful direct impacts to the trunk such as rugby or ice hockey.

- Gentle manual therapies such as massage can be helpful, but therapies that use manipulations or high velocity thrusts are unproven and cannot be recommended in AS.

EXERCISES SHOULD AIM TO:

Strengthen extensor muscle groups
- Low back
- Trunk
- Shoulder blades
- Buttocks

Stretch anterior muscle groups
- Pectorals
- Biceps
- Quadriceps (especially over the front of the hip joint)

Also stretch/keep length in all major muscle groups
- Hamstrings
- Chest
- Triceps/biceps
- Calves
- Inner thigh

Use a regime that involves low weight but high repetition to extensor and anterior muscle groups
- Gradually increase the weight used during extensor exercises (see point 1 above), as tolerated
- Keep anterior muscle work low weight and high repetition at all times

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Figure 8.8: NASS Back to Action programme information for exercise personnel - part 3 (*Back to Action Exercise Programme | National Ankylosing Spondylitis Society* 2019)

8.2 Pain Levels

Table 8.1: Pain levels displayed in design

Pain Level	Overall	Assistance text
1	Faint	My pain is barley noticeable
2	Mild	My pain is light and infrequent
3	Moderate	My pain is bothering but can be ignored
4	Uncomfortable	My pain is constant but not too limiting
5	Distracting	My pain is interfering with my life
6	Distressing	My pain controls my attention
7	Intense	My pain is deteriorating my lifestyle
8	Unmanageable	My pain is so bad I can barley move
9	Severe	My pain is unbearable
10	Debilitating	My pain requires emergency attention

8.3 About AS Intro

hank you for taking the time and participating in the app user study. This is an application tailored for Ankylosing Spondylitis (AS) patients, to encourage: Education on the importance of non-pharmacological treatment (e.g. exercise, journaling, mindfulness, and positivity) Self-management; understanding the importance of treatment means being more proactive, thus improving adherence and treatment outcomes Regular exercise; helps relieve pain and stiffness, hence improving mobility

What is AS? AS is a painful, progressive form of inflammatory arthritis. It mainly affects the spine but can also affect other joints, tendons and ligaments.

Both words come from the Greek language; ankylosing means fusing together, spondylitis means inflammation of the vertebrae. Ankylosing spondylitis describes the condition where some or all of the joints and bones of the spine fuse together.

People with AS are often battling on a daily basis against pain, stiffness and fatigue. This can lead to feelings of isolation, particularly just after diagnosis. As well as the inevitable physical pain of the disease, AS often generates feelings of frustration and fear. To help adjust to the diagnosis, the patients are to be an active part of their own recovery with the support and engagement of family and friends.

People with AS often have to deal with the day to day symptoms of pain and stiffness and the worry about long term effects on the spine and general health. There are now some very effective medical treatments that can reduce pain and stiffness. Exercise can also help relieve these symptoms, as well as help improve sleep and general health. With that, the AS patient will feel better, look better, and get more out of life.

8.4 Self-management prototype testing script

Thank you for taking the time and participating in the app user study. This is an application tailored for Ankylosing Spondylitis (AS) patients, to encourage: Education on the importance of non-pharmacological treatment (e.g. exercise, journaling, mindfulness, and positivity) Self-management; understanding the importance of treatment means being more proactive, thus improving adherence and treatment outcomes Regular exercise; helps relieve pain and stiffness, hence improving mobility

What is AS? AS is a painful, progressive form of inflammatory arthritis. It mainly affects the spine but can also affect other joints, tendons and ligaments.

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People with AS are often battling on a daily basis against pain, stiffness and fatigue. This can lead to feelings of isolation, particularly just after diagnosis. As well as the inevitable physical pain of the disease, AS often generates feelings of frustration and fear. To help adjust to the diagnosis, the patients are to be an active part of their own recovery with the support and engagement of family and friends.

People with AS often have to deal with the day to day symptoms of pain and stiffness and the worry about long term effects on the spine and general health. There are now some very effective medical treatments that can reduce pain and stiffness. Exercise can also help relieve these symptoms, as well as help improve sleep and general health. With that, the AS patient will feel better, look better, and get more out of life.

QUESTIONS

What was your first impression of the app? What do you feel the app is guiding you to do next?

TASK: complete the journal entry on the homepage and type: Although I felt stiff, I still managed to exercised today. Click save when youre done.

If you want to add more details to your journal entry, click on the entry you created.

Spend a minute on the journal page.

3. What are your thoughts? What do you think are some noticeable features here?

4. Do you think its important to mention the benefits of journaling (and of using the other app features) to the user? TASK: Enter a new pain log. Throughout, please speak aloud your thoughts. Record pain as: Overall pain = 4 uncomfortable Pain description: aching and burning Pain location: front 14 & 15 back 34 & 37 Sleep: adequate Mood: hopeful and tired Save your pain log.

5. Do you think the pain log adequately describes potential pain points?

TASK: You just completed a pain log. This is one of your daily goals. Go record and check this achievement in your goals.

TASK: After updating your goal progress, add a new goal. For the name, let the ideas guide you; click on ideas. Spend a minute on this page, scrolling through the different options to explore the ideas. Please speak aloud you thoughts on these options. Choose and click on Make an exercise plan from the exercise option. Save your goal.

TASK: Finally, go to workouts. Spend a minute going over the page, clicking through the options. Does the page educate you on why exercise is beneficial for AS patients.

The tasks are done. Feel free to play with the app, speaking throughout your thoughts on the positives, and if there are any areas of improvement. Is the app user friendly, easy to maneuver? Were there any areas of confusion?

Post Interview Questions How likely is it that you would recommend the product to a friend or patient suffering from Ankylosing Spondylitis (AS)? How well do you think the app meets the needs of AS patients' use case, defined before the study? Any thoughts on how to improve? How satisfied are you with the look and feel of this app? Any other comments? You can comment on anything: including your overall experience, frustrations, areas of confusion, product issues or your brilliant ideas.

8.5 Some notes from think-aloud protocol

- If videos are new everyday = will choose that first. Otherwise would probably go to goals or journals 1st - Put something quantitative; so they can track the average of journals across a week/month; easier to read - If theres a way to see pain logs monthly (I dont personally see the benefit of that) - Set a reminder; when & how many times to be reminded (for exercise) - Put why exercise on the top with safety - Add pictures to the safety option; not easy to follow and people will be discouraged to read through it Toby, POSITIVIES: - Nice colour schemes, eye catching - Likes the streak next to goals - Idea suggestions in goals are good because they are simple & achievable, people will not feel discouraged to use - Information for each exercise is very useful because people forget and disregard the importance of basic exercises - Good encouraging words & mottos

Jasmine - Nice icons - Likes the videos; informative, motivating - Likes the font, easy to read - Likes the pain log scroll - Likes that you can see the past pain log, and weekly logs for journals/pain Toby (negative): sleep hours may confuse some people because what is normal for one may not be normal for others Color the safety and workout button another colour to encourage reading it

8.6 Post think-aloud protocol questionnaire

8.7 Exercise recognition implementation testing data measures

Table 8.2: Exercise recognition implementation testing data measures raw data

Exercise 1: Trunk bend						
TP	TN	FP	FN	Accuracy	Sensitvity	Specificity
3	2	1	0	83.33%	100.00%	66.67%
3	3	0	0	100.00%	100.00%	100.00%
3	3	0	0	100.00%	100.00%	100.00%
2	2	1	1	66.67%	66.67%	66.67%
3	3	1	0	85.71%	100.00%	75.00%
3	3	0	0	100.00%	100.00%	100.00%
2	3	1	1	71.43%	66.67%	75.00%
3	3	0	0	100.00%	100.00%	100.00%
3	3	0	0	100.00%	100.00%	100.00%
3	3	0	0	100.00%	100.00%	100.00%
			MEAN	90.71%	93.33%	88.33%
			SD	13.11%	14.05%	15.32%
Exercise 2: trunk rotation						
TP	TN	FP	FN			
3	3	0	0	100.00%	100.00%	100.00%
3	2	1	0	83.33%	100.00%	66.67%
3	3	0	0	100.00%	100.00%	100.00%
3	1	2	0	66.67%	100.00%	33.33%
3	2	1	0	83.33%	100.00%	66.67%
3	3	0	0	100.00%	100.00%	100.00%
3	3	0	0	100.00%	100.00%	100.00%
3	2	1	0	83.33%	100.00%	66.67%
3	1	2	0	66.67%	100.00%	33.33%

Table 8.2 continued from previous page

Exercise 1: Trunk bend						
3	3	0	0	100.00%	100.00%	100.00%
			MEAN	88.33%	100.00%	76.67%
			SD	13.72%	0.00%	27.44%
Exercise 3: bridge						
TP	TN	FP	FN			
5	1	3	1	60.00%	83.33%	25.00%
6	4	0	0	100.00%	100.00%	100.00%
6	3	1	0	90.00%	100.00%	75.00%
6	3	1	0	90.00%	100.00%	75.00%
6	3	1	0	90.00%	100.00%	75.00%
6	4	0	0	100.00%	100.00%	100.00%
5	2	2	1	70.00%	83.33%	50.00%
6	4	0	0	100.00%	100.00%	100.00%
6	2	2	0	80.00%	100.00%	50.00%
6	3	1	0	90.00%	100.00%	75.00%
			MEAN	87.00%	96.67%	72.50%
			SD	13.37%	7.03%	24.86%

8.8 Exercise recognition implementation data sample count

Table 8.3: Table representing the data sample count of the exercises

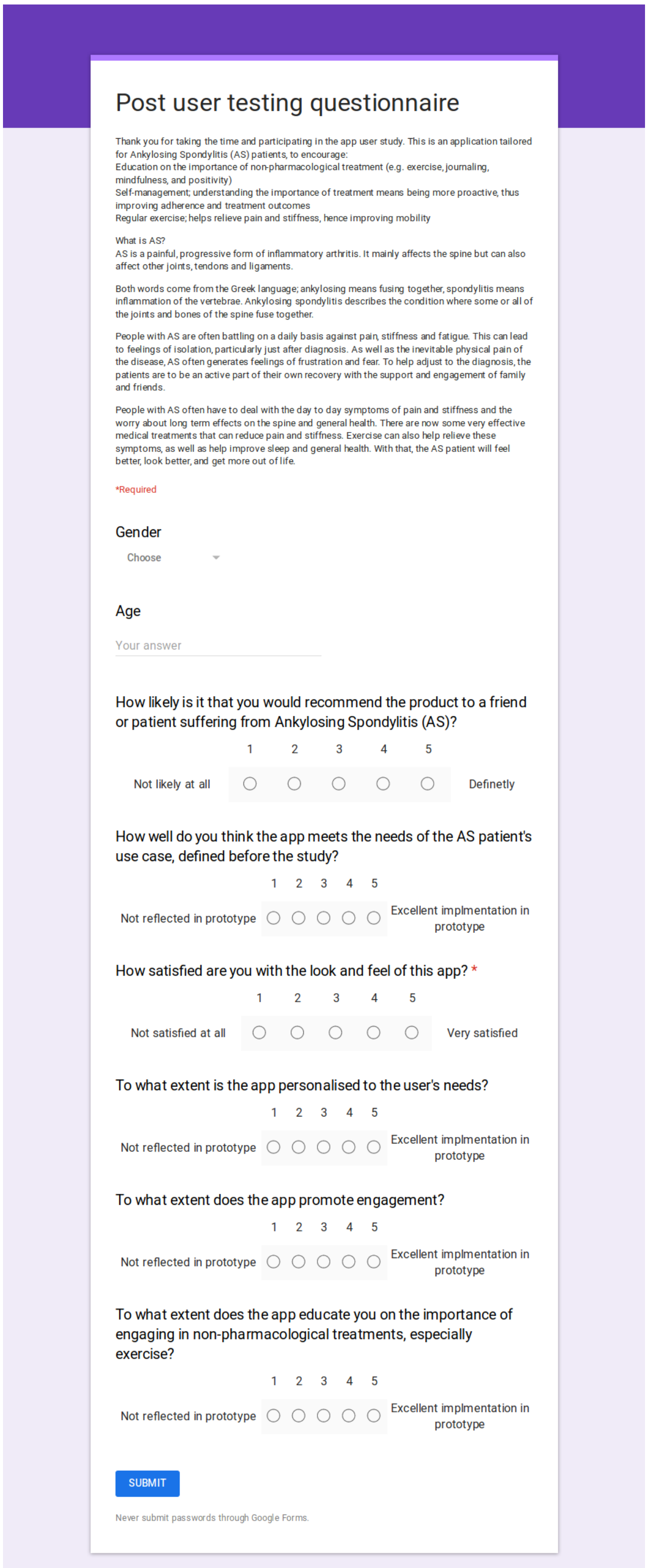
Incorrect movement count	Total count	Incorrect move data count	Per move
Trunk Bend			
130	2477	5.25%	1.75%
89	2477	3.59%	1.20%

Table 8.3 continued from previous page

Incorrect movement count	Total count	Incorrect move data count	Per move
120	2477	4.84%	1.61%
200	2477	8.07%	2.69%
195	2477	7.87%	2.62%
124	2477	5.01%	1.67%
167	2477	6.74%	2.25%
220	2477	8.88%	2.96%
210	2477	8.48%	2.83%
140	2477	5.65%	1.88%
	Mean	6.44%	2.15%
	SD	1.72%	0.57%
Trunk Rotaion			
212	4700	4.51%	1.50%
259	4700	5.51%	1.84%
200	4700	4.26%	1.42%
305	4700	6.49%	2.16%
218	4700	4.64%	1.55%
256	4700	5.45%	1.82%
262	4700	5.57%	1.86%
267	4700	5.68%	1.89%
203	4700	4.32%	1.44%
279	4700	5.94%	1.98%
285	4700	6.06%	2.02%
	Mean	5.31%	1.77%
	SD	0.76%	0.25%
Bridge			
120	4950	2.42%	0.61%
201	4950	4.06%	1.02%

Table 8.3 continued from previous page

Incorrect movement count	Total count	Incorrect move data count	Per move
203	4950	4.10%	1.03%
196	4950	3.96%	0.99%
157	4950	3.17%	0.79%
174	4950	3.52%	0.88%
138	4950	2.79%	0.70%
131	4950	2.65%	0.66%
143	4950	2.89%	0.72%
212	4950	4.28%	1.07%
220	4950	4.44%	1.11%
	Mean	3.48%	0.87%
	SD	0.73%	0.18%



Post user testing questionnaire

Thank you for taking the time and participating in the app user study. This is an application tailored for Ankylosing Spondylitis (AS) patients, to encourage:
Education on the importance of non-pharmacological treatment (e.g. exercise, journaling, mindfulness, and positivity)
Self-management; understanding the importance of treatment means being more proactive, thus improving adherence and treatment outcomes
Regular exercise; helps relieve pain and stiffness, hence improving mobility

What is AS?
AS is a painful, progressive form of inflammatory arthritis. It mainly affects the spine but can also affect other joints, tendons and ligaments.

Both words come from the Greek language; ankylosing means fusing together, spondylitis means inflammation of the vertebrae. Ankylosing spondylitis describes the condition where some or all of the joints and bones of the spine fuse together.

People with AS are often battling on a daily basis against pain, stiffness and fatigue. This can lead to feelings of isolation, particularly just after diagnosis. As well as the inevitable physical pain of the disease, AS often generates feelings of frustration and fear. To help adjust to the diagnosis, the patients are to be an active part of their own recovery with the support and engagement of family and friends.

People with AS often have to deal with the day to day symptoms of pain and stiffness and the worry about long term effects on the spine and general health. There are now some very effective medical treatments that can reduce pain and stiffness. Exercise can also help relieve these symptoms, as well as help improve sleep and general health. With that, the AS patient will feel better, look better, and get more out of life.

*Required

Gender

Choose

Age

Your answer

How likely is it that you would recommend the product to a friend or patient suffering from Ankylosing Spondylitis (AS)?

Not likely at all 1 2 3 4 5 Definetly

How well do you think the app meets the needs of the AS patient's use case, defined before the study?

Not reflected in prototype 1 2 3 4 5 Excellent implmentation in prototype

How satisfied are you with the look and feel of this app? *

Not satisfied at all 1 2 3 4 5 Very satisfied

To what extent is the app personalised to the user's needs?

Not reflected in prototype 1 2 3 4 5 Excellent implmentation in prototype

To what extent does the app promote engagement?

Not reflected in prototype 1 2 3 4 5 Excellent implmentation in prototype

To what extent does the app educate you on the importance of engaging in non-pharmacological treatments, especially exercise?

Not reflected in prototype 1 2 3 4 5 Excellent implmentation in prototype

SUBMIT

Never submit passwords through Google Forms.

Figure 8.9: Questionnaire using Google Forum. Questions also presented in Table 6.3

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