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Rehabilitation of Jumper's Knee Adapted to Daily Life

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Abstract

The famously known ”Jumper’s knee” has always posed as a significant problem in volleyball, forcing the afflicted players to temporarily or even permanently quit their sport. Which is the worst nightmare of many athletes. A rehabilitation process can be tough and take up a lot of time, demotivating them to continue with it as intended. As a result, several researches have been conducted to increase the motivation of the patients throughout the rehabilitation. But still, to this day, many athletes struggle to maintain their motivation.

When it comes to Patellar Tendinopathy (PT) a lot of research has been conducted on which therapy is better and how to improve them, but only a few on how to improve the patient’s motivation, mainly focusing on the extrinsic motivation. But when looking at the problem, there are many more ways to enhance someone’s adherence to the rehabilitation. It can be achieved by limiting the extra time allocated for the exercises, for example, by integrating them into activities of daily living. Or even focus on different aspects of increasing the patients’ motivation, such as intrinsic motivation. The exercise should be made as easy as possible to lower the needed cognitive thinking, so that it can be integrated into an Activities of Daily Living (ADL), limiting the additional needed time in a day for the exercise and consequently increase the intrinsic motivation of the athlete.

Thus, the primary objective of this research was to investigate methods that can enhance engagement and adherence to rehabilitation exercises for individuals dealing with PT, also known as ”jumper’s knee”, by integrating an exercise into a daily life activity. Which means that an interactive prototype had to be developed that could lower the needed cognitive thinking for the exercise so it could successfully be integrated into an ADL, without causing any additional stress.

It was identified that it was possible to integrate the lateral step-up exercise into an ADL. The activity that was chosen for this research was the brushing of the teeth, as the step-up exercise and brushing of the teeth both take around 1.5 to 2 minutes. The step-up device is a small step that includes a platform and a small box with a LED circle in it to give the user feedback on the process throughout the exercise, so that the user does not have to keep track of counting.

The results of the research demonstrated that, despite the limitation of it being a short-term research, it is indeed possible to integrate a rehabilitation exercise into an activity of daily life. However, this research must be re conducted with a long-term test to confirm its findings.

Acknowledgements

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Contents

List of acronyms

ACL	Anterior Cruciate Ligament
ADL	Activities of Daily Living
BADL	Basic Activities of Daily Living
IADL	Instrumental Activities of Daily Living
EET	eccentric exercise therapy
HSRT	heavy slow resistane therapy
IET	isometric exercise therapy
NICE	National Institute for Health and Care Excellence
PT	Patellar Tendinopathy
PTRE	Patellar Tendinopathy rehabilitation exercises
RCT	Rotary Cuff Tendinopathy

Chapter 1

Introduction

1.1 Problem statement

Volleyball stands as one of the top team sports in the Netherlands, boasting a membership of over one hundred thousand individuals within the official Dutch Volleyball Association, Nevobo [1]. However, no sport comes without its disadvantages. Just like any other sports, volleyball players are fragile to several kinds of injuries. Due to the frequency of jumping that occurs in Volleyball, individuals are especially prone to jumping related injuries [2]. These injuries can be both acute and overuse injuries. Acute injuries often manifest suddenly and cause intense pain, while overuse injuries develop gradually. PT is identified as the most common overuse injury [2]. Numerous studies [3]–[6] have explored effective methods for stabilizing or preventing PT injuries. As a result of this research [5], players have learned how to correctly apply tape, patellar straps or do muscle strengthen exercises to mitigate these risks. However, despite these preventive measures, injuries still occur, often necessitating rehabilitation or even surgery. Therefore, it is crucial to prevent these injuries, because these rehabilitation therapies can often be intense and pain inducing [7], [8].

As a result, research [7] has shown that individuals that suffer from PT often find it hard to adhere to the rehabilitation therapy, due to the pain. Even though several studies [3]–[6] have examined effectiveness of different rehabilitation methods for PT, they often encounter challenges with adherence, which can impact trial outcomes [7]. There is a lack of research that focuses on improving this aspect. Luckily, adherence can be improved in different ways. Rio et al. [9] has, for example, addressed how to decrease pain in the rehabilitation therapy, by switching from eccentric exercise therapy (EET) to isometric exercise therapy (IET) when rehabilitating in-season, resulting in a better adherence. However, Covassin et al. [10] claims that cognitive and affective factors also contribute to rehabilitation outcomes. Consequently, showing the importance of motivation during a rehabilitation process.

Monardo et al. [11] has shown that technology assisted rehabilitation can improve motivation and satisfaction in comparable rehabilitation therapies. Motivation is primarily separated into two categories: extrinsic and intrinsic. The difference is that intrinsic motivation comes from within, whereas extrinsic comes from external influences [12]. Currently most research done on increasing adherence in rehabilitation focus on improving extrinsic motivation. However, research focusing on intrinsic motivation, by implementing ADL-based training also show promising results [13]–[15]. Currently, no research has been conducted specifically addressing how to enhance adherence in PT rehabilitation, when looking at intrinsic motivation. With the help of the background research that has been used for the course Academic writing Creative Technology [16], the primary objective of this thesis is set out to answer the following question:

> ***'How to integrate a rehabilitation exercise into an activity of daily living to enhance engagement and adherence for individuals dealing with PT.'***

The following sub-research questions look into the different aspects that support the answer of the main research question:

Sub-Research questions
What methods are used during the rehabilitation process for Patellar Tendinopathy?
What exercises have a positive effect on Patellar tendinopathy?
What factors influence engagement/adherence to rehabilitation exercises for Patellar Tendinopathy?
What rehabilitation tools are available for managing Patellar Tendinopathy?

Table 1.1: List of sub-research questions.

1.2 Order of report

The first chapter covers the needed background information, exploring related studies. Consequently, the second chapter will entail the method and techniques that are used throughout the research. The third chapter includes the methods and techniques, which discusses the structure of how the prototype came to be. Furthermore, the fourth chapter focus on the ideation phase, including the preliminary requirements for the stakeholders. The fifth chapter, specification, details the requirements based on the decided prototype. This leads to the sixth chapter, the realisation, where the first prototypes are developed. The second prototype is then tested and analysed in chapter seven, the user evaluation. Which leads to the eight chapter, which includes all the details on the final prototype. Chapter 9 entails the limitations and achievements of this research and gives a recommendation for future work. Which leads to the last chapter, the conclusion, where the outcome of this research is summarised.

Chapter 2

Background research

Generally sports with a high jump rate are more prone to injuries [2]. This makes volleyball, with the highest jump rate, especially vulnerable to jump related injuries [17]. Which is why ankle sprains, primarily caused by blocking, are the most common acute injury [18] and Patellar Tendinopathy is the most frequent overuse injury, due to the stress exerted on the knees during jumping [2]. There are, however, more injuries that can occur during volleyball, since it is not solely focused on jumping alone. The following table 2.1 outlines the injuries commonly associated with playing volleyball, categorised by acute or overuse injury:

Common Volleyball Injuries

Injury	acute or overuse
ankle sprain	acute
Patellar Tendinopathy	overuse
Anterior Cruciate Ligament (ACL)	acute
finger sprain	acute
thumb sprain	acute
Rotary Cuff Tendinopathy (RCT)	overuse
Concussion	acute

Table 2.1: List of common volleyball injuries categorised by acute or overuse.

Given the likelihood of volleyball players experiencing injuries, it becomes crucial to have effective rehabilitation methods readily available in case of an injury. Luckily, there are many alterations of rehabilitation therapies for each kind of injury out there.

For each therapy it is important that the individuals correctly adhere to the process. Adherence is crucial when it comes to attending appointments, following advice, doing prescribed exercises, sticking to the recommended frequency of exercise, performing exercises correctly, and avoiding doing more or less than advised [19]. Consequently, poor adherence to treatment has a negative effect on the outcome of the therapy [19]. As a result, this research will focus on PT due to the lack of research on improving the adherence of the rehabilitation exercises.

2.1 Understanding Patellar Tendinopathy

PT, known as ”Jumper’s knee” is a chronic sports injury that exhibits a prevalence among athletes engaging in activities such as volleyball, track and field, basketball, long-distance running, and skiing. Predominantly afflicting adolescents and young adults participating in repetitive jumping pursuits, hence the name, Jumper’s knee. The tears predominantly arise from the cumulative stress exerted on the patellar or quadriceps tendon [20]. This condition may result in functional limitations for individuals, affecting athletic performance and potentially disrupting the professional careers of elite players, both within and outside the sport itself [3]. In the initial phases of jumper’s knee, the majority of patients are typically subjected to medical or rehabilitative interventions for management [20].

2.1.1 Commonly used rehabilitation therapies

There are three different methods for PT rehabilitation that show promising results [3], [9], [21]: heavy slow resistane therapy (HSRT), EET, and IET. Among these, EET stands out as one of the most effective and commonly used approaches [3], being endorsed in guidelines by the National Institute for Health and Care Excellence (NICE) [7]. EET induces adaptation in the musculoskeletal unit, aiming to shield itself from the stress associated with physical activity [4]. The main used method for EET is a 25° decline squat, wherein the concentric phase is executed using the non-affected leg or arms, while the eccentric phase is performed on the affected leg [23]. While it is the most recommended treatment, it can induce pain and is therefore not advised during competitive seasons [7], due to its limited short-term effect [9]. A more suitable therapy method during a competitive season is IET. Since isometric and isotonic muscle contractions are able to have a direct effect on the pain caused by PT. IET strengthens the muscles by using exercises that utilize contractions [24].The therapy includes exercises, such as, quad set seated, bug squash, wall squats double leg or single leg, and decline squats [24], as shown in figure 2.2. Compared to EET, isometric contractions can be done without pain occurring [9].

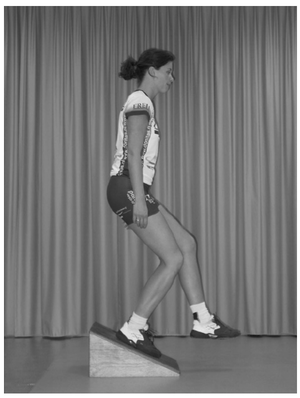


Figure 2.1: Eccentric 25° decline squat [22].

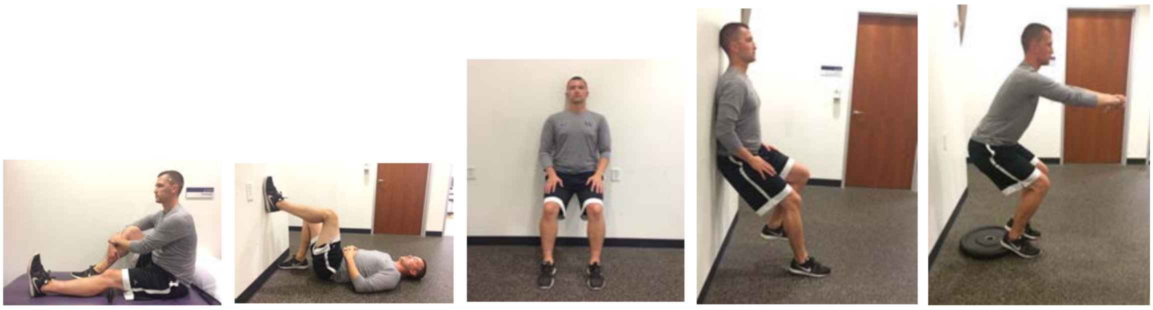


Figure 2.2: Isometric exercises respectively: Quad set seated, bug squash, wall squats double leg, wall squats single leg and decline squats [24].

Lastly, there is also HSRT, which has shown positive effects in both short-term and long-term trials [21]. The therapy exists out of three bilateral exercises: squat, leg press and hack squats [21]. In a conducted trial comparing the therapy to EET [21], there was no significant difference in compliance rate and physical improvement after six months. However, there was a notable difference in satisfaction after a 12-week period, with a satisfaction rate of 70% for HSRT compared to 42% for EET, and after six months, with a satisfaction rate of 73% compared to 22%. Despite the superior test results demonstrated by HSRT in a clinical trial [21], professionals often prescribe exercises based on EET due to its undeniable advantages: the ability for patients to perform the treatment at home and its minimal associated expenses, which align with the preferences of the patients [21].

To summarize, EET effectively relieve stress in the musculoskeletal unit for jumping activity. However, its use during competitive seasons may be limited due to the recurrence of pain during trials. IET is, therefore, a more suitable alternative during competitive seasons, resulting in a direct pain relief for PT short-term. Additionally, HSRT has shown positive effects in both short and long-term trials, with notable satisfaction rates. It is, however, performed under supervision and, therefore, impossible to do the therapy at home. So, despite the superior outcomes, professionals often opt for EET due to its practical advantages, being able to perform exercises at home, and patient preferences [21].

2.1.2 At-home rehabilitation exercises

There are several exercises possible for a successful rehabilitation. As mentioned before, EET, IET and HSRT show promising results in improving on the condition. There are, however, a few more exercises available that can be performed at home that help with PT.

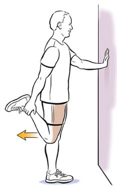


Figure 2.3: Quadriceps stretch [25]

Firstly, Quadriceps stretch helps to increase the flexibility and mobility in the knee [26]. For this exercise you have to stand tall and find support, whether it's a wall, chair, or table, with your right hand. Then, gently bend your left leg behind you, reaching for your ankle with your left hand. Keep your back straight and avoid arching it. Hold this stretch for 30 to 60 seconds, and do it twice. After that, switch legs and arm and repeat the process [25]. As shown in figure 2.3.

Then there is also VMO Inner range quadriceps sitting, shown in figure 2.4. If the exercise is done correctly it can reduce pain at the anterior knee [28]. To be able to do the exercise you have to sit down on the floor and put a rolled-up towel under your knee. First you tighten the thigh muscle, then you lift your heel while pressing your knee into the towel. Make sure only your foot lifts off the floor as your leg straightens. After that you slowly return to your starting position and repeat [29].

Figure 2.4: Inner range quadriceps [27]

Figure 2.5: Quadriceps with a band sitting [29]

Moreover, you can do quadriceps exercises with a band when sitting down, as shown in figure 2.5. This is another way to strengthen the quadriceps [29] and, as a result, relieve pain on the knee [28]. While seated, bend your knee and loop an exercise band around the sole of your foot. Straighten your leg against the resistance of the band. You'll notice the front thigh muscles (quadriceps) working as you do this exercise. After that you slowly go back to the starting position and go again [29].

Additionally, it is also possible to perform quarter wall squats to strengthen the quadriceps. First you stand with your back against a wall and bend your knees into a quarter squat position. You can choose to move up or down or simply hold the squat position. Make sure that the middle of your kneecap aligns with the middle toes of your foot throughout the movement to correctly perform the exercise [29].

Figure 2.6: Quarter wall squat [29]

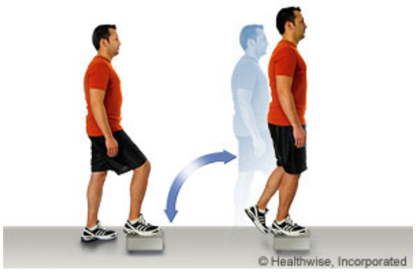


Figure 2.7: Step up exercise [30]

Furthermore, there is also the step up exercise. This is a body resistance exercises that strengthens the quadriceps, hamstrings and gluteal muscles [31]. To do the exercise You first put your affected leg on the step. You start by putting more weight on the leg that's on the step. Lift your other leg up to match the first one, but don't put any weight on it. Try to hold this position for 5 seconds. Then, slowly lower your other leg back down to the ground. You should feel your hip and thigh muscles working during this exercise [32]. This exercise can also be performed lateral.

Lastly, there is the stationary bicycle exercise. This is an exercise that strengthens the quadriceps muscles [33]. You begin the exercise by adjusting the stationary bike seat for optimal knee flexion during pedaling. You start slowly and gradually increases speed and resistance over 10 to 15 minutes, maintaining a steady pace to engage muscles and elevate heart rate. As the session progresses, you reduce the speed and resistance gradually before coming to a complete stop [33].

2.1.3 Motivational factors in a rehabilitation process

Motivational factors play a crucial role in the rehabilitation process, particularly in exercises like EET, IET, and HSRT [7], [9]. Generally, they take considerable time and dedication. They are often characterized as painful and boring, ultimately diminishing patients motivation [9]. Motivation is characterised as the drive to pursue and sustain behaviour towards a goal [34]. Motivation can either be intrinsic or extrinsic. The difference is that intrinsic motivation comes from within, whereas extrinsic comes from external influences [12]. When looking at rehabilitation specifically intrinsic motivation is driven by internal enjoyment or interest in an activity, and extrinsic motivation involves external rewards [34]. It is known that the lack of motivation in, for example, EET has a great influence on the outcome of the trial [7]. The pain that occurs during the therapy is the biggest reason on why there is a lack of continuity in the trials [7], [21]. There have been researches that tried alternate therapies to compare the adherence rate to the original therapy [7], [35]. Moreover, there have been a few researches that focused on the implementation of extrinsic motivation to increase adherence in the rehabilitation of PT [35], [36]. However, until now there has not been any research that specifically focused on the influence of intrinsic motivation in the rehabilitation of PT.

A rehabilitation process comparable to that of sports injuries and has a lot of research about motivation is the rehabilitation for stroke patients. The rehabilitation of stroke patients involves a long-term intensive treatment that is perceived as tiresome and boring, resulting in lack of motivation in patients [37]. Several studies have been conducted on motivation in the rehabilitation process of stroke patients, confirming its significance as the primary factor influencing functional outcomes of the patients [34], [37], [38]. Currently motivation in stroke patients is primarily influenced by factors related to rewards, such as positive feedback from therapists, commendations from medical staff or relatives [34], also known as extrinsic motivation. When looking at improving the motivation of stroke patients the majority of trials focus on interventions such as robotic therapy, exergames, and virtual reality. The results show that these methods are very effective in the increasing of motivation for the rehabilitation exercises among stroke patients [34], [37]. However, these interventions have not only been successful for stroke patients, but for many other rehabilitation processes too [39]. Thus, improvement in motivation and adherence in rehabilitation can be explored through innovative approaches such as robotics, gamification, and virtual reality, which aim to enhance both intrinsic and extrinsic motivation. Gamification and assistive technology have already been explored in the rehabilitation process of PT [35], [36], which is further explained in section 2.3.

As mentioned before, motivation can also be increased by focusing on intrinsic motivation. Over the past few years there have been several researches addressing the effect of ADL-based training on stroke patients, and have shown promising results in improving the motivation in the rehabilitation process [13]–[15]. In this case, a rehabilitation exercise can be combined with exercises that one performs everyday, such as staircase climbing, cooking, eating. According to Hover et al. [13], by implementing ADL-based training the need for intrinsic motivation is bypassed and simultaneously decreases the currently separately allocated time that is needed for the rehabilitation exercises. Consequently, improving the adherence to a rehabilitation therapy [13]. However, for ADL-based training to be effective, the needed motivation threshold must be low enough for the person to engage in the exercises while performing the daily activity, in order for the device to be effective. Therefore, the device must be inviting to the individual, requiring minimal additional effort for the exercise compared to the daily activity [40], to successfully bypass the need for intrinsic motivation.

2.1.4 Objects and tools utilised in Patellar Tendinopathy exercises

Now that is it known what kind of exercises that can be performed at home that are in treatment of PT. The next step is to define which at-home objects can be utilised to create a device that can be used for Patellar Tendinopathy rehabilitation exercises (PTRE). Next to that, some exercises also utilise certain tools to help relieve pain caused by PT. For this research, it is important that the device includes an at-home object, however, it is still possible to have a tool assist the device and user in doing the exercise correctly. Therefore, based on the PTRE mentioned in this paper, the following list, table 2.2, shows what at-home objects and tools are applicable:

At-home objects and tools used in PT rehabilitation

At-home object	Tool
Table	Stretching strap
Chair	25 Degree decline block
Towel	Kneestrap
Small step	

Table 2.2: List of objects and tools utilised in PT rehabilitation.

After evaluating what at-home object can be used in PTRE. The device can be integrated into the following listed exercises, table 2.3:

PTRE that utilise at-home objects

Exercise	At-home object	Tool
Quadriceps stretch	Chair or table	None
VMO inner range quadriceps sitting	Towel	None
Quadriceps with a band	Chair	Stretching strap
Step up exercise	Small step	None

Table 2.3: List of PT exercises that utilise at-home objects.

2.1.5 Activities of daily living

Even though, there are currently only a few PTRE out there that utilise at-home objects, it is possible to implement certain movements of exercises into ADL. ADL is describe as the ability to perform activities independently [41]. it can be categorised as Basic Activities of Daily Living (BADL) or Instrumental Activities of Daily Living (IADL), where BADL is about the required skills for basic physical needs and IADL includes more complex activities that are needed to be able to live independently. [41]. According to Edemekon et al. [41] BADL is divided into six different categories:

1. Ambulating is the ability to move and walk independently.

2. Feeding is the capability of self-feeding.

3. Dressing: Being able to select and put on your own clothes.
4. Personal hygiene includes bathing, grooming, dental hygiene, nail care, and hair care.
5. Continence is about controlling bladder and bowel function.
6. Toileting involves getting to and from the toilet, using it properly, and maintaining personal hygiene.

   And IADL can be defined through the following activities [41]:

7. Transportation and shopping involve procuring groceries, attending events, and organizing transportation.
8. Managing finances includes bill payment and financial asset management.
9. Shopping and meal preparation encompass everything needed to prepare a meal and shop for daily necessities.
10. Housecleaning and home maintenance involve cleaning kitchens, maintaining living areas, and addressing home maintenance tasks.
11. Managing communication with others entails handling telephone calls and mail.
12. Managing medications includes obtaining and taking medications as prescribed.

The rehabilitation process of PT is mainly focused on the knees and the surrounding muscles. This means that some of the ADL do not apply to the PTRE, as they do not require movements of that area. The following table shows what possible knee movements could occur during specific ADL:

Movement of the knee in specific activities of daily living.

ADL	Specific Activity	Movement of the knee
Ambulating	Walking (up the stairs)	Lifting up the knee to take a step forward
Dressing	Putting on pants	Lifting up the knees to get into the pants
Personal hygiene	Stepping into or out of the bath/shower	Lifting up the knees to get into the bath/shower
Toileting	Getting on and off the toilet	Squatting
Transportation	Getting into a vehicle	Lifting up the knees to get into the vehicle

Meal preparation	Taking something out of a high/low cabinet	Moving up and down to reach a cabinet
Housecleaning	Cleaning high and low places	Moving up and down to reach certain places in the house

Table 2.4: List of movements of the knee in specific activities of daily living.

Due to the fact that PTRE consist out of sets that contain a certain amount of each exercise, the ADL has to contain the possibility of doing the exercise multiple times after each other. This means that since, for example, sitting down on a toilet only occurs once, and not multiple times after each other, this activity would not be applicable to the PTRE. With this in mind the following exercises could be integrated in ADL:

Implementation of exercises in ADL.

PTRE	ADL	The activity
Step up	Ambulating	Walking up the stairs
Step up	Meal preparation or Housecleaning	Stepping up and down to reach cabinets
Quadriceps stretch	Ambulating	During walking
Quadriceps stretch	Personal hygiene, meal preparation, or housecleaning	When standing still the exercise can be performed
Quadriceps with a band sitting	Feeding	When sitting on a chair the exercise can be performed

Table 2.5: Implementation of exercises in ADL.

2.2 User characteristics

To find the right solution for the user, it's essential to define the characteristics of the stakeholders involved. These stakeholders include the individual suffering from PT, also referred to as the patient, as well as the caretakers responsible for the patient's well-being.

2.2.1 Individuals suffering from Patellar Tendinopathy

The target user group of this research are the individuals that deal with PT and experience a lack of motivation and adherence throughout the rehabilitation therapy.

Most individuals have to undergo a therapy that can be pain inducing, often leading to a lack of motivation. As a result, these individuals have trouble with adhering to the regulated exercises that are needed to improve the condition.

2.2.2 Caretakers

For the caretakers, physiotherapist or doctors, it is important that their patients correctly adhere to the therapy they set out so that they can help them to the best of their capabilities. This is mostly achieved by supporting and guiding the patient throughout the process. It is important for the caretakers to be able to motivate their patients during the process, however, when these exercises are performed at home they are not able to keep track whether the patient actually does the exercises, or does them correctly. Only the one-on-one contact sessions show whether the patients are on the right track of the process. If the patient does not follow the therapy process as prescribed the caretaker must adapt the original set out therapy, leading to a prolonged process.

2.3 Related technologies

The use of technology in rehabilitation therapies has significantly increased over the past decade. Especially with stroke patients it is very now common to have assistive technology and even gamifications in the rehabilitation process and has shown it's effectiveness [42]. In knee rehabilitation it is, however, not commonly used in rehabilitation practises yet. In 2011 research was conducted [35] on the assistance of robotic technology in knee rehabilitation. The robotic system assists the patient in doing the needed exercises regularly. The device collects the data that is achieved during the exercises and gives feedback. By sending this data also to the doctor or therapist they have a better view of the rehabilitation process, leading to a shortened recovery period. The functional tests in the clinics showed that the device the patient's motivation increased, resulting in a successful research. Showing that the use of assistive technology in knee rehabilitation is very effective. The aim of this project is, however, to design an assistive technology device that can be integrated into a daily life object to improve motivation in PT rehabilitation process and there is currently no existing assistive technology that utilises daily life objects.

In 2017 another research was conducted [36] that tested the effects of implementing games into EET. study investigated both the treatment and motivational aspects of the device. The device, as shown in figure 2.8, has two metal plates connected on one side, with a hydraulic mechanism between them to change the space between. Users, like physiotherapists, can adjust the incline level (measured in degrees) using a menu and screen. It also connects to a computer via Bluetooth to turn patient exercises into actions in a video game, enhancing their rehabilitation experience. The results of the trial showed that the implementation of games increased the motivation of the patient. Next to that the patient also benefited from the feedback that the device provided.

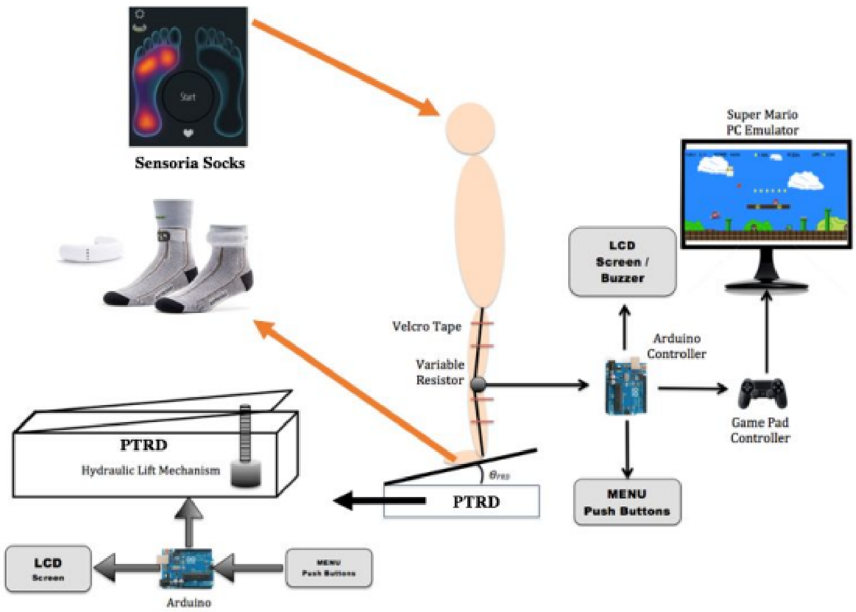


Figure 2.8: Patellar Tendon Rehabilitation Device with Sensoria feedback mechanism [36].

2.4 State of the art

The state of the art can be divided into two categories: the current rehabilitation processes for PT and the technologies capable of assisting in rehabilitation.

2.4.1 Current rehabilitation processes

Based on research by Muaidi et al. [3] the current treatment process of PT includes various options such as resting, changing activities, using anti-inflammatory medicine, getting injections, using tape, doing special exercises, shock wave therapy, electrolysis, and surgery Even though medical therapy is sometimes used for treatment, the effectiveness of non-steroidal anti-inflammatory drugs in treating PT is uncertain, as they may provide short-term pain relief but could hinder long-term tendon healing. Peri-tendinous and intra-tendinous injections, including platelet-rich plasma, corticosteroids, aprotinin, and hyaluronic acid, are commonly used for tendon healing promotion, but their effectiveness remains inconclusive due to a lack of high-quality research and inconsistent procedures. When a physiotherapist or doctor advises a rehabilitation therapy for PT it is chosen so that the patient can build tendon load tolerance, starting with pain reduction and gradually increasing the loading. Exercises such as heavy slow resistance, eccentric, and isometric exercises are used, targeting pain relief and tendon strengthening. Eccentric exercises, especially decline squats, promote collagen remodeling, yet require careful difficulty management. Heavy slow isotonic exercises also alleviate pain and induce tendon structural changes. Compared to methods like steroid injections, eccentric and heavy slow resistance exercises offer better long-term PT management, with higher patient satisfaction.

2.4.2 Rehabilitation tools

Rehabilitation does not solely rely on surgeries and exercises; it also involves tools that aid the process in various ways. This section discusses a few tools that are currently used in different rehabilitation processes.

VR-based therapy

Figure 2.9: The VR system REAL y-Series in action [43].

The Penumbra REAL y-Series is a new type of virtual reality system for rehabilitation that lets patients move freely without being attached to anything, using a virtual body on screen to guide their exercises. With the help of the REAL y-Series the professional caretakers can adjust the exercises to help each patient and improve their performance in real-time. This makes therapy more interesting and helps patients stay focused as they can see themselves do the exercise. REAL y-Series does not only help in rehabilitation therapies but also helps with improving balance, thinking skills, and daily tasks [43].

Exoskeletons and robotic technology

As described in Related Technologies, section 2.3, robotic technology has proven to increase motivation within the rehabilitation of PT. There are, however, different ways of implementing robotic technology to improve rehabilitation. For more severe injuries it is often very painful to start with rehabilitation exercises for injured limb after a surgery, however, with the help of exoskeletons, patients are slowly able to regain strength, improve their range of motion, and restore function in affected limbs, without too much pain occurring. The are numerous variations of exoskeletons, as they can be applied to several different body parts. The exoskeleton in figure 2.10 is, for example, intended for the strengthening of the legs.

Figure 2.10: A lower body exoskeleton in use on a treadmill [44].

Applications

Muvr is a wearable sensor system that tracks joint movements in real-time through a smartphone app, providing precise insights to improve the users rehabilitation. The app ultimately makes the communication easier between patients and caretakers. The application has several functions such as providing information on possible exercises, and reminders. The wearable device is considered non-intrusive and provides real-time monitoring and engagement with the patient that were previously unattainable [45].

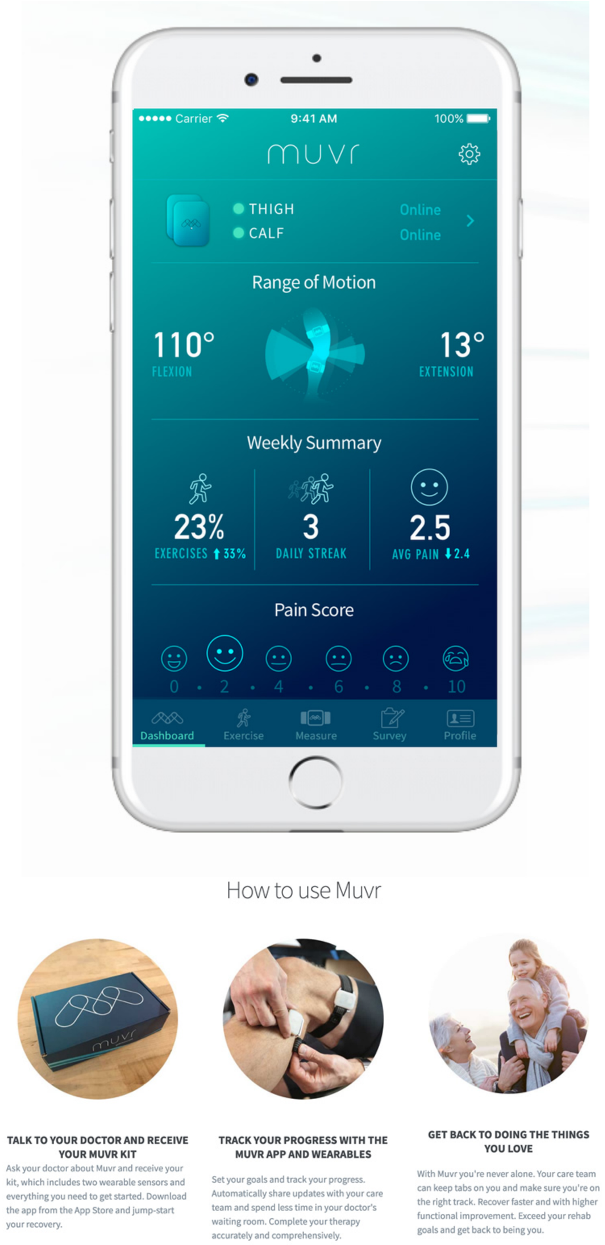


Figure 2.11: The smartphone application named Muvr [45].

Another application that helps with physiotherapy is Pocket Physio. This app takes a different approach compared to Muvr. The app provides instructional videos and guides on exercises for different kinds of injuries. These videos and instructions make sure that the patients can perform the exercises correctly and safely. Pocket Physio makes sure that the user is continuously reminded on anything injury related, such as surgeries, exercise routines etc. Next to that, the application makes sure that the users can always access any needed information on the exercises. By offering these resources, Pocket Physio is able to improve the users engagement in the rehabilitation, adherence and overall recovery results [46]. The application is depicted in figure 2.12.

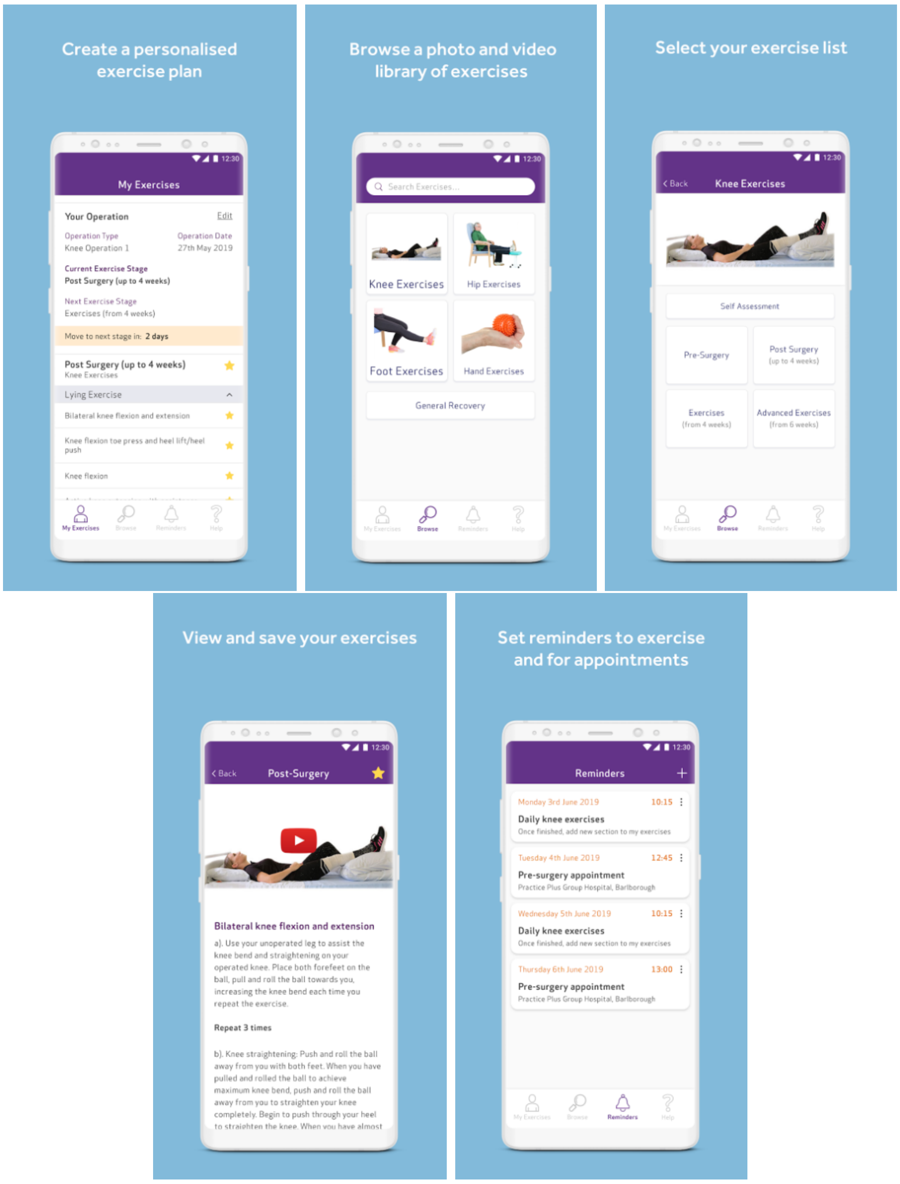


Figure 2.12: The smartphone application Pocket Physio [46].

2.5 Challenges

This research specifically focuses on physical rehabilitation of PT, even though there have been trials of medical therapy. Due to the lack of high quality researches, physiotherapists often recommend physical rehabilitation therapy [3].

Chapter 3

Methods and techniques

This chapter outlines the steps taken to develop a functional prototype from initial idea to final product. The process begins with ideation, where the initial requirements are set, as basis for the brainstorm sessions. Next, the specification phase defines the actual requirements for the prototype. In the realisation phase the chosen idea is developed into a functional prototype. This led to the user evaluation, which describes how the prototype is tested with users to ensure it meets the defined requirements in real-life. With that feedback the final prototype is developed.

3.1 Ideation

The ideation starts by explaining the methods used in developing a functional prototype. The first step involves listing the preliminary requirements that are established, which will be used to brainstorm and evaluate the developed ideas so that one can be developed further.

The third step of the process entails the ideation phase itself, where various concepts are brainstormed. These concepts are then compared against the established requirements. The ideation phase consists out of three iterations to split up the process accordingly and keep a clear overview of the process. The ideation phase entails the following iterations:

1. First ideation session and its challenges.
2. Second ideation session including feedback.
3. Re-evaluating.

The ideation process involves a series of actions outlined in the ideation chapter. These steps are carefully examined to refine concepts and ensure they meet the project's objectives. To provide a clearer understanding of the ideation process, a block diagram has been developed, illustrating the specific journey of the ideation, shown in figure 3.1.

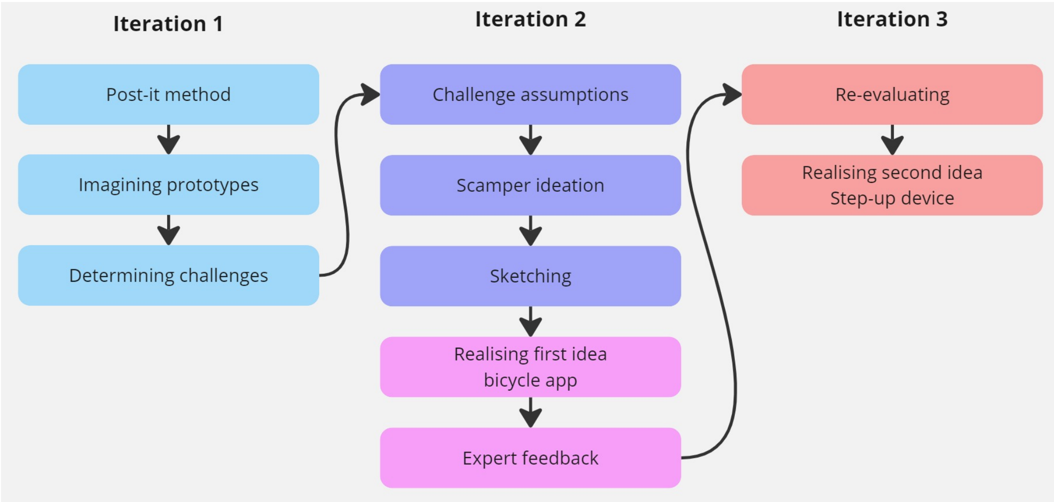


Figure 3.1: The first three ideation iterations

3.2 Specification

The specification phase focuses on defining the criteria for developing the prototype. These criteria are based on both stakeholders' requirements and some general ones. This is to ensure the prototype's effectiveness in meeting the user's needs. Furthermore, the chapter outlines the use of the MoSCoW approach to prioritize features and functionalities, resulting in the identification of essential requirements classified as Must Have, Should Have, Could Have, and Won't Have.

3.3 Realisation

The realisation phase marks the beginning of the second part of the research, which includes a total of three iterations, shown in figure 3.2.

The realisation phase focuses on realisation of the chosen concept from the ideation phase, where the conceptual design is transformed into a practical tool. This chapter details the methods and steps taken to develop the final prototype before the user evaluation, showcasing its functionalities, both internally and externally. To encompass this phase as clearly as possible it has been divided up into two iterations:

4. Prototype first generation.

5. Prototype second generation.

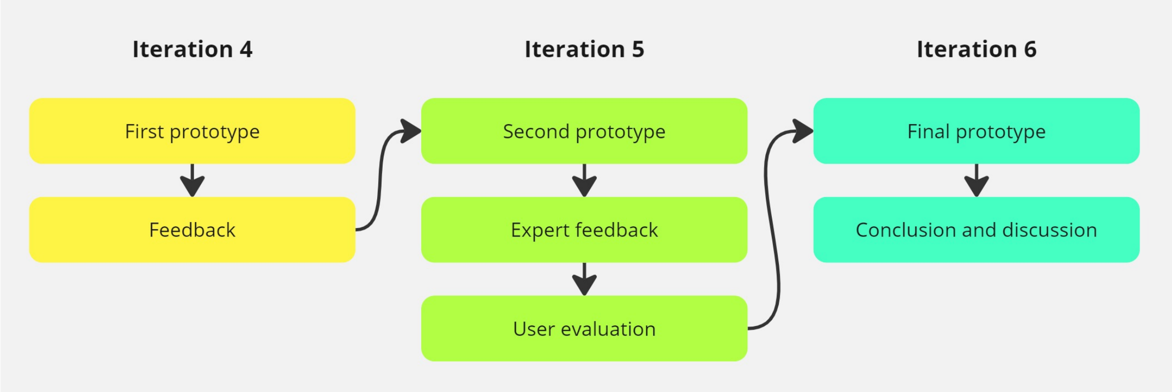


Figure 3.2: This block diagram shows the second part of the iterations which includes the realisation, user evaluation, final prototype, discussion and conclusion.

3.4 User evaluation

Following the completion of the second prototype's development, the next step of the fifth iteration involved evaluating its functionality against the established specifications with the use of user testing. The primary aim of this evaluation was to address specific research questions. This chapter begins with a hypothesis, followed by a methodology that describes how the experiment was structured. It includes details about the participants involved. The results obtained from the experiment are then presented, leading to conclusions drawn from these findings. Ultimately, these conclusions guide the identification of necessary improvements for the final prototype.

3.5 Final prototype

Following the user evaluation, several potential improvements have been identified. These form the foundation for the final iteration: the final prototype. This chapter addresses the development and details of the final prototype. It begins with outlining the adherence of the prototype to the specific requirements. The chapter then delves into the final design of the prototype, discussing the necessary adjustments made during the development process, the selection of materials, and a description of the enclosure. Furthermore, it explains the functionality and the anatomy of the prototype. Lastly, a manual is provided to help guide users actually use the final prototype without assistance.

Chapter 4

Ideation

In this chapter, the ideation process of the daily life object that is utilised in a PT rehabilitation exercise will be explained. First, a list of preliminary requirements based on the user characteristics, described in 2.2, will be compiled and organized. Secondly, the ideation includes the methodology, which shows the creative process of brainstorming, evaluating, and refining ideas to integrate a PT exercise into ADL effectively based on the background research and the requirements. In pursuit of a solution that benefits both stakeholders, several possible considerations have been explored.

4.1 Preliminary requirements

To begin generating ideas and develop potential prototypes, it's crucial to have preliminary requirements based on the background research and user characteristics. These requirements will provide a structured base to help guide through the brainstorming process. The list of requirements is as follows:

4.1.1 Patient's requirements

1. The system must provide feedback to ensure exercises are performed correctly.

2. The system should be safe to use without risk of harm.

4.1.2 Caretaker's requirements

1. The system should adapt exercise intensity as needed.

2. Exercises should be performed in reps of 5 to 10.

4.1.3 Other requirements

1. A PT exercise must integrate seamlessly into ADL.
2. The system's dimensions and weight must be manageable.
3. The system should be accessible to any patient

4.2 Methodology

The ideation process consisted of three main iterations: the first ideation session and its challenges, the second ideation session incorporating feedback, and a final re-evaluation. The methodology outlines these stages and the progress made in each step.

4.2.1 Iteration one

The first iteration existed out of three ideation parts. First, the ideation started off with the Post-it method to get a clear overview of all possible solutions. After that the post-its were used for the second phase: imagining the prototype, also referred to as Solution Design. Lastly, the prototypes were polished and its challenges were determined, in order to prioritise each prototype and its effectiveness. The first ideation phase resulted into three possible systems that could be utilised to integrate PT rehabilitation into ADL and increase the motivation of the patient, however all three systems showed possible challenges when looking at the requirements, which has been tackled during iteration two.

Heuristics Ideation Technique

The first ideation method that has been performed during the first ideation phase is the Heuristics Ideation Technique [47]. It is a method combines two aspects and creates new ideas out of it. In this case, it is an grid that consists out of the PT exercises and the ADL that require knee movement.

This technique shows a clear start of the ideation process. It resulted into the following grid, shown in figure 4.1.

Solution Design

The first possible system utilises 10 or less, depending on the advice of the care-taker, interactive pads in a row on the stairs or on a part of the floor where the patient often walks. The intention of the pads is to motivate the patient to do the

Figure 4.1: Heuristics Ideation Technique [47] combining PT exercises with ADL.

designated exercise when walking up or down the stairs. The pads could be used in the following situations:

Implementation of pads in PTRE when performing ADL.

PTRE	ADL	When
Step up	Ambulating	Walking up the stairs
Quadriceps stretch	Ambulating	Walking over any path/hallway in the house, including stairs

Table 4.1: Implementation of pads in PTRE when performing ADL.

The system of the pads will be installed based on the length of the exercise. The idea of the pads is that an individual steps on the first pad and does the assigned exercise. For example, when doing the quadriceps stretch the individual holds the position for 5 seconds and positions their foot back on the ground. Once the exercise is completed the pad where the individual is standing on turns green. The step up and quadriceps stretch are often done in reps of 10. This means that the individual will then continue to the next pad on the staircase or floor and repeat the exercises until all pads have turned green. This process is shown in figure 4.2. Generally an individual walks up the stairs multiple times per day, which means that a set of this exercise is easily done and only needs intrinsic motivation once. By implementing the system on the stairs, which need to be walked over anyway, it makes it more inviting to the individual to do the exercise, compared to now, without the system.

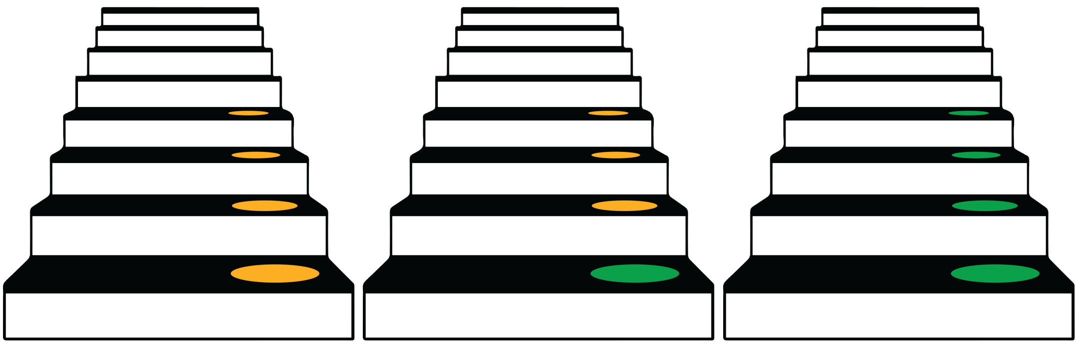


Figure 4.2: Stairs with interactive pads.

The second consideration that is made as a solution is a system that uses a small step, as shown in figure 4.3. This small step can be placed in the kitchen or any cabinet that it normally out of reach. An individually normally steps on a small step when reaching for an item in a high cabinet. Normally the items that are put

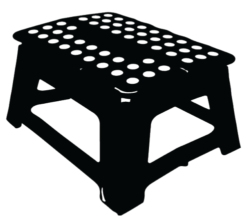


Figure 4.3: A small step

in high cabinets are items that are not frequently used. However, this can be changed to make this consideration more effective. The main daily activities that often utilise cabinets are cooking, for cooking supplies, and house cleaning, for cleaning supplies. With this in mind, the following implementations of PTRE for the small step have been determined:

Implementation of a small step in PTRE when performing ADL.

PTRE	ADL	Where
Step up	Meal preparation	A high cabinet in the kitchen
Step up	Housecleaning	Any preferred high cabinet by the individual in the house

Table 4.2: Implementation of exercises in ADL using a small step.

The exercise can still be performed as the original concept, shown in figure 2.7. However, now the individual will not do the exercise consistently after each other. In this case, the small step is only used when grabbing an item from the cabinet. Due to this, a screen needs to be added that shows the progress of the exercise. As shown in figure 4.4, when one step up sequence has been done a red light becomes green. The exercise is completely finished once all dots have become green. This screen can be attached to a cabinet or to the small step itself.

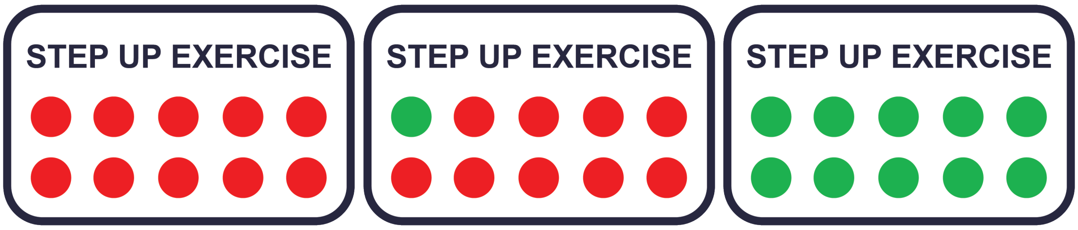


Figure 4.4: Tablet showing the progress of the step up exercise set, positioned on a cabinet.

With the use of this system the individual performs the exercise while doing an ADL. If all 10 exercises are completed from the set, the individual has achieved the goal of the exercise and saved time and needed intrinsic motivation to do the exercise.

The third possible solution that has been considered is a system that is used alongside a chair when doing an ADL. The following table shows what PTRE utilise a chair and table while doing a ADL.

Usage of a chair in PTRE when performing ADL.

PTRE	ADL	Where
Quadriceps with a band sitting	Sitting during feeding or when working behind a desk	Dinner table, work desk or coach

Table 4.3: Implementation of exercises in ADL using a chair and table.

This exercise can be done any time the user is positioned for a longer period of time on the chair. For example, when performing the possible daily activities working behind a desk or eating. The system will detect whether there is someone on the chosen chair and show on the table when the user has to perform the exercise. There are two scenarios where the system could work. First, when an individual is working behind a desk they can align their break times to the system. When the system alarms the individual that the exercise needs to be done, the individual will know to have a break after. The system will be able to detect whether the band has been stretched appropriately and show that the individual is able to have their break. Once the person sits on the chair again the system will reset and start over again. The second scenario is during a meal. If the exercise has to be done 10 times and the individual often eats for around half an hour, the system will now to signal the individual every 3 minutes to stretch their affected leg. In both scenarios the individual will be able to do the exercises without having to think to much about the sets due to the fact that it is now integrated into their daily routine, decreasing the needed intrinsic motivation.

Challenges

All three considerations of the first ideation phase show promising results when looking at the requirements. However, each considered design still comes with its own set of challenges.

The first prototype is presented with the challenge of correctness. With the step up exercise it is possible to measure whether the exercise is done correctly by measuring the weight that is put on the stairs (and the pad) and by putting weight sensors on the railing, to make sure that the user will not cheat during the exercise. However, with the quadriceps stretch it will be difficult to determine whether the exercise is done correctly as the pads are unable to measure the angle the knee turns during the exercise. If the prototype wants to be applicable to both exercises further research needs to be done on detection technology. The question that arises is how to detect with the use of technology whether a rehabilitation exercise is performed correctly.

The second prototype is presented with the challenge of consistency in performing the exercise. The exercise is normally done in reps of 10. However, if the exercise is combined with the ADL the exercise is not performed immediately after each other anymore. In this case the step is only used when an item is pulled or put into the high cabinet, making it unlikely for immediate repetition. Therefore, further research needs to explore the importance of immediate repetition to determine the importance of this challenge and gain insight on the effectiveness of this specific prototype.

The third prototype is confronted with the challenge on whether the prototype will effectively be able to encompass the intrinsic motivation needed for the individual to do the exercise on their own initiative. It is possible that this prototype can be conceived as a disturbance when working or eating. Thus, the prototype should encourage positive emotions associated with the exercise, such as enjoyment or a sense of accomplishment, which should motivate the user to do the rehabilitation exercise. As a result, further research should be conducted on the how to encourage positive emotions, with the use of technology, to increase motivation.

4.2.2 Iteration two

All three possible prototypes after the first ideation session showed conflicts with the requirements, as mention in section 2.5. Therefore, new ideation methods were utilised to reveal other possible solutions. First, I started out with the ideation method called Challenge Assumptions. Secondly, I did the Scamper ideation method. Lastly, I started sketching out the four ideas that were revealed after the methods, which led to the development of the first bicycle prototype.

Challenge Assumptions

For this ideation phase it was important to be able to find alternative ideas. Therefore, I chose to do the Challenge Assumptions method. It is a method that aims to find and question the hidden assumptions behind a problem. By identifying these assumptions, it opens up the possibility of finding new solutions that I might not have thought of before. This approach is known for being able to encourage creative thinking and can lead to discovering new and effective ways to solve problems. Overall, it helps in coming up with more innovative solutions, which was needed for the first phase of second iteration.

As shown in figure 4.5, requirements of the prototype were shortly listed and questioned. This led to a bigger search into finding a possible solution for a prototype. Especially the questioning of the knee movement and existing exercise (for

Figure 4.5: Challenge Assumption ideation Method for PT exercises integrated into ADL.

PT) led to a broader horizon. For example with the knee movement, an exercise can be done in a daily activity that does not require movement of the knee but does give the opportunity for knee movements, such as standing still whilst cooking or brushing your teeth or sitting during working or eating. During these activities it is possible to move the knee even though the activity does not require it. Which put a new light on the step-up exercise and the quadriceps with a band sitting exercise. Next to that the questioning of the existing exercise led to a further search into any exercise that require knee movement, such as cycling. With this in mind I could continue to the next ideation method.

SCAMPER ideation method

The SCAMPER technique is a tool for creative problem-solving that helps generate new ideas by changing existing ones. SCAMPER stands for Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, and Reverse. By thinking through these different strategies, it's possible to look at problems or projects in new ways and come up with unique solutions. This approach generally encourages thinking outside the box and finding innovative solutions by exploring different possibilities. The SCAMPER method is a more specific method compared to the Challenge Assumptions, consequently, creating a better overview of new possible solutions.

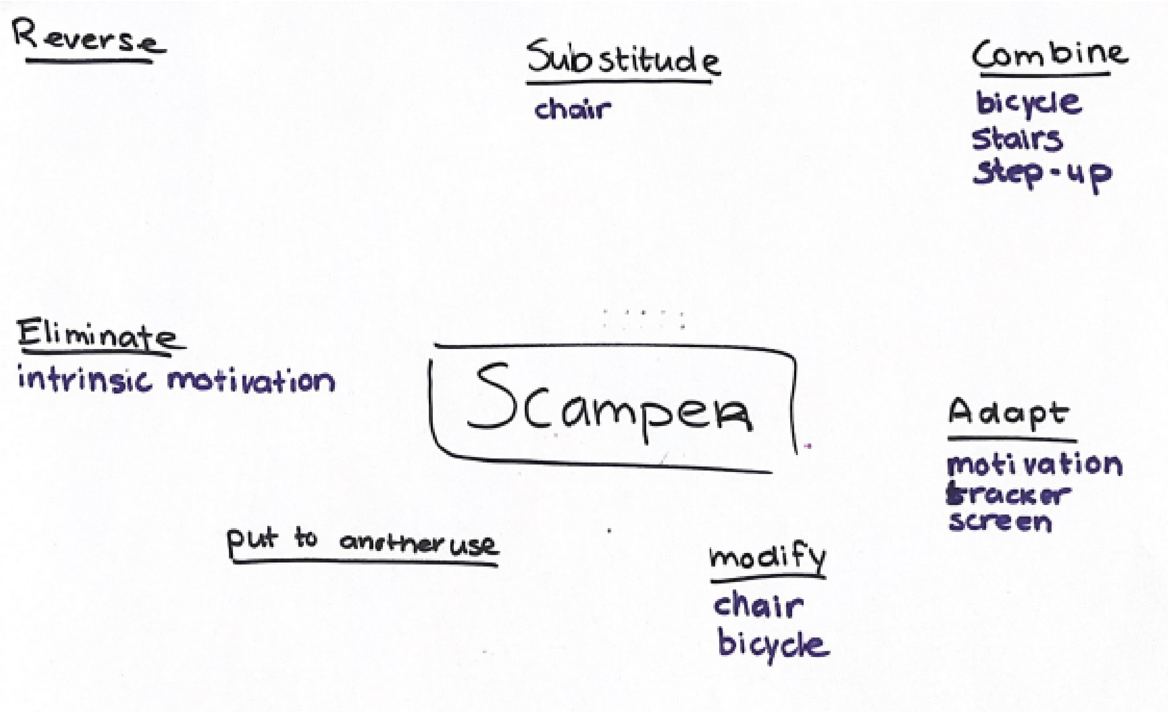


Figure 4.6: SCAMPER ideation method for PT exercises integrated into ADL.

With the use of this method, as shown in figure 4.6, the modify topic showed the possibility of utilising the bicycle for an rehabilitation exercise. According to Dr. Pamela Mehta [33] stationary cycling is a possible exercise for PT. Therefore by modifying the bicycle it would be possible to integrate this exercise into cycling, and consequently, changing the exercise to a daily activity.

Sketching

As I discovered the new possible solution, the bicycle, I started to sketch out the idea, including the two of the original ideas as they showed new promise after the Challenge Assumptions method. These sketches included a simple drawing of the devices/items and what components would be needed to make the device successful, including a few explanations on what some devices do, shown in figure 4.7.

After comparing the sketches it was revealed that the bicycle prototype showed most promise in being able to integrate an exercise as seamlessly as possible into a daily life activity.

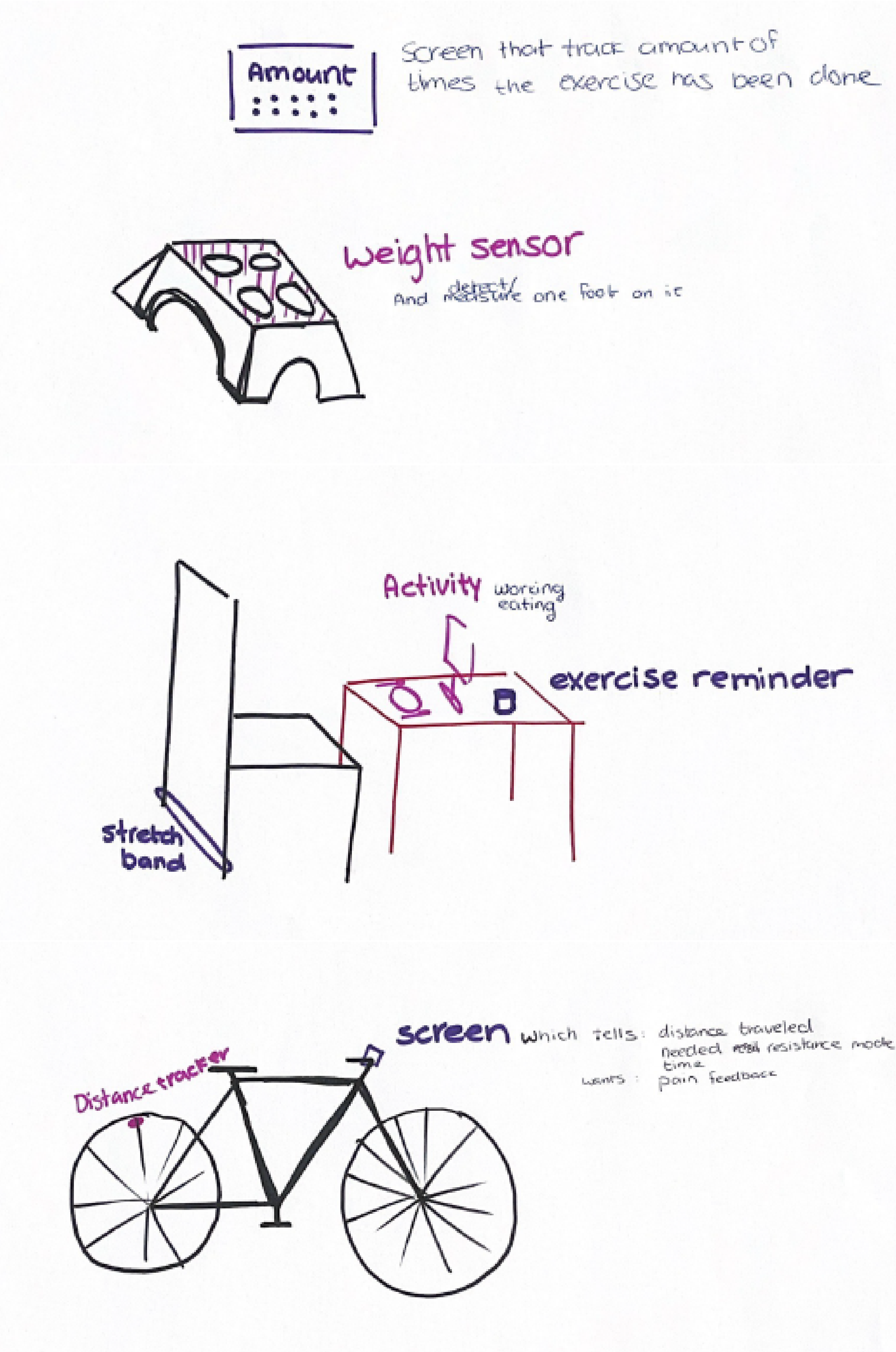


Figure 4.7: Sketches of three possible prototypes: the step-up exercise, Quadriceps with a band stretch sitting exercise, and the bicycle exercise.

Bicycle exercise idea

After the latest ideation session the idea of the bicycle exercise showed the most promise and was, therefore, chosen to be further developed and reviewed by an expert.

The idea of the exercise is that the exercise of the stationary bike is modified so it can be performed on a bicycle that has several gears. After the sketching it was clear that I needed to build an app to be able to change the exercise to the real bicycle.

For this prototype the app would include a traveled distance tracker, speed tracker, and would show when to change your gears so you can perform the exercise correctly. The changing of the gears, and thus the intensity of the exercise would be based on the distance that was going to be traveled and in what stage of the rehabilitation the patient is.

As shown in figure 4.8 the first screen shows you two possible options: to start or see your exercise history. After you click on start it asks you what distance you are going to be travelling and if you are currently experiencing any pain. This is to determine the difficulty and length of the exercise. After you have answered both questions you click on start and can start cycling. Screen 3 shows you speed, how far you are and in which gear you should be. Once you have finished cycling you can click on stop and tell the app how much pain you have experienced during the cycling in screen 4. After that you'll automatically be redirected to the home page, screen 1.

Figure 4.8: Screen 1 to 4 in chronological order.

The first app that I created was with Ionic Framework. The reason why I chose it is because Ionic Framework is an open-source toolkit for building mobile and desk-top applications using web technologies like HTML, CSS, and JavaScript. With it I would be able to create cross-platform apps for iOS, Android, and the web from a single codebase, which was exactly what I needed for the first prototype.

Expert feedback

To confirm and improve the idea for the bicycle prototype an interview with a physiotherapist who is familiar with the rehabilitation process of the knee was conducted. The interview gave a better insight of all what is normally surveilled before, during and after the bicycle exercise. Thus, at the end of the interview it became clear much more needed to be added to the app to make it successful, such as the heartbeat of the patient during the cycling, how much the patient has to stop for traffic lights for example and the current feelings of the patient as it can influence how difficult they want the exercise to be. Notes of this interview can be found (in dutch) in appendix A.

Due to the fact that Ionic is not able to show the current heartbeat of someone I had to switch to another app building platform: Xcode. Xcode is Apple's platform for creating software for iOS and other apple systems. It includes a tools for coding, testing, and debugging applications, along with a user-friendly interface builder. The app can then be tested on a simulator but also on the actual device. Xcode showed all the possible requirements to make this app a possibility. However, when looking further into Xcode it was a very complex building system and without any prior experience it would become to difficult for me to make this app fully functional. Therefore, after weeks of trying I had to go back to the drawing table and see what other exercise still could show promising results regarding my research question.

4.2.3 Iteration three

This iteration exists out of re-evaluating the previous possible designs, due to the fact that the previous device showed to be too complex to integrate into a bicycle. This led to the continuation of the step-up exercise under different conditions and start prototyping.

Re-evaluating

Due to the fact that the bicycle prototype with the use of an app was not a possibility anymore I looked at alternatives for sensors that could be put on the bike to get the same results as the app, however, this showed extensive work that would need to be done to any bike that would use this system and, therefore, I restrained from continuing with that specific exercise.

The step-up exercise still showed a lot of potential for during brushing the teeth, when done in a lateral position. As a result, I decided to continue with that idea and draw it out once again to see what sensors would specifically be needed.

Step-up exercise device

The first step of creating the step-up device was to realise the needed functionality of the device and find the right components for each of the functions, based on the preliminary requirements, from section 4.1. For this I made a basic version and an advanced one of the possible device, as shown in figure 4.9. The basic device will first be developed to test out what was really needed from the advanced version to make the device completely feasible or if some components could be unnecessary, due to the fact that the basic version already adheres to the listed preliminary requirements.

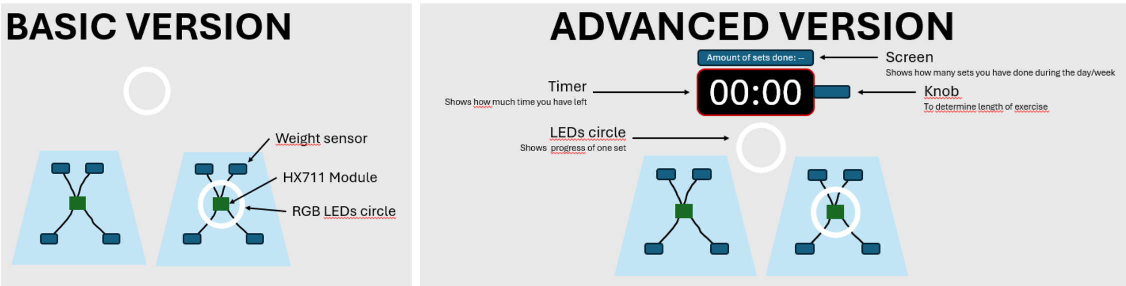


Figure 4.9: Basic and advance drawing of the step-up exercise.

The exercise works as follows. The device is first in a resting mode. When the user steps on the device the LED circle will turn red. This means the user can start doing the exercise. When the user lifts the foot that is positioned on the ground 2 or 3 LED's slowly turn green. Once those LED's are green the user steps back on the ground. By repeating this the circle gets completed and after 10 reps is completely green. When the circle is completely green it flickers the lights a few times and after that goes back to the resting mode.

The weight sensors that were initially placed underneath the plates appeared to be too thick for the ground plate, lifting the plate, making it too high. As a result, the weight sensors were swapped with one LDR sensor on each plate that measures the lack of light when someone is standing on it.

The exercise can now be performed whilst brushing your teeth without having to think about how many reps you did or still have to do. This ensures that most of the attention of the user can go to the brushing of the teeth ensuring that the user does not have to think about how long or when he or she has to step up or down.

Once the components of the step-up device were identified, the next step was to enter the prototyping phase and construct the initial prototype that has just been identified.

Chapter 5

Specification

5.1 Requirements

In order to create a prototype that effectively integrates a PT exercise into ADL, a list of requirements must be defined. These specifications provide a clear framework for the design and development process, ensuring the prototype meets its intended objectives and performs as expected. After the users' characteristics has been defined and the ideation showed more clarity on the path that has to be taken it is possible to list the requirements for both stakeholders, the patients (individuals dealing with PT) and the caretaker properly. These requirements are listed in order of prioritisation by the Must have, Should have, Could have and Will not have (MoSCoW) method.

5.1.1 Patient's requirements

1. The system must provide feedback to the user on their performance during exercises to ensure it is performed correctly.
2. The system must be safe to use and not pose any risk of harm to the patient.
3. The system should be inviting and motivate the user into doing the intended exercise regularly.
4. The system should motivate the user by lowering the needed intrinsic motivation.
5. The user interface should be easy to understand.
6. The system should not contribute to stress that possibly arises during the ADL.
7. The system should not hinder the user's daily way of living, taking as little time as possible away from the ADL.

8. The system should feel intuitive, the user should know what to do after a one-time explanation.

5.1.2 Caretaker's requirements

1. The system should be adaptive to the needed intensity of the exercise.
2. The exercise should be performed in reps of 5 to 20, depending on the advice of the caretaker.
3. The system could show the collected data achieved by the patient performing the exercise to monitor the process.

5.1.3 Other requirements

1. A PTRE must be integrated into an ADL.
2. The system should have a reliable power source, so that the system takes as little time as possible away from daily life.
3. The dimensions of the system must not exceed the dimensions of the average sink.
4. The weight of the system is limited at 10 kg.
5. The system should be accessible to any PT patient.
6. The system should be easy portable.
7. The system could work alongside a daily life object.

Chapter 6

Realisation

This chapter delves into the realisation of the prototype, detailing the development process leading up to the final version. The following sections highlight the progress of each iteration and the corresponding adjustments made.

6.1 Methodology

To ensure that the final prototype meets the established requirements, a structured methodology was implemented. Consequently, the realisation phase consists of two stages: initially, it focuses purely on functionality, as shown in iteration four. Thus, the primary focus was on the integration of the components such as hardware and software. Once the functionality has been defined, the focus shifts to achieving the remaining defined requirements. Both iterations include detailed descriptions of the enclosure, hardware, software, and the functionality of the prototype.

The description of the enclosure section provides a detailed account of the physical structure and design of the prototype's housing or casing. It includes dimensions, materials used, and any notable features or components integrated into the enclosure.

The hardware section outlines the physical components that make up the prototype. This includes a list of all electronic and mechanical parts, their specifications, and their roles within the prototype's overall functionality.

The software section discusses the non-physical aspects of the prototype. It covers the programming, and software architecture used to control and operate the hardware components.

This functionality of the prototype section explains how the prototype operates and achieves its intended purpose. It describes the key functions and capabilities of the device, including its modes of operation and the feedback that the device gives.

6.2 The step-up exercise

The exercise that was chosen for this prototype is the lateral step-up exercise, which is a variation of the step-up exercise shown in the background research, figure 2.7. The exercise is performed exactly the same, but then sideways, which is depicted in the following figure 6.1:

Figure 6.1: Lateral step-up exercise [48].

6.3 Iteration four

The first prototype is based on the ideation of the step-up device, discussed in section 4.2.3. This iteration primarily addresses the functionality of the prototype following the initial code development. The goal is to identify the (un)necessary components or any that are still lacking. As a result, this iteration focuses solely on the essential requirements during this phase.

This prototype is based on the following requirements:

- The system must provide feedback to the user on their performance during exercises to ensure it is performed correctly. (Requirement 5.1.1.1)
- The system must be safe to use and not pose any risk of harm to the patient. (Requirement 5.1.1.2)
- The PTRE must be integrated into an ADL. (Requirement 5.1.3.1)

These requirements shaped the development of the initial prototype, which is shown in the following figure 6.2:

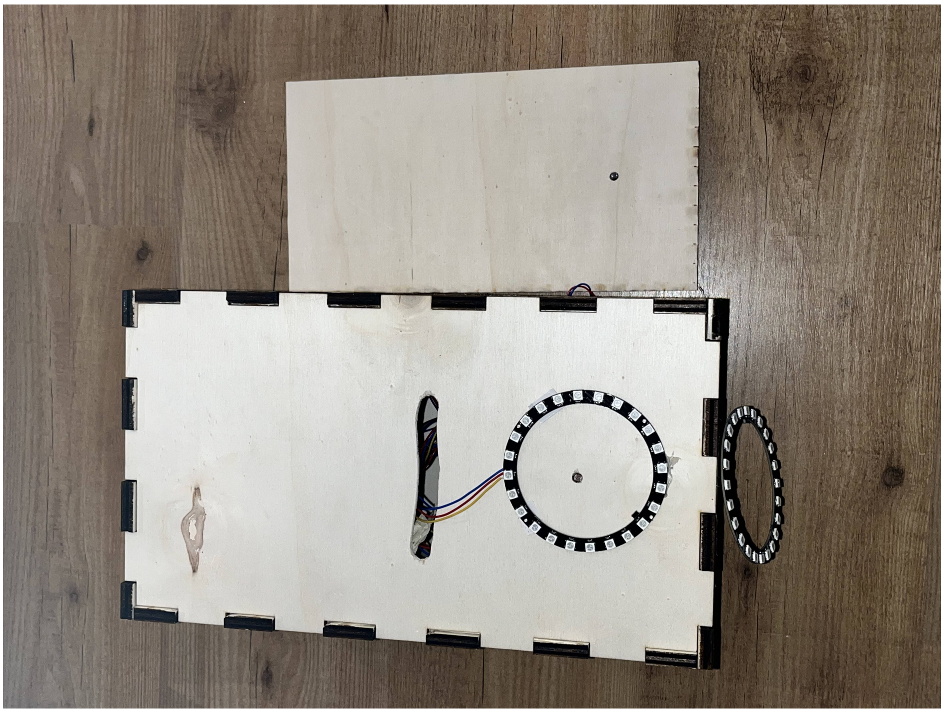


Figure 6.2: The first step-up prototype.

6.3.1 Description of the enclosure

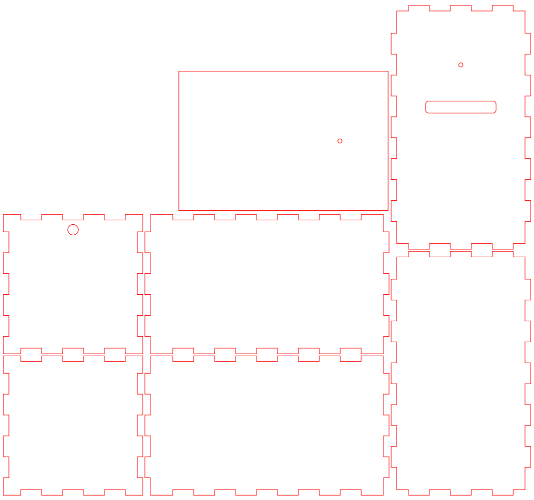


Figure 6.3: Box plans of the wooden components of the first prototype.

The first prototype measures 20x35x20cm and is constructed using 8mm wood. The top wooden plate is 4mm thick and topped by a plate made of plexiglass that has the same dimensions, excluding the holes in the wooden plate as it has to be a solid plate to stand on. An adjacent 20x30x0.8cm plate is also included, as illustrated in figure 6.2. The plans for the wooden components of the device are shown in figure 6.3. Both the ground plate and top wooden plate are equipped with an LDR sensor, requiring small holes to accommodate them. The highest plate also features an LED circle, which is positioned through a rectangular hole cut in the top layer to fit the LED circle. Additionally, the prototype includes a second LED circle connected by a 1.5-meter wire, which can be extended to position it at eye level for the user. This necessitates a small hole in the 20x20cm plate as well. The real-life appearance of the enclosure is depicted in figure 6.2.

6.3.2 Functionality

The prototype functions as follows:

1. The LEDs circle starts in rest mode, this is when the user is not interaction with the prototype.
2. Once the user positions their feet on the device the LED circle turns completely red, indicating the user can start.
3. When the user lifts their foot off the ground plate, the first section of the LED's slowly turn to green.
4. Once the section is completely green the user can position their foot back on the ground plate, initialising the next section of LEDs.
5. The user repeats step 3 and 4 until the whole circle is green.
6. Once the circle is completely green, the LEDs flicker their lights a few times indicating that the exercise is done. After the flickering the devices resets itself back to the rest mode.
7. Once the device is back in rest mode, the user can repeat the steps as many times as they want.

Hardware

The prototype consist of the following hardware components:

Component	type	functionality
Arduino NANO	Arduino Nano - ATmega328	The Arduino acts as a light-sensitive device that detects changes in surrounding light using the LDRs. The arduino is then able to adjust the settings of the LED circle accordingly.
LED circles	24-bit RGB LEDs WS2812b circle	The LED circles show the progress of the step-up exercise.

Component	type	functionality
Ground plate LDR	Sensor LDR 16-50kΩ	The LDR that positioned in the ground plate measures whether the user has positioned one of their feet on the ground plate.
Top plate LDR	Sensor LDR 16-50kΩ	The LDR that positioned in the top plate measures whether the user has positioned one of their feet on the top plate.

Table 6.1: Functionality of each hardware component of the first prototype.

Anatomy of the prototype

As listed in the hardware section, section 6.3.2. The first prototype includes two LED circles and two LDRS, which are connected through an Arduino Nano. One LDR is currently positioned in the ground plate and one in the top plate, which is in between the LED circle. They measure whether the user is standing on the platforms, which is shown on figure 6.2. Next to that the two LED circles visually show the progress of the exercise. The wiring of the prototype and its schematic can be found in figure 6.4.

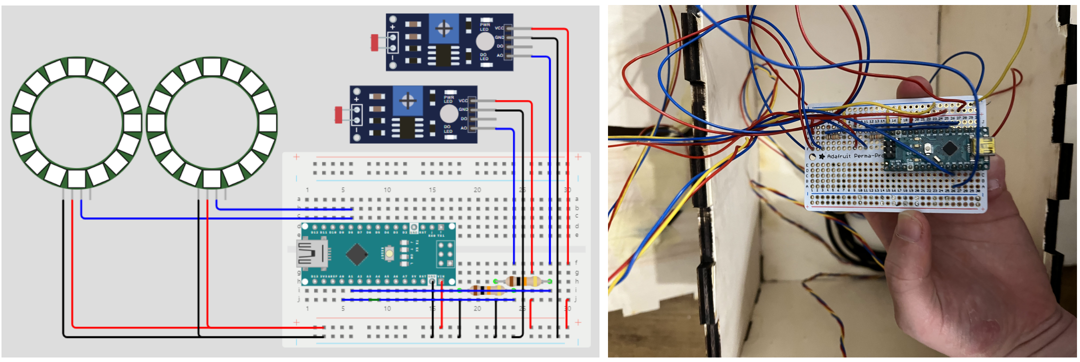


Figure 6.4: Schematic designed on Wokwi [49] and wiring of the first step-up prototype.

Software

The software for this project is developed using the Arduino programming language and operates on an Arduino Nano. This microcontroller is used to successfully make the hardware components communicate, such as LDR sensors and LED circles. This section details the software architecture. The code for the first prototype can be found in section B.1. The table below, table 6.5, illustrates the connections of components and their respective functions within the software.

Port	Component	Software
D8	2 LED circles (actuator)	The LED circle acts as an actuator and responds to the interactions detected by the LDRs. The software ensures that the LED circle receives the appropriate response based on the sensor inputs.
A0	LDR top plate (sensor)	The LDR detects whether the person is standing on the plate. If the LDR value is lower than 650 the person is standing on it, if it is higher than 650 the person is not on the top plate.
A1	LDR ground plate (sensor)	The LDR detects whether the person is standing on the plate. If the LDR value is lower than 650 the person is standing on it, if it is higher than 650 the person is not on the ground plate.

Table 6.2: Information about the software side of the hardware components of the first prototype.

6.3.3 Feedback

After the initial prototype was realised, it was necessary to test its effectiveness. Upon testing the device myself and feedback from the supervisor, several modifications were identified. The following list outlines the improvements that are needed for the current prototype and the specific requirements each addresses:

1. Add lights (LED strip) on the side of the box to enhance the functionality of the LDR sensor in the ground plate.
2. Incorporate additional LDRs on both plates.
3. Reduce the length of the device (requirement 5.1.3.5).
4. Increase the sturdiness of the structure (requirement 5.1.1.6).
5. Add internal sections to maintain cleanliness.
6. Add wire protectors.
7. Add a bag to the prototype so it is easily portable (requirement 5.1.3.6).
8. Change the red light to light blue or white (requirement 5.1.1.3/5).
9. Ensure it is clear which side to stand on (requirement 5.1.1.5).
10. Design the device to accommodate both knees.

11. Make the height adjustable (requirement 5.1.1.1).

12. Remove the LED circle under the foot, as it was deemed unnecessary.

13. Ensure that the LED circle positioned at eye level can be placed on the sink or in its surroundings.

14. Replace the rest mode with a mode that allows you to adjust the number of repetitions and the duration in seconds for the exercise.

6.4 Iteration five

Based on the previous iteration, this section focuses on implementing the feedback points into the second prototype and ensuring it adheres to as many requirements as possible. This section will detail the specific changes made and present the new enclosure, functionality, design, hardware, and software of the second prototype.

6.4.1 Adjustments

To incorporate the feedback into the second prototype, several adjustments were made based on the suggestions and observations gathered from the initial iteration. These adjustments are crucial for enhancing the functionality, usability, and overall performance of the prototype. Table 6.3 provides a detailed overview of these modifications, highlighting the specific changes implemented in response to the feedback.

Feedback number	**What has been adjusted**	**Effect**
1	One LEDs strip has been added to the longer side of the box	It makes sure the LDRs on the ground plate always receive enough light in order to calibrate the LDRs correctly.
2, 9 and 10	Both the top plate and the ground plate now have 2 LDRs each on opposite side of the plates.	The complete device can now be rotated, allowing the user to practice on both the left and right knee, this immediately makes it clear what side the user should stand on.

Feedback number	What has been adjusted	Effect
3 and 11	The dimensions of the box have been changed to 20x30x9cm with table legs that can extend the length of the device from 10cm to 16 cm and the platform is now 20x30x3.3cm	Making it smaller makes the device easilier portable and fit better to the required dimensions, taking up less space on the floor.
4	The boxes are now constructed entirely from 8mm wood and have an additional layer of plexiglass on top.	This improves the sturdiness of the device, making it feel safer to the user.
5 and 6	Tape and wire protectors have been used to position the components correctly. Tape keeps the wires in place, while wire protectors ensure that the wires do not touch each other if they, somehow, shift from their positions.	These preventions keep the device from malfunctioning
7	A bag has been added to the device, allowing the prototype to be easily transported to different locations.	This increases the portability of the prototype
8	The red lights have been changed to blue.	This makes the prototype look less aggressive.
12	The LED circle that was originally placed under the foot has been removed	This causes for less detraction as there are less components to look at.
13	A small box with dimensions of 12x12x4cm has been added to house the LED circle.	The box ensures that the LED circle can be positioned anywhere on the sink, making sure that the user is able to continuously see the progress of the exercise.
14	The rest mode has been replaced with a settings mode, which includes a rotary knob in the small box on the side to adjust the settings.	The exercise is now adjustable to the preference of the therapist and user.

Table 6.3: Specific list of adjustments of the second prototype based on the first one.

These adjustments led to the following prototype, illustrated in figure6.5:

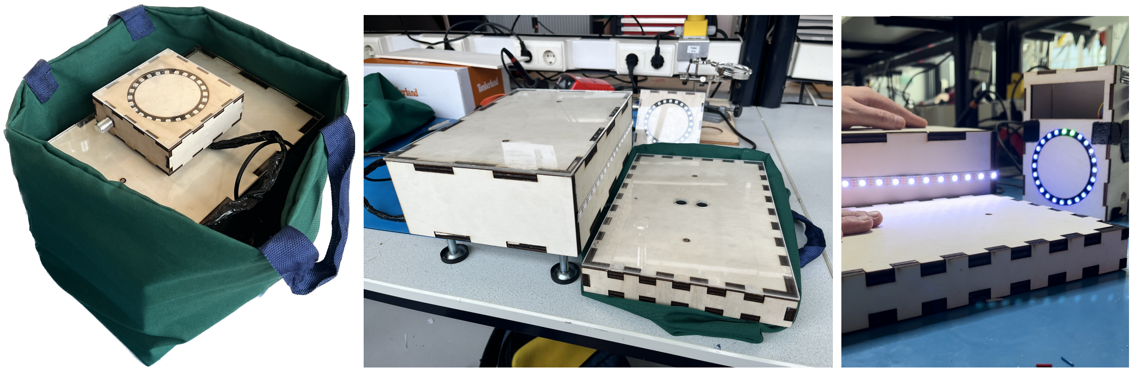


Figure 6.5: The second prototype, shown sequentially when packed for travel, when set up, and when in use.

6.4.2 Enclosure

The prototype now consists of three wooden boxes, each with a protective plexiglass layer. The ground plate measures 20x30x3.3cm with a bag attached to it, as shown in first two images of figure 6.5. The big box has dimensions of 20x30x9cm, but measures 20x30x10cm because of the attached table legs underneath and can be adjusted in height to 16 cm tall. The LED box is 12x12x4cm. The box plans of all 3 boxes can be found in figure 8.3.

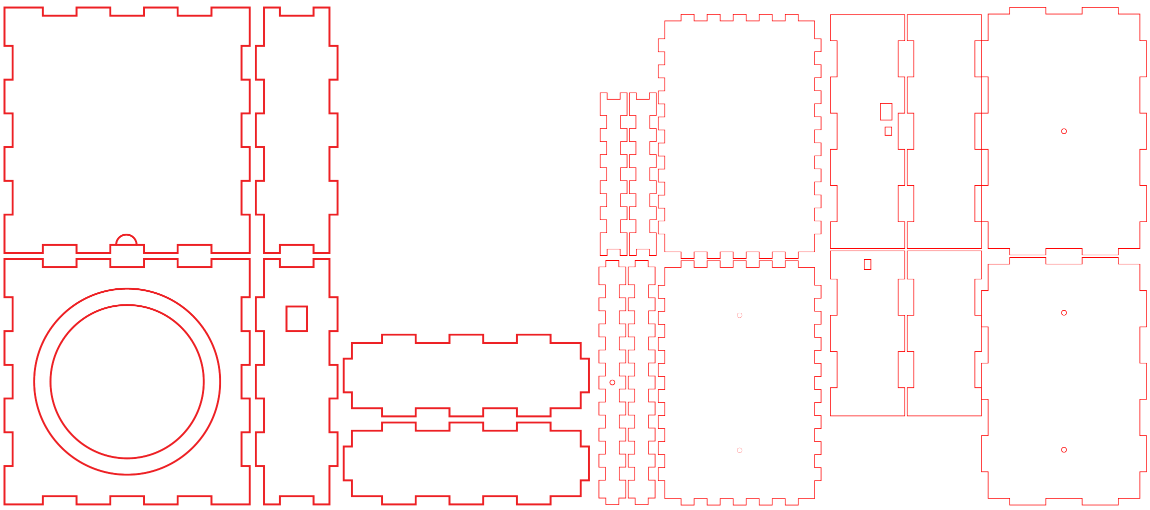


Figure 6.6: The wooden box plans the second prototype, demonstrating the LED box, platform and big box respectively.

6.4.3 Functionality

The prototype functions as follows:

1. The device has to be turned on.
2. The LEDs circle starts in settings mode, first showing how many repetitions the exercise will have.
3. The User adjusts the amount of LEDs that are on to the amount of reps the user wants.
4. Once the user is satisfied with the amount he/she steps on the ground plate, initiating the second settings mode, the amount of seconds the exercise will take.
5. The User adjusts the amount of LEDs that correlate to the amount of seconds the user wants per rep.
6. Once the user is satisfied with the amount the user positions their feet on the device the LED circle to make it completely turn blue, indicating the user can start.
7. When the user lifts their foot off the ground plate, the first section of the LED's slowly turn to green.
8. Once the section is completely green the user can position their foot back on the ground plate, initialising the next section of LEDs.
9. The user repeats step 7 and 8 until the whole circle is green.
10. Once the circle is completely green, the LEDs flicker their lights a few times indicating that the exercise is done. After the flickering the devices resets itself back to the rest mode.
11. Once the device is back in setting mode, the user can repeat the steps as many times as they want or turn the device off.

Hardware

The prototype consists of the following hardware components:

Component	Type	Functionality
Arduino Nano	Arduino Nano - ATmega328	The Arduino acts as a light-sensitive device that detects changes in surrounding light using the LDRs. The arduino is then able to adjust the settings of the LED circle accordingly.
LED circle	24-bit RGB LEDs WS2812b circle	The LED circles show the progress of the step-up exercise.
Two ground plate LDRs	Sensor LDR 16-50kΩ	The LDRs that are positioned in the ground plate measure whether the user has positioned one of their feet on the ground plate.
Two top plate LDRs	Sensor LDR 16-50kΩ	The LDRs that are positioned in the top plate measure whether the user has positioned one of their feet on the top plate.
Rotary knob	Switch rotary encoder	The rotary knob allows the exercise settings to be adjusted during the settings mode.

Table 6.4: Functionality of each hardware component of the second prototype.

Anatomy of the prototype

As shown in figure 6.7, the prototype now includes two more LDRs and one rotary knob and uses one less LED circle.

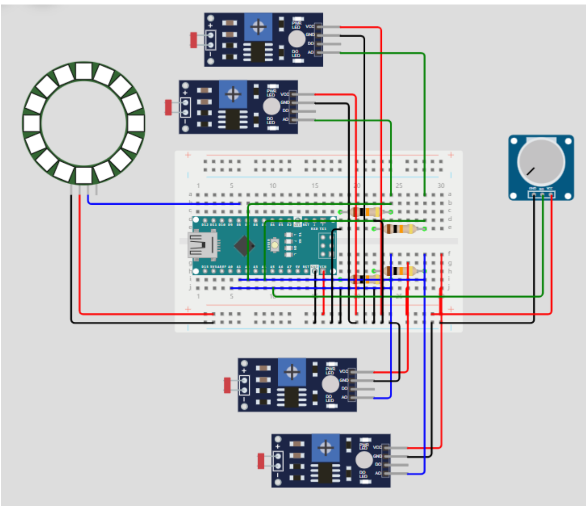


Figure 6.7: Schematic of the components of the second prototype designed on Wokwi [49].

Software

This section details the software architecture, based on the software of the first prototype. The improved code for the second prototype can be found in appendix B.2. The table below, table 6.5, illustrates the connections of components and their respective functions within the software.

Port	Component	Software
D8	LED circle (actuator)	The LED circle acts as an actuator and responds to the interactions detected by the LDRs. The software ensures that the LED circle receives the appropriate response based on the sensor inputs.
A0	Top plate LDR (sensor)	The LDR detects whether the person is standing on the plate. If the LDR value is lower than 650 the person is standing on it, if it is higher than 650 the person is not on the top plate.
A1	Ground plate LDR (sensor)	The LDR detects whether the person is standing on the plate. If the LDR value is lower than 650 the person is standing on it, if it is higher than 650 the person is not on the ground plate.
A2	Second top plate LDR (sensor)	This LDR has the same function as the other top plate LDR, but then for the other side of the plate.
A3	Second ground plate LDR (sensor)	This LDR has the same function as the other ground plate LDR, but then for the other side of the plate.
A5	Rotary knob (sensor)	The rotary knob provides values ranging from 0 to 1024, which are mapped to control a maximum of either 20 LEDs or 10 LEDs. This adjustment ensures the correct number of LEDs light up based on the visible repetition and seconds modes.

Table 6.5: Information about the software side of the hardware components of the second prototype.

Chapter 7

User evaluation

This chapter evaluates the integration of step-up exercises during teeth brushing. The usability test involved 8 healthy participants to address the following questions.

- ’Do participants find the step-up exercise easy to integrate into their tooth brushing routine?’
- ’Does the step-up exercise affect the overall time taken to brush teeth?’
- ’Are there any discomforts or difficulties reported by participants while performing the step-up exercise during tooth brushing?’

This chapter includes an hypothesis, methodology, a description of the participants, the results of the evaluation and the conclusion, including a list with the needed improvements for the final prototype.

7.1 Hypothesis

Based on the background research and ideation the following expectations can be formulated:

1. The prototype is expected to demonstrate more consistent performance times among participants regarding the time required to perform the exercise.
2. Participants will need to be less attentive to the exercise compared to the standard exercise.
3. Generally, the step-up prototype will be perceived more favorably than the original.
4. Small discomforts will likely be found when testing the prototype.

7.2 Methodology

This section outlines the methodology of the experiment, which entails the structure of the test and the measuring of the results.

The structure of the experiment shows the testing phase of the user evaluation, which was divided into two parts: an evaluation test and a survey entailing the feedback of the participants. The main goal of the user testing is to get the participant's feedback on the functionality and overall experience of the prototype.

The test phase produces two types of results: feedback and time measurements. The duration times will be averaged, and the standard deviation will be calculated to assess whether the prototype improved the consistency of the exercise and the feedback will help improve the functionality of the prototype.

The survey results will be measured by collecting open feedback from the participants. This feedback will evaluate the prototype's effectiveness in requiring low cognitive effort, determining if the step-up exercise with the prototype can be easily integrated into daily activities. Consequently, this will address the user evaluation research questions.

7.3 Structure of the experiment

The experiment begins by informing the participant about the test, its rationale, and the procedures involved in the testing phase. After that, the participant can read the information that has just been told again and has to fill in the consent form, depicted in appendix D. Before starting the test, they are asked four demographic questions about their age, sex, prior experience with the exercise, and any prior knee injury. The researcher shortly demonstrates the step-up exercise, so that the participant can determine whether they are familiar with the exercise.

The participant is then asked to perform the step-up exercise as typically prescribed by a therapist. the participant does 15 reps of 5 seconds without any assistance. The time the exercise takes is recorded. Following this, the researcher sets up the prototype for the second exercise and briefly demonstrates how the prototype works on settings: 3 reps for 3 seconds, while the participant observes.

After the demonstration, the participant tests the prototype. They set it to 15 reps of 5 seconds and perform the exercise. Again, the duration time is recorded starting from the first rep. Excluding the setup time of the prototype, both exercises should take between 1.5 to 2 minutes, accounting for one to three seconds of rest on the ground plate before lifting the foot again. After both tests, the participant puts the prototype back in the bag to test its portability and is given the opportunity to provide open feedback on the prototype to capture their fresh opinions and observations.

The final component of the experiment is a survey designed to address the research questions of the user evaluation. The survey only includes open-questions. The survey questions the participant about the effect of the prototype on low cognitive thinking and its ease of use. The survey also includes demographic questions, such as age and gender, but also other informative questions such as whether the participant is familiar with the step-up exercise and if they have had a knee injury prior to this experiment. The specific questions can be found in appendix C. Lastly, the participants are thanked by the researcher for their participation, informing them, in case of any question, they can contact the researcher personally or via email.

7.4 Participants

Eight people, five male and three female, took part in the user evaluation. The requirements of the evaluation were that at least half of the participant had either experienced a serious knee injury that needed recovery prior to the testing, or had experience with the exercise itself. An important requirement was that the participant must be fully healthy to participate. There were three different aspects that could influence the results of the testing, age, injury and experience.

The evaluation included a range of ages between 20 and 56 years old. Which is specifically shown in the following figure, figure 7.1:

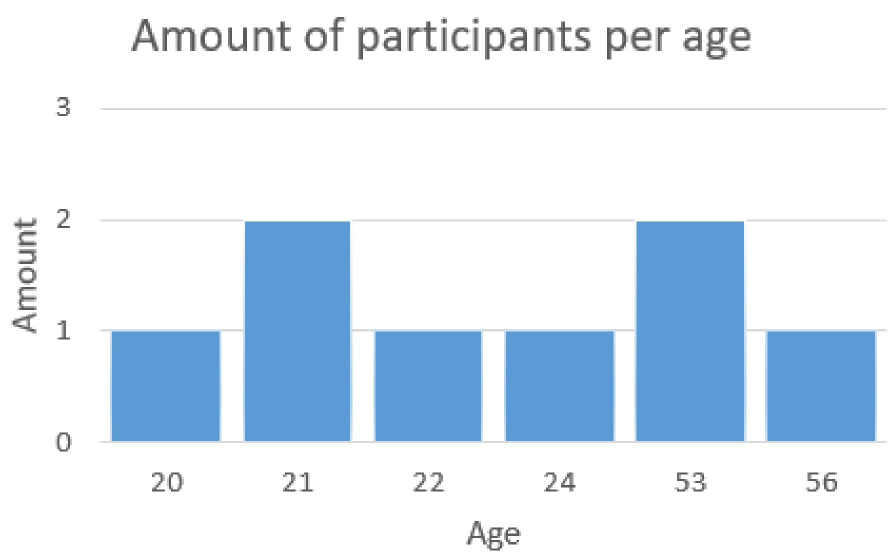


Figure 7.1: The ages of the participants of the user evaluation.

Secondly, the evaluation also included people that were either experienced with the exercise, had a prior knee injury, both or neither. The following pie diagram shows that the evaluation included two participants with prior experience, two with a prior knee injury, two with both and two with neither, shown in figure 7.2.

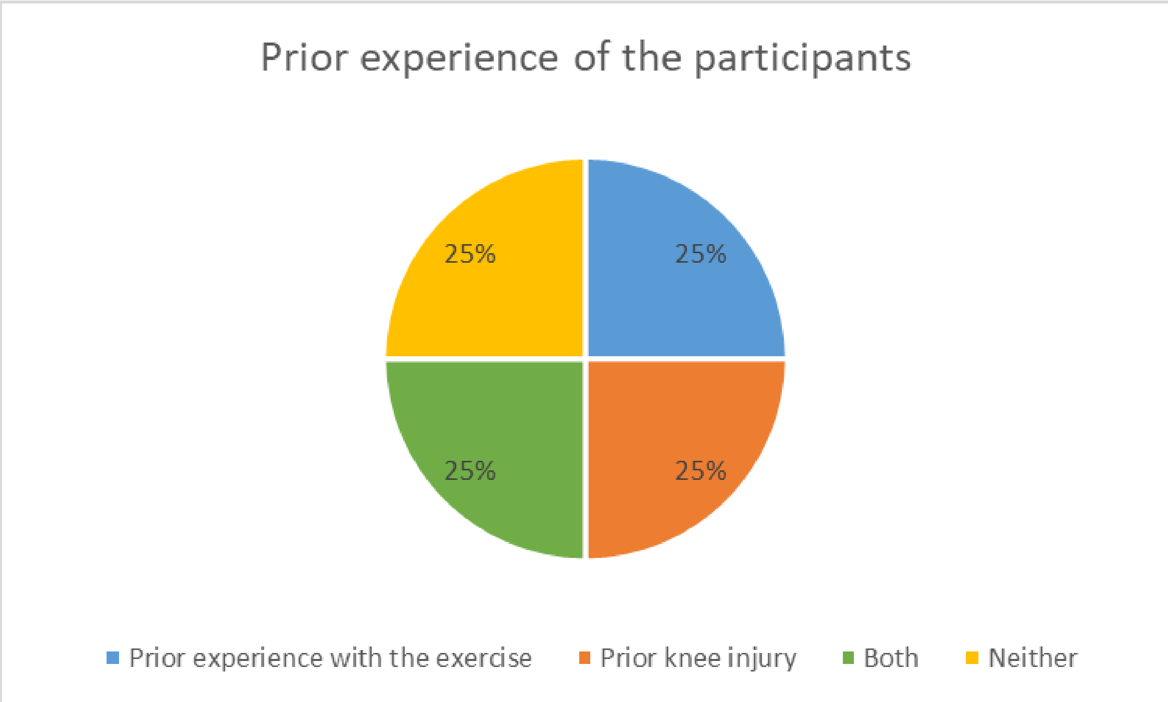


Figure 7.2: Pie diagram depicting the prior experiences, or lack thereof, of the participants of the user evaluation.

7.5 Results

7.5.1 Expert feedback

The intention of the feedback session with the physiotherapist was to gather more details on the step-up exercise for testing and any additional insights that could relate to the step-up prototype.

The session started with the researcher performing the intended step-up exercise for the prototype. The physiotherapist quickly noted that for the rehabilitation two other step-up exercises could also be utilised, which could potentially be integrated into the device.

The first exercise is known as the step up and down exercise, depicted in figure 7.3.

Figure 7.3: Step up and down exercise [50].

This exercise is more intended for cardio and does not focus specifically on the rehabilitation of the knee, which is why this exercise will not be tested in the user evaluation, as it does not address the research question. The prototype can, however, already perform this exercise if the user puts the settings on one second.

The second exercise that was suggested was slow up and down step-up exercise, which is a more difficult version compared to the chosen step-up exercise. Which can only be performed when the prototype is in a higher position. The chosen exercise focuses more on the balance and the pressure that is put on the knee when the other knee is positioned in the air. This exercise puts more pressure on the knee as the patient slowly has to move their leg up and down, instead of simply balancing it up in the air as done in figure 6.1.

Since this exercise puts more pressure on the affected knee, and is deemed more difficult, it was decided that it was smart to do the testing with the original chosen exercise as some of the participants may not familiar with the exercise, which could cause for more faults compared to the easier version and, consequently, more diverse results. However, this exercise is a nice addition to the prototype and should definitely be implemented.

Since the prototype supports multiple exercises, it is crucial to inform the user on how to install and configure it properly. Clear instructions on setting the prototype to each mode and explaining the purpose of each exercise are essential.

7.5.2 Test results

As previously mentioned, the test results consist of two parts. First, the exercise duration was measured to determine if the prototype improved aspects like consistency. Second, the participants give feedback on their testing experiences to enlighten the researcher on the observations that were made about the performance of the exercises and give physical feedback to on the prototype's functionality.

Exercise duration

The duration times of the participant were as followed:

Recorded exercise times of each participant

Participant	Normal exercise	Prototype
1	00:01:13	00:01:34
2	00:01:38	00:01:50
3	00:01:38	00:01:57
4	00:01:44	00:01:36
5	00:01:03	00:01:36
6	00:01:37	00:01:43
7	00:01:35	00:01:54
8	00:01:13	00:01:48

Table 7.1: Performance times of participant for the original and prototype exercise.

Two conclusions can be drawn from the exercise time results. Firstly, the exercise, when performed correctly, should take between 1.5 and 2 minutes. This indicates the expected duration for a correctly performed exercise. Secondly, the consistency among participants can be determined by calculating the standard deviation of the exercise times. A lower standard deviation indicates that the exercise was performed more consistently among participants, demonstrating consistency in doing the exercise.

Calculation of exercises

Exercise	Average time	Standard deviation
Standard step-up exercise	00:01:28	00:00:14
Prototype step-up exercise	00:01:45	00:00:08

Table 7.2: Average time and its standard deviation of the standard and prototype step-up exercise.

As shown, the average time for the standard exercise is 1:28, while the prototype averages 1:45, indicating the prototype aligns better with the expected duration range. Secondly, the consistency among participants can be assessed by calculating the standard deviation of the exercise times. The standard exercise has a standard deviation of 0:14, whereas the prototype has a lower standard deviation of 0:08. This lower standard deviation suggests that the exercise was performed more consistently among participants using the prototype compared to the original one. The following line graph gives a visual overview of the collected data:

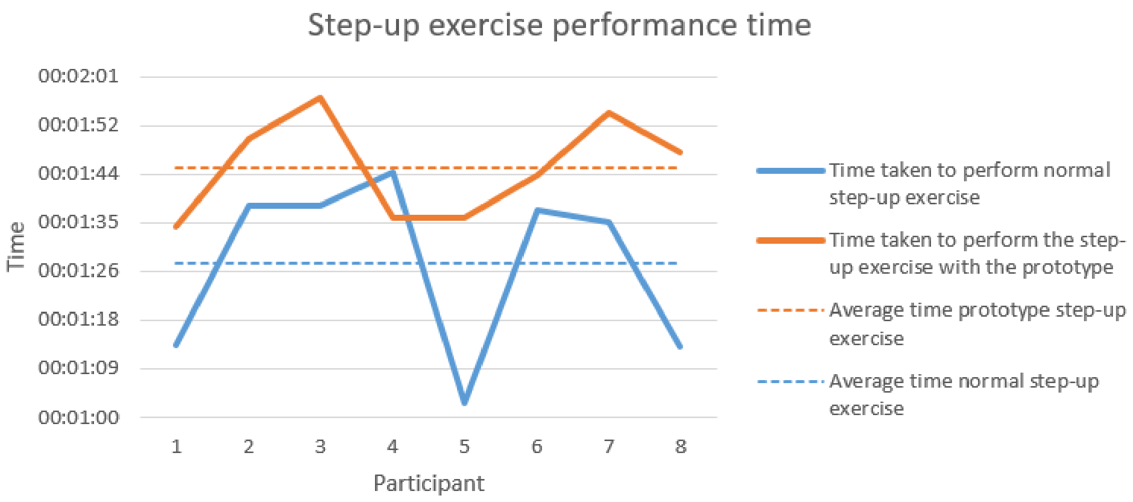


Figure 7.4: Step-up exercise performance time including its averages.

Feedback

The participants were asked to give physical feedback on the test after performing the exercises to give more insight on the results of the recorded times and to give their comments on the functionality of the prototype, before filling in the survey.

The feedback showed that many participants struggled to accurately keep track of their exercise repetitions with the standard exercise. They often lost count or miscounted when counting to five, either counting too quickly or too slowly. This could be an indicator as to why the prototype is perceived as more consistent and a better average time.

When looking at the functionality of the prototype the participants appreciated the clarity of the LED lights, which helped them keep track of their progress and reduced the likelihood of losing count compared to the normal step-up exercise. However, some found the platform not sturdy enough, causing them to maintain tension in both legs. Next to that, the prototype's green light took a bit of time to get used to, but overall, the visual feedback was well-received.

When looking at the functionality of the prototype the participants mentioned a few points of possible improvements to the prototype. They mentioned that the ground platform had crack sounds, which affected the performance of the participants. Next to that, they mentioned that a counter should be placed around the LED's as it would enhance user experience and alleviate common challenges like losing count. Despite these challenges, the prototype generally provided a more relaxed experience by eliminating the need to count repetitions manually.

7.5.3 Survey results

Based on the feedback provided by participants in the survey, the following conclusions can be drawn:

Thoughts on the Step-Up Exercise

The LEDs helped keep participants motivated by removing the need to count reps and time simultaneously during the exercise. Users found the prototype made the exercise simpler and more enjoyable, although some initially struggled with balance.

Functionality of the Prototype

The prototype was generally considered intuitive and easy to use after an initial explanation. Moreover, the participants appreciated the feedback from the lights during the exercise. One participant especially liked the final light animation as it felt as a rewarding feature.

Aspects to improve on considering the functionality of the prototype is that several participants suggested adding numbers along the LEDs to enhance clarity, as they had trouble counting how many reps or seconds they were selecting and had to re-count it. Next to that, some participants were initially confused about when to return to the ground, why the lights were not fully green yet, or that the amount of LEDs that light up per rep could differ. But most of the time they understood it completely after a few reps, not repeating the problems that occured in the beginning. The feedback showed that by creating a manual participants should be able to understand the functionalities of the prototype clearer and perform the exercise without explanation of the researcher.

Feedback of the prototype

Suggestions for improvement considering the feedback mostly included the comments about adding numbers along the LEDs for clarity. Next to that one participant mentioned that it could be nice to also include auditory feedback, in case the user does not want to pay attention to the LEDs.

Portability

The prototype was considered portable, with the bag being a useful accessory. However, a few participants indicated they would likely keep it in one location rather than move it frequently.

Exercise While Brushing Teeth

Participants generally found the idea of combining the exercise with brushing their teeth to be a good use of time, although some mentioned potential issues with maintaining balance. Thus, for those who struggle with balance, an electric toothbrush is recommended. Generally, the ease of integrating this into their daily routine was highlighted as a positive aspect. One participant even commented: ”Being able to do this exercise during brushing my teeth would motivate me more to do my exercises regularly”.

Comparison to Normal Brushing Time

Participants generally found the exercise duration to align well with their usual tooth brushing time, suggesting the prototype could help ensure they brush for a sufficient amount of time. One participant even mentioned: ”I now take longer brushing my teeth, which I should actually do”.

Attention Required for Exercise

The prototype significantly reduced the cognitive load required to perform the exercise compared to the traditional method. Participants appreciated not having to count reps and time themselves, which allowed them to focus more on the exercise itself.

Likelihood of Increased Exercise Frequency

Many participants indicated they would likely perform the exercise more frequently if the prototype were available, especially if it was conveniently located in their bathroom. Not having to count was one of the important aspects as to why someone would do the exercise more often. One even referred to the prototype as an possible ”empty headed habit”.

Unpleasant Experiences

There were very few unpleasant experiences reported, with some participants expressing initial concerns about the stability of the prototype, due to the cracking of the ground plate.

Difficulties Encountered

One test encountered problems with the calibration of the LDRs because the prototype was placed in complete shadow. Therefore, the prototype should be improved to function fully both in shadow and in light. The was one other participant that had troubles with balancing for five seconds.

7.5.4 Survey analysis

The survey consisted entirely of open-ended questions. However, by categorising the responses as positive, negative, or inconclusive, it was possible to calculate the prototype's effect on the step-up exercise. The questions that led specifically addressed the research were rephrased into yes or no questions, which resulted in the following findings, shown in table 7.3. The detailed interpretation of each participant's responses can be found in Appendix E.

Interpreted answers of survey questions.

Question	Yes	No	Inconclusive
Is the functionality of the prototype clear?	100%		
Is it possible to perform the exercise while brushing the teeth?	87.5%	12.5%	
Do you need to pay less attention to the exercise when using the prototype?	75%	12.5%	12.5%
Does the prototype increase your motivation to perform the exercise?	100%		
What is your opinion on the portability of the prototype? (Positive feedback is considered yes)	62.5%	25%	12.5%
Did the prototype have no effect or a positive effect on the brushing of the teeth?	75%	12.5%	12.5%

Table 7.3: Analysis of the interpreted results of the survey questions.

7.6 Conclusion

The test results showed that the step-up exercise prototype offers several improvements over the original method. Participants generally found the prototype was more consistent and easier to use, mainly due to the clear visual feedback that the LEDs provided, which helped them keep track of their repetitions without manually counting. As a result, the average exercise duration with the prototype was closer to the wanted range of 1.5 - 2 minutes, and the lower standard deviation in exercise times indicates better consistency among participants. Overall, the prototype made the exercise more relaxed and enjoyable by removing the need to count manually. This could encourage users to exercise more often. To reflect on the the first two user evaluation research questions. The participants found with a 87.5% agreeance that the prototype was easily integratable into their brushing routine. 75% found that the prototype had either a positive or no effect on their current brushing routine.

Lastly the third question showed that despite these positive outcomes, there are several areas for improvement. The prototype showed shortcomings as, for example, the small crack sounds from the platform, making it feel unstable and risky, and the need for a counter next to the LEDs to further enhance usability. The improvements are specifically listed in the next section. Additionally, the initial unfamiliarity with the green light and balance issues during exercises, particularly while brushing teeth, highlighted the need for better stability and perhaps auditory feedback. Adding the numbers on the display, making the platform more stable, and making a clear manual would likely fix the remaining issues and further enhance the prototype's effectiveness and user satisfaction.

7.6.1 Needed improvements

Based on the feedback of the expert and results of the test and survey the following aspects of the prototype should be improved to increase the functionality of the prototype, separated into expert and test feedback:

Expert feedback

- Add distance sensors so that you can implement a third step up exercise.
- Make it clear to the user what mode is for what kind of exercise and its purpose.

Test feedback

- Change the ground platform so that the crack sounds will not appear anymore.
- Have numbers (and lines) next to the LEDs for a clearer overview of the LEDs.
- Calibrate Leds, so that the device can both correctly function in the shadow and light.
- Make the bag removable from the device.
- (Add some form of auditory feedback)
- (Add a separate compartment for the small box in the bag)

Chapter 8

Final prototype

This chapter provides an overview of the final prototype, detailing its design, material selection, construction, and functionality. It outlines how the prototype meets the specified requirements and offers insights into both its external appearance and internal components. Additionally, the functional capabilities of the prototype are explained, demonstrating how it operates and interacts with users.

8.1 Adherence to the requirements

To create a prototype that effectively integrates a PT exercise into a ADL, a clear list of requirements is essential. These specifications provide a framework for the design, ensuring the prototype meets its goals and works as intended. The requirements are prioritised using the MoSCoW method, which categorises them into must-haves, should-haves, could-haves, and won't-haves. The prototype strives to adhere to all the must-haves and as much as possible should-haves. This section lists these requirements and assess whether the final prototype meets them.

8.1.1 Adherence to the patient's requirements

<table>
<tr><th>Priority</th><th>Requirement</th><th>Adhere</th></tr>
<tr><td>Must have</td><td>The system must provide feedback to the user on their performance during exercises to ensure it is performed correctly.</td><td>Yes</td></tr>
<tr><td colspan="3">The LED circle provides feedback on how far the user is with the exercise. Feedback on the performance is done in a way that the user has to put the foot back on the platform and redo the rep if it is performed incorrectly.</td></tr>
</table>

<table>
<tr><th>Priority</th><th>Requirement</th><th>Adhere</th></tr>
<tr><td>Must have</td><td>The system must be safe to use and not pose any risk of harm to the patient.</td><td>Yes</td></tr>
<tr><td>Should have</td><td>The system should be inviting and motivate the user to perform the intended exercise regularly.</td><td>Undecided</td></tr>
<tr><td colspan="3">The results of the user evaluation showed that the participants would be motivated to do the exercise more regularly if the prototype is available, however, to confirm this conclusion a long-term test must be performed.</td></tr>
<tr><td>Should have</td><td>The system should motivate the user by lowering the required intrinsic motivation.</td><td>Yes</td></tr>
<tr><td colspan="3">The results of the user evaluation showed that the participants would be more motivated to do the exercise more regularly if the prototype is available, however, to confirm this conclusion a long-term test must be performed.</td></tr>
<tr><td>Should have</td><td>The user interface should be easy to understand.</td><td>Yes</td></tr>
<tr><td colspan="3">The user interface is explained in the manual, which includes an instruction video. The user evaluation showed that 100% found the functionality of the prototype clear to understand.</td></tr>
<tr><td>Should have</td><td>The system should not contribute to stress that may arise during the ADL.</td><td>Yes</td></tr>
<tr><td colspan="3">87.5% participants of the evaluation agreed that they were able to perform the exercise while brushing their teeth. Only one participant showed struggles during the activity.</td></tr>
<tr><td>Should have</td><td>The system should not hinder the user's daily way of living, taking as little time as possible away from the ADL.</td><td>Yes</td></tr>
<tr><td colspan="3">50% of the participants were of opinion that the exercise had a positive effect on their current brushing routine and 25% noted that it had no effect. Hence, it can be concluded that the device does not hinder the brushing routine.</td></tr>
<tr><td>Should have</td><td>The system should feel intuitive; the user should know what to do after a one-time explanation.</td><td>Yes</td></tr>
<tr><td colspan="3">After a one-time explanation all participants were able to perform the step-up exercise successfully on the prototype, with only a few participants showing small struggles at the beginning, that were resolved during the exercise itself.</td></tr>
</table>

Table 8.1: Adherence of the final prototype to the patient's requirements

8.1.2 Adherence to the caretaker's requirements

<table>
<tr><th>Priority</th><th>Requirement</th><th>Adhere</th></tr>
<tr><td>Should have</td><td>The system should be adaptive to the needed intensity of the exercise.</td><td>Yes</td></tr>
<tr><td colspan="3">The height of the small step can change from 10cm to 16 cm. The reps are adjustable from 5 till 20 and the length of a rep can take 1 till 10 seconds long.</td></tr>
<tr><td>Could have</td><td>The exercise should be performed in reps of 5 to 20, depending on the advice of the caretaker.</td><td>Yes</td></tr>
<tr><td colspan="3">The user can change the settings of the reps after turning the prototype on.</td></tr>
<tr><td>Could have</td><td>The system could show the collected data achieved by the patient performing the exercise to monitor the process.</td><td>No</td></tr>
<tr><td colspan="3">It was deemed unnecessary, in order to keep the costs of the prototype lower, since the primary functions of the prototype already functioned as wished.</td></tr>
</table>

Table 8.2: Adherence of the final prototype to the caretaker's requirements.

8.1.3 Adherence to the other requirements

<table>
<tr><th>Priority</th><th>Requirement</th><th>Adhere</th></tr>
<tr><td>Must have</td><td>A PTRE must be integrated into an ADL.</td><td>Yes</td></tr>
<tr><td colspan="3">The lateral step-up exercise is combined with the brushing of the teeth.</td></tr>
<tr><td>Should have</td><td>The system should have a reliable power source, so that the system takes as little time as possible away from daily life.</td><td>Yes</td></tr>
<tr><td colspan="3">The prototype has to be plugged in an electronic socket to function. The user only has to plug it in for it to work. The device also includes an on/off button so it can stay plugged in, saving even more set up time.</td></tr>
<tr><td>Should have</td><td>The dimensions of the system must not exceed the dimensions of the average sink.</td><td>Yes</td></tr>
<tr><td colspan="3">The prototype can easily be placed in front of a sink and does not exceed the width of a sink, in case of a small bathroom.</td></tr>
<tr><td>Should have</td><td>The weight of the system is limited to 10 kg.</td><td>Yes</td></tr>
<tr><td colspan="3">The prototype is light in weight and easily portable.</td></tr>
<tr><td>Should have</td><td>The system should be accessible to any PT patient.</td><td>Yes</td></tr>
</table>

<table>
<tr><th>Priority</th><th>Requirement</th><th>Adhere</th></tr>
<tr><td>Should have</td><td>The system should be easy to transport/portable.</td><td>Yes</td></tr>
<tr><td colspan="3">The prototype includes a bag to make it easy to transport.</td></tr>
<tr><td>Could have</td><td>The system could work alongside a daily life object.</td><td>Yes</td></tr>
<tr><td colspan="3">The prototype can be used alongside the toothbrush.</td></tr>
</table>

Table 8.3: Adherence of the final prototype to the other requirements.

8.2 Final prototype

This section presents the final prototype, which is based on the feedback from user evaluation and the second prototype. It explores the chosen materials and their contributions to the prototype's durability and functionality. This section also includes a detailed descriptions of the device's functionality, including the hardware and software components. Additionally, a manual is included with the intent to guide the users through the device's usage and explain the specific physical benefits associated with each exercise. The following photographs show the prototype in use, figure 8.1, and packed up in its bag, figure 8.2.

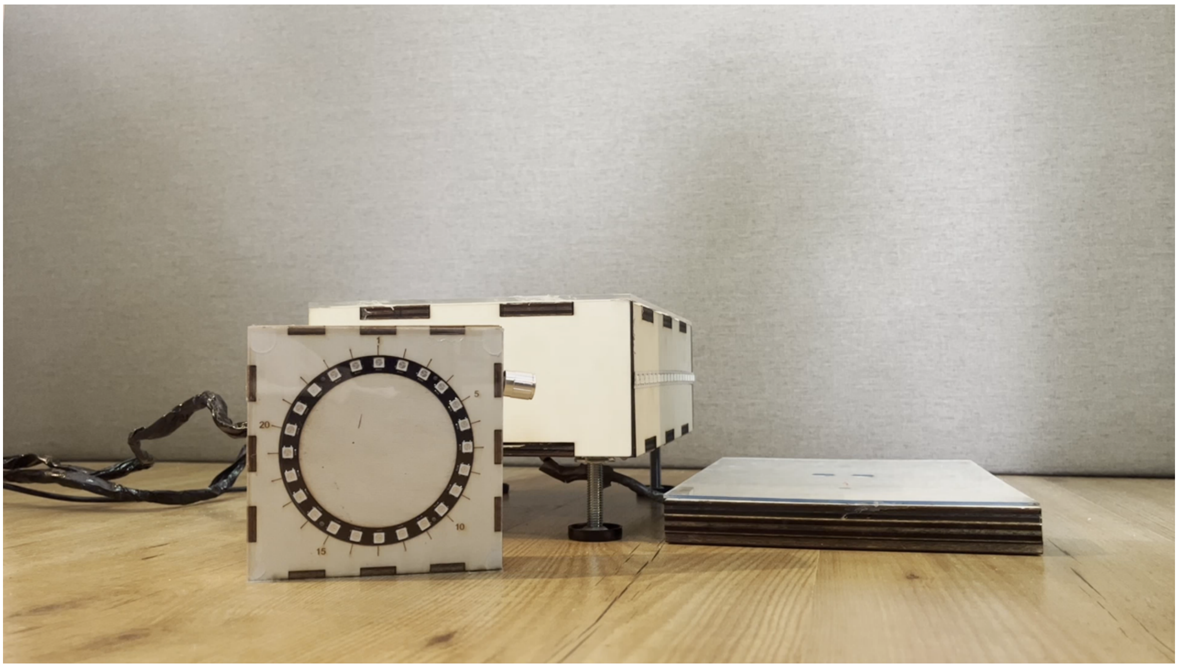


Figure 8.1: The final prototype.

Figure 8.2: The final prototype packed up in the bag.

8.2.1 Adjustments

Based on the needed improvements of the user evaluation, section 7.6.1. The following adjustments have been made:

1. Two distance sensor have been added, so that a third exercise can be performed on the device.
2. A manual, describing the usage of the prototype and the effect of the exercises has been made.
3. The ground platform has been made completely solid, making it impossible for crack sounds to appear.
4. There are now the numbers: 1, 5, 10, 15 and 20 next to the corresponding LEDs.
5. LEDs have been calibrated so it can also function in the shadows.
6. The bag has been deattached and is now a seperate part of the prototype.

8.2.2 Material selection

Component	Why
Poplar wood	Poplar wood is chosen for the boxes due to its cost-effectiveness and suitability for laser cutting. It is a relatively inexpensive material, it helped keep my project costs low without compromising on the quality. Additionally, poplar wood is an ideal material for laser cutting, ensuring accurate cuts for the prototype components, making the prototype as sturdy as possible.
Plexiglass	Plexiglass is selected for the boxes due to its durability and transparency. It allows light from the LDR to shine through the glass without obstructing its function. Additionally, plexiglass does not get damaged from weight of the users and water, ensuring the LDR remains protected even if the user spills any liquids during the exercise. Next to that, it also makes it easier to clean the device after usage.
Furniture adjustment bolt	It was crucial for the prototype to be adjustable in height. An important consideration was ensuring it could support the user's weight. To achieve this, bolts specifically designed for heavy furniture were chosen, providing the necessary strength and stability.
Bag	The bag was added to the prototype specifically for the portability of it. This allows for easy transportation, making it convenient to carry the device to different locations. Next to that, the bag ensures that all components are securely stored and protected.
Arduino Nano	The Arduino Nano was chosen for its compact size and ease of soldering, ensuring that wires remain securely attached and reducing the risk of malfunctions. This makes it a reliable choice for maintaining stable connections within the prototype.
LED circle	The LED circle was selected because it can display the user's exercise progress clearly, by showing its progress till the circle is complete. Its compact size allows for easy placement on the sink, ensuring it is easily visible and readable while not occupying too much space.
LED strip	The LED strip was added to the side of the small step to make sure that the LDRs on the platform always have a consistent value when measuring incoming light.
LDRs	The LDRs were selected for their reliability in detecting the presence of someone standing on the platform, whether there is light or darkness. Their small size and ease of implementation make them practical for integrating into the prototype.

Component	Why
Distance sensor	Distance sensors were added to measure the height at which a person lifts their foot. These sensors activate only when the LDRs on the ground plate detect light. This combination is necessary because distance sensors seemed not to be reliable at very short distances, so the LDRs are used for close-range detection instead.
Rotary knob	A rotary knob was added to allow users to easily select the number of repetitions they want to perform and the duration of each repetition in seconds.
ON/OFF switch	The switch was added so that the device can be turned on and off, while still being plugged in.

Table 8.4: Material selection and its reasoning

8.2.3 Description of the enclosure

The final prototype consists of a small step, also referred to as a big box, which measures 20x30x10-16 cm including the extendable table legs. Furthermore, it includes a platform measuring 20x30x2.6 cm and a LED box measuring 12x12x4.2 cm. Each box include a protective layer made of plexiglass on top. The enclosure can be seen in figure 8.1.

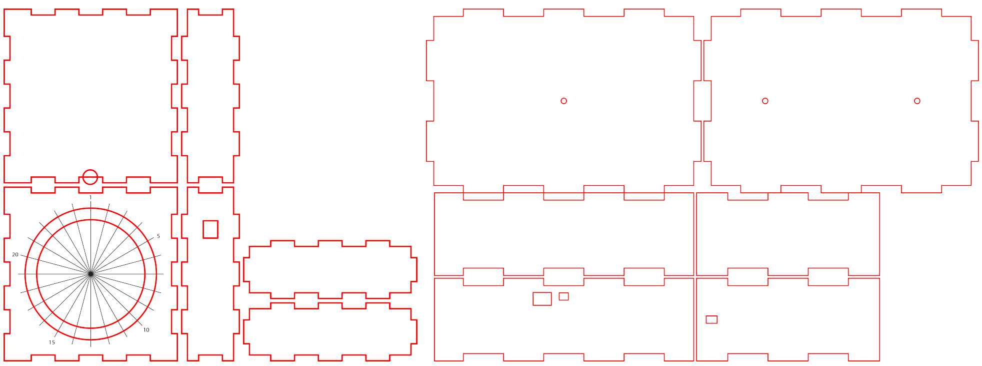


Figure 8.3: The wooden box plans the final prototype, demonstrating the LED box, and the big box respectively.

8.2.4 Functionality

It was, however, discovered that two other exercises could be added to the prototype to give the physiotherapist more variation in assigning exercises. As a result, the step-up prototype can switch between three exercises, each exercise is explained in the manual, shown in appendix F. The **lateral step-up exercise** is still performed the same way as the second prototype, mentioned in section 6.4.3.The second option is the **step up and down exercise**, as depicted in figure 7.3, which goes as follows:

1. The device has to be turned on.
2. The LEDs circle starts in settings mode, first showing how many repetitions the exercise will have.
3. The User adjusts the amount of LEDs that are on to the amount of reps the user wants.
4. Once the user is satisfied with the amount he/she steps on the ground plate, initiating the second settings mode, the amount of seconds the exercise will take.
5. The User adjusts the amount of LEDs to one LED, which corrosponds to one second.
6. Once the user is satisfied with the amount the user positions both feet on the platform so that the LED circle will completely turn blue, indicating the user can start.
7. When the user lifts their foot quickly one by one onto the small step. Once on top the section of LEDs should turn green.
8. Once the section is completely green the user can position their feet, one by one, back on the ground plate, initialising the next section of LEDs.
9. The user repeats step 7 and 8 until the whole circle is green.
10. Once the circle is completely green, the LEDs flicker their lights a few times indicating that the exercise is done. After the flickering the devices resets itself back to the rest mode.
11. Once the device is back in setting mode, the user can repeat the steps as many times as they want or turn the device off.

The last option is the **slow lateral step-up exercise** which goes as follows:

1. The device has to be turned on and extend the small step to its tallest length. This should initialise the rest more presented by the LEDs turning into an animated rainbow.
2. To continue to the setting mode the user must put their foot shortly on the platform.

3. Once the foot is back on the ground LEDs circle shows the first settings mode which is how many repetitions the exercise will have.

4. The User adjusts the amount of LEDs that are on to the amount of reps the user wants.

5. Once the user is satisfied with the amount he/she steps on and off the ground plate, initiating the second settings mode, the amount of seconds the exercise will take.

6. The User adjusts the amount of LEDs to one LED, which corresponds to one second.

7. Once the user is satisfied with the amount the user positions their feet on the device the LED circle to make it completely turn blue, indicating the user can start.

8. When the user lifts their foot a bit of the platform the section of LEDs should turn more to white, gradually go more up in that temp until the section is completely white.

9. Once the section is completely write the user can go back down the same way as going up, but instead of the LEDs turning white it will gradually turn green.

10. The user repeats step 8 and 9 until the whole circle is green.

11. Once the circle is completely green, the LEDs flicker their lights a few times indicating that the exercise is done. After the flickering the devices resets itself back to the rest mode.

12. Once the device is back in setting mode, the user can repeat the steps as many times as they want or turn the device off.

8.2.5 Anatomy of the prototype

The final prototype consists out of an arduino nano that is connected to a LED circle, 4 LDRs, 2 distance sensors, a rotary button, a LED strip and a on/off switch. The function and placement of each component is described in table 8.5. How they are connected can be found in figure 8.4.

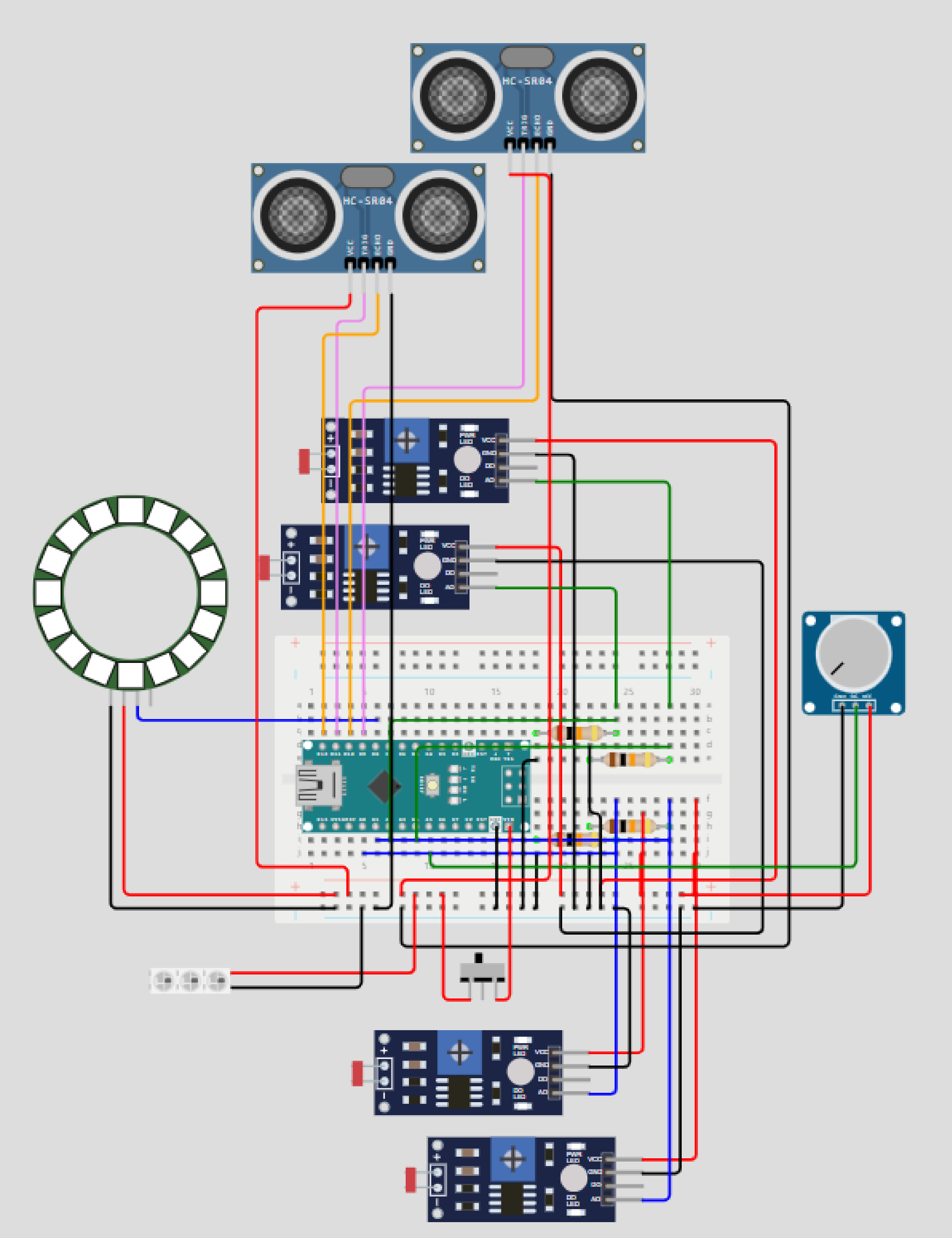


Figure 8.4: Schematic of the hardware components of the final prototype designed on Wokwi [49].

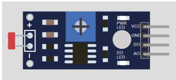
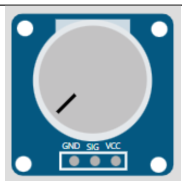
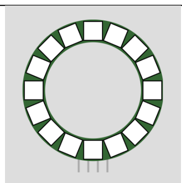
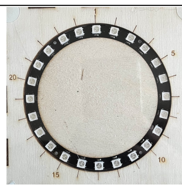
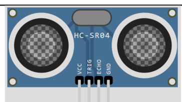
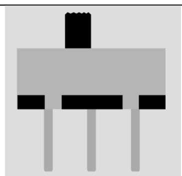
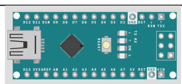
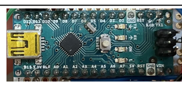
Port	**Component**	**Schematic**	**Real-life**	**Function**
A0, A1, A2, A4	LDR			LDRs are used to detect light levels. The resistance of the LDR decreases as the light intensity increases.
A5	Rotary knob (potentiometer)			Potentiometers work as voltage dividers. They can adjust the voltage output to a circuit and accurately measure electric potential.
D8	LED circle			LED circles function as a display that can show RGB colour combinations in a circle.
(D9 and D10), (D11 and D11)	Distance sensor			Distance sensors measure the distance between the emitted signal and its return by calculating the time it takes for the signal to travel to from the emitted place the transducer.
5V	Switch			The function of the switch is to turn the device on and off.
5V	LED strip			LED strips function as a display that can show RGB colour combinations in length.
	Arduino Nano			Arduino Nanos are microcontroller-based devices that handle numerous hardware components and make them communicate with the use of software.

Table 8.5: Functions of all the hardware components, including the ports each component is connected to, how it is depicted in the schematic with the use of Wokwi [49], what it looks like in real-life and how each component operates.

8.2.6 Manual

As the prototype had gotten more complex it was important to add a manual to make sure the users understand how to operate the step-up device without any physical explanation or guidance of the developer. This led to the manual shown in appendix F.

Chapter 9

Discussion and future work

The goal of this thesis was to address the following research question:

> ***'How to integrate a rehabilitation exercise into an activity of daily living to enhance engagement and adherence for individuals dealing with PT.'***

This chapter looks back at the research questions, discusses the impact the device has made based on the original concept, the limitation of this research and presents recommendations for future work and research.

9.1 Discussion of the research question

When reflecting on the research question, two aspects need consideration: whether rehabilitation was successfully integrated into ADL, and whether it enhances engagement and adherence.

First, lets look at the integration of the rehabilitation exercise into the ADL, in this case, brushing your teeth. Based on the user evaluation 7 out of 8 were successfully able to brush their teeth while performing the exercise, the one that was not able to do it was also not able to perfectly perform the normal step-up exercise. From this can be concluded that if the person is able to perform the exercise without any problems normally, it is indeed possible to integrate the exercise into the activity of brushing your teeth.

When considering the second part of this question regarding whether the prototype increases motivation and adherence, the evidence suggests that it can indeed enhance engagement by reducing the required intrinsic motivation. However, since this research has not been tested over an extended period, this conclusion is drawn based on the background research and subjective feedback of the user evaluation, and not on objective collected data for this specific prototype. Nonetheless, all participants expressed that they would do the exercise more often if the prototype was available, showing that the prototype should enhance engagement and adherence for individuals dealing with PT.

Therefore, combining both aspects, the step-up prototype can be successfully integrated into daily activities, showing great potential to increase motivation and adherence among individuals managing physical therapy.

9.2 Scientific contributions

The step-up exercise has showed a different approach to enhancing motivation within the rehabilitation process for PT patients, as it focuses on the intrinsic motivation, compared to the related work, which focuses mainly on extrinsic motivation, for example, gamification. It shows that focusing on intrinsic motivation can also be effective in this specific field of rehabilitation.

9.3 Limitations and recommendations

This study did not evaluate the prototype's effectiveness over an extended duration, which limits the ability to conclusively determine if the observed increase in motivation and adherence is sustainable over time. The subjective answers of the participants may not accurately reflect the long-term impact on user behavior and engagement in the performing of the exercise regurlarly.

Next to that, did the study rely on feedback from only one expert in physiotherapy, which may not capture diverse perspectives or insights that could further validate or refine the prototype's design and implementation. Additional input from a broader range of experts could provide more comprehensive insights and recommendations for improving the prototype's effectiveness and usability.

Moreover, the sample size of participants in the study could be considered relatively small. A small sample size increases the risk of sampling bias, where the characteristics of the participants may not adequately represent the broader population of individuals undergoing physical therapy. This reduces the study's ability to draw robust conclusions about the prototype's effectiveness and impact across different user demographics and contexts.

Another limitation of this study is that the testing was conducted exclusively on healthy participants rather than individuals currently experiencing PT. As a result, the findings may not fully reflect how the prototype would perform or be perceived by those with the condition, potentially creating a different kind of results than wanted. Future research should include testing with patients diagnosed with PT to better understand the prototype's effectiveness and usability in rehabilitation.

Based on the previous limitations, further research should have a long-term user evaluation to test that the prototype actually has a positive impact on engagement and adherence. Additionally, conducting tests with individuals diagnosed with Patellar Tendinopathy would offer more valuable insights into its effectiveness within the actual rehabilitation. Lastly, it should include more experts and participants in the testing to get a more generalised data collection and diverse feedback on the prototype. Addressing these points would improve understanding the prototype's effect and optimize the prototype's application in physical therapy contexts.

9.4 Potential improvements for the step-up prototype

It is possible to replace the LED box with an app on the user's phone. Replacing the LED box with an app allows users to view the LED circle directly on their mobile device during exercises, making it easier to place it on the sink as the LED's are now shown wireless. Furthermore, the app can collect the data of all the performed exercises, including the number of reps performed, the duration of each rep, and the total exercise duration. You can categorise them by day, week, month, or maybe even year. This improvement informs the user better on their performance, but can now also be used as a tool to show the result to the physiotherapist so it can be evaluated and discussed.

Chapter 10

Conclusion

This thesis has explored how to successfully integrate a PTRE into an ADL for patients dealing with PT to enhance the engagement and adherence to the rehabilitation process. With the use of the background research, professional feedback and evaluation it was possible to develop the step-up prototype. The prototype is a device based on three step-up exercise variations that promotes low cognitive thinking by giving visual feedback throughout the exercise. The exercise is performed while brushing teeth to minimise the impact on the user's daily routine and take up as little extra time as possible to lower the needed initial intrinsic motivation.

The background research showed that engagement and adherence could be increased by improving the patient's motivation, either intrinsic or extrinsic. As there had been previous research on extrinsic motivation in the rehabilitation process of PT but not intrinsic, I decided to focus on intrinsic motivation instead. To be able to increase intrinsic motivation, it was needed to lower the needed cognitive thinking [40] and integrate a rehabilitation exercise into an ADL [13]–[15].

Based on the user evaluation the prototype was able to successfully lower the cognitive thinking during the exercise, as users did not have to count or keep track of the repetitions. The evaluation also showed that it was indeed possible to combine the exercise with the ADL. This indicates that the intrinsic motivation, based on the background research in combination with the results of the user evaluation, should be high enough to keep doing the exercise regularly long-term. However due to the fact that the test was done short-term it is difficult to draw this conclusion on a long-term basis.

Even with the limited conclusion that can be drawn, the prototype should, in theory, elevate the user's engagement and adherence to the rehabilitation process. Future research should be conducted to validate the prototypes effectiveness long-term. All things considered, the step-up prototype is successfully integrated into an ADL and seems to have the potential to increase the user's engagement and adherence to the rehabilitation process.

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Appendix A

Interviews

A.1 Notes of interview with physiotherapist (in Dutch)

The following two pages portray the notes that were taken during the interview with a physiotherapist about the bicycle exercise prototype. Page one includes text and a picture from the website from Dr. Pamela Mehta that shows several exercises for PT [33].

Wat is belangrijk voor een fysiotherapeut

Feedback

- Snelheid
- versnellingsstand
- Pijn
- (Afstand)
- Houding

NPRCS score

De rehab opdracht

11. Stationary Cycling

This exercise targets the Quadriceps muscles.

1. **Sit on a stationary bike** with the seat adjusted to a height that allows for slight knee flexion when pedaling.
2. **Begin pedaling at a slow pace** and gradually increase your speed and resistance.
3. **Maintain a steady pace** for 10 to 15 minutes.
4. **Gradually decrease your speed** and resistance and then stop.

Standard meet process

Nrpcs score

Pijn ervaren in begin, tijdens en na de tijd

Vragen hoe zwaar iemand het vind

Spieruithoudings vermogen word took getest

Borg vermoeidheid vragenlijst 0 tot 10

Waar zit die pijn dan? – pijnklachten aan de heup?

Vermoeidheid is anders dan hoe zwaar is het?

Fysiotherapeut bepaald hoe moeilijk de training is

Met stoplichten kan alleen in het begin van het rehabilitatie process gebruikt wordne

Je bent er niet als therapeut niet bij

Je weet niet hoe iemand zich voelt of hoe het gaat

Zelf aangeven of het programma een niveau lager kan (als je je niet goed voelt) of juist andersom

Je hebt nu een training gedaan, wat mag iemand verwachten aan pijn (aan het iende van de oefening)

Wielrenfiets is anders dan een stadsfiets – wat wil je bereiken van de training? Versterken of uithoudingsvermogen?

Combinatie van soorten trainings

Training begint vaak op de fiets

Doel van de fiets met jumpers knee als warming up

Intervalletje op doen (berg op moeten)

Krachtuithoudingsvermogen

Objectief voor hartslag bijhouden – uithoudingsvermogen

Van te voren meten – maximale hart schok meten

- Niet zwart op wit
- Visueel laten zien
- Hartslag moet niet hoger komen dan …
- Harstlag te hoog, dus fiets langzamer

Bij jumper's knee kijk je niet echt naar hartslag

- De optie geven om de hartslag te laten zien

Appendix B

Step-up Prototype Code

The codes are also published on gitHub:

https://github.com/MelissavdPol/Graduation-Project.git

B.1 Code of first step-up prototype

```
// A basic everyday NeoPixel strip test program.
#include <Adafruit_NeoPixel.h>
#ifdef __AVR__
#include <avr/power.h> // Required for 16 MHz Adafruit Trinket
#endif

#define LED_PIN    8

// How many NeoPixels are attached to the Arduino?
#define LED_COUNT 24

// Declare our NeoPixel strip object:
Adafruit_NeoPixel strip(LED_COUNT, LED_PIN, NEO_GRB + NEO_KHZ800);

int res = 0; /* declaring the variable that will store the value of
photoresistor*/
int sensor = A0; /* assigning Arduino pin for photoresistor*/
int res2 = 0; /* declaring the variable that will store the value of
photoresistor*/
int sensor2 = A1; /* assigning Arduino pin for photoresistor*/
const int buttonPin2 = 3;
```

```
// variables will change:
int buttonState = 0;         // variable for reading the pushbutton status
int buttonState2 = 0;
float Lon = 0;
int redValue = 255;
int greenValue = 0;
int changeStep = 50;  // Adjust for faster/slower transition
bool started = false;
int brightness = 255;
int turn = -50;
int amount = 0;
int rep = 0;
bool nextRep = true;

void setup() {
  Serial.begin(9600);
  // These lines are specifically to support the Adafruit Trinket 5V 16 MHz.
  // Any other board, you can remove this part (but no harm leaving it):
#if defined(__AVR_ATtiny85__) && (F_CPU == 16000000)
  clock_prescale_set(clock_div_1);
#endif
  // END of Trinket-specific code.
  //  pinMode(buttonPin, INPUT);


  strip.begin();           // INITIALIZE NeoPixel strip object (REQUIRED)
  strip.show();            // Turn OFF all pixels ASAP
  strip.setBrightness(50); // Set BRIGHTNESS to about 1/5 (max = 255)

}
void(* resetFunc) (void) = 0;//declare reset function at address 0

// loop() function -- runs repeatedly as long as board is on ---------------

void loop() {

  //  Serial.println(Lon);
  // read the state of the pushbutton value:
  //  buttonState = digitalRead(buttonPin);
```

```
  buttonState2 = digitalRead(buttonPin2);

  res = analogRead(sensor); /* getting the value of photoresistor*/
  res2 = analogRead(sensor2); /* getting the value of photoresistor*/
  Serial.print(res);
  Serial.print("  ");
  Serial.println(res2);

  if (!started) {
    rainbow(10);
    if (res2 <= 650) {
      for (int i = 0; i < strip.numPixels(); i++) {
        strip.setPixelColor(i, strip.Color(255, 0, 0));
      }
      strip.show();
      started = true;
    }
  }

  if (res2 <= 650) {
    nextRep = true;
  }

//  Serial.print(nextRep);

  if (nextRep == true & res2 >= 650 & greenValue >= 255 & Lon <
  strip.numPixels()) {
    redValue = 255;
    greenValue = 0;
  }

  if (nextRep == true & res <= 650 & res2 >= 650 & greenValue <= 255) {
    redValue -= changeStep;
    greenValue += changeStep;

    //    Limit values to 0 - 255 range
    redValue = max(redValue, 0);
    greenValue = min(greenValue, 255);
  }
```

```
if (greenValue <= 255 & (res2 <= 650 or res >=650)) {
  redValue = 255;
  greenValue = 0;
  strip.show();
  delay(30);
}


if (nextRep == true & res <= 650 & res2 >= 650) {
  // Fill along the length of the strip in various colors...
  colorWipe( strip.Color(redValue, greenValue, 0), 100); // Green
  if (greenValue >= 255) {
    rep += 1;
    Lon = 2.5 * rep;
    Lon = min(Lon, strip.numPixels());
    nextRep = false;
  }
}

// starting the end phase

if (Lon >= 24 ) {
  for (int amount = 0 ; amount <= 200; amount++) {
    for (int i = 0; i < strip.numPixels(); i++) {
      strip.setPixelColor(i, strip.Color(0, brightness, 0));
    }
    strip.show();
    delay(30);

    if (brightness <= 0 ) {
      turn += 50;
    }
    if (brightness >= 255) {
      turn = -50;
    }
    brightness = turn + brightness;

    brightness = min(brightness, 255);
```

```
      brightness = max(brightness, 0);
    }
    resetFunc(); //call reset
  }
}



void colorWipe(uint32_t color, int wait) {
  for (int i = Lon ; i < Lon + 2; i++) { // For each pixel in strip...
    strip.setPixelColor(i, color);         //  Set pixel's color (in RAM)
    strip.show();                          //  Update strip to match
    delay(wait);                           //  Pause for a moment
  }
}


// Rainbow cycle along whole strip. Pass delay time (in ms) between frames.
void rainbow(int wait) {

  for (long firstPixelHue = 0; firstPixelHue < 65536; firstPixelHue += 256) {
    strip.rainbow(firstPixelHue);
    strip.show(); // Update strip with new contents
    delay(wait);  // Pause for a moment
  }
}
```

B.2 Code of second step-up prototype

```
#include <Adafruit_NeoPixel.h>
#ifdef __AVR__
#include <avr/power.h> // Required for 16 MHz Adafruit Trinket
#endif

#define LED_PIN    8

// How many NeoPixels are attached to the Arduino?
#define LED_COUNT 24
```

```
// Declare our NeoPixel strip object:
Adafruit_NeoPixel strip(LED_COUNT, LED_PIN, NEO_GRB + NEO_KHZ800);

//  LDRs
int res = 0;
int sensor = A0;
int res2 = 0;
int sensor2 = A1;
int res3 = 0;
int sensor3 = A2;
int res4 = 0;
int sensor4 = A4;

//  Potentiometers
const int analogInPin = A5;  // Analog input pin that the potentiometer is
attached to

// Startvalues of potentiometers
int sensorValue = 0;

float Lon = 0; // Amount of LEDs that are lighted up
float amountReps = 0;
float amountLeds = 0; // amount of leds that have to turn on each rep

int blueValue = 255;
int greenValue = 0;
int changeStep = 50;  // Adjust for faster/slower transition
int brightness = 255;
int turn = -255; // amount blue/green value have to change per time
int amount = 0;
int rep = 0; // Which rep you are currently doing
int change = 700; // LDR dark or light difference
int repTime = 0;
int greenLight = 0; // check which LEDs are already green
int timer = 0; // absence timer for reset
int switchTimer = 0; // switch is turned on timer

bool started = false;
bool nextRep = true;
```

```
bool switchState = true;
bool firstCheck = true;
bool secondCheck = false;

void setup() {
  Serial.begin(9600);

  strip.begin();           // initialise NeoPixel strip object
  strip.show();            // Turn OFF all pixels ASAP
  strip.setBrightness(50); // Set the brightness

}

void(* resetFunc) (void) = 0;//declare reset function at address 0

void loop() {

  sensorValue = analogRead(analogInPin);
  if (!started) {
    if (firstCheck) {
      amountReps = map(sensorValue, 0, 1024, 1, 21);
    } else {
      repTime = map(sensorValue, 0, 1024, 1, 11);
      changeStep = 255 / repTime ;
    }
  }

  amountLeds = strip.numPixels() / amountReps;

  /* getting the value of photoresistor*/
  res = analogRead(sensor);
  res2 = analogRead(sensor2);
  res3 = analogRead(sensor3);
  res4 = analogRead(sensor4);


  if (res == 0) {
    switchState = false;
  }
```

```
if (switchState == false and res > 0) {
  switchTimer += 1;
} else {
  switchTimer = 0;
}
if (switchTimer == 10) {
  switchState = true;
  resetFunc(); //call reset
}


if ((res >= change & res3 >= change) or (res2 <= change & res4 <= change)) {
  timer += 1;
  //    Serial.println(timer);
} else {
  timer = 0;
}
if ((started & timer >= 500) or (!started & timer >= 2000) ) {
  resetFunc(); //call reset
}

if (!started) {

  if (firstCheck) {
    for (int i = 0; i < strip.numPixels() ; i++) {
      strip.setPixelColor(i, strip.Color(0, 0, 0));
    }

    for (int i = 0 ; i < amountReps ; i++) {
      strip.setPixelColor(i, strip.Color(0, 255, 255));

    }
    strip.show();
  }

  if ((res2 <= change or res4 <= change) & !secondCheck ) {
    firstCheck = false;
    timer = 0;
  }
```

```
    if (secondCheck) {
      for (int i = 0; i < strip.numPixels() ; i++) {
        strip.setPixelColor(i, strip.Color(0, 0, 0));
      }

      for (int i = 0 ; i < repTime ; i++) {
        strip.setPixelColor(i, strip.Color(255, 255, 0));
      }
      strip.show();
    }

    if ((res2 >= change & res4 >= change) & !firstCheck) {
      secondCheck = true;
    }

    if ((res2 <= change or res4 <= change)  & secondCheck) {
      secondCheck = false;
      for (int i = 0; i < strip.numPixels(); i++) {
        strip.setPixelColor(i, strip.Color(0, 0, 255));
      }
      strip.show();
      timer = 0;
      started = true;
      Lon = amountLeds;
    }
  }

  if (started & switchState) {

    if ((res2 <= change || res4 <= change) ) {
      nextRep = true;
    }

    if (nextRep == true & (res2 >= change || res4 >= change) & greenValue >=
    255 & Lon < strip.numPixels()) {
      blueValue = 255;
      greenValue = 0;
    }
```

```
if (nextRep == true & (res <= change || res3 <= change) & (res2 >=
change || res4 >= change) & greenValue <= 255) {
  blueValue -= changeStep;
  greenValue += changeStep;

  //    Limit values to 0 - 255 range
  blueValue = max(blueValue, 0);
  greenValue = min(greenValue, 255);
}

if (greenValue <= 255 & ((res2 <= change || res4 <= change) or (res >=
change or res3 >= change))) {
  blueValue = 255;
  greenValue = 0;
  strip.show();
  delay(30);
}

if (nextRep == true & (res <= change || res3 <= change) & (res2 >=
change || res4 >= change)) {
  // Fill along the length of the strip in various colors...
  colorWipe( strip.Color(0, greenValue, blueValue), 600); // Green

}
if (greenValue >= 255 & nextRep == true) {
  rep += 1;
  greenLight = Lon;
  if (greenLight < Lon) {
    greenLight += 1;
  }

  Lon = amountLeds * (rep + 1);
  nextRep = false;
}

// starting the end phase
if (Lon >= (strip.numPixels() + amountLeds) ) {
  timer = 0;
```

```
      for (int amount = 0 ; amount <= 200; amount++) {
        for (int i = 0; i < strip.numPixels(); i++) {
          strip.setPixelColor(i, strip.Color(0, brightness, 0));
        }
        strip.show();
        delay(30);

        if (brightness <= 0 ) {
          turn += 50;
        }
        if (brightness >= 255) {
          turn = -50;
        }
        brightness = turn + brightness;

        brightness = min(brightness, 255);
        brightness = max(brightness, 0);
      }
      resetFunc(); //call reset
    }
  }
}

void colorWipe(uint32_t color, int wait) {
  for (int i = greenLight; i < Lon; i++) { // For each pixel in strip...
    strip.setPixelColor(i, color);         //  Set pixel's color (in RAM)
  }
  delay(wait);
  strip.show();
}
```

B.3 Code of the final prototype

```
    #include <Adafruit_NeoPixel.h>
#ifdef __AVR__
#include <avr/power.h> // Required for 16 MHz Adafruit Trinket
#endif
```

```
#define LED_PIN    8

// How many NeoPixels are attached to the Arduino?
#define LED_COUNT 24

// Declare our NeoPixel strip object:
Adafruit_NeoPixel strip(LED_COUNT, LED_PIN, NEO_GRB + NEO_KHZ800);

// defines pins numbers of the two distance sensors
const int trigPin = 9;
const int echoPin = 10;

const int trigPin2 = 11;
const int echoPin2 = 12;

// variables of the distance sensors
long duration;
long duration2;
int distance;
int distance2;

//  LDRs
int res = 0;
int sensor = A0;
int res2 = 0;
int sensor2 = A1;
int res3 = 0;
int sensor3 = A2;
int res4 = 0;
int sensor4 = A4;

//  Potentiometers
const int analogInPin = A5;  // Analog input pin that the potentiometer is attached to
const int analogInPin2 = A7;

// Startvalues of potentiometers
int sensorValue = 0;
int sensorValue2 = 0;
```

```
float Lon = 0; // Amount of LEDs that are lighted up
float amountReps = 0;
float amountLeds = 0; // amount of leds that have to turn on each rep
float footDistance = 0;
float footHeight = 0;
float footTooHigh = 0;
float footTooLow = 0;

int blueValue = 255;
int greenValue = 0;
int changeStep = 50;  // Adjust for faster/slower transition
int brightness = 255;
int turn = -255; // amount blue/green value have to change per time
int amount = 0;
int rep = 0; // Which rep you are currently doing
int change = 700; // LDR dark or light difference
int repTime = 0;
int lastLed = 0;
int greenLight = 0; // check which LEDs are already green
int timer = 0; // absence timer for reset
int switchTimer = 0; // switch is turned on timer
int startTimer = 0;


bool started = false;
bool nextRep = true;
bool switchState = true;
bool firstCheck = true;
bool secondCheck = false;

bool rainbowMode = false;
bool rainbowCheck = false;
bool rainbowCanStart = false;
bool up = true;


void setup() {
  Serial.begin(9600);
  // These lines are specifically to support the Adafruit Trinket 5V 16 MHz.
```

```
  // Any other board, you can remove this part (but no harm leaving it):
#if defined(__AVR_ATtiny85__) && (F_CPU == 16000000)
  clock_prescale_set(clock_div_1);
#endif
  // END of Trinket-specific code.

  strip.begin();           // INITIALIZE NeoPixel strip object (REQUIRED)
  strip.show();            // Turn OFF all pixels ASAP
  strip.setBrightness(50); // Set BRIGHTNESS to about 1/5 (max = 255)

  pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output
  pinMode(echoPin, INPUT); // Sets the echoPin as an Input
  pinMode(trigPin2, OUTPUT); // Sets the trigPin as an Output
  pinMode(echoPin2, INPUT); // Sets the echoPin as an Input

}
void(* resetFunc) (void) = 0;//declare reset function at address 0


void loop() {
  startTimer += 1;

  if (startTimer <= 5) {

    if (!started) {
      // Clears the trigPin
      digitalWrite(trigPin2, LOW);
      // Sets the trigPin on HIGH state for 10 micro seconds
      digitalWrite(trigPin2, HIGH);
      digitalWrite(trigPin2, LOW);
      // Reads the echoPin, returns the sound wave travel time in microseconds
      duration2 = pulseIn(echoPin2, HIGH);
      // Calculating the distance
      if (duration2 > 0 & duration2 < 100 / 0.034 * 2) {
        distance2 = duration2 * 0.034 / 2;
      } else {
        distance2 = 0;
      }
    }
```

```
}

  sensorValue = analogRead(analogInPin);
  sensorValue2 = analogRead(analogInPin2);

if (startTimer > 5) {
  if (!started) {
    if (distance2 > 5) {
      rainbowMode = true;

      if (!rainbowCanStart & !rainbowCheck) {
        rainbow(10);
      }

    } else {
      //      rainbowCanStart = true;
      //      rainbowCheck = false;
      rainbowMode = false;
    }

    if ((rainbowCanStart & rainbowMode) or (!rainbowCanStart &
    !rainbowMode)) {
      if (firstCheck) {
        amountReps = map(sensorValue, 0, 1024, 1, 21);
      } else {
        repTime = map(sensorValue, 0, 1024, 1, 11);
        if (rainbowMode) {
          repTime = map(sensorValue, 0, 1024, 1, 6);
        }
        changeStep = 255 / repTime ;
        footDistance = 15 / repTime;
      }
    }
  }


  amountLeds = strip.numPixels() / amountReps;

  /* getting the value of photoresistor*/
```

```
res = analogRead(sensor);
res2 = analogRead(sensor2);
res3 = analogRead(sensor3);
res4 = analogRead(sensor4);


if (res == 0) {
  switchState = false;
}
if (switchState == false and res > 0) {
  switchTimer += 1;
} else {
  switchTimer = 0;
}
if (switchTimer == 10) {
  switchState = true;
  resetFunc(); //call reset
}


if ((res >= change & res3 >= change) or (res2 <= change & res4 <= change))
{
  timer += 1;
} else {
  timer = 0;
}
if ((started & timer >= 500) or (!started & timer >= 2000) ) {
  resetFunc(); //call reset
}



if (!started) {

  if (rainbowMode & (res2 <= change or res4 <= change) & !secondCheck) {
    rainbowCheck = true;
    for (int i = 0; i < strip.numPixels() ; i++) {
      strip.setPixelColor(i, strip.Color(0, 0, 0));
    }
```

```
    strip.show();
  }

  if ((rainbowMode & !rainbowCanStart & rainbowCheck & !secondCheck &
  (res2 >= change and res4 >= change))) {
    rainbowCanStart = true;
  }

  if ((rainbowCanStart & rainbowMode) or (!rainbowCanStart &
  !rainbowMode)) {
    if (firstCheck) {
      for (int i = 0; i < strip.numPixels() ; i++) {
        strip.setPixelColor(i, strip.Color(0, 0, 0));
      }

      for (int i = 0 ; i < amountReps ; i++) {
        strip.setPixelColor(i, strip.Color(0, 255, 255));

      }
      strip.show();
    }

    if ((res2 <= change or res4 <= change) & !secondCheck ) {
      firstCheck = false;
      timer = 0;
    }

    if (secondCheck) {
      for (int i = 0; i < strip.numPixels() ; i++) {
        strip.setPixelColor(i, strip.Color(0, 0, 0));
      }

      for (int i = 0 ; i < repTime ; i++) {
        strip.setPixelColor(i, strip.Color(255, 255, 0));

      }
      strip.show();
    }
```

```
      if ((res2 >= change & res4 >= change) & !firstCheck) {
        secondCheck = true;
      }

      if ((res2 <= change or res4 <= change)  & secondCheck) {
        secondCheck = false;
        for (int i = 0; i < strip.numPixels(); i++) {
          strip.setPixelColor(i, strip.Color(0, 0, 255));
        }
        strip.show();
        timer = 0;
        started = true;
        Lon = amountLeds;
      }
    }
  }


  if (started & switchState) {
    if (!rainbowMode) {
      if ((res2 <= change || res4 <= change) ) {
        nextRep = true;
      }


      if (nextRep == true & (res2 >= change || res4 >= change) & greenValue
      >= 255 & Lon < strip.numPixels()) {
        blueValue = 255;
        greenValue = 0;
      }

      if (nextRep == true & (res <= change || res3 <= change) & (res2 >=
      change || res4 >= change) & greenValue <= 255) {
        blueValue -= changeStep;
        greenValue += changeStep;

        //    Limit values to 0 - 255 range
        blueValue = max(blueValue, 0);
        greenValue = min(greenValue, 255);
```

```
    }

    if (greenValue <= 255 & ((res2 <= change || res4 <= change) or (res >=
    change or res3 >= change))) {
      blueValue = 255;
      greenValue = 0;
      strip.show();
      delay(30);
    }



    if (nextRep == true & (res <= change || res3 <= change) & (res2 >=
    change || res4 >= change)) {
      // Fill along the length of the strip in various colors...
      colorWipe( strip.Color(0, greenValue, blueValue), 600); // Green

    }
    if (greenValue >= 255 & nextRep == true) {
      rep += 1;
      greenLight = Lon;
      if (greenLight < Lon) {
        greenLight += 1;
      }

      Lon = amountLeds * (rep + 1);
      //        Lon = min(Lon, strip.numPixels());
      nextRep = false;
    }
  }
  // The mode for the step up and down exercise
  if (rainbowMode) {

    digitalWrite(trigPin, LOW);
    // Sets the trigPin on HIGH state for 10 micro seconds
    digitalWrite(trigPin, HIGH);
    digitalWrite(trigPin, LOW);
    // Reads the echoPin, returns the sound wave travel time in
    microseconds
    duration = pulseIn(echoPin, HIGH);
```

```
// Calculating the distance
if (duration > 0 & duration < 100 / 0.034 * 2) {
  distance = duration * 0.034 / 2;
} else {
  distance = 0;
}

// determining when the foot is too high or low.
footTooHigh = footHeight + footDistance ;
footTooLow = footHeight - footDistance;

//Making the outcome of the distance sensor more reliable when
standing on it.
if (greenValue == 255 & footHeight == 0 ) {
  footHeight = 2;
}

// User is standing on the platform
if (distance <= 2) {
  nextRep = true;
  if (greenValue == 0) {
    footHeight = footDistance;
  }
}

// Changing the values of the colours during a rep
if (nextRep == true & (res <= change || res3 <= change) & ( greenValue
<= 255 or blueValue >= 0) ) {
  if (up & distance > footTooLow & (distance < footTooHigh or distance
  > 15) & distance >= footHeight ) {
    greenValue += changeStep;
    footHeight += footDistance;
  }
  if (!up & distance >= footTooLow & (distance < footTooHigh or
  distance > 15) & distance < footHeight) {
    blueValue -= changeStep;
    footHeight -= footDistance;
  }
```

```
    footHeight = min(footHeight, 15);

    //    Limit values to 0 - 255 range
    blueValue = max(blueValue, 0);
    greenValue = min(greenValue, 255);
  }

  // If you go too fast or slow it blinks red to show you have to go
  back down.
  if (((distance > footTooHigh & distance < 15) or distance <
  footTooLow)) {
    blueValue = 255;
    greenValue = 0;
    colorWipe( strip.Color(255, 0, 0), 600); // Red
    footHeight = footDistance;
    up = true;
    strip.show();
  }

  //Changing the colour of the LEDs
  if (nextRep == true) {
    // Fill along the length of the strip in various colors...
    if (up) {
      colorWipe( strip.Color(greenValue, greenValue, 255), 300); // White
    } else {
      colorWipe( strip.Color(blueValue, 255, blueValue), 300); // Green
    }

  }

  //Going back down
  if (greenValue >= 255 & up  == true & distance >= 15) {
    up = false;
    footHeight -= footDistance;
  }

  // Conintue to the next rep
  if (blueValue <= 0 & greenValue >= 255 & nextRep == true) {
    blueValue = 255;
```

```
      greenValue = 0;
      footHeight = footDistance;
      up = true;
      rep += 1;
      greenLight = Lon;
      if (greenLight < Lon) {
        greenLight += 1;
      }

      Lon = amountLeds * (rep + 1);
      //        Lon = min(Lon, strip.numPixels());
      nextRep = false;
    }

  }

  // starting the end phase

  if (Lon >= (strip.numPixels() + amountLeds) ) {
    timer = 0;
    for (int amount = 0 ; amount <= 200; amount++) {
      for (int i = 0; i < strip.numPixels(); i++) {
        strip.setPixelColor(i, strip.Color(0, brightness, 0));
      }
      strip.show();
      delay(30);

      if (brightness <= 0 ) {
        turn += 50;
      }
      if (brightness >= 255) {
        turn = -50;
      }
      brightness = turn + brightness;

      brightness = min(brightness, 255);
      brightness = max(brightness, 0);
    }
    resetFunc(); //call reset
```

```
      }
    }
  }
}

// Changing the colors of selected LEDs
void colorWipe(uint32_t color, int wait) {
  for (int i = greenLight; i < Lon; i++) { // For each pixel in strip...
    strip.setPixelColor(i, color);         //  Set pixel's color (in RAM)
    lastLed = i;
  }
  delay(wait);
  strip.show();
}


// Rainbow cycle along whole strip. Pass delay time (in ms) between frames.
void rainbow(int wait) {
  for (long firstPixelHue = 0; firstPixelHue < 65536; firstPixelHue += 256) {
    strip.rainbow(firstPixelHue);
    strip.show(); // Update strip with new contents
    delay(wait);  // Pause for a moment
  }
}
```

Appendix C

User evaluation survey

C.1 Prototype questions

- What were your thoughts on the step-up exercise?
- What is your opinion about the functionality of the prototype? Was it clear to you?
- Was anything at any point unclear to you?
- How do you feel about doing this exercise while brushing your teeth?
- How did your needed attention to the step-up exercise compare to the original one?
- How likely are you to do the exercise more often if this prototype were available?
- What kind of feedback, if any, did you feel was missing from the prototype?
- Can you describe any instances where the prototype did not function as you expected?
- How did the time it took to brush your teeth compare to what you would normally like it to be?
- What unpleasant experiences, if any, did you encounter?
- What difficulties, if any, did you experience during the step-up exercise?
- What did you think about the portability of the prototype?
- Do you have any comments on the prototype that were not mentioned in this survey?

C.2 Informative and demographic questions

These questions were asked before testing the prototypes.

- What is your age?
- What is your sex?
- Were you familiar with the exercise before performing it?
- Did you have a knee injury prior to this experiment?

Appendix D

Consent form

The consent form is signed by the researcher and all 8 participants and can be found on the following two pages.

This research aims to improve rehabilitation adherence for volleyball players with Patellar Tendinopathy (PT). Current methods like taping and exercises exist to prevent PT, but adherence to rehab after injury is low due to the occurrence of pain during the rehabilitation. While most current research explores improving adherence through pain reduction, this study focuses on lowering the needed intrinsic motivation for an exercise. As a result, this research investigates how to incorporate PT rehab exercises into an everyday activity to make them more engaging and increase adherence.

The participant will perform the step-up exercise with the use of the prototype whilst brushing their teeth. Performing the exercise itself will take around 2 to 3 minutes.

The step-up exercise is a body resistance exercises that strengthens the quadriceps, hamstrings and gluteal muscles. This research project has been reviewed by the Ethics Committee Information and Computer Science.

After the testing of the prototype a survey will be handed out to the participant for feedback on the functionality, feeling, what is missing, what feels unnecessary and the portability of the prototype. Along with open (opinion) questions and demographic questions.

If the participant chooses to withdraw from the study at any point, they can inform me by contacting me personally (during the testing) or via the following email: m.c.w.h.vanderpol@student.utwente.nl .

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

The participant is not required to provide a reason for withdrawing.

The collected data from the survey will solely be used to improve the prototype and formulate the conclusion of the research.

Consent Form for Rehabilitation of Jumper's Knee Adapted to Daily Life

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	O	O
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	O	O
I understand that taking part in the study involves performing the step-up exercise with the use of the prototype whilst brushing their teeth. Performing the exercise itself will take around 2 to 3 minutes and filling in a survey after doing the exercise.	O	O
Use of the information in the study		
I understand that information I provide will be used to improve the prototype and formulate the conclusion of the research.	O	O
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team.	O	O
Future use and reuse of the information by others		
I give permission for the feedback that I provide to be archived in the survey's database so it can be used for future research and learning.	O	O

Signatures

______________________ ______________________ ________

Name of participant [printed] Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ___________________ ________

Researcher name [printed] Signature Date

Appendix E

Participant results

Based on the following questions, the results of the participants could be determined and calculated in the corresponding order:

- What is your opinion about the functionality of the prototype? Was it clear to you?
- How do you feel about doing this exercise while brushing your teeth?
- How did your needed attention to the step-up exercise compare to the original one?
- Would you do the exercise more often if this prototype were available?
- How did the time it took to brush your teeth compare to what you would normally like it to be?
- What did you think about the portability of the prototype?

The questions for the calculations were rephrased so that the open feedback could be translated into definitive responses, such as ”yes” or ”no.” If no specific result came of the feedback it was deemed inconclusive. Consequently, the final row shows the percentages of the amount of participants who provided positive feedback for each specific question. The interpreted results are shown in the following figure E.1:

Participant	Is the functionality of the prototype clear?	Is it possible to perform the exercise while brushing the teeth?	Do you need to pay less attention to the exercise when using the prototype?	Does the prototype increase your motivation to perform the exercise?	What is your opinion on the portability of the prototype?	Did the prototype have no effect or a positive effect on the brushing of the teeth?
1	Yes	Yes	Yes	Yes	Good	Positive
2	Yes	Yes	Yes	Yes	unneccesary	Positive
3	Yes	Yes	Yes	Yes	unneccesary	no effect
4	Yes	Yes	Yes	Yes	Good	shorter
5	Yes	Yes	Inconclusive	Yes	Good	Inconclusive
6	Yes	Yes	No	Yes	Good	no effect
7	Yes	No	Yes	Yes	Good	Positive
8	yes	Yes	Yes	Yes	Could improve	Positive
Positive:	100%	87,50%	75%	100%	62,50%	75%

Figure E.1: Interpreted answers of the survey of each participant, showing the percentage of positive responses per question.

Appendix F

Manual

The manual can be found on the following six pages: The manual is made in Canva and includes images from different websites [48], [50], [51].

Manual

Step-up device

exercises

Balance

Lateral step-up exercise
You lift your foot off the platform, wait for the LEDs to turn green, and then lower your foot back down.

Why

This exercise will increase the strength of your quadriceps and improve your balance.

How

You first adjust how many reps you want to do, then how long you want each rep to take. After that you can start the exercise, as described in the step-by-step guide.

Cardio

Step up and down exercise
You quickly step up the small step and then back off again.

Why

This exercise improves your cardiovascular fitness, agility and coordination by quickly, without breaks, stepping up and down

How

By putting the seconds setting on one second you will be able to perform the cardio step-up exercise, as depicted on the LED circle:

Strength

Slow lateral step-up exercise
You slowly lift your leg up and down. As you lift, the LEDs gradually turn white. Once all the LEDs are white, you can slowly lower your leg, turning the LEDs green. When they are fully green, you can go back up again. If you go too fast or make another mistake, the LEDs will turn blue again.

Why

This exercise strengthens your quadriceps even quicker than the first lateral step-up exercise, by putting more stress on your higher positioned knee.

How

When you make the small step as tall as possible you can perform the strength exercise.

You will notice that it is the correct mode if a rainbow appears on your LED circle. The seconds can now be put max on 5, as that represents 5 seconds going up and 5 down.

INSTRUCTIONS
LED circle

Select amount of reps

Select duration of one rep

Rainbow mode

If you see this you have selected the strength exercise.

If you want to do the balance or cardio exercise, lower your small step to get out of this setting.

Step by step

Scan the QR code to watch a video with instructions on how to perform the step-up exercise,

or turn to the next page for a step-by-step guide.

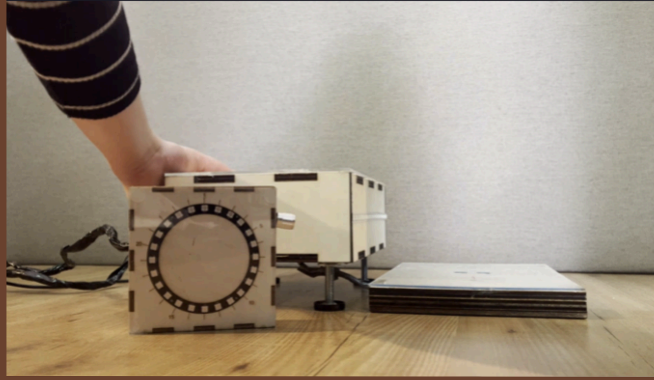
IMPORTANT NOTE

Note that if you do a rep wrong the device will make you re-do the rep.

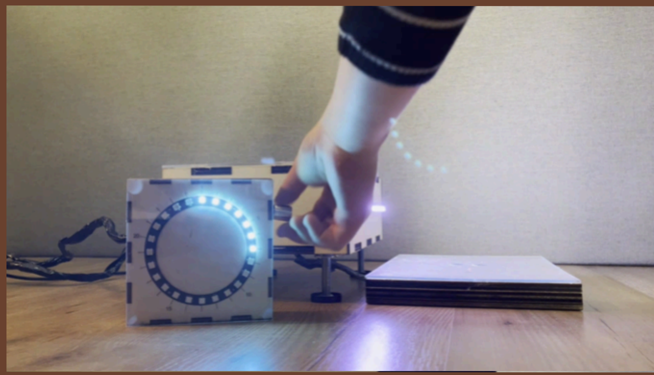
The balance exercise will simply go back to its previously blue colour.

The strength exercise will shortly blink red to make it clear that you have to go back to the starting position.

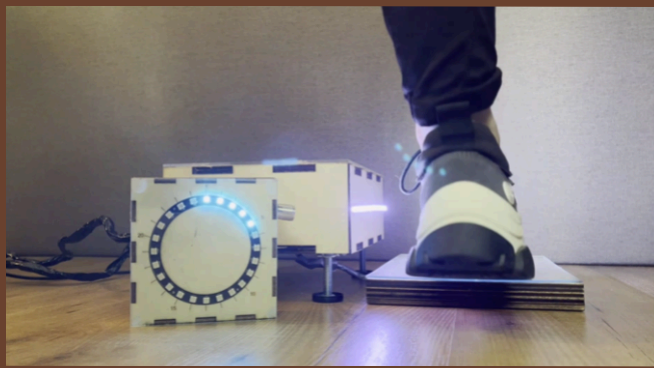
Turn the device on



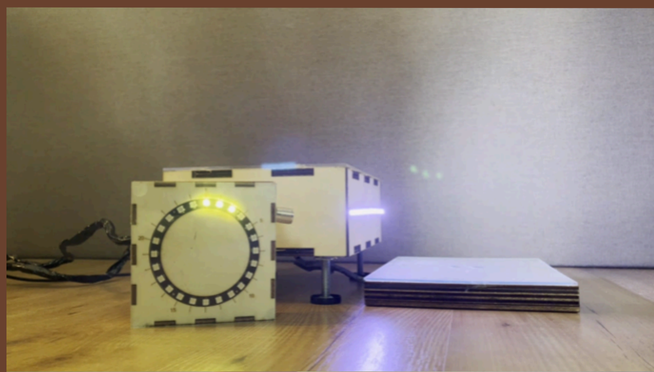
Select how many reps you want to do



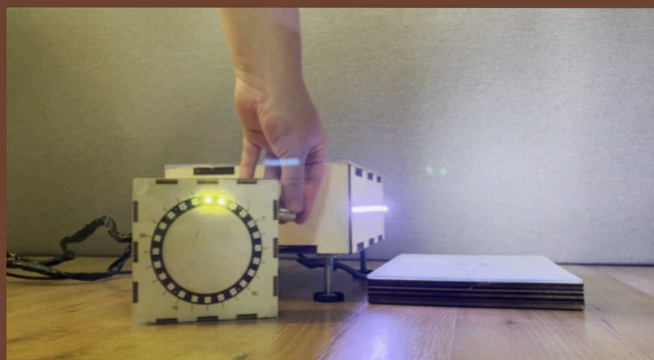
Step on the platform to continue to the next setting



The next setting appears when you step off the platform

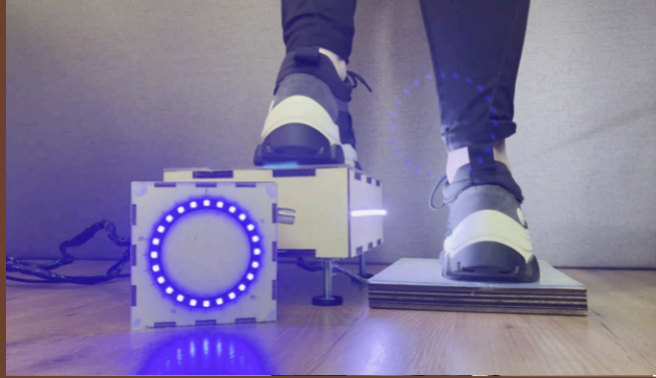


Select how long you want one rep to take

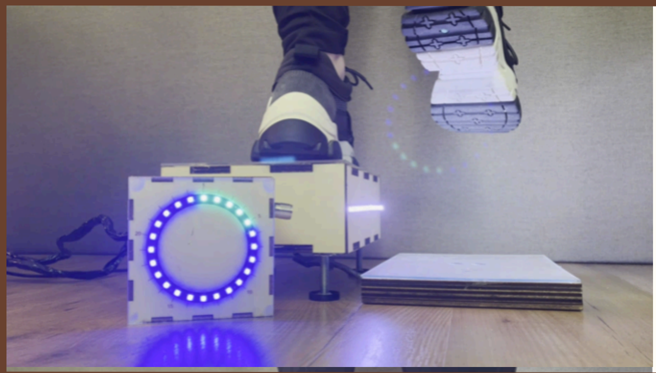


Step with both feet on the device to start the exercise

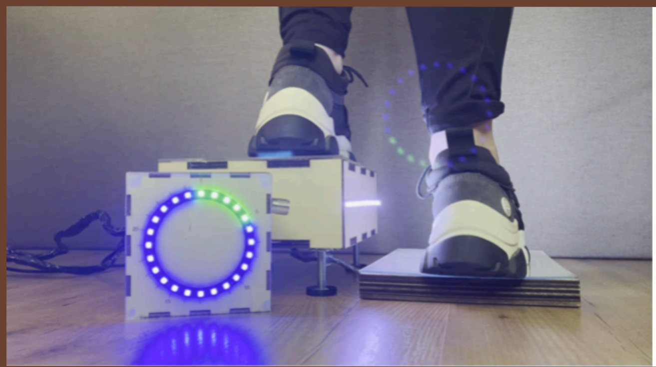
Lift up your foot from the platform



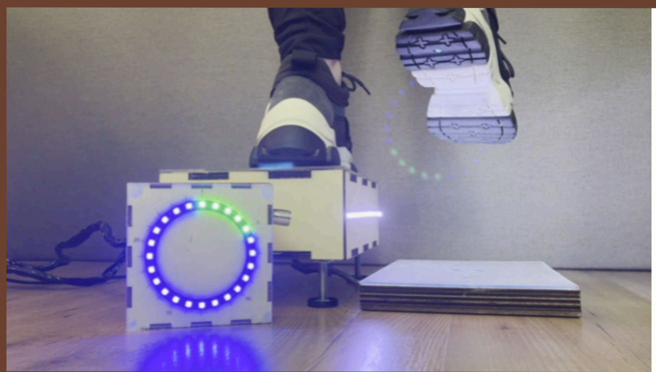
Wait till the selection of LEDs have completely turned green

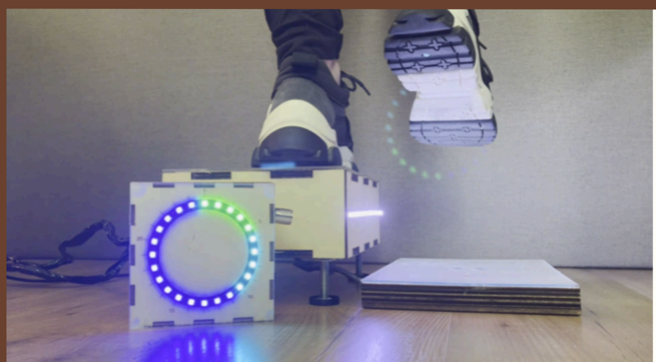


Put your foot back on the platform

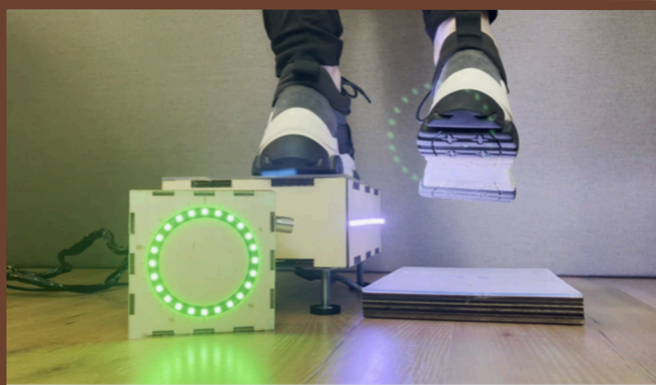


Lift up your foot from the platform again to continue to the next selection of LEDs

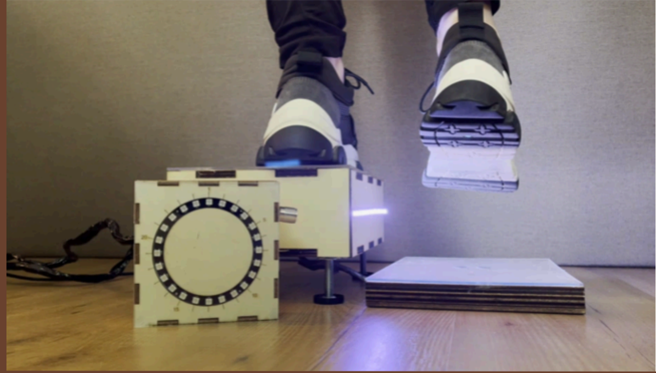




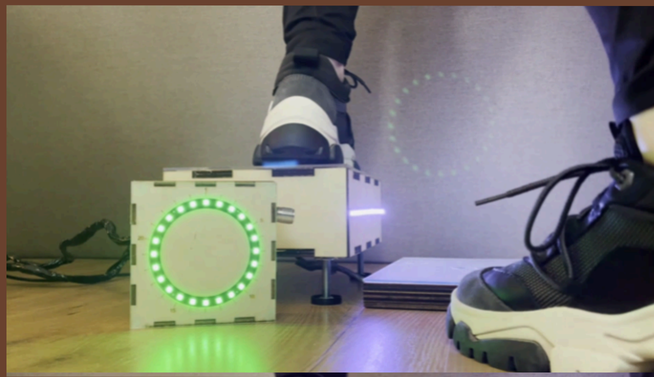
Repeat the steps until all LEDs have turned green



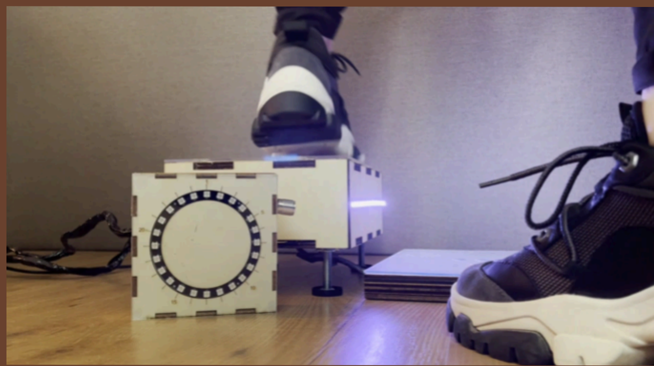
The LEDs start flickering, indicating that you're done



You may now step off the device.



The LEDs continue flickering for a short while to make sure you notice that you are finished



The device resets itself after flickering, returning to the initial setting.

You can now restart the exercise or turn off the device.