INTEGRATION OF REHABILITATION EXERCISES FOR RUNNING INJURIES IN DAILY LIVING

Bachelor Thesis Creative Technology

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ABSTRACT

In recent years, the development of rehabilitation tools and technologies has evolved, especially for complex injuries and conditions like individuals who have experienced a stroke. Trends of methods that support or alternatively improve rehabilitation have emerged, like Wearable Technologies, VR treatments and Telerehabilitation. Also, innovations such as running rehabilitation, like Gait retraining therapy, have been coming into the foreground. Finally, interactive rehabilitation exercises that are integrated into ADL, activities of daily life, designed for stroke hand rehabilitation, have shown promising results. However, the situation differs regarding interactive ADL rehabilitation exercises for running injuries. So there still may be undiscovered potential in interactive ADL rehabilitation exercises for running-related injuries. Therefore there is a need for research, focused on exploring new ways to design and integrate interactive running rehabilitation exercises in ADL. This is needed because the main problem with the rehabilitation process is that consistency is important. However, a lack of time management for example can make integrating these exercises into your routine difficult. Thus, the goal of this research was to explore how rehabilitation exercises for running injuries could be integrated into ADL to increase adherence and engagement to these exercises. This meant that a prototype had to be created where this was made possible. After the creation of this tool, a footrest that integrates heel raises into the activity of sitting, user tests and interviews were held to understand the effectiveness of the core goals of this tool. Results showed that, regardless of certain design changes that have to be taken into account when trying to increase adherence, the core principles of integrating an exercise into ADL are possible and worthwhile. However, further testing over a longer period with an improved prototype should be done to conclude the long-term impact of such a tool. For now, this research serves as a starting point for tools to be developed that integrate rehabilitation into ADL.

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RE	Rehabilitation exercise
RRI	Running related injury
RQ	Research question
ADL	Activities of daily living

1 INTRODUCTION

This chapter consists of the introduction, the context and relevance of this research paper, which focuses on the integration of a running injury rehabilitation exercise in daily life. First, the challenges within the project are explained. Next, the current situation on running injury rehabilitation and the relevance for this project is explained and research question with its applicable sub-research questions are presented and finally, an outline of the research report is mentioned.

1.1 CHALLENGES

The main challenge in the current context lies in maintaining motivation and consistency and therefore, adherence during rehabilitation exercises over a longer period. Athletes often face physical discomfort, frustration, and mental fatigue during the rehabilitation process, leading to a decrease in adherence to the rehabilitation exercises [2], [3]. This could be because of the severity of the injury, or because the athlete is unable to see the progress they made towards recovery [4], [5], [6]. Additionally, the repetitive nature of rehabilitation exercises can contribute to boredom and disengagement, further hindering progress [7]. Moreover, external factors such as busy schedules, competing priorities, and lack of social support could hinder athletes' ability to carry out the necessary rehabilitation exercises [5], [6], [8].

Next to the main challenge, another obstacle has to do with the need for “personalised design” or Human-centred Design (HCD). When an athlete needs to adhere to certain rehabilitation exercises, they are frequently catered towards the specific person's needs [8], [9]. This may prove a challenge when designing a prototype aimed to help, multiple people with different needs, recover from their running injury.

1.2 CONTEXT AND RELEVANCE

In recent years, the development of rehabilitation tools and technologies has become more prevalent [10], especially for cases that handle complex injuries and conditions like individuals who have experienced a stroke. Therefore, there has been an emerging trend of methods that support or alternatively improve rehabilitation, like Wearable Technologies, VR treatments and Telerehabilitation, which refers to the delivery of rehabilitation services provided through digital means[11], [12], [13]. Moreover, innovation regarding running rehabilitation, like Gait retraining therapy, has been coming into the foreground [14]. Gait Retraining therapy suggests that through retraining wrong Gait cycle habits (“Running gait is the cycle a leg travels through during one step when running.” [15], [16]), pains in specific areas lessen and overuse injuries can be prevented [14], [17], [18]. Although successful results have been presented, more research is still needed. Finally, interactive rehabilitation exercises that are integrated in ADL, designed for stroke hand rehabilitation, have shown promising results [19], [20]. Rehabilitation exercises designed for complex injuries and conditions like stroke built around interactive ADLs are being researched and designed.

However, the situation differs regarding interactive ADL rehabilitation exercises for RRIs. Many Apps like “Recover Athletics” [21] and corresponding Wearables exist to try to support and improve the rehabilitation process, and Virtual Reality Rehabilitation that simulates ADLs for RRIs does exist [11]. Yet there still may be undiscovered potential in interactive ADL rehabilitation exercises for RRIs. Therefore there is a need for research, focused on exploring new ways to design and integrate interactive running rehabilitation exercises in ADL.

1.3 Research Questions

With regard to the challenges discussed previously, the following research question and sub-research questions can be stated:

- RQ1: How can injury rehabilitation tools for running injuries be effectively integrated into daily activities to enhance engagement/adherence to rehabilitation exercises?
    - ◊ RQ1.1: What are the injuries that runners often experience?
    - ◊ RQ1.2: What rehabilitation exercises are recommended for running injuries?
    - ◊ RQ1.3: What are the aspects that determine engagement/adherence to running injury rehabilitation exercises?
    - ◊ RQ1.5: What are the requirements associated with integrating rehabilitation tools into daily activities?
    - ◊ RQ1.6: What solutions that are integrated into daily life are currently out there?

1.4 Report Outline

This research paper seeks to provide a complete overview of the development and design approach of the fully finalised design and solution. Chapter 2 dives into the background and state-of-the-art research on the topic, to provide an overview and lay the foundation for the ideation phase of the project. Thereafter, chapter 3 discusses and explores the Ideation phase, which contains the process that was done to finalise and choose an idea to continue with during the next part of the thesis. Chapter 4 focuses on the specification of the chosen idea by creating and further developing a requirements list that the final design has to adhere to. Furthermore, the design and functions are explained. Chapter 5 expands on the realisation phase of the prototype. This involves creating a functional tool based on the conceptual design. The process and the accompanying schematics are mentioned to give a complete explanation of how the tool was realised. The next chapter, chapter 6, describes the evaluation phase. Here the evaluation plan and phases are described. Furthermore, the results of the user tests and interviews are analysed and findings are reported. The following chapter, chapter 7, dives into the discussion about the research done. The results and limitations of the research are discussed and future research perspective are suggested. Finally, chapter 8 aims to conclude and close the research by answering the main research question.

2 BACKGROUND RESEARCH

This chapter delves into the background research carried out, which focuses on possible running injuries and their applicable rehabilitation exercises, aspects of rehabilitation engagement/adherence and possible risks attached to interactive ADL rehabilitation tools. The goal is to review and gather existing works and knowledge on the injuries and rehabilitation exercises attached to running and behavioural theories and aspects of adherence to rehabilitation exercises.

2.1 LITERATURE REVIEW

This literature review is aimed at providing a comprehensive overview of running injuries and their corresponding rehabilitation exercises. Furthermore, an exploration of possible aspects that may increase, decrease or limit rehabilitation adherence is done. Next, possible risks or challenges faced when implementing Interactive ADL Rehabilitation Tools will be assessed. Finally, a conclusion will be made which provides the guidelines and recommendations used in the Ideation phase. Part of this literature review was performed as an assignment for the EEMCS CreaTe Bachelor 2024 course "Academic Writing", and was carried out by Erik Schuit. Chapters included in the "Academic Writing" assignment are 2.1.1 & 2.1.2.

2.1.1 Overview of Potential Running Injuries

Understanding the range of the most common potential RRIs can help to understand when specific can injuries occur. Together with the complete overview of running injury rehabilitation exercises, which can be read in "Chapter 2.1.2 Running Injury Rehabilitation Exercises", specific rehabilitation exercises can be chosen to focus on in the Ideation phase.

When discussing running injuries or general injuries, one must categorise them into two categories, acute and chronic injuries, where "Acute injuries happen suddenly, such as a person falling, receiving a blow or twisting a joint, while chronic injuries are usually result from overuse of one area of the body and develop gradually over time." [22] This categorisation is important to know and to uphold, because certain acute injuries may not directly benefit from rehabilitation exercises, but only after an operation has been done may the individual benefit from said exercises. Moving forward in this review, injuries will be categorised by Acute or Chronic.

A study performed by Nielsen et al. [23] was done on [n=2002] injury cases and the frequency of specific diagnoses comparing volumetric running injuries and pacing injuries. The results from this, as seen in *Table 1*, show the 6 most common injuries of the 2002 running injury cases in percentages. Accordingly, the most commonly encountered injury is Patellofemoral pain syndrome (PFPS), which occurs due to a change in running volume (16.5%). The highest risk of a pacing injury (7.9%) is Plantar fasciitis (PF). Furthermore, volume injuries are injuries that occur when the volume, or distance, of running is changed, whereas pacing injuries occur with a change in pace.

Table 1: *The frequency (percentage) of specific diagnoses Nielsen et al.* [23]

Diagnosis	**Frequency (%)**	**Volume injury**	**Pacing injury**
Patellofemoral pain syndrome (PFPS)	16.5%	Yes	

Diagnosis	**Frequency (%)**	**Volume injury**	**Pacing injury**
Iliotibial band friction syndrome (ITBFS)	8.4%	Yes	
Plantar fasciitis (PF)	7.9%		Yes
Patellar tendinopathy (PT)	4.8%	Yes	
Achilles tendinopathy (AT)	4.8%		Yes
Gastrocnemius injuries (GI)	1.4%		Yes
TOTAL	**43.8%**	**29.7%**	**14.1%**

PFPS, also known as Runners Knee, was the most common injury, which can be recognised as a dull pain around the front of the knee. Furthermore, this injury is also labelled as a volumetric injury, which is <u>not</u> the same classification as a chronic injury. Moreover, both ITBFS, which can be felt as sensitive pain on the outside part of the knee, and PT, which is also known as Jumpers Knee and is caused by small tears in the patella tendon, are knee injuries and are both also classified as a volume injury. The three pacing injuries are (1) Plantar fasciitis, which is a pain felt in the connective tissue between the heelbone and the base of the toes, due to degeneration, (2) Achilles tendinopathy, which results in pain stiffness and swelling around the heel and (3) Gastrocnemius injuries also known as calf strains.

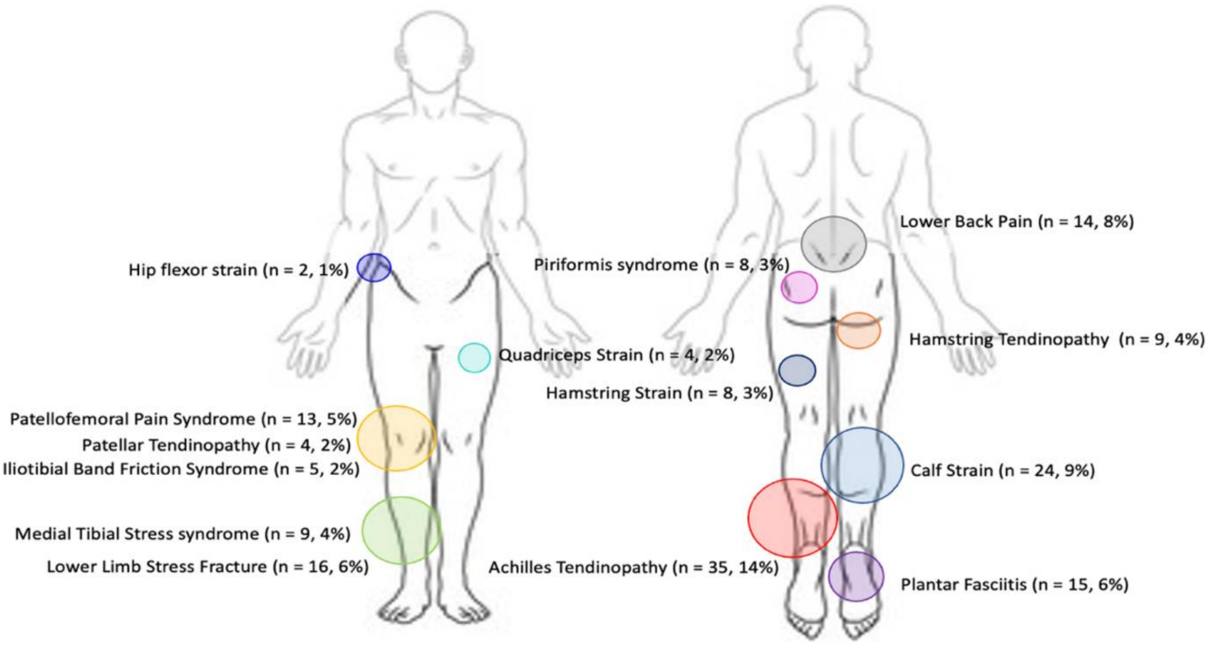


Figure 1: *Running-related injury pathologies Burke et al.* [24]

Other research by Burke et al. [24] which was done on 310 recreational runners, supports the findings of Nielsen et al. [23]. However, they expand on the injuries reported as seen in *Figure 1*, where additional commonly occurring injuries were reported. These 310 recreational runners were monitored for 12 months in total and one hundred and thirty-two runners (51%) sustained an RRI during this period. The results of this research showed that some athletes were at higher risk of injuries like lower spinal and hip injuries, due to their relative higher BMI, anatomic malalignments or previous injury history. Regarding the importance of taking into consideration the different causes of RRIs, Benca et al. [25] support these claims. Moreover, they came to a similar conclusion regarding the most commonly occurring RRIs. PFPS, ITBFS and PT, together with lower leg, ankle, hip and lower back injuries were found to be the most common RRIs. Furthermore, they could attribute the cause of all injuries to overuse.

In conclusion, while certain aspects like anatomic malalignments influence the risks of particular injuries, throughout research there is an agreement on the most commonly occurring RRIs. Therefore, an overview of the most common RRIs, which can be seen in *Table 2*, could be made. In the table a description of the injury can be seen, what type of pain you would experience, what the cause of the pain could be and symptoms of the injury. Furthermore, the location of the injury is shown to give a clear overview.

Table 2: *Overview of most common RRIs*

Injury	**Description**	**Injury Location**
Patellofemoral pain syndrome (PFPS)	Runners Knee, with a dull pain around the front of the knee	Knee
Iliotibial band friction syndrome (ITBFS)	Sensitive pain on the outside part of the knee	Knee
Patellar tendinopathy (PT)	Jumpers Knee, which is a small tear in the patella tendon	Knee
Plantar fasciitis (PF)	A pain felt in the connective tissue between the heelbone and the base of the toes, due to degeneration	Foot
Achilles tendinopathy (AT)	An injury to the tendon that connects the lower leg to the heel bone, which causes pain, stiffness and swelling around the heel.	Lower Leg
Gastrocnemius injuries (GI) or Calf strain	The calf muscle stretches too much causing pain, stiffness or weakness	Lower Leg
Medial Tibial stress syndrome (MTSS)	A pain over the front tibia and is an early stress injury in the stages of tibial stress fractures	Lower Leg
Lower Limb stress fracture (LLSF)	Stress fractures to the tibia and/or metatarsal bones	Lower Leg & Foot
Hamstring strain	One or more of the hamstring muscles gets stretched too far and starts to tear	Upper Leg
Hamstring Tendinopathy (HT)	Inflammation of the tendons at the back of the thigh	Upper Leg
Quadriceps strain	An overstretch or pull of the quadriceps muscle	Upper Leg
Piriformis syndrome (PS)	An injury where the piriformis muscle, located in the gluteal region, spasms and causes pain.	Gluteal

Injury	Description	Injury Location
Lower Back pain	A pain felt in the lower back which may make moving or standing upright difficult	Lower Back
Hip Flexor strain	An injury that may occur when the muscle and tendon attached to the pelvic bone are overstretched starting to tear	Hip

2.1.2 Overview of Running Injury Rehabilitation Exercises

With regard to RRIs, understanding the corresponding rehabilitation exercises (REs) can help in creating an overview of all injuries and REs. Understanding what type of REs are practised for specific RRIs, may also give insight in REs that may be applicable for multiple RRIs. With this overview, a specific RE can be chosen to focus on during the ideation phase.

Research suggests that for Patellofemoral pain syndrome (PFPS), both hip and knee strengthening are effective in reducing pain and improving rehabilitation and that strengthening exercises are recommended to reduce pain in short, medium and long-term periods [26], [27]. Furthermore, results seemed to suggest that a combination of both hip and knee strengthening exercises is beneficial in recovery. It is recommended that a combination of strengthening exercises is the most beneficial during the rehabilitation period. However, there was insufficient evidence to support or disprove their effectiveness in improving the strength of the muscles that the exercises targeted [27]. While PT (Patellar Tendinopathy) is not the same injury as PFPS, the recommended REs are similar as they also need to strengthen the hip and knee. As research suggests, REs such as eccentric decline squats and slower isotonic seated leg raises have shown promising results during rehabilitation in both professional and amateur athletes [28]. However, the major component of the RE has to be eccentric training of the knee. Lastly, a significant importance is mentioned of the needed combination in Res [26], [27].

In disagreeance with previously mentioned statements, research suggests that eccentric exercises are painful and only have poor effectiveness. It is argued that the poor effectiveness of the exercise type is a consequence of the painfulness of the exercise, which therefore in turn results in poor adherence [29]. However, these suggestions have only been based on athletes who play in competitive seasons where there is constant pressure to perform, thus failing to include amateur athletes. It is proposed that isometric exercises which target only a small muscle group during the exercises and provide “immediate” pain relief. Furthermore, the clinical implications of the research done, are that apart from pain relief, isometric exercises can be done by people with PT without losing muscle strength.

Besides knee injuries, Plantar Fasciitis (PF) is a common RRI that plagues athletes. Research recommends certain REs, with the main option being a “Plantar facia stretch”. They propose this exercise relieves pain and improves function which is maintained at a two-year follow-up [30]. Many orthopaedic and physiotherapists like the Washington University Physicians [31], recommend the same exercise with slight variation. Furthermore, it is suggested that in rehabilitation for knee injuries, hip-strengthening exercises are an appropriate way to prevent and recover. However, even though some research found that there were possible correlations between hip-strengthening exercises and improvements during gait movements, there is currently no evidence that validates that theory [30]. Furthermore, research indicates a support for a similar stretching exercise where using a tool such as a towel to pull the area underneath the toes and forefoot towards yourself. Furthermore, they suggest “rolling” exercises, where the foot is placed on a small ball or a frozen water bottle and rolled around [32]. This RE is also supported and can be found in many rehabilitation protocols from institutions like the Washington University Physicians [31].

Moreover, Achilles tendinopathy (AT) is a significant concern for runners, especially long distance runners [32]. Suggested REs after a period of rest include towel stretches, toe raises and resistive tubing, which is a resistant tube which is used during stretching exercises. When athletes are further along in the recovery process, lunges and eccentric exercises for the Triceps Surae (calf muscle). These suggested REs are supported by the rehabilitation protocol from the Oxford University Hospitals Department of Physiotherapy [33], were they suggest an eccentric exercise program. Additionally, variations of stretching exercises are also mentioned as a method to reduce tightness felt across the Achilles tendon. At the same time, Gastrocnemius Injuries (GI) follow the same trend of suggested REs such as towel stretches and various standing stretch exercises [34]. Besides lower leg injuries, upper leg injuries are also a possible RRI a running athlete can obtain. Similar to the previously mentioned injuries, eccentric exercises are proposed that resolve symptoms and help recover the injury [35]. Suggested exercises are hamstring bridge, laying down stretches, jumping lunges and half-kneel heel raises [36]. These exercises all have in common that they are eccentric, which means their goal is to gradually extend and stretch muscles.

In conclusion, while certain REs and methods are not unanimously agreed upon throughout research, there is an agreement on the most commonly used REs. Therefore, an overview of the most common RRIs and their corresponding REs, which can be seen in *Table 3*, could be made.

Table 3: *Overview of most common RRIs and corresponding REs*

Injury	**Description**	**Rehabilitation Exercise**	**Injury Location**
Patellofemoral pain syndrome (PFPS)	Runners Knee, with a dull pain around the front of the knee	Squats, leg raises, standing calf stretch, lunges, bridging	Knee
Iliotibial band friction syndrome (ITBFS)	Sensitive pain on the outside part of the knee	Squats, leg raises, standing calf stretch, lunges, bridging	Knee
Patellar tendinopathy (PT)	Jumpers Knee, which is a small tear in the patella tendon	Squats, leg raises, standing calf stretch, lunges, bridging	Knee
Plantar fasciitis (PF)	A pain felt in the connective tissue between the heelbone and the base of the toes, due to degeneration	Towel stretch, rolling stretch, toe stretch, standing calf stretch	Foot

Injury	Description	Rehabilitation Exercise	Injury Location
Achilles tendinopathy (AT)	An injury to the tendon that connects the lower leg to the heel bone, which causes pain, stiffness and swelling around the heel.	Towel stretch, toe raises, resistive tubing, standing calf stretch	Lower Leg
Gastrocnemius injuries (GI) or Calf strain	The calf muscle stretches too much causing pain, stiffness or weakness	Towel stretch, toe raises, resistive tubing, standing calf stretch	Lower Leg
Medial Tibial stress syndrome (MTSS)	A pain over the front tibia and is an early stress injury in the stages of tibial stress fractures	Calf/heel raises, wall squats, standing stretch	Lower Leg
Lower Limb stress fracture (LLSF)	Stress fractures to the tibia and/or metatarsal bones	Calf/heel raises, wall squats, standing stretch	Lower Leg & Foot
Hamstring strain	One or more of the hamstring muscles gets stretched too far and starts to tear	Bridging, lay down stretch, (jumping) lunge, calf/heel raises	Upper Leg
Hamstring Tendinopathy (HT)	Inflammation of the tendons at the back of the thigh	Bridging, lay down stretch, (jumping) lunge, calf/heel raises	Upper Leg
Quadriceps strain	An overstretch or pull of the quadriceps muscle	Bridging, lay down stretch, (jumping) lunge, calf/heel raises, quad stretch	Upper Leg
Piriformis syndrome (PS)	An injury where the piriformis muscle, located in the gluteal region, spasms and causes pain.	Bridging, leg raises, lunge, cross-body stretch, knee-to-chest stretch	Gluteal
Lower Back pain	A pain felt in the lower back which may make moving or standing upright difficult	Bridging, leg lifts, wall squat, standing calf stretch, knee-to-chest stretch	Lower Back
Hip Flexor strain	An injury that may occur when the muscle and tendon attached to the pelvic bone are overstretched starting to tear	Lay down stretch, lunge, kneeling stretch, quad stretch	Hip

2.1.3 Rehabilitation Engagement/Adherence Aspects

Rehabilitation adherence play a pivotal role in the rehabilitation process. Most if not all REs require discipline and motivation and if they are not done correctly, may even injury the athlete more. With the concluding goal of this thesis being creating an integrated rehabilitation tool, it is necessary that this tool will ease and encourage the adherence to the RE. Therefore, aspects of rehabilitation adherence need to be mapped.

Research done on athlete adherence to REs, suggest based upon initial evidence that autonomous treatment and autonomous treatment support are positive influences on the athlete's rehabilitation adherence. While controlled treatment made for negative influences on the motivation. However, it must be noted that it needs to be taken into account that there are different sources of motivation [7]. There are different aspect and factors that influences once motivation. They suggest that there are personal factors and situational factors that influence the response to the injury and to the rehabilitation process (these can be seen in *Figure 2.* The consequences of the injury on the rehabilitation process can be negative when, athletes experience anxiety after their injury. Furthermore, stress can be experienced when suffering from an RRI [3]. It is mentioned that when athletes experience stress, their attention narrows, they are more easily distracted and experience a higher level of muscle tension. These factors all can have a negative impact on rehabilitation. However, what research also says is that ways to increase rehabilitation adherence are effective communication for education on the injury and the rehabilitation process. People that want to recover, have increased adherence to REs when they know what the objective of the exercises are. Furthermore, a goal-setting process is beneficial because it holds the athlete accountable. Lastly, introducing performance imagery will help visualise what it will be like when they return to their sport, which helps to motivate them to adhere to the REs [3], [7].

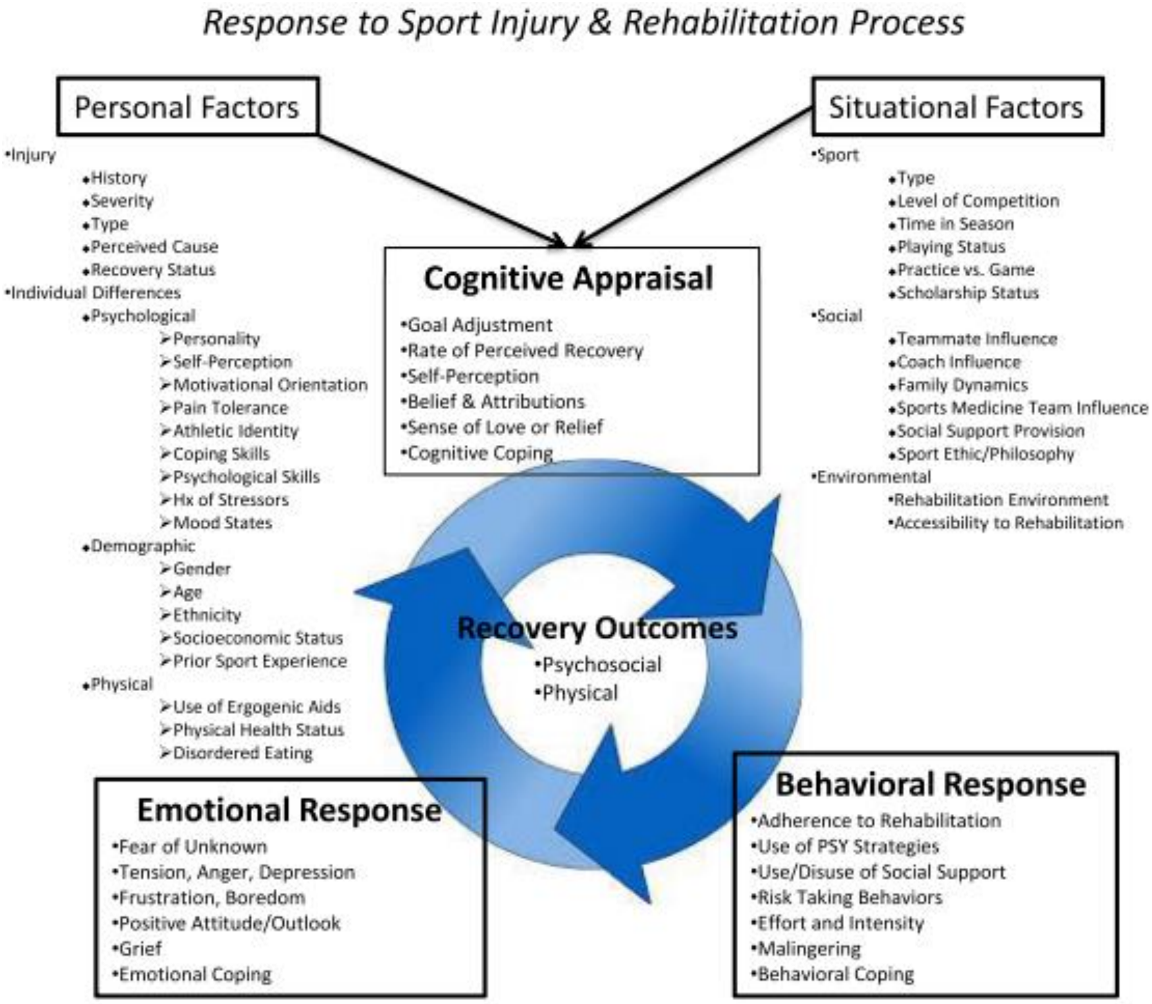


Figure 2: *Overview of responses to a sports injury and the rehabilitation process. Personal and situational factors that influence the cognitive appraisal which guides the outcome of the rehabilitation Covassin et al.* [3].

In addition to the engagement aspects of the rehabilitation process itself, it is also important to understand what determines engagement with technology. This importance is due to the goal of designing an integrated rehabilitation tool. A suggestion based upon research, is that there are different attributes to engagement. These in turn could have influence and relevance to engagement in certain engagement theories. These theories include the flow theory, aesthetic theory, play theory and the information interaction theory. The attributes from these theories should be taken into account when designing an interaction tool. The following attributes are mentioned [37] in *Table 4*.

Table 4: *Engagement attributes O'Brien and Toms* [37]

Aesthetics	Affective appeal	Attention	Challenge	Feedback
Goal-directed	Meaningfulness	Motivation	Perceived control	Sensory appeal

While it is not a requirement for designing an integrated rehabilitation tool, gamification is often used as a tool to engage users [37], [38]. These four theories were applied on 4 different applications, video games, educational applications, online shopping and web searching. The 2 applications of video games and educational applications do apply to a tool that could make use of gamification or educational elements. Besides the previously mentioned engagement attributes in *Table 4*, other attributes were suggested that applied to the video games and educational applications. These attributes were, interactivity, endurability and variety/novelty[37].

Research results suggested a proposed model of engagement. This model includes 4 stages of engagement including the engagement attributes that identify each stage. The first stage is engagement, which is initiated by the looks or 'Aesthetics' or the novelty of the interface/technology, the interests and motivations of the user and the goal of the user using the technology. The second stage is the sustaining of engagements and is categorised by a list of attributes called the period of engagements attributes which can be seen in *Figure 3*. The third stage is called the disengagement stage which can occur when users experience certain difficulties which include, usability issues or challenges or interruptions and distractions from their environment [37].

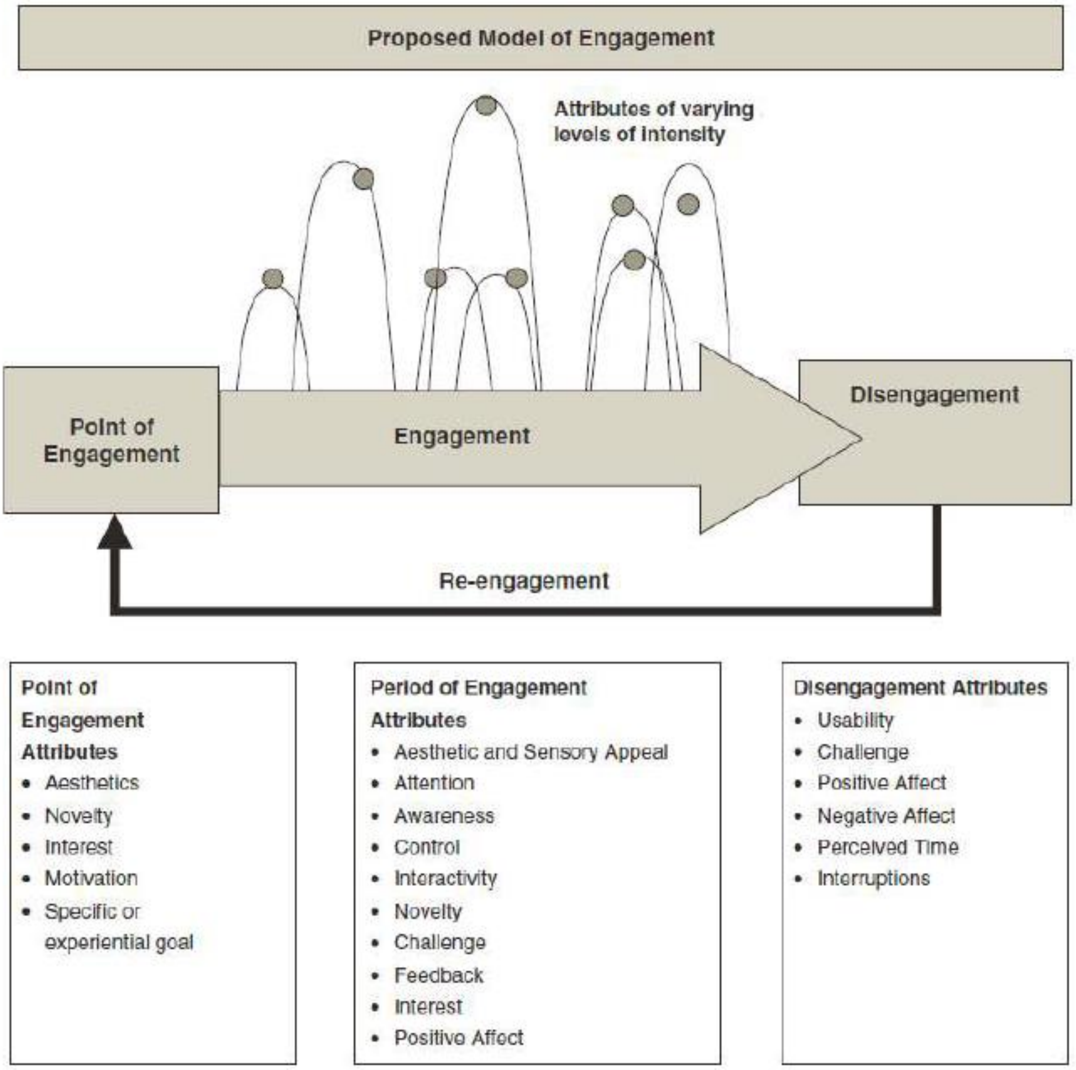


Figure 3: *The Model of Engagement by O'Brien and Toms* [37]

Finally, re-engagement is a core aspect of the model of engagement. Re-engagement can occur when users return to a previous attribute of aspect of the technology that they were previously engaged with, or something may be so engaging that the previous task is abandoned.

2.1.4 Requirements of Interactive ADL Rehabilitation Tools

When designing an interactive ADL rehabilitation tool, certain requirements are necessary to the usability and effectiveness of the tool. To ensure that such a tool can be designed with these characteristics, requirements based on the different facets, are needed. The requirements will be sorted in a list and scored on importance. The scoring is done based on the gathered research in the "Background Research" chapter.

Research has shown that there is a list of most common RRIs [23], [24], [25]. The first requirement of an interactive ADL rehabilitation tool, that is to be created within the boundaries of this thesis and based upon the most common RRIs, is that the tool should target a commonly occurring RRI. This is due to the fact that later on if testing is done, users with said RRI have to be found. The tool targeting a commonly occurring RRI, makes the process of finding users easier. The tool should incorporate an easy to apply RE. By this it is meant that the RE has to be easily adapted together with an ADL. Another way to phrase this would be that the RE has to be seamless to the users. To achieve seamlessness there are certain characterizations that influence the seamlessness of an object. Firstly, for an object to be seamless, the user must interpret it to be simple and easy to use [39]. Furthermore, the object should be interacted with in a familiar environment to the user [40]. Besides seamlessness, other factors are also important, time availability for instance is one of the reason why adherence to REs can go down. Also forgetting and routine issues are often a reason for bad adherence [41]. Therefore, the tool should be usable within an efficient timeframe and easily fit within a routine. Furthermore, the tool should provide reminders to encourage users to use to tool.

The next requirement for the tool should be that it engages the user. To do this, research [3], [37], [42] has shown that attributes and factor should be considered and included in the design. These attributes are as follows: The tool should be aesthetically pleasing, the tool should include feedback for the user, keep the user accountable through goal-setting process, the tool should invoke perceived control and finally the tool should include novelty during the usage process. Research shows that these attributes are important during the full process of engagement, which includes the first interaction and the re-engagement with the object or tool [3], [37].

The first scoring will be done through the requirements that influence the chosen RE that will be used. This scoring is done because to go to the ideation phase the list of possible REs has to be narrowed down. A top three will be chosen to continue with. Therefore, the corresponding requirements will be rephrased to target REs. The other mentioned requirements will be used in Chapter 3. Ideation where concepts will be scored with the full requirements list. The following requirements will be used in the scoring of REs:

- ◊ **RE should target commonly occurring RRIs**, because of the reason mentioned in the previous paragraph.
- ◊ **RE should mimic ADL movements.** This is a requirement because this is a part of the seamlessness that needs to be achieved. If the RE mimics the movements of an ADL, the exercises are done in a "familiar environment" for the user.
- ◊ **RE should be adaptable into a routine.** This requirement plays into the seamlessness factor and the suggestion that routines are important for adherence.
- ◊ **RE should be time efficient**. This requirement will score the RE on how much time it takes to fully execute a set of said RE.
- ◊ **RE should be executable with daily (available) equipment**. This is a requirement because one should be able to execute the RE through the execution of an ADL.

- ◊ **RE should be low impact (easy of use & simple).** This requirement states the importance of non-complexity when it comes to the seamlessness of the RE.
- ◊ **RE should be effective within sets of 10 or more.** Finally, this requirement is based on the average of the most common RRIs and their effectiveness.

Table 5: *RE Weighted Scoring Table, based on requirements*

Requirements	Weight	Exercise Evaluation								
		Heel Raises	Squats	Calf Stretch	Lunges	Leg Raises	Bridging	Lay down stretch	Knee-to-chest stretch	Quad stretch
RE targets commonly occuring RRI	3.5	5	5	5	3	2	3	3	2	1
RE mimics ADL movements	3	2	4	2	1	3	1	3	1	2
RE should be adaptable into a routine	3.5	2	4	3	2	4	1	3	1	3
RE should be time efficient	2.5	4	3.5	2	3	4	1	2	2	2
RE should be executable with daily equipment	2.5	5	5	4	4	5	3	2	2	4
RE should be low impact (Ease of use & Simple)	2.5	3	4	4	3	5	1	3	2	3
RE should be effective in sets of 10 or more	3	5	5	2	5	5	2	2	2	2

Total (out of 35)	26	27	22	21	28	12	18	12	17
Weighted Score	21	27	12	18	24	9	15	9	12
Rank	3	1	5	4	2	7	5	7	6

What *Table 5* shows is the total points achieved per exercise, the weighted score in the row underneath, which is calculated based on the weights attached to the requirements, which are based on the conclusions for the background research so far. Finally, a rank is given to each exercise based on their weighted scores. The results from *Table 5* show that there are 3 exercises which clearly rank higher than the other REs. These exercises are, squats, leg raises and heel raises.

2.1.5 Conclusion and Discussion

This literature review's primary aim was to create an overview of common RRIs and the corresponding REs. Furthermore, the objective was to get an understanding of the aspects that influence adherence to REs and engagements to a future rehabilitation tool. The literature review brought to light that besides certain aspects like anatomic malalignments that influence the risks of particular injuries, throughout research there is an agreement on the most commonly occurring

RRIs. These injuries include knee-related injuries like Patellar Tendinopathy, Patellofemoral Pain Syndrome and Iliotibial Band Friction Syndrome. Furthermore, injuries to the lower back, feet (such as Plantar Fasciitis) and legs were reported to be the most common. Regarding the corresponding REs, it was found that there were multiple REs for the different RRIs. However, a multitude of those REs are versatile and could be applied to multiple RRIs. Furthermore, different types of exercises were found, both with benefits and disadvantages when it comes to pain experience and effectiveness. The REs, that Chapter 3. “Ideation” will focus on, was chosen based on the outcomes of this literature review, including the requirements. Squats, leg raises and heel raises were chosen as the REs, because of their multi-applicability shown in the weighted scored they received during the scorings process in *Table 5*.

Furthermore, the literature review brought up the different factors and aspects that influence engagement/adherence. Research [3], [43] told that there are personal and situational factors that influence the athletes ability to recover and rehabilitate. These include stress, pain tolerance, communication and support options. Finally, research [37] showed that there are attributes that influence engagement to technology, which can be used in a suggested model that sketches the cycle a user goes through when engaging with technology. Attributes such as aesthetics, novelty and interest came through as important aspects.

A limitation of the research is the broad variety of common RRIs and their corresponding REs. The difficulty here is creating an overview of all suitable injuries and REs within the scope of this review. Moreover, not all possible REs were mentioned in the review due to the lack of supporting scientific peer-reviewed sources. Only a select number of sources were found that could provide suggested theories and REs. This lack of peer-reviewed sources also makes it difficult to create a “complete” overview, which is the goal. However, non-academic sources have only been used in a few situations as supporting material. This could make them interesting to look at to create a complete overview.

Consequently, an interesting future research direction is the adherence to specific rehabilitation exercises that are integrated in activities of daily living and the specific aspects that influence said adherence. Therefore, finding out what makes recovering athletes adhere to integrated REs tools might give insight into specific REs that are fit for further ideation in creating an integrated RE for RRIs in ADL.

2.2 STATE-OF-THE-ART

This chapter contains the state-of-the-art surrounding the rehabilitation field, which focusus on different types of tools that are used to help aid or guide the user in their rehabilitation process. Tools like applications, wearables, tangibles, serious games and VR are discussed.

2.2.1 Applications

Applications are a well-known and common version of a rehabilitation tool. Tools like Brace [1] introduce users to exercise plans, reminders, and communities with athletes going through a recovery journey themselves. The applications make use of the users own ability to provide the appropriate data on their injury, their habits and measurements to provide them with the appropriate REs and long-term recovery plans.

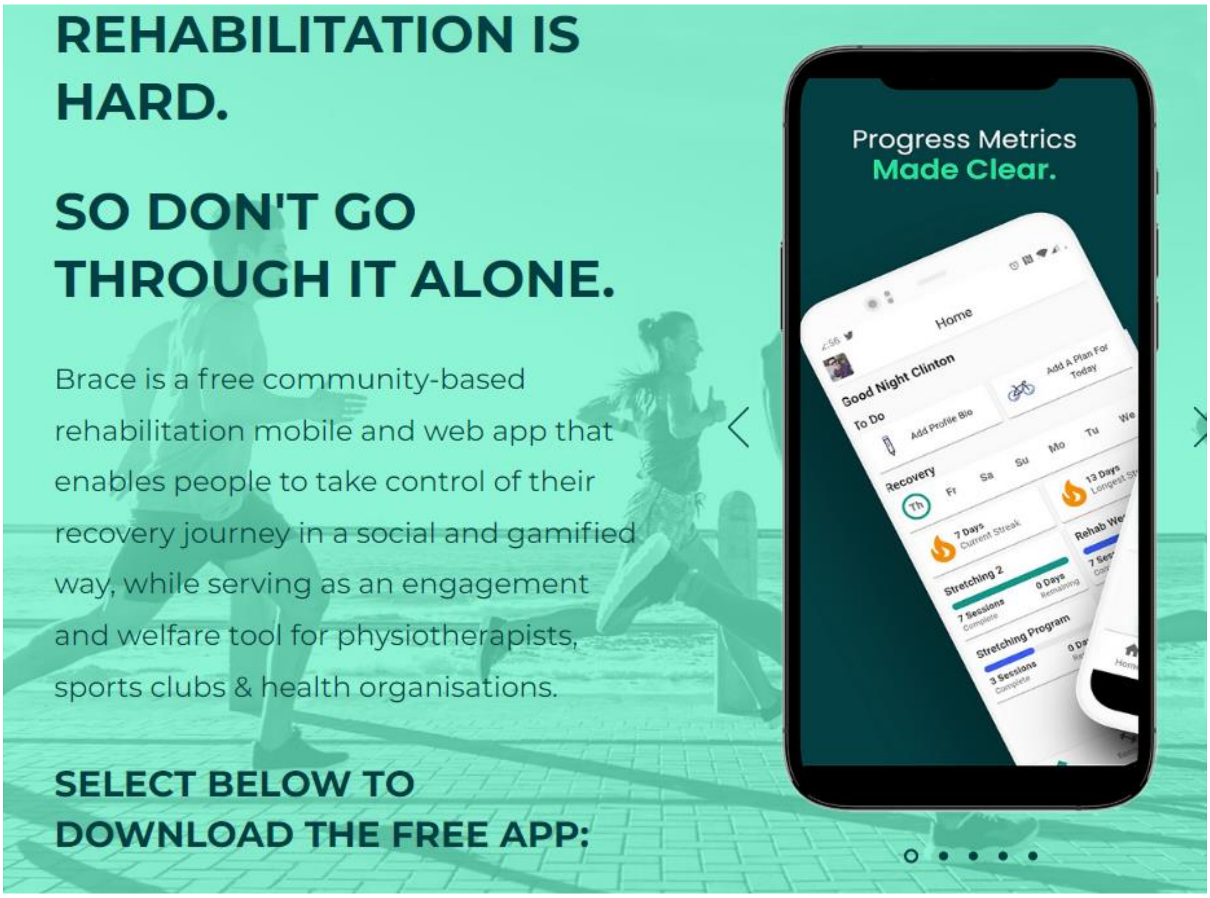


Figure 4: *Brace* [1]*, a rehabilitation application that helps users during their rehabilitation phase. Using reminders, a community and an engaging interface to remind and motivate users to continue to adhere to the REs.*

The sportsrehab.app [44] is another rehabilitation application. The premise of the application is the same as the Brace application. A rehabilitation plan for the specific injury of the user is provided including 4 different phases of rehabilitation. In this application however, physiotherapists can be seen throughout the app's rehabilitation process, as a guide for the user.

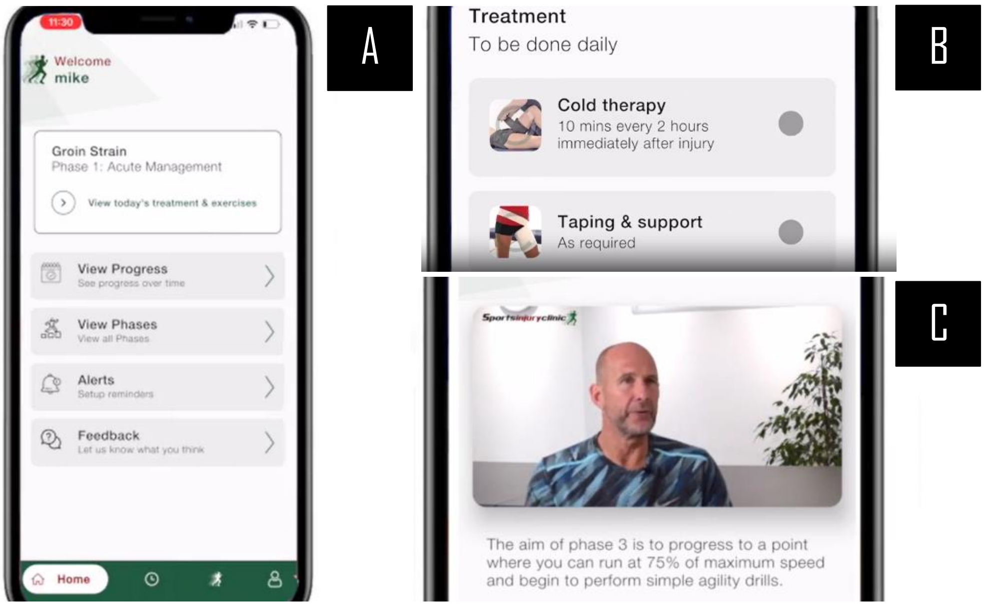


Figure 5: *The sportsrehab.app* [44] *is another rehabilitation application. When using the app, a recovery plan is made specifically for the user (A) and corresponding treatments are suggested (B). Through the process of using the application the user will be guided by physiotherapists along their recovery journey (C)*

2.2.2 Wearables

Besides rehabilitation applications, wearables serve as another supporting technology in rehabilitation processes [12], empowering users to access data and metrics about their own body. For example, the TracPatch [45] is a wearable device that enables users and healthcare providers to monitor the post-surgical implications. Healthcare providers can therefore, through this wearable technology, engage with the users during their need for care, and helps users feel motivated to reach their rehabilitation goals. They achieve this by combining the wearable with an application.

Figure 6: *TracPatch* [45] *wearable device. A sensor which is put on the users body, enables the user and the healthcare provider to stay connected. It monitors data in real time, making changes to a rehabilitation plan possible.*

Another wearable technology that aims to support in the rehabilitation process is called GaitUp [46], which is a sensor that measures the walking or running motions of the body, also known as gait [15]. The services that GaitUp provides are the wearable sensors and software for motion analysis. Through this wearable sensor, the user is able to understand how they move and what they need to improve to recover and prevent further or future injuries.

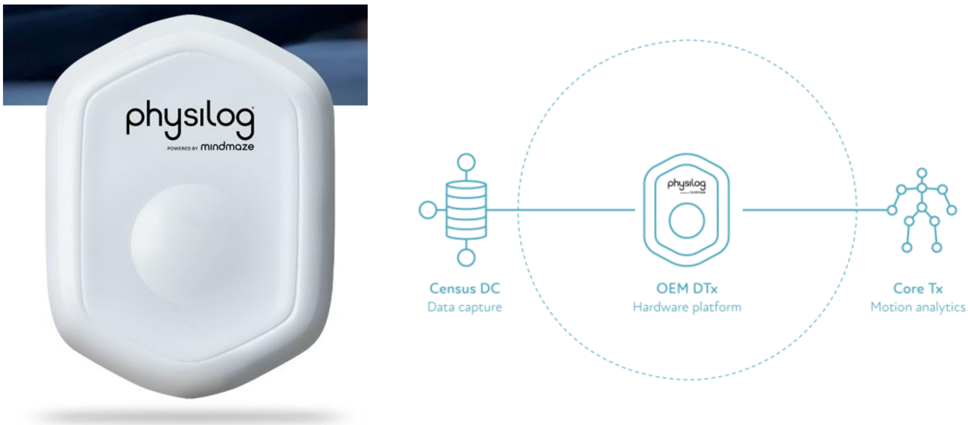


Figure 7: *The GaitUp* [46], which is a wearable technology that supports the user in their rehabilitation process. It is a sensor that measures the “gait” or running/walking motions of the user. This makes the user able to understand how they are walking and what they need to adjust.

2.2.3 Tangible & Serious Game

Furthermore, tangibles, which are physical objects, are used together with other game elements to mimic or integrate a rehabilitation exercise. The Ergotact [47] for example, is a prototype with a tangible cylindrical object with its shape mimicking a glass or cup. The object can be interacted with to play the game, by either squeezing, rotating or sliding the object. These movements were chosen to help people who suffered a stroke to keep practicing their hand and wrist mobility. The game is displayed onto a tablet.

Figure 8: *The Ergotact* [47]. *This is a prototype tangiblee that uses the shape of a glass or cup, which users have to interact with in order to play the game. By either, squeezing, rotating or sliding the object the game can be won. The game was made for people that suffered a stroke, to help them keep practizing their wrist mobility. Here you can see the tangible standing on the tablet on which the game is displayed.*

2.2.4 AR/VR

Finally, VR and AR environments offer a unique space for rehabilitation, because tasks or exercises can be integrated into a simulated environment. An example of this concept is the Virtual Reality Rehab Trainer [48] made in collaboration with ReflexArc. This software incorporates game elements into rehabilitation exercises that the physiotherapists see fit, which are executable in the VR environment.

Figure 9: *The Virtual Reality Rehab Trainer* [48]*. A proof of concept software that was tested with physiotherapists at the Royal London hospital. The VR software integrates rehabilitation exercises into the VR environment and includes gamefication elements to motivate users to succeed and complete their exercises.*

EvolveRehab [49] is another example of using VR that combines gamification with therapy to create an engaging and fun experience for the users that need physical therapy. The difficulty of the interactive games that incorporate REs can be scaled to each users needs and skill level. Furthermore, the physiotherapists that work with the users can gather performance data from the game, which in turn could help the overall recovery process.

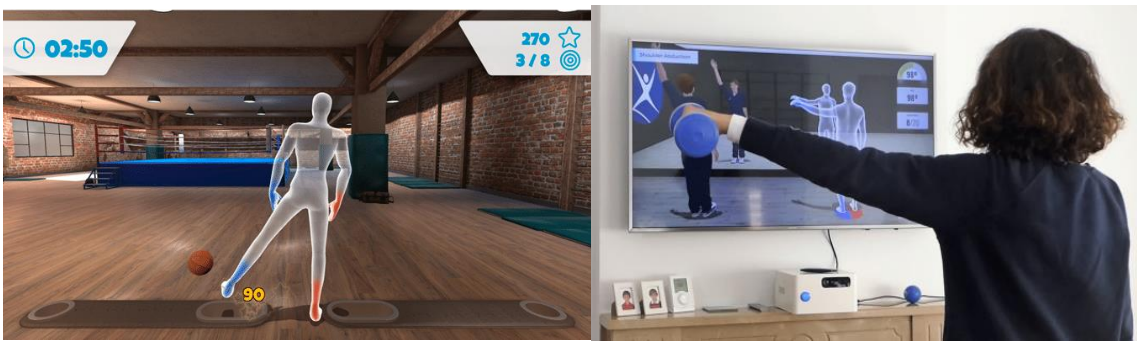


Figure 10: *EvolveRehab* [49]*. A VR concept that combines the fun experience of playing a game together with physical therapy. Difficulties can be adapted to the users capability and skills, dynamically even as data is being gathered while the user is using the device.*

2.3 Conclusion

In conclusion, chapter 2 reviewed literature and the state-of-the-art to research the most commonly occurring RRIs, existing REs and methods to recover from RRIs and RE adherence aspects. The goal of this review was to create a full overview of the most commonly occuring RRIs and the corresponding REs. Furthermore, getting an understanding of the aspects that influence adherence to REs and engagements to a future rehabilitation tool was needed.

The review showed that there are various RRIs and corresponding REs that can occur. However, this review showed that even though there are a lot of different REs that are sufficient in helping recovery, only a few REs are significantly sufficient to integrate in an interactive ADL rehabilitation tool. These REs show potential in being incorporated into a rehabilitation tool, because they passed through requirements that were based on literature regarding both RE adherence and engagement and seamlessness. That's why they show potential for integration in an interactive ADL rehabilitation tool.

Furthermore, the state-of-the-art review shows various existing methods for RRI rehabilitation, that show common adherence traits throughout. Providing feedback and educational data back to the user seemed to be a common aspect, which background research supported. Moreover, the emphasis on routine cannot be understated, which shows the importance of the seamlessness that should be integrated into the potential rehabilitation tool. Since these aspects may work in theory and in previously mentioned state-of-the-art, its worth considering their integration into an interactive ADL rehabilitation tool.

Generally, the background research showed the various aspects that are a priority in designing a rehabilitation tool. However, while the state-of-the-art methods seem to be effective and worth exploring, alternative approaches in designing a tool for rehabilitating by integrating an RE into an ADL seem to show a lot of potential in improving rehabilitation adherence and therefore recovering from an RRI.

3 IDEATION

This chapter describes the ideation phase of the project. First the methods used in this chapter are explained. To develop a fitting and functional prototype, the first step in this process is the problem which this project is trying to solve. The second step is to set up the requirements that the concepts have to adhere to and will be scored on later in the process. The third step of the process is the ideation process itself whereafter the concepts will be compared with the requirements and afterwards a top three concepts will be elaborated upon.

3.1 METHODOLOGY

This chapter follows the first phase of the Creative Technology design process [50], where narrowing down the problem statement and specifying the needs of the users and goals of the tool will help to create the initial concepts during the ideation process. The concepts will be created by combing the efforts of brainstorming sessions, while keeping in mind the important aspects of the background research that were found. After the brainstorming sessions concepts wil be created which will be compared with the requirements set, which will result in a top three of concepts.

3.2 DEFINING THE PROBLEM

A detailed description of the problem statement will help to grasp the full scope of the project. When designing a rehabilitation tool it should be clear what elements need to be taken into account. Using the gathered information from the chapter two background research, the following aspects need to be taken into account.

Firstly, the biggest problem is inciting motivation or adherence to the selected RE. The methods that are already out there Background research showed that there are multiple ways to achieve this. The following methods are spoken for in chapter 2.1.4: "making the tool aesthetically pleasing, the tool should include feedback for the user, keep the user accountable through the goal-setting process, the tool should invoke perceived control and finally the tool should include novelty during the usage process. Research shows that these attributes are important during the full process of engagement, which includes the first interaction and the re-engagement with the object or tool [3], [37]." Other than the previously mentioned ways to increase adherence, seamlessness is another method to achieve this. Seamlessness can be achieved by integrating the RE into an ADL, which in turn integrates it into the routine of the user. Furthermore, keeping the complexity low will increase the seamlessness of the tool [39], [40], [41]. However, the previously mentioned ways to increase adherence have their downsides. When increasing the seamlessness of the tool, and thus keeping the complexity of the tool low and incorporating it into the routine of the user, the act of performing the RE might become boring [7].

Furthermore, another problem why athletes or amateurs do not recover is because they do not perform their REs at all, this could be due to busy schedules competing or simply not having the time [5], [6], [8]. So the tool must be integrated in such a way that the users can perform the RE without spending a significant amount of time on a special rehabilitation plan, but rather perform their ADL and simultaneously perform the needed REs.

3.3 PRELIMINARY REQUIREMENTS

To conduct thorough brainstorming sessions, preliminary requirements are created, which have to be met by the concept. These requirements are based on the previously gathered knowledge through background research. Chapter five will refine and define the final requirements using both background research and feedback.

The first concepts of the ideation phase need to conform to the following requirements wich are based upon the background research and include adapted variations of the RE requirements set in chapter two:

Table 6: *Preliminary concept requirements*

The tool needs to integrate one of the three chosen RE
The tool must encourage seamless integration of the RE into an ADL • The tool must invoke mimicking of ADL movements • The tool must be adaptable into a routine • The tool must use daily equipment • The tool must be low-impact (Easy to use or self-explanatory)
The tool must encourage atleast sets of 10 of the designated RE
The tool should be time efficient in use
The tool should be aesthetically pleasing
The tool should provide feedback to the user
The tool should invoke perceived control
The tool could include novelty during the usage
The tool could include a goal-setting process

3.4 Ideation Process

3.4.1 Brainstorming

During the start of the brainstorming phase, a mindmap was created to get an overview of all the ADL that would correspond with the three chosen REs, being squats, heel raises and leg raises.

Figure 10 shows the three different REs that link to the associated ADL movements. For squatting,

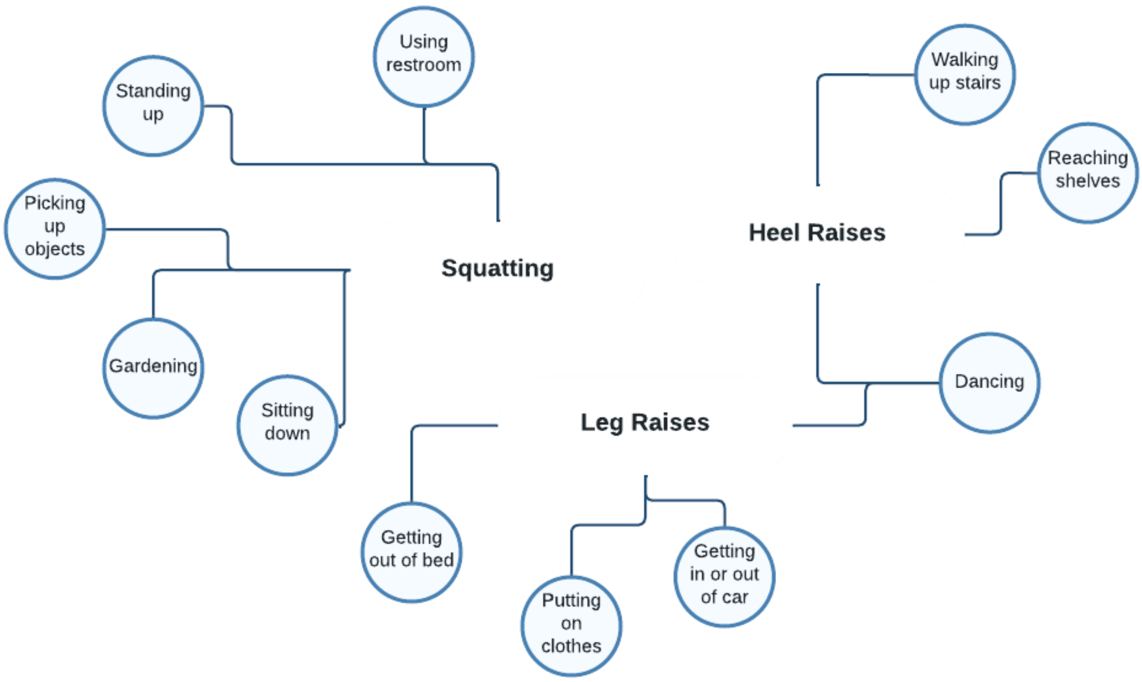


Figure 11: *A mindmap of the associated ADL with the three chosen REs*

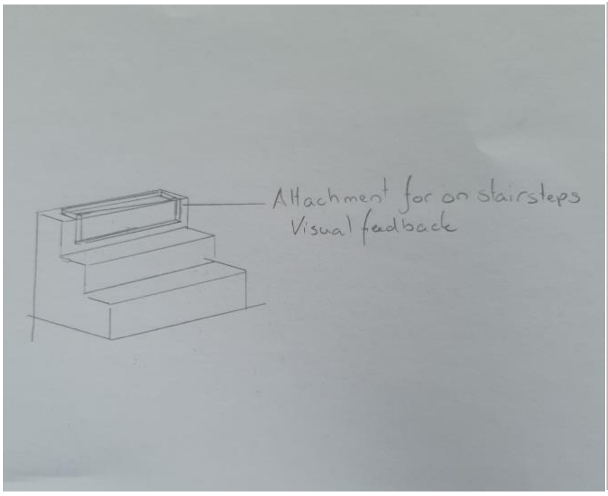
sitting down and standing up were the obvious options, which overlap with using the restroom. Furthermore, Picking up objects and gardening were found to mimic the movements of a squat. Regarding heel raises, ADL movements that mimic the RE were more limiting, as walking up stairs and standing on your toes to reach some shelves were the logical ones. Dancing could be an activity that could be considered an ADL, however it is a weaker suggestions as not everyone practices this activity. Finally, leg raises can be found in getting out of bed and putting on clothes. Also dancing is linked to this RE, but as previously mentioned it is a weaker suggestion. After the ADL movements of the three REs were scoped out as in *Figure 10*, brainstorming of concepts could begin. This was done by using the Heuristics Ideation Technique [51], creating a grid where the REs were matched with their associated ADL movements. Cells were grayed out when the ADL and RE did not correspond.

3.4.2 First Iteration

Table 7: *heuristics Ideation Technique Grid*

	Squats	Heel raise	Leg raise
Stand up	A voice assistant speaks up and motivates user when standing up to complete a set of squats		
Sit down	Squatting chair, with visual guide lights for rhythm and starting cue		
Using restroom	A smart mirror that tracks squats and provides data, which motivates users to engage in a set of squats as part of their restroom routine		
Gardening	Smart watering planting pot, that starts watering when a set of squats is completed		
Pick up objects	A squatting game that provides realtime feedback		
Walking up stairs		Other type of stair steps that provide different heights to encourage heel raises	
Reaching shelves		A touch target in a cabinet that counts the amount of touches	
Dancing		A smart dancing mirror that provides feedback on movements	Shoes that track the movements of the dancer and give visual feedback
Getting in or out of bed			A "just dance" mirrored image that is projected and needs to be mimicked by the user
Putting on clothes			An interactive closet light
Getting in or out of a car			-

The ideas stated in *Table 7* were evaluated, based on the previously created preliminary requirements. Before the evaluation of the ideas were done, three ideas were discarded. One idea was discarded based on the fact that the environment of the ADL provided no safe and realistic ideas during the brainstorm. This concerns the “getting in or out of a car” ADL. Furthermore, both the dancing ideas were discarded based on the fact that not every body perform any form of dancing during their day. An added column to the evaluation was added to indicate if the idea felt especially promising. This part of ideation was done as a first iteration, which concluded in two ideas that felt promising. However, including the received feedback during the midway presentation and supervisors, these first ideas lacked the essence of seamlessness. A reason for this was the focus on “gamification” in the first iteration of ideas, which is not necessarily a second-rate aspect of a design, but could distract from the seamlessness of the tool. Therefore the second iteration of ideas was done with this in mind.



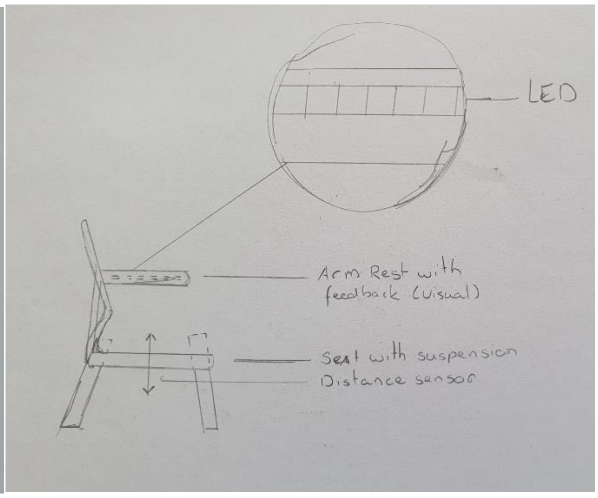


Figure 12: *First iteration ideas, a start step attachement and a squat chair with visial feedback*

3.4.3 Second Iteration

The second iteration and brainstorming was done using the tool Miro as this brought a better overview of the brainstorming that was already done.

Figure 13: *Heuristic ideation sheet with different ADL on the left axis and REs on the top axis*

When comparing the resulting ideas to the requirements set in chapter 3.3, again two ideas showed promise and warranted the need for fleshing out the idea. The ideas are an active chair that encourages heel raises by playing on the intrinsic motivation of users to “rock back and forth” in their chair. The second idea uses the daily activity of walking up the stairs to create a heel raise exercise, by altering the stair railing into an active activity.

The ideation phase naturally shifted to the next phase after putting these ideas in front of the supervisor. The relevation from the discussion that followed highlighted the missing piece of the proposed ideas thus far. While the essence of this research is designing a tool which integrates a running RE into ADL, brainstorming suggested that acquiring seamlessness of that level could be very difficult. Furthermore, an important aspect was that everybody would have access to the tool, whereas there could be users that do no have access to a rocking chair or stairs (due to living in a single storey building). So there is a need to transform this everyday object into a tool. Therefore, the final brainstorm session took into consideration the "goal" of the design, which is motivating users, while encompassing as many different users, to perform the necessary REs. To get to that point the idea of the rocking chair was modified to be accessible to everybody.

3.4.4 Third Iteration

As previously mentioned, the third iteration brainstorm idea is a modification of the idea describing a rocking chair which encourages users to do heel raises. The ideation process for the new idea was done by creating a scenario in which the tool will be used, whereafter a "black box" was introduced as a placeholder for the eventual tool. Using the method, design choices and requirements could be added based upon the needs of the scenario. The final chosen idea will be a "step" that can be put under the users feet whenever they sit on a chair, which will encourage them to perform heel raises by subtly reminding them and providing encouraging feedback to keep them motivated. The sketch can be seen in *Figure 14*.

3.4.5 Scenario

3.4.5.1 Background

You are an amature or professional athlete/runner, who has recently sustained an injury to your lower leg. Following the physiotherapists advice, you need to include the heel raise exercise into your daily routine. The exercise needs to be done consistently to help your recovery. However, due to lack of motivation, time scheduling issues or a lack of general engagement, sticking to the exercise routine has been challenging.

3.4.5.2 Setting

The situation where the tool will be used is when people are sitting on a chair. Different areas where this could be is at home at their desk, at work at their desk, sitting at a (dinner)table.

You are sitting in a chair at your desk. Your normal workspace accommodates work productivity, however now it also needs to accommodate your rehabilitation needs.

To help you adhere to the RE, you have gotten/bought the "Black box" into your routine. This "Black box" makes it easy to integrate the RE into your daily life, without taking up time from your normal workflow.

Using the aforementioned scenario, the black box could be filled in, furthermore taking into account the preliminary requirements. Figure… shows the tool within the scenario. The way the tool works is it can be put under your feet whenever sitting in a chair, when it is not working, it provides a surface to put your feet on to prevent pressure on the knees. When the user uses the tool, they need to put their feet on the marked areas on the tool. A vibration that will be felt under the feet, will indicate that the user needs to start performing the RE. To start the user will have to slowly lift their heels of the platform, making the chair tilt backwards. This ensures that there will be sufficient pressure to perform effective heel raises. Pressure and distance sensors will be able to sense if the RE is being performed correctly. If a sufficient set of heel raises has been performed, the tool will indicate this by lighting up with a green light. The user can put their feet down again. The user does not have to stop performing any other task they were doing while using the tool.

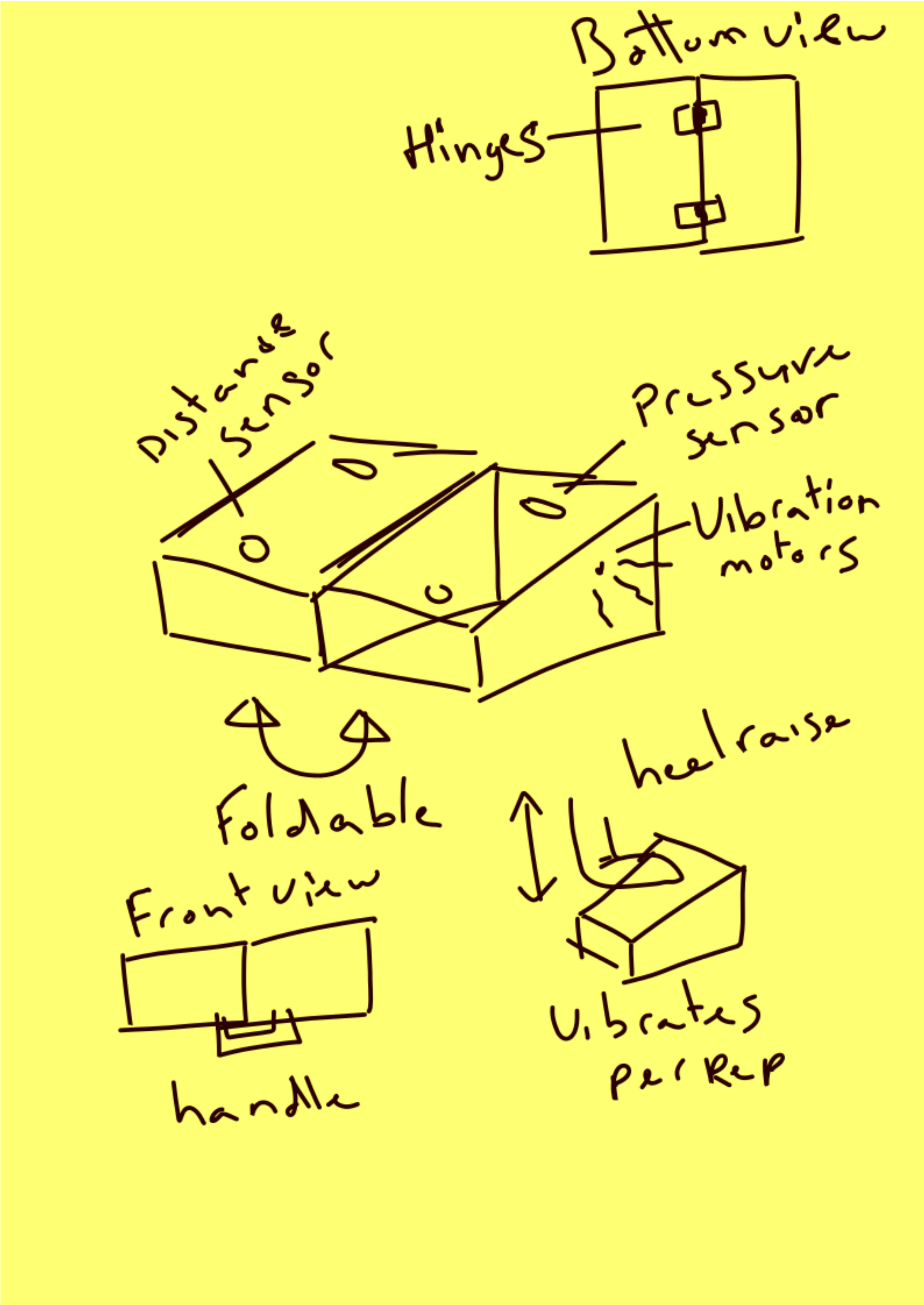


Figure 14: *Rudimentary sketch of the final idea with a front and top view, showing functionality*

3.4.6 Preliminary Requirements Check

Taking the third iteration concept, a check was done to determine its potential and if it was worth it to continue expanding the idea by choosing it as a final concept. The check can be seen in *Table 8*.

There were liberties taken with No. 2 and 3 when deciding whether they met the concept met the requirements. This was done because of the lack of measurability in the phrasing of the requirements.

Table 8: Preliminary Requirements Check Table, where X = meets requirement and - = does not meet requirement or O if this requiremnt could not be determined.

No.	Preliminary Requirement	Meets Requirements
1	The tool needs to integrate one of the three chosen RE	X
2	The tool must encourage seamless integration of the RE into an ADL • The tool must invoke mimicking of ADL movements • The tool must be adaptable into a routine • The tool must use daily equipment • The tool must be low-impact (Easy to use or self-explanatory)	X
3	The tool must encourage atleast sets of 10 of the designated RE	X
4	The tool should be time efficient in use	X
5	The tool should be aesthetically pleasing	X
6	The tool should provide feedback to the user	X
7	The tool should invoke perceived control	O
8	The tool could include novelty during the usage	-
9	The tool could include a goal-setting process	-

After this check, it was determined that the third iteration idea had enough potential and conformed with essence of the research.

4 Specification

This chapter will expand on the chosen ideation concept which is presented in section 3.4 and take it to the next step of product development. The chapter is split into three sections. Firstly, methods used during this chapter will be highlighted and explained. Furthermore, the chosen concept is specified in this chapter through identifying important elements and requirements.

4.1 Methodology

During the specification, the exact requirements will be set using the preliminary requirements from the ideation and the background research. Because the final concept will be concrete, the preliminary requirements will be sorted, specified and narrowed down. The measurability will also be increased such that during the evaluation, it can be checked if the requirements are fulfilled. Furthermore, the MoSCoW method [52] is used to sort the requirements in importance.

4.2 Requirements

Using the preliminary requirements, feedback received between GP I and GP II, and the background research, the requirements were narrowed down and sorted into “Must”, “Should” and “Could”. This was done to know what requirements need to be prioritised. Furthermore, the requirements have been made as measurable as possible.

Table 9: Requirements list, prioritised using the MoSCoW method

No.	Requirement	Must	Should	Could
1	The tool integrates one of the three chosen RE	X		
2	The tool is adaptable into a routine		X	
3	The tool is low-impact (Easy to use or self-explanatory)		X	
4	The tool incorporates daily equipment/objects in its design	X		
5	The tool encourages atleast sets of 10 of the designated RE		X	
6	The tool is adjustable for different heights		X	
7	The tool is comfortable to use		X	
8	The tool is time efficient in use		X	
9	The tool is aesthetically pleasing		X	
10	The tool provides haptic feedback for starting an exercise	X		
11	The tool provides visual feedback for the performance of the exercise		X	
12	The tool invokes perceived control		X	
13	The tool includes novelty during the usage			X
14	The tool includes a goal-setting process			X
15	The tool is portable (Easy to take with you)		X	
16	The tool makes sure faulty usage of the tool is as impossible as can be		X	
17	The tool can be used in as many scenarios where a chair is available		X	
18	The tool increases adherence/engagement to the rehabilitation exercise	X		
19	The tool will send the feedback to the mobile phone of the user			X

4.3 Defined Specification

The following section includes a defined description of the final tool concept, its design and a visual explanation. The decision on the final concept was made in chapter 3.4.6. However, specification is needed to realise a prototype. Using the description of the concept in the ideation chapter, a more defined description of the prototype can be made.

4.3.1 Design

The tool will have a dynamic arch and a flat top part. The dynamic arch will create a surface which will help fit the feet comfortably on the tool. The top flat part of the tool will give space for the feet when the exercise needs to be performed. The way the tool works is it can be put under your feet whenever sitting in a chair. The user puts their feet on the tool where they can rest throughout their daily activity. There are foot marks on the tool so that the user will know where to place their feet. The tool can be folded so that it becomes easier to carry. This can be seen in figure 15.

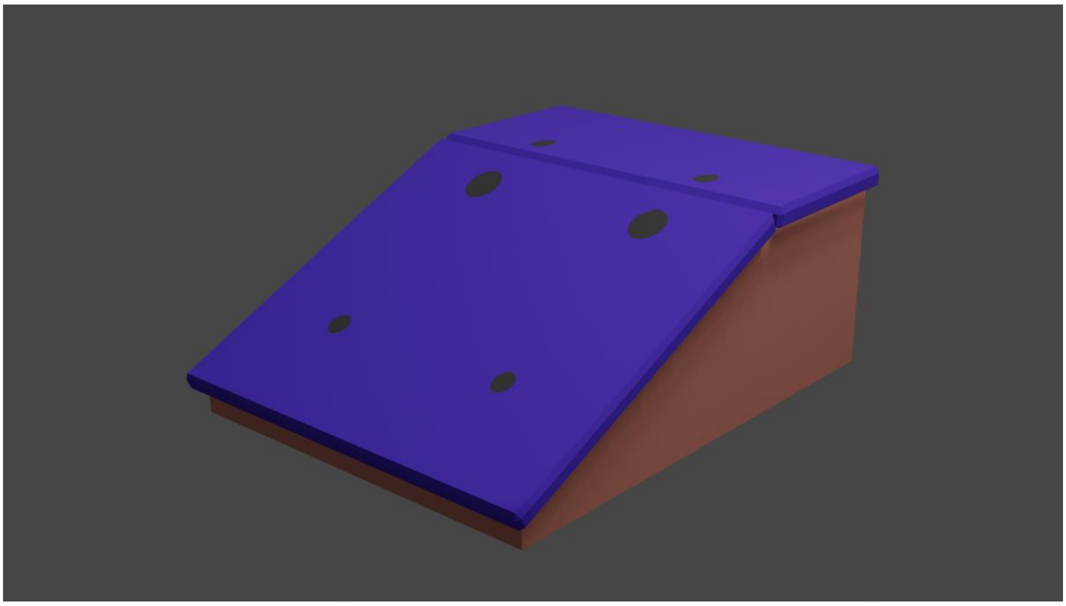


Figure 15: *The tool when it is in use, with subtle marks*

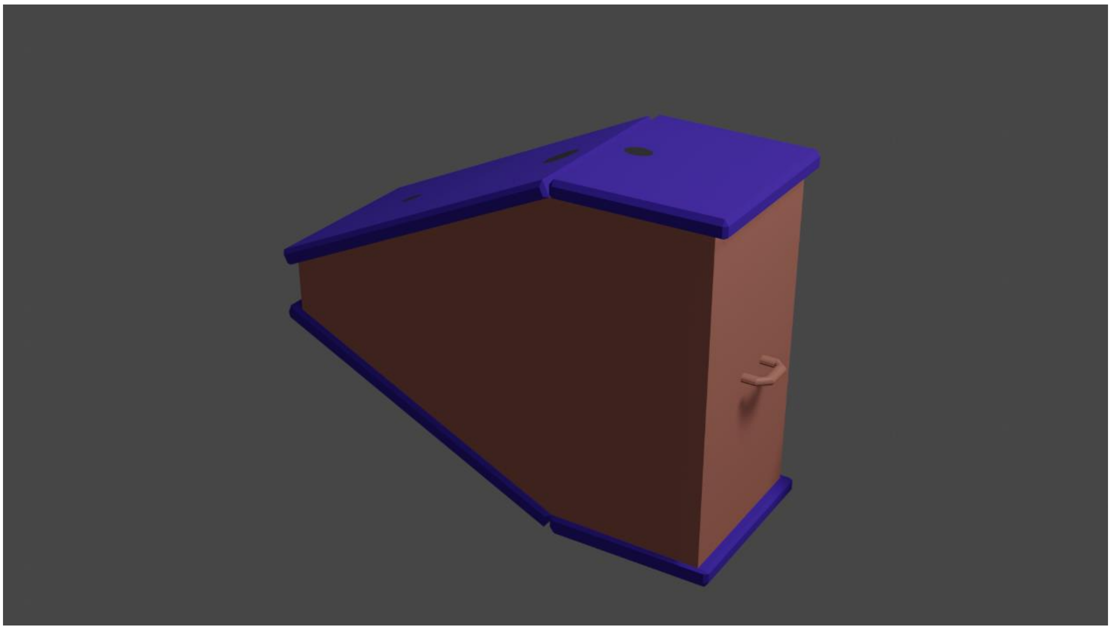


Figure 16: *The tool when it is closed and can be carried with*

4.3.2 Functions

The functions of the tool are split up into functions with priority and functions with Non-Priority.

Priority:

- The foot markings will make sure that the feet are correctly aligned for comfortable seating and correctly performing the RE.

- Haptic feedback in the form of vibrations, which can be felt in the feet, will indicate when the user needs to perform the exercise.
- Pressure and distance sensors, which will be integrated in the foot markings, will measure the “correctness” of the exercise done. They will also make sure that the tool “knows” when it is being used, so if the feet are place on the tool.
- If a sufficient set of heel raises have been performed, the tool will indicate this by lighting up a green light between the feet.
- The time between the sets will be measured so the tool knows when to “encourage” the user again.

Non-Priority:

These functions are added to the concept of the design. However, they are a non priority.

- Feedback in the form of LEDs lighting up, that start flickering when the tool is not in use but it is there as a reminder to start using it again.
- The tool will sent data back to the phone which is received in a very simple format.
- A goal setting process option will be available in the application.

After usage, the user can put their feet down again.

5 REALISATION

This chapter expands on the realization of the prototype, which involved a process of translating the conceptual design into a functional tool. This chapter details the methods and steps taken to achieve the final prototype, highlighting key components and assembly processes.

5.1 METHODOLOGY

To ensure the prototype met the defined requirements, a structured methodology was employed. The process involved several stages: design finalization, material selection, component integration, and assembly. The methodology focused on precision, usability, and portability.

Design Finalization: The first step that was taken to finalize the design, involved the 3D modelling software Blender to refine the initial sketches and Fusion 360 to turn the sketches into files that could be processed by a lasercutter. These sketches were then exported into PDF files so that the lasercutter could process them.

Material Selection: Wood was chosen for the main structure of the tool due to its relative durability and ease of use due to the availability of laser cutting. Furthermore, foam was used to create cushions for the feet. Cloth was used as a soft casing surrounding the foam.

Component Integration: The Arduino board, distance sensors, pressure sensors, and vibration motors were selected based on the initial sketched designs and ideas. The were assembled using jumper wires.

Coding: The coding was done using the Arduino coding platform. Built in examples were used for the corresponding sensors and modules. These principles were then brought and used into the the main code.

Assembly: Laser cutting was utilized to create precise wooden boxes. Components were then integrated into these boxes, ensuring a compact and foldable design.

5.2 Realisation Process

The realization process encompassed several critical steps, from initial design to the final assembly.

5.2.1 Laser Cutting Wooden Boxes

The first step in the realization process was creating the structural base of the prototype using laser cutting. The design files, were uploaded to the laser cutter. The structures, which can be seen in *figure 17*, used for the wooden boxes were generated via the MakerCase website [53]. Afterwards a six millimeter woodensheet was chosen as the base material for the boxes. This was done because the boxes need to be sturdy enough to partly hold the weight of the user when using the tool.

5.2.2 Component Integration

Each wooden box houses a copy of the used components. However, the “left foot” box houses the Arduino:

Box 1: Contains the Arduino board, which needs to be plugged in to supply power to the complete circuit. Furthermore, a distance sensor and two pressure sensors are used. These sensors provide the tool with the “knowledge” to understand when the tool is in use, and how well the exercise is being performed. The pressure sensors are located in the area where the front of the foot sits, while the distance sensor is placed around the heel area. These areas have been chosen as an average, to maintain the the possibility for as many users to be able to use the tool. Lastly, three vibration motors are located around the foot area, which provide haptic feedback to the user. This feedback will be given through several intervals of vibrations.

Box 2: This box contains the same amount of sensors and vibration motors. However, there is no Arduino module and power supply needed for this part.

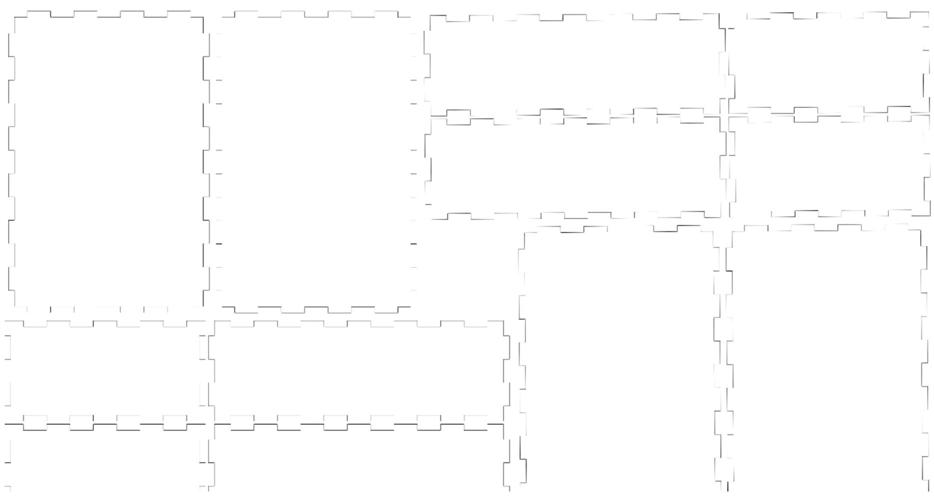


Figure 17: *Lasercut pattern of the boxes used in the prototype*

5.2.3 Assembly and Portability

The assembly of the prototype was planned in such a way as to ensure that all components fit together as seamlessly as possible and that the device could be easily transported.

Structural Assembly: The two wooden boxes were assembled using glue to ensure a sturdy structure. Hinges were added to one side of the boxes to allow them to fold against each other. This folding mechanism was crucial for portability, allowing the user to carry the prototype easily.

Wiring and Connections: All wiring was routed through designated channels, which were drilled in two places within the wooden boxes, to prevent tangling and keep the folding functionality working. The wires were made to the needed lengths to minimize clutter and ensure a nice and clean internal layout. Furthermore, the wires leading from the "power supplying" box were threaded through one hole in the sides of the boxes, which is strategically placed in such a way that when the boxes are folded against each other, minimal wiring can be seen.

5.2.4 Functional Integration

The final step in the realization process was to ensure that all components worked together seamlessly to create a functional prototype.

Programming the Arduino: The Arduino board was programmed to process inputs from the distance and pressure sensors and to control the vibration motors. This involved writing and testing code to ensure accurate sensor readings and timely haptic feedback. Furthermore, the feedback was programmed in such a way that the tool will vibrate within a certain time limit to remind the user that it is time to use the tool. This is done by letting the tool vibrate 4 times.

Table 10: *User Cycle, which explains what happens during every section of the cycle*

Part of the cycle	Feedback
Starting the exercise	2 vibrations will be felt, which indicates the exercise is starting.
During the exercise	After each rep of a heel raise, using the sensors, the rep will be scored on performance, which can be felt in vibrations. The scoring table is set from 1-5. With 1 being the worst and 5 being the best. The scoring is done by measuring the separation from the distance sensor, the pressure of the front foot on the sensors and the time it takes to perform a rep.
After the exercise (Scoring)	After the exercise is done, the set will be graded using the average of the reps, which afterwards will be felt again using the vibrations.
Not using the tool	As mentioned before, when the tool is not in use, but is turned on, the tool will remind the user when it is time to perform the exercise again by vibrating 4 times.

Testing and Calibration: Each sensor was tested individually to ensure accuracy. The distance sensors were calibrated to measure foot movements correctly, while the pressure sensors were adjusted to respond accurately to average levels of pressure. The vibration motors were tested to ensure they provided the correct feedback, and that they could be felt through the cushions.

User Interface Considerations: The prototype was designed with the user in mind. Cushions were placed to where to place feet. These markings include a softer cushion that is place on top of the tool, which loosely indicates the placement of the feet, without limiting any users which have smaller of bigger average feet. The wirings can be be seen in the following schematic.

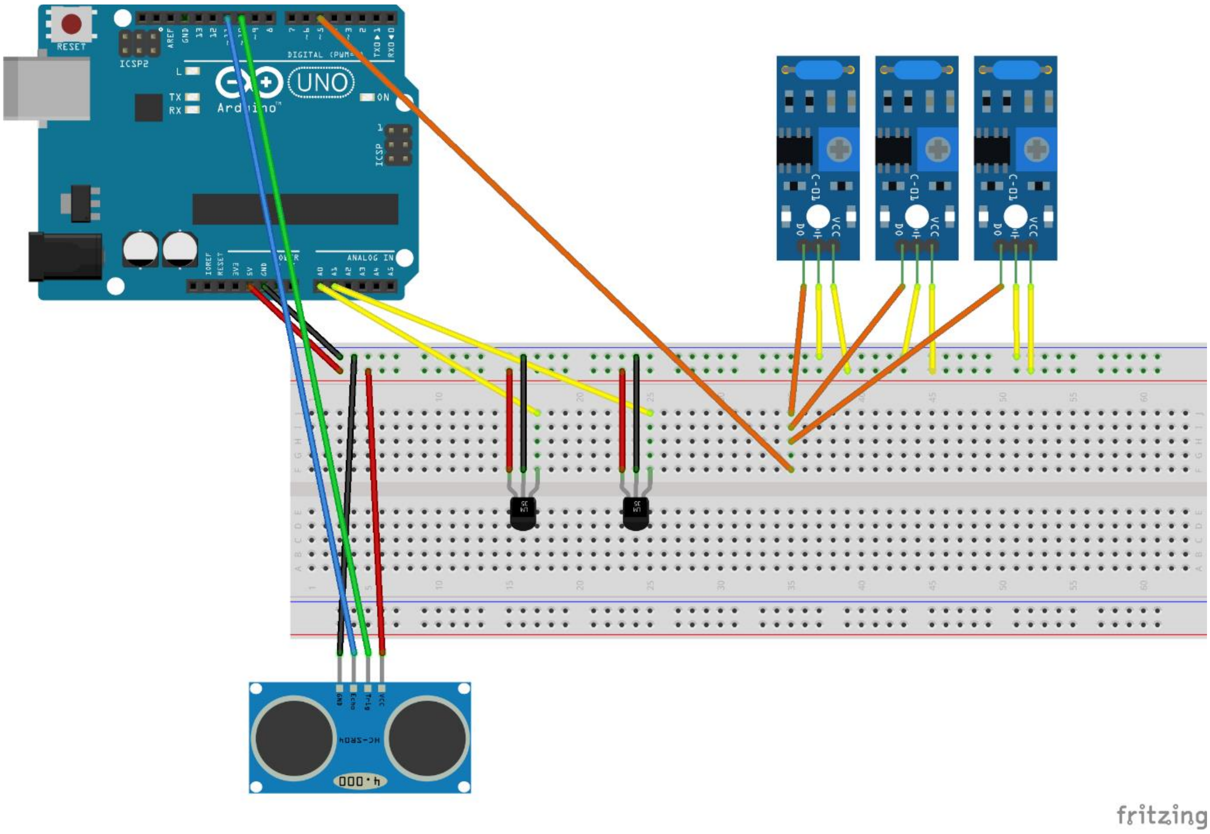


Figure 18: *Schematic of the electronics inside one of the baxes of the prototype. This includes a distance sensor, two pressure sensors and three vibration motors*

6 EVALUATION

This chapter explains the process of planning the evaluations and the results. The evaluation of the prototype, like is mentioned in the Design Process for Creative Technology [50], is essential to determine its functionality and user experience. The evaluations are based on the requirements set in chapter 4, and will therefore conclude if the requirements have been met. Furthermore, the user testing will showcase if the design choices that have been made will indeed provide a complete experience and a working prototype.

The chapter is split in three sections with the first part being the methodology, which explains what methods have been used during this chapter and the processes that are being explained. Secondly, the evaluation plan will be expanded upon, to create a complete overview of everything that went into the usertesting and evaluation of the prototype.

The question that will be answered during the evaluation of the prototype is: “How do users undergo the experience of using the prototype and how well does the prototype lend to its function?" With the answers to this question, the usability and overall experience of the prototype can be determined.

6.1 Evaluation Methodology

User testing: Participants will test the prototype in a room with the same materials and surroundings. Beforehand, a consent form will be provided such that the tester can give their consent, so that the gathered data can be used for this research. Furthermore, an information brief will be provided to explain any unanswered questions surrounding the research and user testing (These can be seen in their respective Appendices).

The main goals of the user testing are getting feedback on the usability and overall experience of the prototype. Usability in this scenario means the understandability of how to use the tool (intuitiveness), and how well a user is able to perform the heel raise. It is important to get feedback on these aspects, because in a scenario where the tool is used it is important that the threshold to use the tool is as low as possible. Also, it is important that a wide variety of users is able to perform the heel raise correctly. Furthermore, the overall experience of the tool is crucial to the seamlessness of the tool, which again is important, because it lowers the threshold of using the tool.

A/B Testing: Participants will be divided into two groups: Group A will receive instructions, while Group B will not. This will help evaluate the intuitiveness of the prototype. If the prototype is intuitive, there should be not significant difference between the two test groups.

Interview: After testing, participants will be asked questions to provide feedback on their experience. This is done to get feedback on what the prototype could need to improve on the overall user experience. Because, while the prototype is made to be seamless, feedback is given only through vibrations. If any additions should be necessary, the feedback from the interview will highlight this need.

6.2 Evaluation Plan

The evaluation plan consists of five steps. First of all, a minimum of 10 people need to test the prototype [54], [55]. This is done so that there are enough participant to test and point out weaknesses and strengths in the design. Because after this minimum of 10 participants, the data saturation of the aspects that are tested could be met. If after 10 participants, it is believed that this saturation is not met, more participants will be added to the study. The participants are split into two groups, with one group not getting instructions on the functionality of the tool while the other group does. This is done to determine if the tool is self-explanatory enough to provide an experience that can be performed by oneself.

Furthermore, during testing, observations will be made to determine if the sensors and feedback mechanisms work as intended and if there are any holes in the experience like a lack of understanding regarding the use of the prototype or issues with setting up the tool, and workings of the prototype. Statistical analysis will be performed to identify significant differences between the groups.

After the user testing is done, feedback will be collected on the usability and overall experience of the prototype. This will be done using a semi-structured interview, where the participant still has the freedom to express any other feedback without being limited to only answering questions. The interview questions can be found in the appendices. Afterwards, analyzing the differences between Group A and Group B to understand the impact of instructions on user performance will be done to determine the understandability of the tool. Moreover, all other feedback will be processed and used to improve the design and prototype.

6.2.1 Usertest phases

The user testing will be done in the following phases:

- Before the testing is performed, the participant will be asked to fill in a consent form so that they will be made clear on their right to withdraw their consent, and what will be done with their collected data.
- The next step is the briefing of the tester. This will be done using an information brief (that can be seen in the appendices). Here any necessary prior information will be made available to the tester, both through the information brief and any other questions they might have.
- The third phase is the testing phase, where the user will perform the test which will take between 10-15 minutes. Group A will receive instructions will be given the necessary information that explains how to handle the prototype, while group B will be asked to start the test without any provided infromation. They will be asked to set up the tool themselves and start using it. Observations will be made by the researcher during this phase. The observations consist of, how the participant handles the “setting up” phase and if the participant experiences issues regarding the placement and orientation of the tool. For the usage of the tool, feet placement and exercise execution will be looked at. Participants will be timed on their reps to see how consistent they complete one set of reps. Both groups will receive instructions on the type of exercise, and how one would perform it, regardless of any guiding tools.
- After the test is done, the participant will be asked to participate in a short interview, where they are able to give feedback on the experience and any other feedback they might deem necessary. The questions will consist of questions about the design, usability and their experience.
- The last phase consist of thanking the participant and briefing them on the fact that they have been timed for testing the prototype and informing them that if they might have any lingering questions later on, they are able to reach the researcher via email.

6.3 Results

After all the user tests had been performed, the collected data of all participants was sorted and stored. The data included both the observations made, and the answers to the interview questions. Together, the goal of this data is to give insight into the effectiveness of the prototype and receive feedback that would improve the prototype in further iterations and revisions.

Before the analysis was done the data was sorted to get an overview for clarity. The pool of participants was determined to consist of equal female and male participants. This distinction of biological sex was made to see if significant differences were within the analysed data. Furthermore, 80% of the participants were between the ages of 20-24. Moreover, all participants were asked to participate in an interview after the testing phase.

6.3.1 Observation Analysis

The observational results of all the participants were combined and can partly be seen in *Table 11*, where the participants are divided into their respective age groups and can be seen if they are currently active in sports. This distinction was made to see if participants who are currently not active in sports show significantly different results or would give different feedback regarding the participants who are active in sports. Any other returning observations were noted down.

Table 11: *Distinction of participants based on age and activity in sports*

Count of Participant Age	Active in sports?	Gender F	M	Grand Total
20-24		**80,00%**	**80,00%**	**80,00%**
	No	20,00%	20,00%	20,00%
	Yes	60,00%	60,00%	60,00%
50-54		**20,00%**	**20,00%**	**20,00%**
	No	20,00%	20,00%	20,00%
Grand Total		**100,00%**	**100,00%**	**100,00%**

A quantitative analysis was performed on the average time the participants completed a set of heel raises. This was done to determine if there would be a significant difference between participants who did get instructions on how to perform the heel raise exercise with the tool and participants who did not get any instructions. If there is a significant difference, it could mean that the assumption that participants without getting instructions are unable to utilise the prototype sufficiently, meaning that the prototype does not fulfil its purpose. *Table* 12 shows the recorded times from all participants divided by “if they got instructions”. A two-sample T-test assuming equal variance was done to determine the significance, which can be seen in *Table 13*. The chosen significance level for this t-test is $\alpha = 0.05$. This was done to be strict and increase the plausibility that the conclusion made from the results is correct.

Table 12: *Recorded completion times of participants, sorted by "if they got instruction"*

Count of Participant Completion time	Got instructions? No	Yes	Grand Total
35-36	0,00%	20,00%	10,00%
37-38	40,00%	0,00%	20,00%
39-40	20,00%	20,00%	20,00%
41-42	20,00%	0,00%	10,00%
43-44	0,00%	20,00%	10,00%
45-46	0,00%	20,00%	10,00%
47-49	20,00%	20,00%	20,00%
Grand Total	**100,00%**	**100,00%**	**100,00%**

Table 13: *Two-sample t-Test assuming equal variances*

t-Test: Two-Sample Assuming Equal Variances	Got instructions	Did not get instructions
Mean	42,2	40,8
Variance	29,2	15,7
Observations	5	5

t-Test: Two-Sample Assuming Equal Variances	Got instructions	Did not get instructions
Pooled Variance	22,45	
Hypothesized Mean Difference	0	
df	8	
t Stat	0,467186051	
P(T<=t) one-tail	0,326413695	
t Critical one-tail	1,859548038	
P(T<=t) two-tail	0,65282739	
t Critical two-tail	2,306004135	

What can be gathered from *Table 13*, is that the two-tailed p-value, which is 0,65, is bigger than the significance level:

$$p > 0.05$$

$$0.65 > 0.05$$

Because this is true, it could be assumed that the difference between participants that got instructions and the participants that did not get instructions, is not significant.

6.3.2 Interview Analysis

Continuing the analysis, the interview results were put together and sorted. Any common or outstanding remarks between the interview answers were noted down and put together into *Table 14*. This analysis contains the commonly mentioned feedback from all participants regardless if they received instructions or not. The analysis was done this way, partly because there was no significance found between the performance of the participants that had or had not received instructions.

Table 14: *Common statements made during the interview with the frequency of agreeance*

Participant	Agreeance
I had difficulties setting up the prototype	36%
I found the setting up of the prototype intuitive	55%
The prototype needs more feedback other than vibrations	36%
The tool needs foot-shaped markers to help with feetplacement	82%
I need an extra module to understand my feedback better	45%
After a few tries, I felt more confident in using the tool correctly	64%
After using the tool for some time, I felt the exercise taking effect	73%
The tool should be height adjustable	36%
I found the prototype accurate in giving feedback	82%

	Participant Agreeance
I never felt unsure about my safety using the tool	91%
The cushions felt comfortable and helped with the overall comfort	91%
The prototype lends itself the ability to be portable	82%

6.3.3 Findings

This final section of the evaluation the collection of all findings will be summarised. The resulting interpretations of these findings are general interpretations of both the measures made combined with the relevant research. This section is spilt up into two parts, the first one discussing the findings done during the testing phase. The second part will go over the findings done after analysing the interview results. Both these parts delve into how effective and usable the prototype has been.

6.3.3.1 Testing Phase

First of all, what the analysis of the testing phase showed is the time the participants took to complete one set of heel raises, which cointained 10 reps. Using the t-test to analyse these results, which can be seen in *Table 13*, it was found that so far there was no significant difference found in people that did or did not receive instructions. Furthermore, the observations made of the participants showed a similar overall ability to perform the set of heel raises. However, it cannot be definitevly concluded that this holds truth if the user testing sample size increases. Additionally to these results, observations did point out that a multitude of participants had some form of difficulties setting up the tool. Most participants figured out after some time, with help of the slope of tool and the positioning of the sensors, the right orientation of the tool needed. Conslusions about how intuitive the setting up process is cannot be made solely of observations, therefore this will be touched on in the interview part of this section.

Furthermore, observations of the performance of the exercise itself showed that without proper instructions on how to perform a “normal” heel raise, participants were unable to utilize the tool effectively. Participants had difficulty following the right tempo of moving up and down. However, after a initial correction together with the feedback the tool provides, participants showed that they were using the tool correctly. What this could mean for the prototype itself is that the feedback provided right now does not give enough guidance to follow a specific tempo. Lastly, what was observed surrounding the feet placement of the participants, is that it took some trial in error to find their correct feet placement. An assumption could be made that perhaps clearer foot markings are needed to achieve better foot placement.

6.3.3.2 Interview phase

The semi-structured interview held right after testing provided interesting elements and feedback that could help improve the prototype. The main common statements that were made during the interview will be discussed, however singular standing out statements that could be necessary to mention will be discussed also. The standing out statements that will be mentioned have potential and could be useful to discuss.

As mentioned previously during observations, some participants had difficulties setting up the tool. Interviews show that 36% of the participants themselves felt like they had difficulties setting up the tool. Additional statements regarding this showed that, for some the slope of the tool was not enough to determine the correct orientation of the tool. Suggestions such as arrows and foot markers, which 82% of participants agreed on, would help them with an easier setup process. With these results, it can be assumed that although the prototype has some qualities that lend themselves positively during the setting up process, additions should be made to improve the part of the experience. However, what was not accounted for during the user test is that in the ideal situation, a physiotherapist or other health specialist would give clear instructions and possibly a manual that could help the participants understand the setting up process. However, what participants did mention is that the foldability and portability did add to the intuitiveness of the whole experience.

Regarding the haptic feedback, two common statements were made. While under 40% of participants felt that the haptic feedback alone was not enough for them, 80% of participants did mention that they feedback that they got, was accurate. Furthermore, 45% of participants felt that they needed an extra module, like an application on their device or small screen on their desk, to understand their feedback better. Right now the prototype does not have the ability to track progression. These participants mentioned that they felt that the tool would be more effective to them if they could visibly see their progress. Additionally, a singular statement was made regarding the haptic feedback. This participant did mention that they felt the haptic feedback was enough for them. Moreover, it was mentioned that they thought haptic feedback was the most accessible feedback for all possible future users, including deaf and blind people. Although it can be assumed that the inclusion of better progression tracking could increase the effectiveness of the tool, haptic feedback as the basis of feedback provided makes a strong point as being inclusive and accessible to more possible users.

Furthermore, 64% of participants felt like they improved their effective use and be more confidant in their correct usage of the tool after a few tries. So a possible assumption would be that the tool has a learing curve or that some participants were not able to confidently use the tool. However, the users that did not mention this during the interview were able to use the tool confidently and effectively the first time they tried it. Moreover, 74% of the users felt that after some time of using the tool, they felt the exercise taking effect. However, what was not taken into account during testing was the “free choice” of the user to perform a variant of the heel raise. The main two forms of the heel raise require different amounts of skill and leg strength, with a consequence being that not every participant performed both variants. This could be an explanation for the fact that not all participants felt the exercise after some time. Additionally, the test lasted between 10-15 minutes. This time includes the setting up time, which could also indicate that for some participants, the remaining time using the tool was not effective enough. However, because this thesis does not concern the medical aspect of the exercise no further assumptions should be made regarding this and future research could include this aspect.

Lastly, other common statements about the comfort and usability of the design were expected before performing the user test. It was expected that the height of the prototype could be an issue because the prototype was made with the core functionalities in mind. Therefore, 36% mentioned that the tool should be height adjustable. It can be assumed that this is a point of improvement due to the fact that the length of 36% of the participants were unable to effectively and comfortably use the prototype. Additionally, 91% of the participants mentioned that the prototype was sturdy and that the cushions added comfort to the tool which made it more pleasurable to use. Finally, singular statements with similar core meanings were made regarding the “seamlessness” of the tool. Overall the participants did see the potential in using the tool as a means to lower the threshold for performing the needed RE for future users. They mentioned that the portability and the general ease of use would help them in performing their potential RE.

Some final interesting statements that were made regarding the future iterations and uses of the tool included a charging station that always sits underneath the desk so that when travelling the user is able to take it with them and when they return put it into the charging station. Furthermore, it was mentioned that the tool could also be adapted into a multidisciplinary tool that can be used for more than one exercise, to increase the overall capability of the tool.

7 Discussion & Future Work

This chapter will discuss and interpret the findings of the research. For clarity, the chapter will be split into three parts. First, exploring the significance and implications of the findings in Chapter 6 will be discussed. Furthermore, the quality of the research will be discussed with the limitations of the conducted research being mentioned. Lastly, recommendations will be made regarding future work.

7.1 Interpretation

As discussed in Chapter 6, the design of the tool included issues that came to light in the results of the user test. The first issue that became apparent was the lack of guidance, regardless if the participant received instructions, to set up the tool. This made it so that some participants spent too much time struggling to set up the tool, which they should have spent using the tool. Changes that could make the setup process better were also suggested and received during the interviews, where indication arrows and foot markers were the key suggested additions.

However, what can be taken from the analysis is that the tool, with or without provided instructions, did make the participants able to perform the heel raises the intended way. This suggests that the prototype did meet the main goal of the tool. Further compliance with the set requirements will be shown in *Table 15*.

Table 15: *Requirements table that has checked the cell of which requirement the tool complies with*

No.	Requirement	Yes	No	Undicided
1	The tool integrates one of the three chosen RE	X		
2	The tool is adaptable into a routine	X		
3	The tool is low-impact (Easy to use or self-explanatory)		X	
4	The tool incorporates daily equipment/objects in its design	X		
5	The tool encourages atleast sets of 10 of the designated RE	X		
6	The tool is adjustable for different heights		X	
7	The tool is comfortable to use	X		
8	The tool is time efficient in use	X		
9	The tool is aesthetically pleasing			X
10	The tool provides haptic feedback for starting an exercise	X		

No.	Requirement	Yes	No	Undicided
11	The tool provides visual feedback for the performance of the exercise		X	
12	The tool invokes perceived control	X		
13	The tool includes novelty during the usage			X
14	The tool includes a goal-setting process		X	
15	The tool is portable (Easy to take with you)	X		
16	The tool makes sure faulty usage of the tool is as impossible as can be			
17	The tool can be used in as many scenarios where a chair is available	X		
18	The tool increases adherence/engagement to the rehabilitation exercise	X		
19	The tool will send the feedback to the mobile phone of the user		X	

What *Table 15* shows is that the prototype is compared with the requirements list made in chapter 4. Now one can easily see where improvements lie and what the essence of the prototype already provides to the potential users, after taking the findings in the analysis of chapter 6 into account. For numbers 2, the adaptability of the tool into the routine, all participants mentioned that the portability and lower threshold of the RE that they felt would make it easily adaptable into their daily life. However, after user testing the prototype failed requirement three. There were a significant amount of issues with the intuitiveness and design of the prototype their made the tool too complex to set up. Regardless of the fact that most participants felt that the haptic feedback was enough for them to understand, instructions were still necessary sometimes. Therefore, to improve and meet this requirement previously mentioned alterations to the design are necessary. Furthermore, the tool is not adjustable for different heights, which would make the tool more effective in use for a broader range of users. Moreover, a goal setting process and feedback to a device were not main focus points during the making of the prototype, but testing did show that there are viable additions to the design and could warrant more iterations. Additionally, due to holes in the design, faulty usage was possible as participants did have the ability to set up the tool incorrectly. Lastly, there are three undecided requirements. The first one is the aesthetics of the prototype. As no questions were asked about this, and too few statements were made about this requirement during the interviews no assumptions and conclusions can be made. The same can be said for novelty, as testing was only done for a 10-15 minute period and not done for throughout monthly usage, novelty could not be tested.

7.2 Limitation

Throughout this thesis, certain limitations were encountered that could have or have had an impact on the results of the prototype and the user evaluation. The first limitation encountered was experience. During the development of the prototype, certain design choices were made based on a lack of experience that resulted in later design issues. Better planning and consulting of experts could have helped making better design choices during this process. One of the issues with the design was that the user of the prototype was able to fully put their heel on the distance sensor leaving no space, which introduced problems for the sensor reading faulty distances. This resulted in some inaccuracies during testing. Furthermore, although the budget was not an impactful limitation, the lack of better-quality materials did cause some small issues regarding broken sensors during and after testing.

Regarding the user evaluation, not all testing was done under the same circumstances. With chairs and other environmental aspects not being the same. These could have caused unstable or inconsistent results, which in turn could have been interpreted incorrectly. Furthermore, not all participants had experience with doing REs, which could have been a reason why certain participants had trouble interpreting the prototype and knowing how to perform the heel raise correctly. Additionally, relying on participants to give retrospective feedback after using the prototype could have resulted in inaccurate responses. Furthermore, due to the choice of splitting the participants into two groups, the effective sample size was split in half. Therefore potentially impacting the potential extra, more varied feedback.

Choosing a short testing period, limited the time the participant was able to try and adapt and understand the prototype. A longer testing period, as suggested before, could reveal more insight into the long-term usability and any potential issues.

7.3 Recommendation

The following recommendations aim to provide a path for future work and research. Enhancing future results and exploring more options to get a better understanding of the topic of this thesis.

Firstly, although this thesis and the background research done do provide interesting and worthwhile information and results, more research and testing surrounding the seamless integration of an RE tool is recommended. Future research should focus on longer tests that aim to find out what helps lower the threshold of performing an RE while using such a tool as presented in this thesis.

In addition to this, the suggestions made and gathered from the user test should be implemented and tested again on a larger sample size. This would allow a better and more complete experience to be tested by those participants. Additionally, other approaches to this tool should be considered as testing showed general promise, but another approach to the design or an RE could reveal other useful ways to integrate REs into the routine of potential users.

Lastly, optimizing the current prototype and creating more iterations would provide further research with better testing possibilities and more accurate results regarding the effectiveness of the prototype.

8 Conclusion

This thesis aimed to explore the possibility of integrating an RE into the routine of users with an RRI, helping them increase the adherence and engagement to perform the needed RE which in turn helped to be consistent. The findings of the research and evaluation provided the insight needed to perhaps create a tool that would help increase this adherence and lowering the threshold of performing the RE.

The aim of this research, as mentioned in Chapter 1, was to answer the main research question: "How can injury rehabilitation tools for running injuries be effectively integrated into daily activities to enhance engagement/adherence to rehabilitation exercises?". To answer this main question several sub-questions were devised to help answer the main question. In the following section first the answers to the sub-questions will be briefly reviewed again, as part of these questions have already been concluded in chapter 2.3. However, additions will be made to these conclusions, as the user test and interviews showed additional elements. This is then followed by the answer to the main question.

The literature review showed that there are various RRIs and corresponding REs that can occur. However, this review showed that even though there are a lot of different REs that are sufficient in helping recovery, only a few REs are significantly sufficient to integrate into an interactive ADL rehabilitation tool. During the user test, the chosen RE, being heel raises, showed that the complexity of the RE was not taken into account. The knowledge of how to perform the RE should be made aware of by the tool.

Furthermore, the previously mentioned state-of-the-art review shows various existing methods for RRI rehabilitation, that show common adherence traits throughout. Providing feedback and educational data back to the user seemed to be a common aspect, which background research supported. What the user test made clear is that providing the user with sufficient feedback, through different means is very valuable and should be made a priority.

Moreover, the emphasis on routine cannot be understated, which shows the importance of the seamlessness that should be integrated into the potential rehabilitation tool. Since these aspects may work in theory and in previously mentioned state-of-the-art, its worth considering their integration into an interactive ADL rehabilitation tool. Although the seamlessness was not directly tested, interviewees did point out that design elements that increased seamlessness were not only corrolated to the functionality of the design but also to the full experience. Therefore, aspects like mobility and the setting up process of the tool is also very important, giving enough subtle guidance.

Generally, the background research showed the various aspects that are a priority in designing a rehabilitation tool. Moreover, the user tests and interviews support these theories, with giving users educational feedback that makes them able to see their progress is very important.

Thus, applying the sub-conclusion it can be said that to integrate injury rehabilitation tools for RRI and enhance engagement/adherence, multiple aspects are at play. However, theory and testing show that providing the user with educational feedback and progression tracking is an important aspect that should be heavily considered when designing or creating such a tool. Furthermore, sufficient guidance to enhance and simplify the utilization of the tool increases the seamlessness of the tool. As mentioned in the background research, the lack of complexity (ease-of-use), will increase the seamlessness of the tool. Ultimately, these aspects should be combined and tested to further establish how to effectively integrate REs into the daily lives of users.

APPENDIX A

CONSENT FORM

Consent Form for Rehabilitation Tool Testing

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 [date not yet final], 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.	○	○
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.	○	○
I understand that taking part in the study involves being interviewed after testing a prototype, where written notes will be made of my answers.	○	○
Use of the information in the study		
I understand that the information I provide will be used for a research report about the development of a rehabilitation tool.	○	○
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.	○	○
I agree that my information can be quoted in research outputs.	○	○

Signatures

______________________ ______________________ ________

Name of participant

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

Study contact details for further information:

Erik Schuit, e.m.a.schuit@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

APPENDIX B

INFORMATION BRIEF

Welcome to the footrest rehabilitation prototype testing!

Purpose of the Research

Thank you for participating in the testing of our innovative rehabilitation device. Rehabilitation for running injuries is important which includes being consistent with the rehab exercises. This compact and portable step is designed to assist in heel-raise exercises, whether you're sitting or standing. With this tool, we want to stimulate and help people include rehabilitation more seamlessly into their routine. Your feedback is invaluable to us in refining the prototype and therefore creating a better tool.

What is the footrest rehabilitation prototype?

The device is a small, lightweight device that can be easily carried to your workplace or used at home. It features various sensors to ensure you perform heel raises correctly and provides real-time feedback.

Data Usage

The data gathered during the testing phase will only be used in this research and afterwards will not be made public. The retention period of the gathered data will end when this research is finished, which is estimated to be the 5th of July.

Withdrawal

Participants can at any moment before, during or after the prototype testing withdraw their consent.

How to use the footrest?

1. Setup:

- Place the device under your feet while sitting on a chair.
- Ensure your feet align with the cushions on the platform.

2. Performing Heel Raises:

- Slowly lift your heels off the ground, keeping your forefoot and toes on the platform.
- Follow the cushions for proper foot placement and alignment.

- Vibrations will indicate when you need to perform the exercise, which is done with a 1, 2, 3 countdown.

- One vibration can be felt when a well done rep is performed. One set consists of 10 reps.

- The sensors will provide real-time feedback.

3. Monitoring Progress:

- The device tracks your performance and timing for when you need to do the exercise again.

- Use the feedback to improve your technique.

Participation Instructions

- Duration: Test the device for a minimum of 5 minutes, performing exercises as instructed.

- Feedback: Share your experience, including comfort, ease of use, and any improvements you suggest.

Contact Information

For subsequent feedback, please contact:

Email: e.m.a.schuit@student.utwente.nl

Thank you for your participation and support in developing a better rehabilitation solution. Your feedback is crucial in helping us make this device as effective and user-friendly as possible.

APPENDIX C

INTERVIEW QUESTIONS

Introduction

Thank you for participating in the testing of our rehabilitation prototype. We would like to ask you some questions about your experience to help us improve the design and functionality of the prototype. Your feedback is invaluable to us. This interview will take approximately 10-15 minutes.

Setup and Usability

1. **Setup Experience**
    - Can you describe your experience setting up the prototype? Were there any difficulties?
    - How intuitive did you find the setup process? Was there anything that was unclear?
2. **Usability**
    - How easy was it to understand how to use the prototype without any instructions?
    - If you received instructions, did they help you understand the prototype better? In what ways?
    - Did you feel confident using the prototype after a few trials?

Functional Experience

3. **Exercise Execution**
    - How did it feel to perform the exercises using the prototype?
    - Did you encounter any issues while performing the exercises? If so, what were they?
    - How would you rate the accuracy of the feedback given by the prototype during the exercises?
4. **Feedback Mechanisms**
    - How did the vibrations as feedback feel to you? Were they noticeable and clear?
    - Was the feedback provided at the right moments? If not, when should it have been given?

Safety and Comfort

5. **Safety Perception**
    - Did you feel safe while using the prototype? Why or why not?

- Were there any moments when you felt unsure about the safety of the device?

6. **Comfort**
    - How comfortable was the prototype to use over the testing period?
    - Did the materials used in the prototype affect your comfort in any way?

Design and Improvement

7. **Design Feedback**
    - What are your thoughts on the overall design of the prototype?
    - Are there any specific aspects of the design that you particularly liked or disliked?
8. **Suggested Improvements**
    - What features do you think could be added to improve the prototype?
    - Is there anything that could be changed to enhance your experience with the prototype?

Overall Experience

9. **General Impressions**
    - What were your overall impressions of using the prototype?
    - Do you have any additional comments or feedback that was not covered by the previous questions?

A/B Testing Feedback (if applicable)

10. **Instruction Impact**
    - For those who received instructions: How helpful were the instructions provided?
    - For those who did not receive instructions: How did you navigate figuring out how to use the prototype on your own? Did you feel this impacted your experience?

APPENDIX D

PARTICIPANT INTERVIEW RESULTS

Participant	I had difficulties setting up the prototype	I found the setting up of the prototype intuitive	The prototype needs more feedback other than vibrations	The tool needs foot-shaped markers to help with feetplacement	I need an extra module to understand my feedback better	After a few tries, I felt more confident in using the tool correctly	After using the tool for some time, I felt the exercise taking effect	The tool should be height adjustable	I found the prototype accurate in giving feedback	I never felt unsure about my safety using the tool	The cushions felt comfortable and helped with the overall comfort	The prototype lends itself the ability to be portable
A	Yes	No	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes
B	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
C	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
D	No	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes	No
E	No	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes
F	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes
G	No	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
H	Yes	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
I	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
J	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Agreeance	36%	55%	36%	82%	45%	64%	73%	36%	82%	91%	91%	82%

APPENDIX E

ARDUINO CODE

```
//Include Libraries
#include <VibrationMotor.h>

//Set variables
int pres1;
int pres2;
int grade;
long duration1;
long duration2;
unsigned long startTime;
unsigned long currentTime;
unsigned long elapsedTime;

int distance1 = 200;
int distance2 = 200;
int start = 0;
int counter = 0;
int repCounter = 0;
int rememberTime = 60;
int absentTime = 30;
int presMin = 5;
int reps = 10;

//Set exercise boolean
bool exercise = false;
bool exerciseFinished = false;
bool heelUp = false;
bool heelDown = false;

// defines pins numbers
const int motorPin = 3;
const int trigPin1 = 9;
const int echoPin1 = 10;
const int trigPin2 = 6;
const int echoPin2 = 5;
const int pressurePin1 = A0;
const int pressurePin2 = A1;

// Specify the pin to which the vibration motor is connected
VibrationMotor myVibrationMotor(motorPin);

void setup() {
  //Setting Pins for Input
  pinMode(pressurePin1, INPUT);
  pinMode(pressurePin2, INPUT);
  pinMode(trigPin1, OUTPUT); // Sets the trigPin as an Output
  pinMode(echoPin1, 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
  myVibrationMotor.pulse(2);
  Serial.begin(9600);
}

void loop() {
  // put your main code here, to run repeatedly:
  distance1Check(); //distance1 sensor checking distance1
```

```
  pressureSensor();
  if (exercise == false) {
    exerciseSwitch();
    counter++;
    if (counter >= rememberTime) {
      rememberExercise();
      counter = 0;
    }
  }
  if (exercise == true) {
    exerciseStart();
    unsigned long startTime = millis();
    if (exercise == true && start == 0) {
      exerciseCheck();
      //absentCheck();
    }
  }
  if (exercise == true && exerciseFinished == true) {
    unsigned long currentTime = millis();
    unsigned long elapsedTime = (currentTime - startTime) / 1000;
    exerciseEnd();
    exercise = false;
    exerciseFinished = false;
  }
}

void distance1Check() {
  // Clears the trigPin
  digitalWrite(trigPin1, LOW);
  digitalWrite(trigPin2, LOW);
  delayMicroseconds(2);
  // Sets the trigPin on HIGH state for 10 micro seconds
  digitalWrite(trigPin1, HIGH);
  digitalWrite(trigPin2, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin1, LOW);
  digitalWrite(trigPin2, LOW);
  // Reads the echoPin, returns the sound wave travel time in microseconds
  duration1 = pulseIn(echoPin1, HIGH);
  duration2 = pulseIn(echoPin2, HIGH);
  // Calculating the distance1
  distance1 = duration1 * 0.034 / 2;
  distance2 = duration2 * 0.034 / 2;
  // Prints the distance1 on the Serial Monitor
  Serial.print("distance1 and distance2: ");
  Serial.println(distance1);
  //Serial.println(distance2);
  delay(100);
}

void pressureSensor() {
  pres1 = analogRead(A0);
  pres1 = map(pres1, 0, 1023, 0, 10);
  pres2 = analogRead(A1);
  pres2 = map(pres2, 0, 1023, 0, 10);
  Serial.print("Pressure: ");
  Serial.println(pres1);
  //Serial.println(pres2);
  delay(100);
}
```

```
void exerciseStart() {
  if (start == 1 && exercise == true) {
    // Pulse the motor for 2 times
    myVibrationMotor.pulse(1);
    // Wait for 1 second
    delay(1000);
    myVibrationMotor.pulse(1);
    // Wait for 1 second
    delay(1000);
    myVibrationMotor.pulse(1);
    // Wait for 1 second
    delay(1000);
    start = 0;
  }
}

void exerciseEnd() {
  if (elapsedTime >= 25 && elapsedTime <= 30) {
    grade = 5;
  } else if (elapsedTime >= 31 && elapsedTime <= 35) {
    grade = 4;
  } else if (elapsedTime >= 36 && elapsedTime <= 40) {
    grade = 3;
  } else if (elapsedTime >= 5 && elapsedTime <= 24) {
    grade = 1;
  } else {
    grade = 1;
  }
  delay(4000);
  myVibrationMotor.pulse(grade);
  delay(1000);
}

void rememberExercise() {
  // Pulse the motor for 4 times
  myVibrationMotor.pulse(4);
  // Wait for 1 second
  delay(1000);
}

void exerciseCheck() {
  if ((distance1 >= 6 && distance1 <= 12) || (distance2 >= 6 && distance2
<= 12)) {
    heelUp = true;
  }
  else if (distance1 <= 5 || distance2 <= 5) {
    heelDown = true;
  }
  if (heelUp == true && heelDown == true) {
    repCounter++;
    myVibrationMotor.pulse(1);
    heelUp = false;
    heelDown = false;
  }
  if (repCounter >= reps) {
    exerciseFinished = true;
    repCounter = 0;
  }
  Serial.print("distance1 Counter: ");
  Serial.println(repCounter);
}
```

```
void exerciseSwitch() {
  if (distance1 <= 3) {
    exercise = true;
    start = 1;
  }
}

void absentCheck() {
  currentTime = millis();
  elapsedTime = (currentTime - startTime) / 1000;
  if (elapsedTime >=  absentTime && (distance1 >= 50 || distance2 >= 50)) {
    exercise = false;
  }
}
```

APPENDIX F

PROTOTYPE PICTURES

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