Improving the Meta-Grip: Redesigning for unsupervised use

Master Thesis

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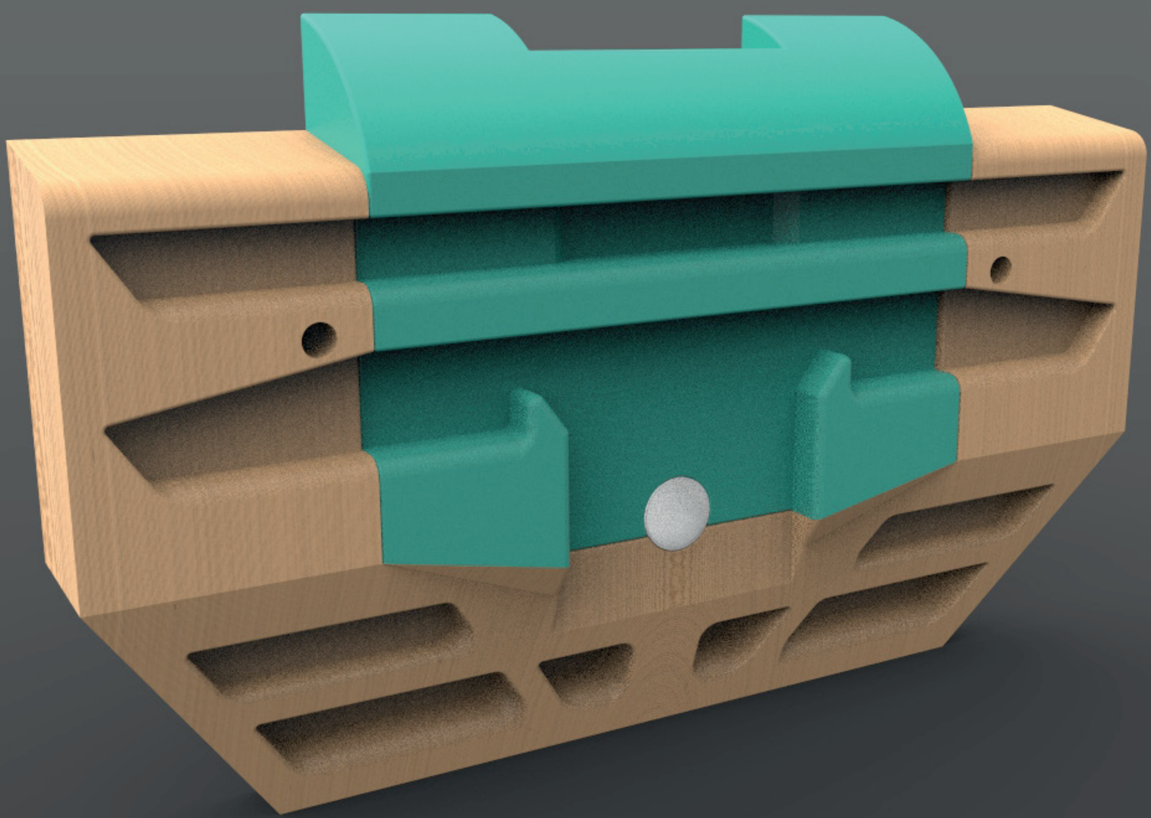
Date: 31.07.2020



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Acknowledgments

After five months of redesigning the Meta-Grip, this graduation project has come to an end. During this graduation project I had to deal with a pandemic; Covid-19. This made me rely more on myself than I would ever want again during a design project. However some people have been helping a lot during my graduation and I would like to thank them personally.

I want to thank the Vrije Universiteit in Amsterdam for the opportunity to redesign the Meta-Grip. You made it possible for me to graduate on a project combining climbing with designing. I want to thank Dr. John van der Kamp for making the time to attend meetings and give valuable feedback. I want to thank Dr. Dominic Orth for always defending the core functionalities of the Meta-Grip and for initially giving me this opportunity. I want to thank Nikki van Bergen for being involved in the project as a researcher and climber; this combination and the experience you have is something I am still developing.

In addition I want to thank my supervisor, Dr. Toon Huysmans, and my mentor, Ir. Stefan van de Geer, for their supervision. After presenting my work, you gave comments I would not have thought about. Your comments made me see the bigger picture again at moments that I was too focussed on details. I want to thank Stefan for checking on me personally whether I was doing alright, not project related.

I want to thank the participants of my questionnaires, interviews and user test, especially Don van Laere, Sander ter Steege and Jelle Schouten.

Lastly, I want to thank my parents, sister and friends for proofreading my report whenever I asked for it, helping me build prototypes or being a listening ear and distracting me from my report when needed!

Executive summary

The Meta-Grip is a tool for climbers to measure hand and finger strength. A climber uses the Meta-Grip by hanging on either a sloper or crimp. The Meta-Grip measures the force through a load cell and transfers the data to a computer where the data can be viewed and analyzed. The current Meta-Grip is built for research. Because of this, the current Meta-Grip cannot be used unsupervised, the embodiment needs improvements and the price of 2520 euros for the costs is too high for the intended market. The current Meta-Grip can only do measurements, an addition to its functionalities would be the ability to also train on the Meta-Grip. This let to the following goal for redesigning the Meta-Grip: "Redesign the Meta-Grip in such a way that it becomes an affordable and recognizable tool that measures finger and hand strength and provides immediate and understandable feedback to the climber, that can be used unsupervised by climbers and is an addition to the currently available training tools.".

To redesign the Meta-Grip, the design process is structured in four phases: analysis, ideation, concept design and final validation. The following methods were used: literature research, online market research, online surveys, sketching, prototyping, user testing, hosting creative sessions and expert interviews.

The redesigned Meta-Grip is a product-service system. The Meta-Grip, made for fanatic climbers, has a range in holds that differ in type and difficulty. Holds are available in alder wood for skin friendliness or polyurethane coated with quartz sand for high friction, to the user's discretion. With two load cells and a Bluetooth module , a connection can be established to the mobile phone application of the Meta-Grip. This application, the service, is used to execute measurements, follow exercises and training plans and determine climbing goals. A button on the Meta-Grip allows users to turn the Meta-Grip on and connect the Meta-Grip via Bluetooth to the application on their phone. To instruct the user on how to use the Meta-Grip before the Bluetooth connection is available, instructions are placed on the left side of the Meta-Grip. The system is powered by a 9V battery. The installation of the Meta-Grip is made such that it will fit any normal climbing gym with two M10 bolts.

This research has shown the potential of a redesigned Meta-Grip. Through the application, the Meta-Grip can be used unsupervised and changing the design has made the Meta-Grip more versatile and recognizable for climbers. The cost price is estimate at 120 euros, making it a large price reduction. The next step is to further elaborate the concept and all parts of the product-service system to make it ready for launching the Meta-Grip to the market.

Chapter 1

Introduction

Recently, climbing has become an increasingly popular sport; in the Netherlands there are already 32.000 climbers and it has recently been added to the Olympic Games (Sport Climbing, sd). Climbing can be done indoors on artificial holds or outdoors on natural rock. In every climbing discipline, hand and finger strength is essential for athletes. While climbing, hands and fingers are challenged in a variety of ways that differ significantly from general day-to-day activities. In studies across climbers it is found that hand and finger injuries occur more frequently than other injuries among climbers (Jones & Johnson, 2016). Tools exist with which climbers can train their hand and finger strength, such as hangboards. However, without direct monitoring and feedback it is difficult to be aware of the efficiency and effectiveness of the training. This is the topic of this research project. The first section presents an introduction to climbing. The second section elaborates on the topic of this research/design project: a device for measuring and training hand and finger strength. The third sections will elaborate on the method and this chapter is concluded with a reading guide for the rest of this report.

1.1 Introduction to climbing

This section provides a short introduction to climbing so that non-climbers can obtain a basic understanding of the sport. For more detailed information about climbing, see appendix A: Introduction into climbing on page 70.

Climbing can be divided into different types. The most common types are bouldering and sport climbing. Bouldering (figure 1.1 and figure 1.2) is climbing up to four meters with only thick mats beneath the climber to catch the fall. Sport climbing (figure 1.3 and figure 1.4) is either lead climbing or climbing on belay of short routes. Both bouldering and sport climbing can be executed indoors in climbing gyms. Recently, the amount of gyms for bouldering and sport climbing has been growing, so the availability is much higher (figure 1.5) (Hoeijmakers & Romijn, 2018), which indicates the growing popularity of the sport.

Figure 1.1: Outdoor bouldering

Figure 1.2: Indoor bouldering

Figure 1.3: Indoor sport climbing

Figure 1.4: Outdoor sport climbing

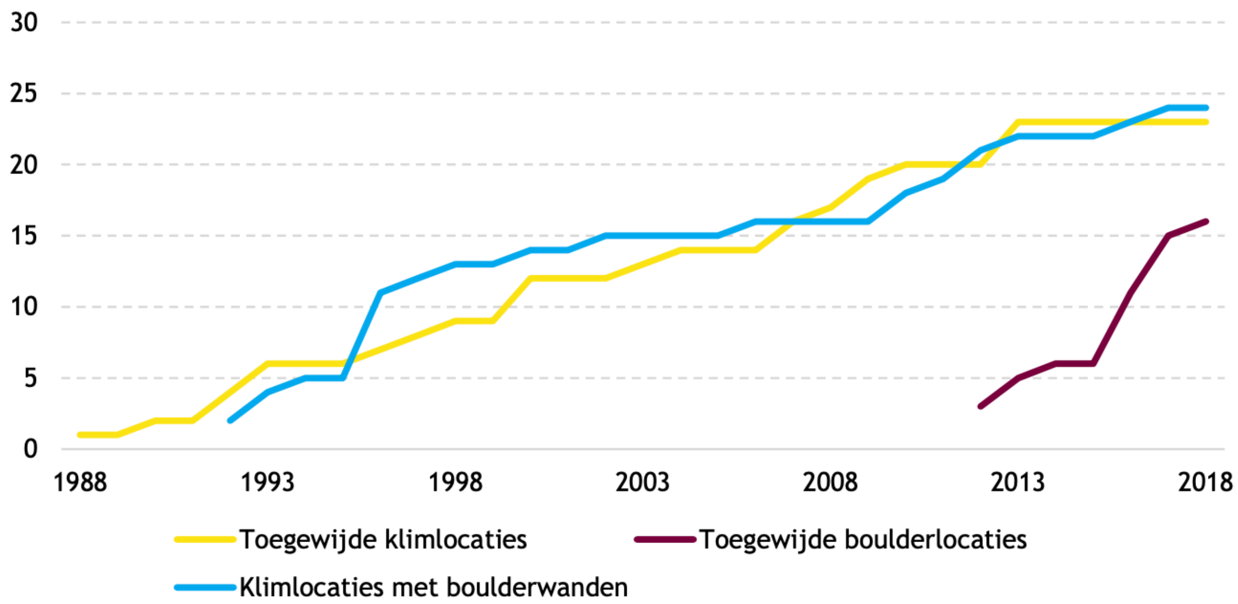


Figure 1.5: Growth climbing gyms

To indicate the climbing level of the athletes, a universal grading system, the International Rock Climbing Research Association (IRCRA) scale, has been developed (Draper & Giles 2016). Different countries in the world have developed their own grading systems, but they all link back to the universal grading system. In this report, the IRCRA scale will be used. In this scale, a five is the easiest route that can be found in most climbing gyms and a 29 is a route that can only be climbed by a handful of people in the whole world (appendix A: Introduction into climbing page 70). Besides climbing grades, there is also a difference in how a route or boulder can be accomplished (appendix A: Introduction into climbing page 70) (Onsight / Flash / Redpoint and Freepoint, 2008). In this report, the redpoint grade will be used; finishing a route without straining the rope at all.

When climbing, the only connection with the wall is via the hands and feet of a climber. It is important that climbers have strong hands and fingers since they have to be able to hold on to a hold. In research it is found that climbers have a better physique in their fingers and hands compared to non-climbers; their maximum voluntary contraction (MVC), the ability to execute a lot of power with their fingers, is higher than for non-climbers (Macleod, et al., 2007).

Since hands and fingers are essential for climbing, training facilities that specifically target hands and fingers are important. The first training facility for this was introduced in the climbing world in 1988 (Campus Board Brochure, sd) and tools have developed ever since. There are two common ways of training hands and fingers; with a campus board (figure 1.6) or a hangboard (figure 1.7). It has been argued that by executing a proper hangboard training routinely finger strength can be improved by 32 % (Anderson, Anderson, & Sanders, An innovative hangboard design to improve finger strength in rock climbers, 2016). Since the feet are not used when hangboarding, a lot of load is applied on the hands and fingers, making hangboarding sensitive to injury. Skin injuries can occur, but also internal injuries, such as in muscles, tendons and ligaments, in the shoulder, elbow, wrist and finger (Anderson, Anderson, & Sanders, An innovative hangboard design to improve finger strength in rock climbers, 2016) (Appendix B: Hand anatomy, physiology and biomechanics on page 76). This asks for a proper hangboard training and posture (Appendix C: Hangboard routine on page 79).


Figure 1.7: Hangboard

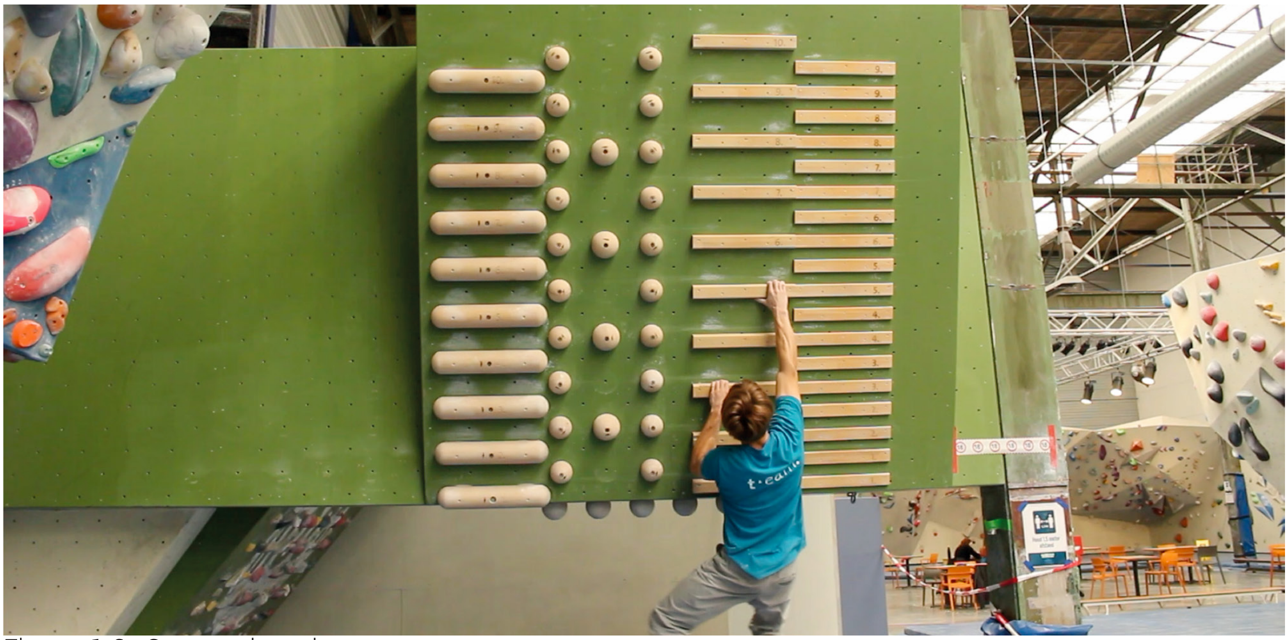


Figure 1.6: Campus board

1.2 Measuring and training hand and finger strength

Currently, a new instrument, the Meta-Grip (figure 1.8 and figure 1.9), developed by the Vrije Universiteit (VU) in Amsterdam, is used for research to measure hand and finger strength among climbers, and to broaden the knowledge about its importance in climbing. The goal of the Meta-Grip as declared by the team at the VU is: "Monitoring grip force to minimize hand injuries and improve climbing performance" (Orth, 2019).
The Meta-Grip allows a measurement with three specific hand positions for climbers: a sloper (figure 1.10), a crimp (figure 1.11) and an empty space to which any hold that fits can be attached (figure 1.12). Through a single load cell, the data is transformed with a bridge amplifier and an analog-to-digital (AD) converter to a computer with LabVIEW (figure 1.13 on page 14). Here, the magnitude of the force applied to the grip is shown over time. The maximum voluntary contraction (MVC) (Peak force), rate of force development (RFD) (time needed to obtain peak force), critical force (stamina) and power endurance (recovery ability) are calculated and subsequently interpreted by the researcher.

Figure 1.8: Overview Meta-Grip

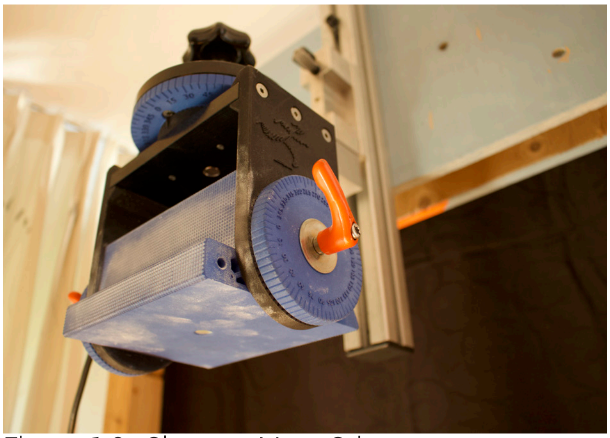


Figure 1.9: Close-up Meta-Grip

Figure 1.10: Sloper

Figure 1.11: Crimp

Figure 1.12: Hold

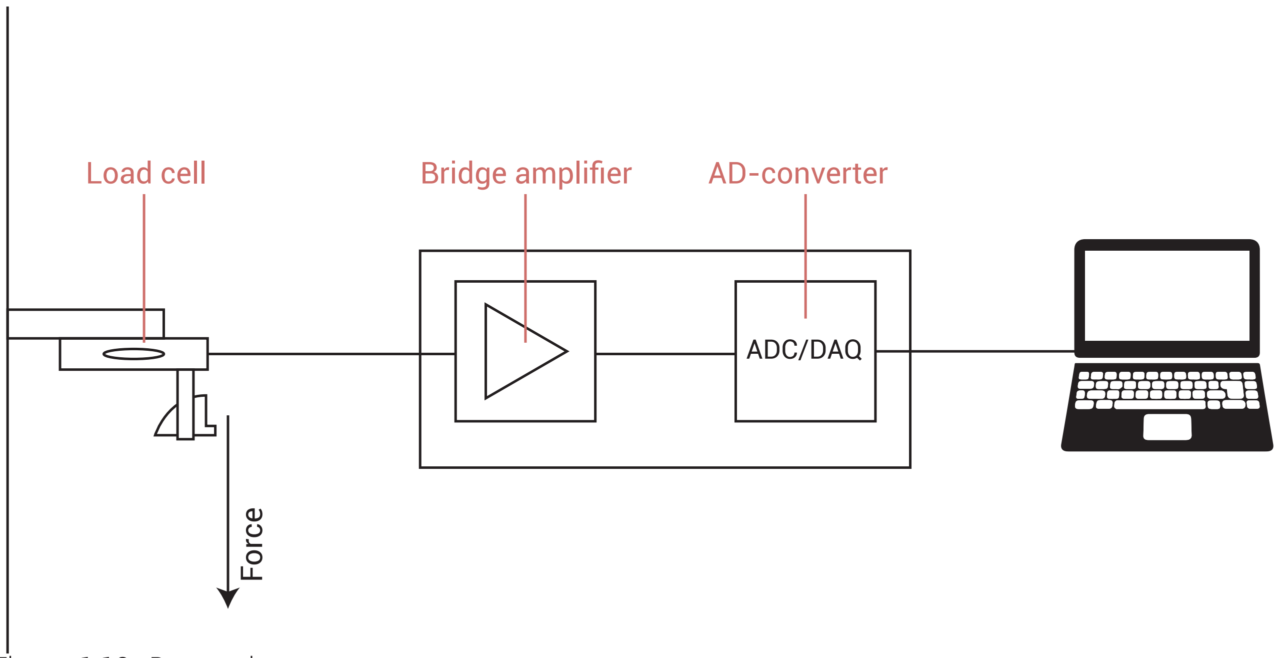


Figure 1.13: Data path

The Meta-Grip has the potential to improve training of climbers significantly by monitoring and giving feedback to climbers. The Meta-Grip can provide the climber with an objective measurement showing the finger and hand strength of the climber. To know objectively the strength of a climber can help prevent injury and train precisely on what is missing. However, to achieve that potential, it must enable regular use by climbers to train and to measure their improvement (or decline). For regular and frequent use, the Meta-Grip should be attractive and easy to use. Currently, the Meta-Grip is fairly expensive (€ 2520,00) due to expensive manufacturing techniques and data transfer systems. The high price makes it unattractive for users to buy (Orth, 2019). Furthermore, the digital interface is difficult to understand and during a 10-week test with physiotherapist, it was found that the current realization of the Meta-Grip is not ideal in terms of material, size and difficulty of the holds (Jans, 2019).

Four potential user and buyer groups that would benefit from a hand and finger strength measuring device are physiotherapists, climbing gyms, trainers and individual climbers. Depending on the cost, the detail of feedback and ease of use, the Meta-Grip will be used by one or more of these user groups. The Meta-Grip should ultimately allow unsupervised use by climbers at every location the Meta-Grip is available.

The aim of this research project was to develop the Meta-Grip further with already identified points of improvement in previous research and new points of improvements from current research and user tests. Accordingly, the embodiment of the product should be improved in terms of manufacturing, form and materials. The feedback system should be made such that end-users can easily interpret the data on their own and eliminating the need of a laptop connected with a wire. Important for interpreting the data is the ability to obtain direct feedback. Overall, an effective cost reduction must be realized, for example by the use of different manufacturing methods and sensors.

1.3 Design method

The project followed the four different phases of a design project according to the model of Pahl and Beitz (Roozenburg & Eekels, 2003). In the first phase, the analysis, research was done on the current Meta-Grip and climbing. Through desk research, a questionnaire and a evaluation of the current Meta-Grip. In the second phase, the ideation, ideas were sketched based on the outcomes of the research, resulting in a concept. In the third phase, the concept design, the concept is designed in more detail and design choices are made. This is done with users in questionnaires and user tests. In the fourth phase, the final evaluation, the concept is evaluated by multiple different users. Each phase is structured by the basic design cycle (appendix AC: Methods on page 209).

1.4 Reading guide

This report is written according to the Pyramid Principle, developed by Barbara Minto (Minto, 2002). The most important thing about the Pyramid Principle is that the answer to the main question or assignment is given first, after which

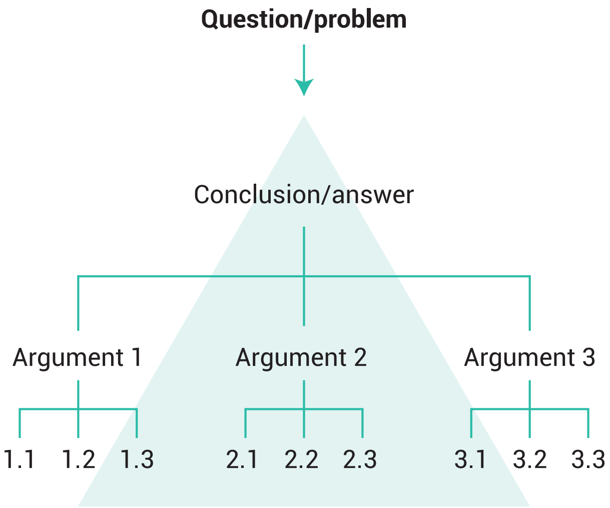


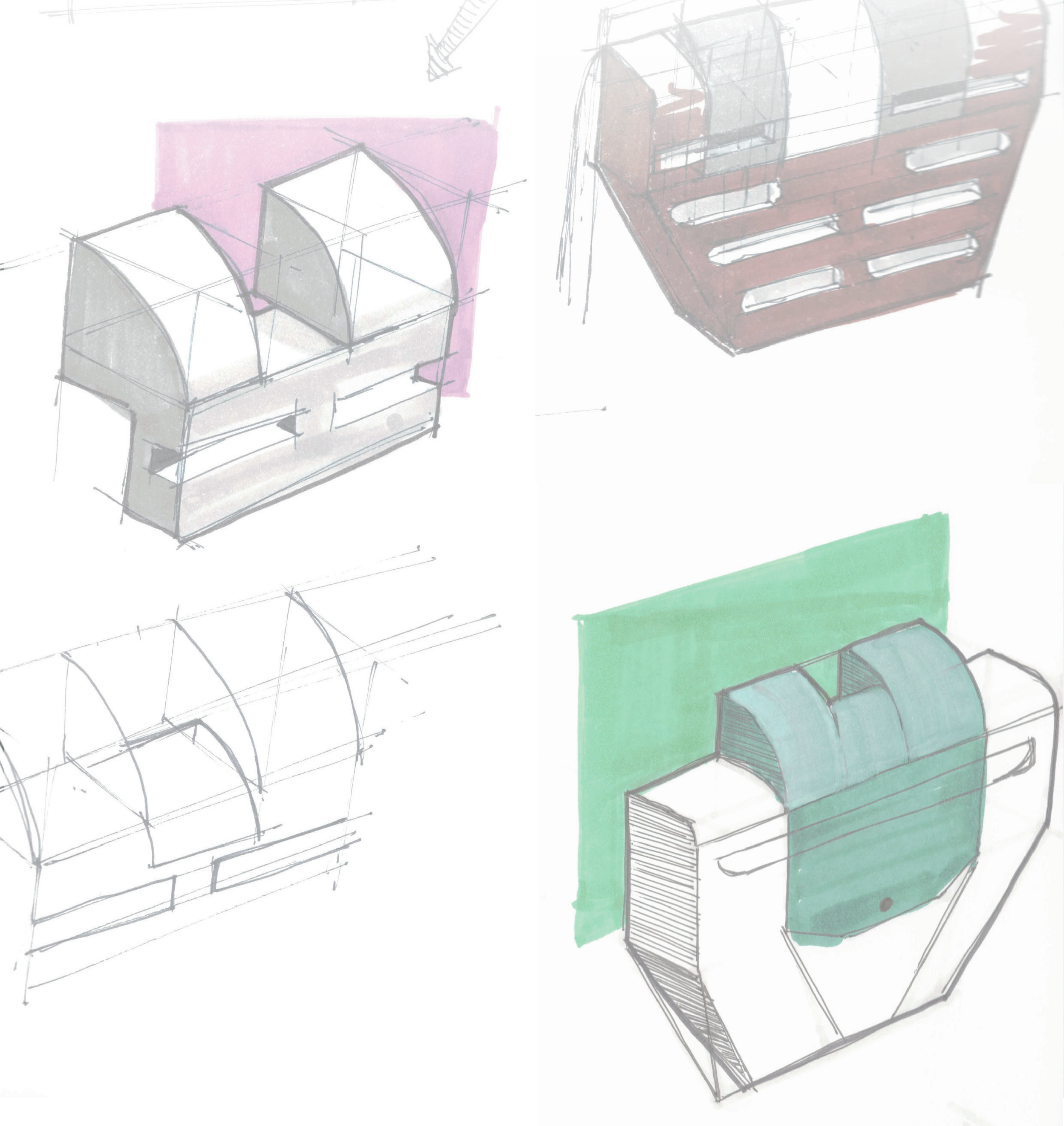
Figure 1.14: Pyramid Principle.pdf

arguments are given to support the answer (figure 1.14). In writing this report, this principle was applied.

The report is divided into three different parts. The first part, 'The design', chapter 2 and 3, include research on the current Meta-Grip, the assignment that followed and the redesigned Meta-Grip. This part describes the problem with which this research project started and describes the solution that resulted from this research project. The second part, 'Details and choices', chapter 4 till 6, provides more in-depth information about the different parts of the Meta-Grip. Within this part, arguments supported by research findings are given on why certain decisions and choices were made. The third part, 'The next step', chapter 7 and 8, give recommendations and a conclusion for the overall project. For each of the three parts in the main body of this report, appendices are added that contain more detailed information for the interested reader.

Part 1: The design

This part describes the question or problem with which this research project started, based on an analysis of the current Meta-Grip in chapter 2. Chapter 3 describes, on a high level, the solution that resulted from this research project. According to the Pyramid Principle, a more detailed description of the redesigned Meta-Grip is given in part 2.



Chapter 2

Meta-Grip analysis

In this chapter, the current Meta-Grip (figure 2.1) as developed and used by the Vrije Universiteit will be analyzed. This will be done on two aspects, by describing the stakeholder, users, and competitors (appendix D: Involved parties with the Meta-Grip on page 80) and by presenting the current design and evaluation points based on existing research (appendix E: The current Meta-Grip on page 96). The Meta-Grip has already been used by multiple groups of climbers. The Meta-Grip has been tested and evaluated with physiotherapists within a ten-week timeframe (appendix E: The current Meta-Grip on page 96) (Jans, 2019). The physiotherapists believe the potential of the Meta-Grip is high but improvements need to be made. Besides the physiotherapists, the Dutch National Climbing Team has used the Meta-Grip for multiple measurements, under supervision and with assistance of Nikki van Bergen. This chapter ends with a conclusion. For the future business around the Meta-Grip, the following statement was created: "Build tools for individuals to improve themselves and their sport" (Orth, 2019).

Figure 2.1: Current Meta-Grip

2.1 Stakeholders, users and competitors

There are several main stakeholders regarding the Meta-Grip: the researchers and engineers of the Vrije Universiteit (VU) in Amsterdam who designed and developed the Meta-Grip; physiotherapists and trainers who will supervise the use of the Meta-Grip in their practice; climbing gyms, which will provide the Meta-Grip to their clients; competitors and suppliers of materials and parts used to construct the Meta-Grip. The climbers are sub-stakeholders since they either make use of the Meta-Grip through climbing gyms or under the supervision of a physiotherapist or trainer (figure 2.2). The most influential stakeholders are the buying stakeholders and the stakeholders through which the climber obtains access to the Meta-Grip.

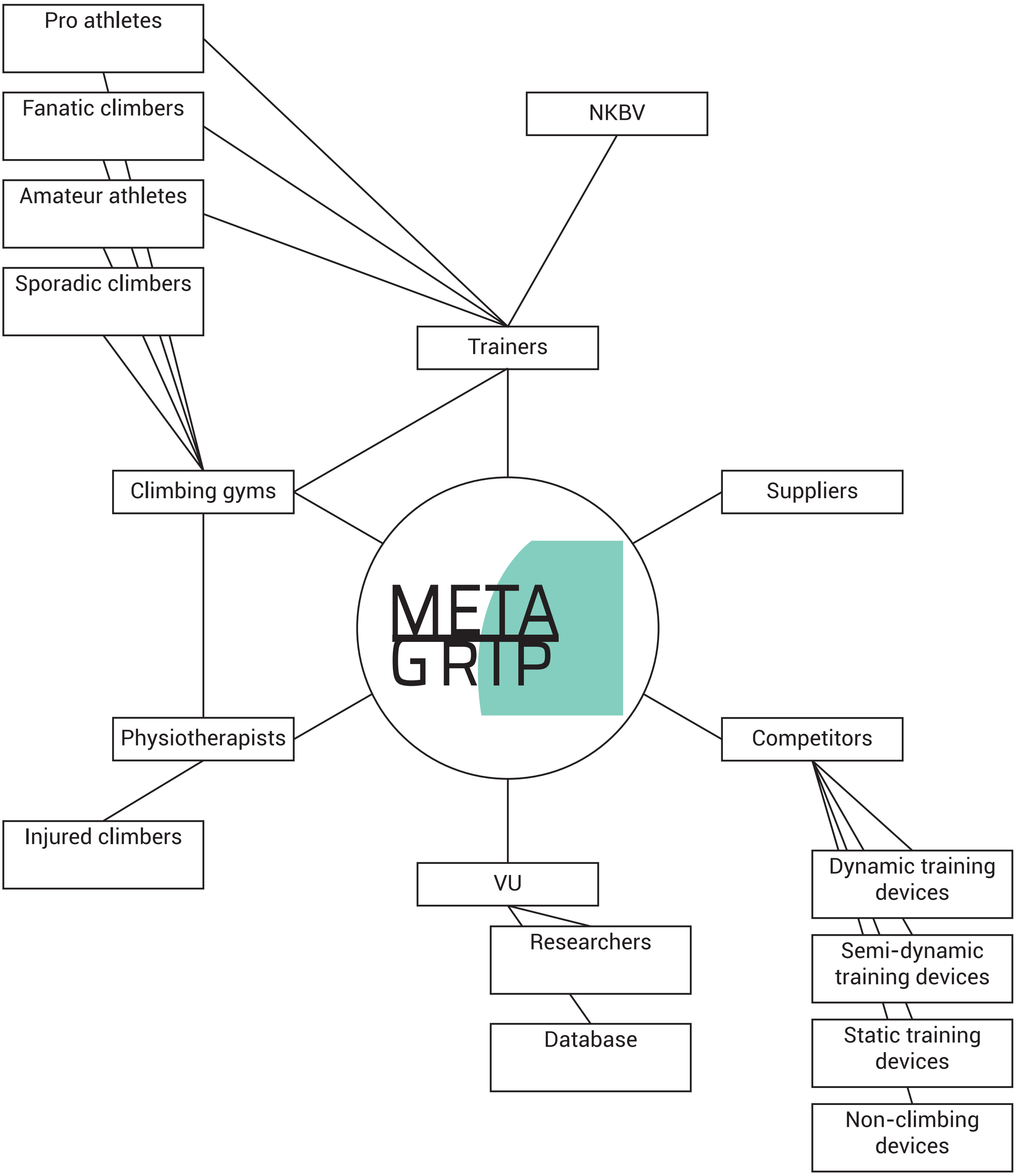


Figure 2.2: Stakeholders

Five user groups are distinguished: sporadic climbers (1), fanatic climbers (2), pro athletes (3), amateur athletes (4) and injured climbers (5) (figure 2.3) as was found using a questionnaire (n=21, age 36 stdev 15) (appendix F: Defining the user group climbers on page 104). This questionnaire started with questions to determine what type of climber the participant is. After a very brief explanation and picture of the current Meta-Grip, open questions about the Meta-Grip were asked. Open questions allowed the users to give their own opinion; this input was used to determine the user groups. The categorization in five user groups was positively evaluated with five climbers. The user groups differ in their training effort (from occasional to structured) and in the goal of their training (from leisure to improvement centered climbing) (figure 2.3). Fanatic climbers will be the focus group of the redesigned Meta-Grip. According to Frank Loeve (owner of climbing gym "De Campus" for three years now, appendix G: Interviews on page 110) and Sander ter Steege (owner of climbing gym "Delft's Bleau" for eight years now, appendix G: Interviews on page 110), the largest group in regular climbing gyms are the fanatic climbers, hence this group is chosen. The most important needs for fanatic climbers, based on the results from the questionnaire and prior knowledge about climbers are:

- Regular measurements to track their progress.
- Unsupervised measurements.
- Comparison of different measurements over time.
- A suggestion for a training plan.

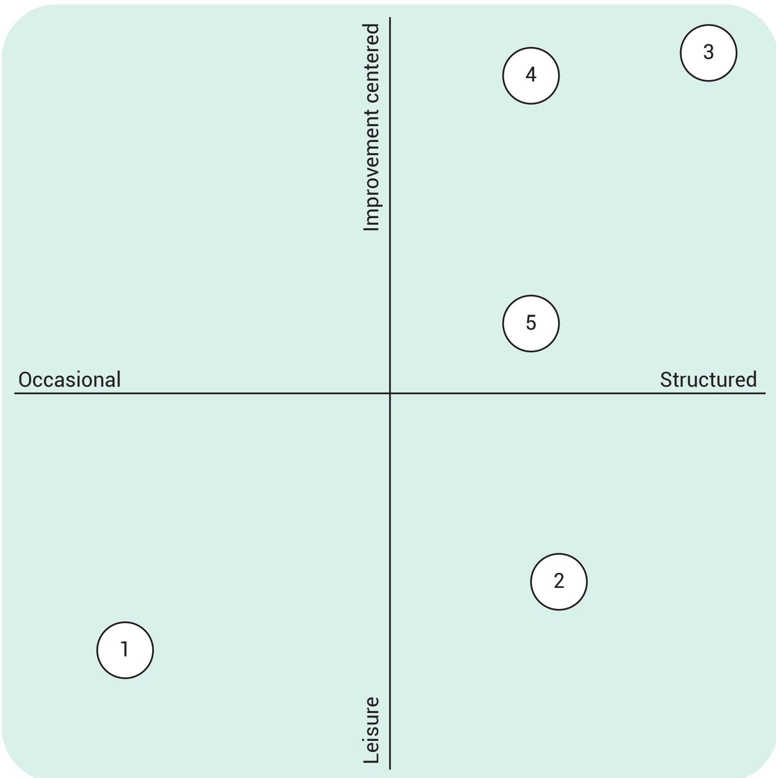


Figure 2.3: User groups

Competitive products can be divided into four categories (figure 2.4), see appendix D: Involved parties with the Meta-Grip on page 80:

1. Dynamic training devices, that include a force measurement system and a feedback system to show what this force is.
2. Semi-dynamic training devices, which only have a feedback system that can detect if any force or no force is applied by using the gyroscope in the phone.
3. Static training devices, which include neither a measurement system, nor a feedback system.
4. Non-climbing devices which can measure and give feedback only are not specificly made for climbing.

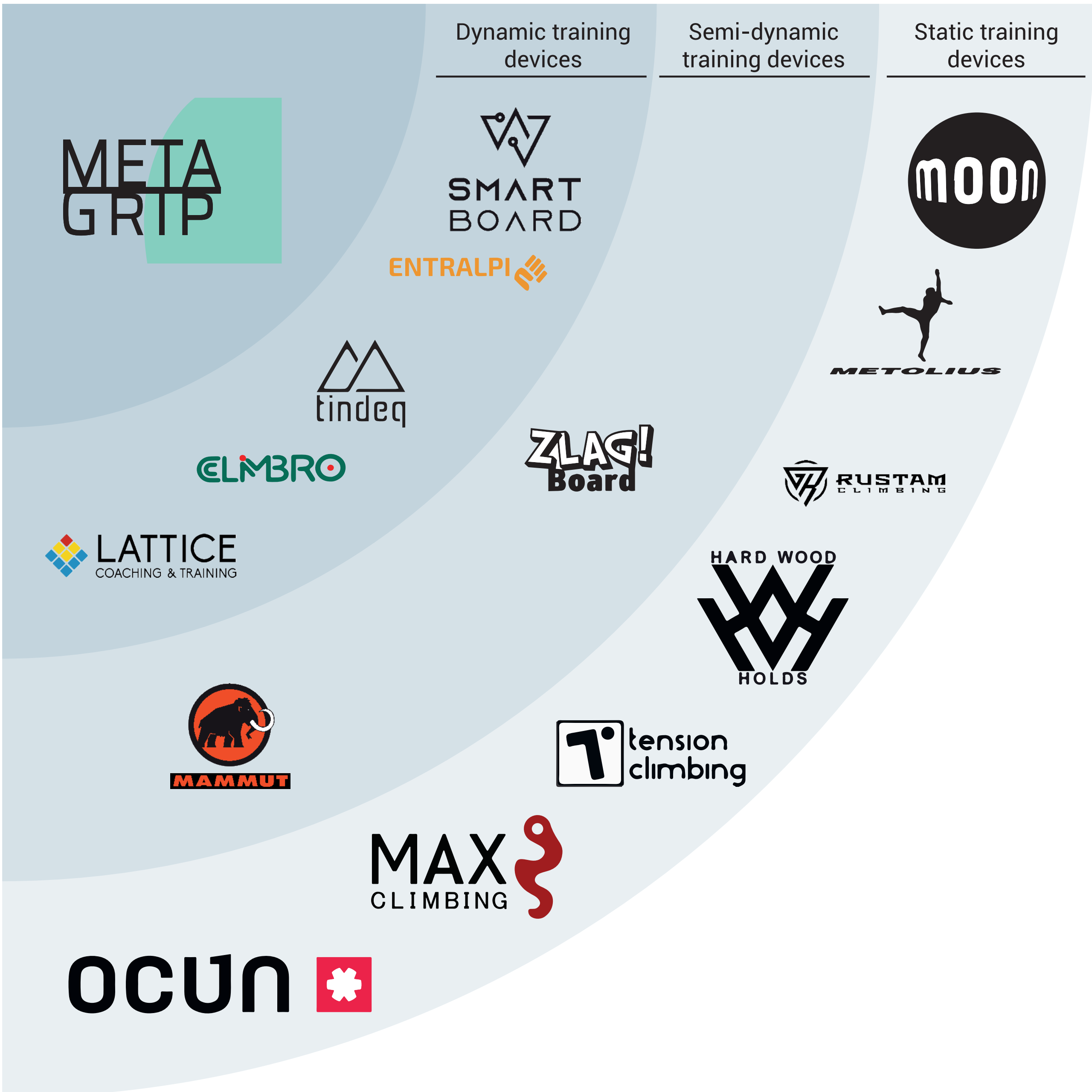


Figure 2.4: Competitors

The closest competitors (figure 2.5) and the product category of the Meta-Grip are the dynamic training devices. This is a relatively small product category and the Meta-Grip can possibly set a standard for competing products within this category.

Brand	Smartboard	Entralpi	Tindeq	Climbro	Lattice
Transmission	Bluetooth	Bluetooth	Bluetooth	Bluetooth	Wire
Sample rate	-	80 Hz	80 Hz	-	80 Hz
Prize	€ 3000	€ 133	€ 135	€ 800	€ 1112
Feedback	Training plan	Training plan	Values	Training plan	Values
View history	Yes	Yes	Yes	Yes	Yes

Figure 2.5: Dynamic training devices

2.2 Current design

The current Meta-Grip was primarily made for researchers to obtain data for their research on hand and finger strength and subsequently to explore whether it is an interesting product for the market. This also reflects in how the Meta-Grip is designed and built, it arguably looks very educational, unique and modular and not like a recognizable tool for climbers. This might make the climber less aware of the Meta-Grip as being a tool that every climber can use. The Meta-Grip could look more like a common climbing tool, handing in on uniqueness, which would create more awareness and trust and subsequently more users.

The Meta-Grip consists of two types of fixed holds and one interchangeable hold, which can all be placed in a large range of angles, both horizontally and vertically (figure 2.6). Besides adjusting the angle, the height of the Meta-Grip on the wall can also be adjusted allowing smaller and taller people to use the Meta-Grip (figure 2.7).

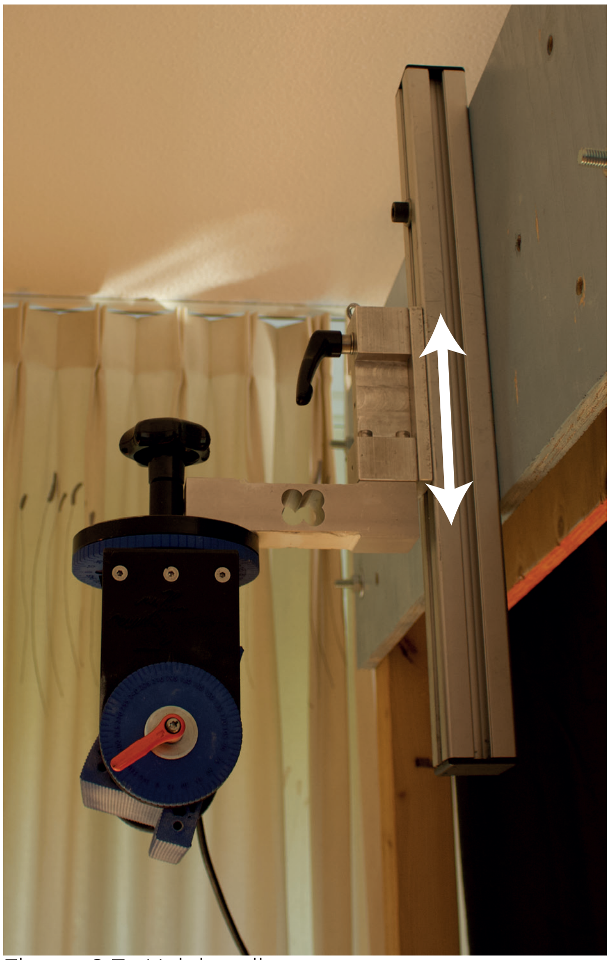


Figure 2.7: Height adjustment

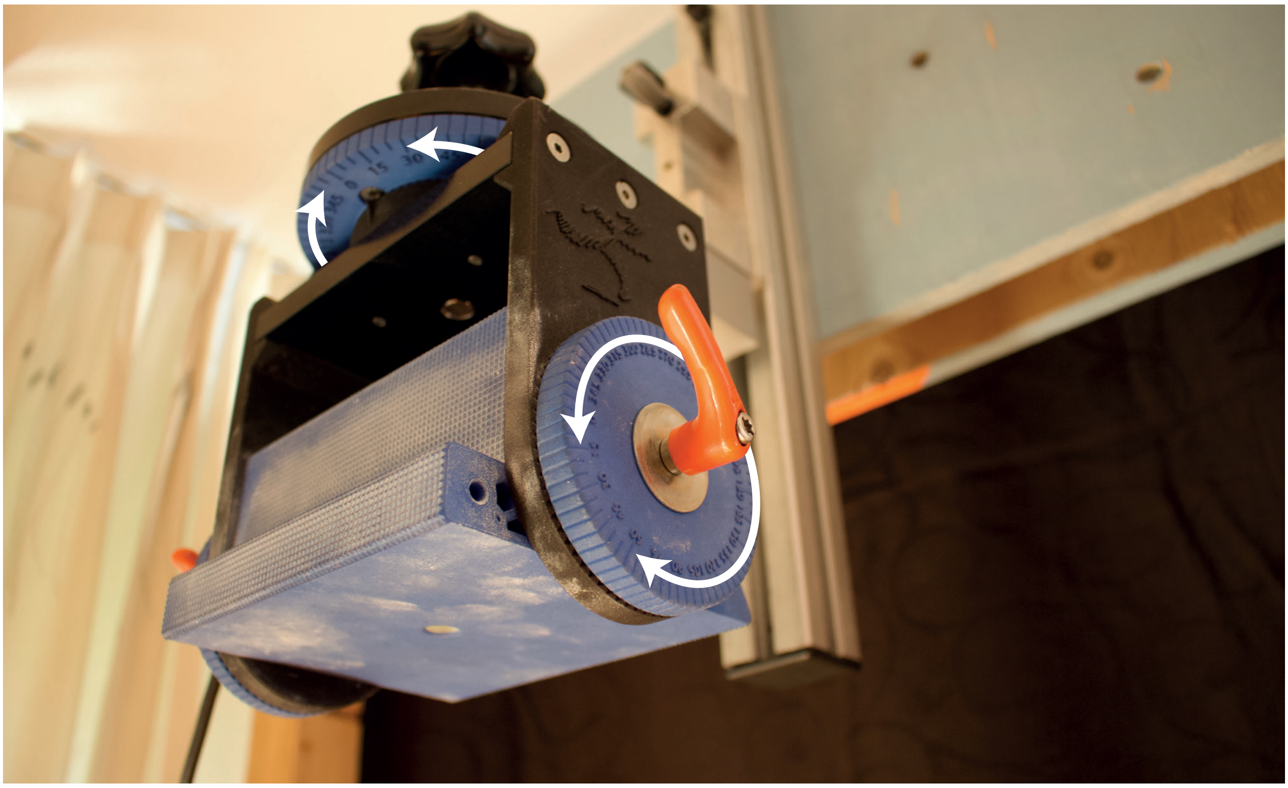


Figure 2.6: Horizontal and vertical angle

Despite the adjustable design of the Meta-Grip, the current design does not allow for quick switching between different climbing hold. Adjusting the holds to the right position needs to be done accurately and this is quite cumbersome. Furthermore, physiotherapists believe the shape was not optimal and does not fit every user (Jans, 2019). The Dutch National Climbing team reported that they want smaller edges (8 mm) as well as pockets and pinches since this is a very different posture then when using edges or slopers.

The associated mechanics make the Meta-Grip very sensitive to malfunctioning due to chalk (often used by climbers) and dust. The materials of the self-developed parts used in the Meta-Grip are polyamide 12 (PA12) (appendix H: Polyamide-12 on page 113) and aluminum. There are also standard parts in the Meta-Grip like bolts and turning knobs. Physiotherapist indicated that the texture was too rough (figure 2.8) and the material too slippery at the same time (Jans, 2019).

The Meta-Grip can currently execute four measurements, all targeted at different muscles and energy supplies in the hand and fingers in defined protocols (appendix A: Introduction into climbing on page 70), see ennumeration. After doing all four measurements, a proper estimation of someone's climbing level can be made. The climbers in the Dutch National Climbing Team were fairly positive about the objective measurements that the Meta-Grip enables. Physiotherapists indicated it is preferred to not only perform a complete measurement, but also perform a partial measurement (Jans, 2019).

- Maximum voluntary contraction (MVC) or the maximum finger strength measures the maximum force a climber can pull on a hold and is displayed in Newton or kilograms.
- Rate of force development (RFD) or explosiveness measures how fast a climber can reach their maximum finger strength and is displayed in Newton per milliseconds or kilogram per milliseconds.
- Power endurance measures how long a climber is able to apply finger strength within a certain force range and is displayed in the amount of repetitions that can be made before reaching the lower end of the range.
- The critical force (CF) or stamina measures the maximum power a climber can give during 24 repetitions and is displayed as the average of the last six repetitions in Newton or kilograms.

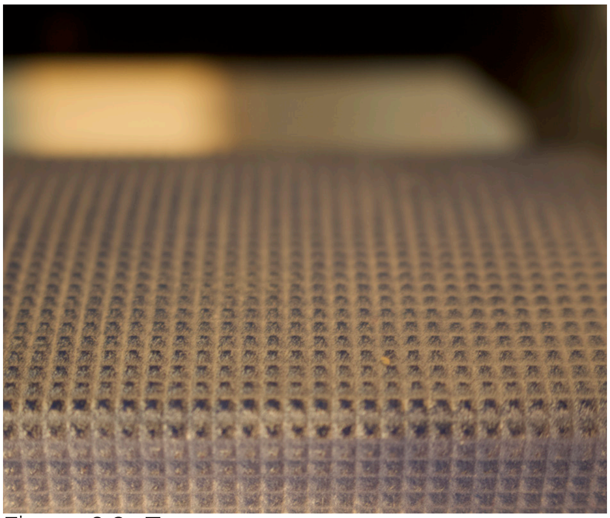


Figure 2.8: Texture

Receiving the data of a measurement is currently done via a wire connection between the Meta-Grip, an AD-converter and bridge amplifier and finally a laptop with LabVIEW (figure 2.9). Having a wire connection is less than ideal since it can cause accidents from tripping and the laptop, the analysis device, always needs to be as close to the Meta-Grip as the wire is long. Physiotherapists indicated that the wiring is an obstruction during measurements (Jans, 2019).

Since the device is built by researchers and for researchers without involving regular climbers along every step of the process, less attention is paid to the data and the interpretation of it. Interpreting the data is quite difficult and requires expertise as confirmed by the physiotherapists (Jans, 2019). As a result the use of the Meta-Grip requires constant attendance of an expert. The physiotherapists in Jans (2019) research indicated that the data should be in units that the user can understand.

Currently, the purchase and manufacturing costs are a grand total of 2520 euros. Most of the manufacturing, the 3D printing, is outsourced to an external company called Oceanz which costs a total of 500 euros. Outsourcing the production of 3D printing can save money with a small batch size. However, when the batch size gets larger outsourcing the 3D printing is not cost-effective anymore. The components needed to transfer the data to the computer form the largest share of the costs, a total of 1920 euros. The assembly and the frame combine to a total cost of 100 euros (appendix E: The current Meta-Grip on page 96). Previous research shows that 2520 euros is too high of a price for potential investors to be interested in the Meta-Grip (Orth, 2019).

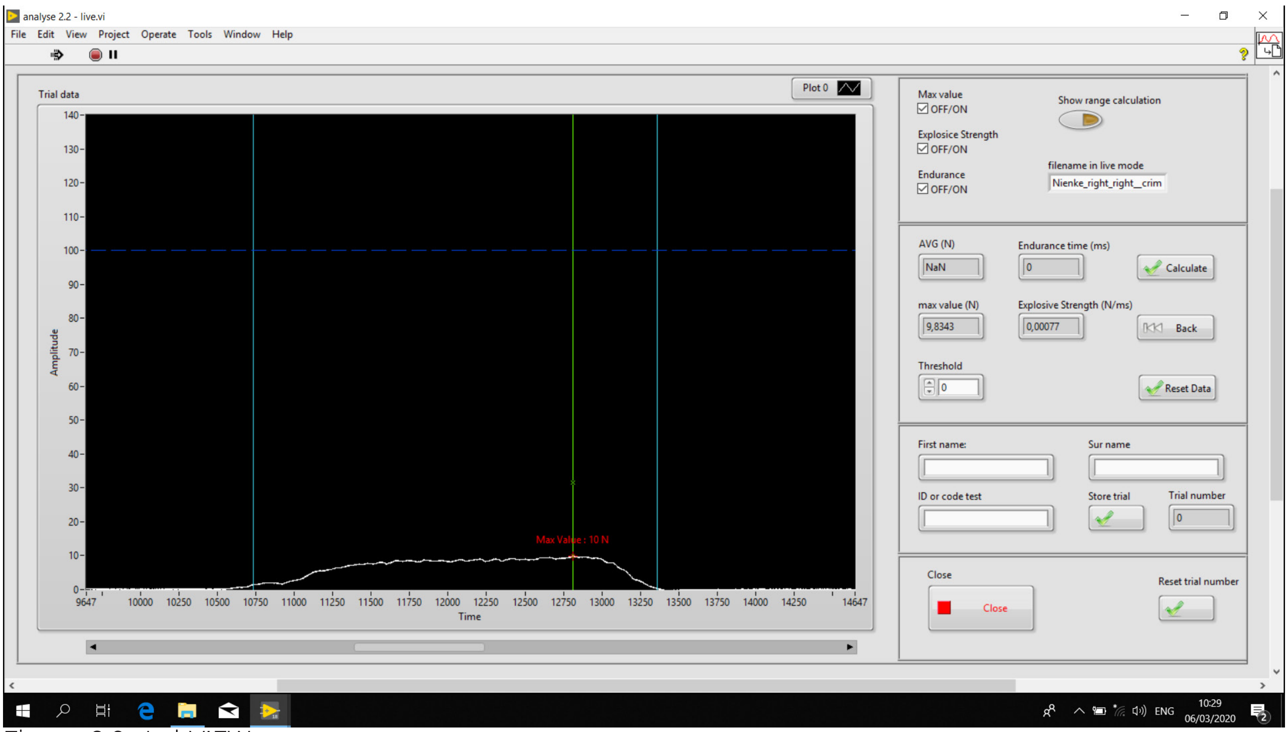


Figure 2.9: LabVIEW

2.3 Conclusion

From this analysis, it can be concluded that the current Meta-Grip is designed for researchers or other knowledgeable experts and not for regular climbers: the data is difficult to interpret and the design does not allow for multiple and quick variations in holds. Furthermore, with the current manufacturing costs, the Meta-Grip will not be likely to be sold a lot due to the high price. Lastly, the embodiment does not look like a general training tool and the shape, form and material are not ideal for use according to climbers.

Based on the analysis of the current Meta-Grip and discussion with the developers at the VU and other important stakeholders, the assignment for this research/design project was formulated with wishes and requirements (appendix Z: Requirements and wishes on page 202)and an ideal use scenario was created (appendix S: Ideal use scenario on page 163):

"Redesign the Meta-Grip in such a way that it becomes an affordable and recognizable tool that measures finger and hand strength and provides immediate and understandable feedback to the climber, that can be used unsupervised by climbers and is an addition to the currently available training tools."

There are three key challenges within the assignment:

1. The Meta-Grip should be lowered in price drastically.
   The manufacturing costs are currently 2520 euros which is too high for the intended user group.
2. The climber should be able to use the Meta-Grip unsupervised.
   Currently, interpreting the data can only be done by experts on a laptop. Furthermore, the use with the Meta-Grip is not intuitive and not fool proof to be used unsupervised.
3. The embodiment needs to attract the climber more and be comfortable to use.
   Currently, climbers do not recognize the Meta-Grip as a tool they can easily use to assess and improve their climbing. It is not very functional in terms of availability since the current Meta-Grip is not installed permanently in a climbing gym.

Based on the research done in previous projects and the desk research, interviews and questionnaires carried out in this project, a design vision was formulated:

"The Meta-Grip offers climbers a tool to improve their hand and finger strength and therefore their climbing safely and injury free. The Meta-Grip gives guidance on how and what to improve in climbing and stimulates climbers to keep improving. Using the Meta-Grip gives climbers confidence and pleasure while being motivated by the improvement visible through in objective measurements. "

The next chapter presents the result of the assignment.

Chapter 3

The redesigned Meta-Grip

In this chapter, the redesigned Meta-Grip will be explained. The redesigned Meta-Grip is a product-oriented product-service system (figure 3.1 and figure 3.2). Product orientated means that the client will be the owner of the physical product and there are additional services. This product-service system enables climbers to measure and train their hand and finger strength. The product, the embodiment of the Meta-Grip, is property of a buyer like a climbing gym. The mobile phone application, the service, is available to users of the Meta-Grip, in this case for example visitors of the climbing gym. With only one physiclal product, multiple climbers can use the service system. Using a product-service system allows for constant improvements of the service since updates of the service can be provided without changing or interrupting the use of the product (Mont, 2001). Application updates are not infinite, they need to be supported by the physical constraints the Meta-Grip has (hold type and size). The product and the application are described in more detail in the following two sections. For a full report on the redesigned Meta-Grip, see appendix T: The redesigned Meta-Grip on page 167. The third section presents a use scenario for the redesigned Meta-Grip. This chapter ends with conclusions in which a reflection is given on how the redesigned Meta-Grips addresses the key challenges presented in the previous chapter.

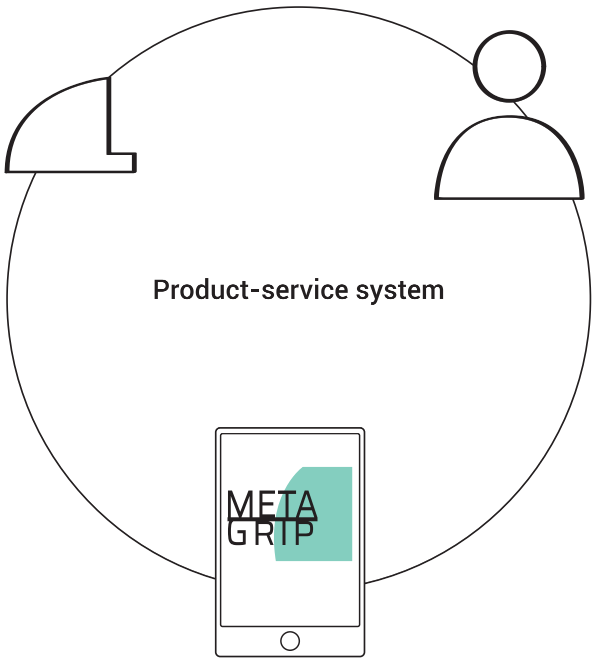


Figure 3.1: Product-service system

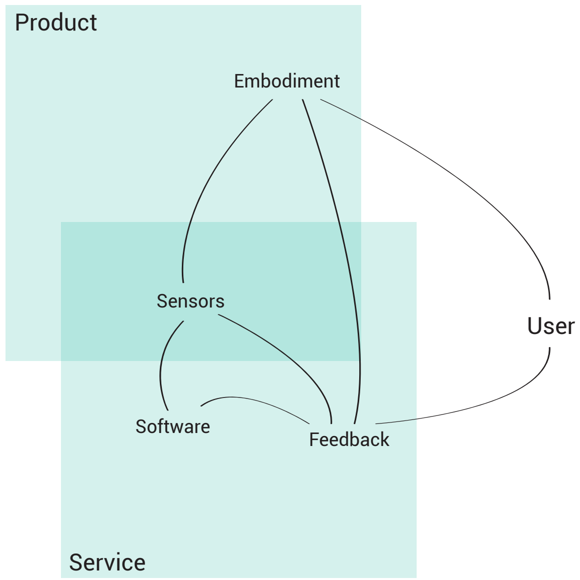


Figure 3.2: Parts of the product service system

3.1 The product

The physical Meta-Grip consist of multiple elements to be classified as hardware or skin (figure 3.3). Combined together this makes the Meta-Grip an interactive hangboard. The hardware enables measurements as well as user-friendly interaction of the climber with the Meta-Grip. The hardware is hidden away behind the skin. The skin of the Meta-Grip is designed as a hangboard and made replaceable. The designed skin has relatively easy hold sizes, making this hangboard a good entry-level model. This skin is intended for the fanatic climber as a user group. The fanatic climber is interested in progression and can improve with relatively general advice. However, to also supply the amateur athletes and pro athletes with a hangboard matching their level of expertise, different skins can be made available (figure 3.4). There will be multiple different skins ranging in difficulty from easy to hard, all compatible with the same hardware module.

The climber only interacts with the skin. The skin consists of different holds: slopers, crimps and pockets (appendix I: Climbing holds on page 114) in different sizes, which the climber can use for measurements and in their training. There is a switch on the left side of the Meta-Grip with which the power supply is turned on and off. The left side also shows instructions with which the initial interaction of the Meta-Grip will be clarified (figure 3.5 on page 31). The

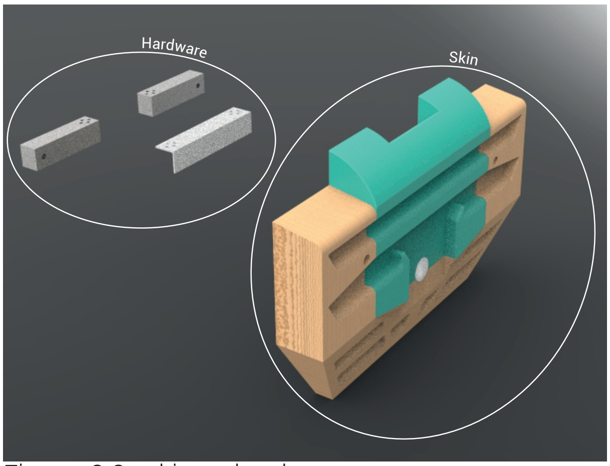


Figure 3.3: skin en hardware

button on the front of the Meta-Grip (figure 3.6 on page 32) is used to turn the Meta-Grip on (one push), reset the Bluetooth (two fast pushes) and turn the Meta-Grip off (hold button for three seconds). To make the initial interaction transparent, there is light feedback from within the button where a green solid light (Meta-Grip is ready for use), a blue flickering light (Resetting Bluetooth) and a red solid light (Bluetooth not connected) (figure 3.7 on page 32) can be visible.

The material prices of the product (with one skin) is estimated to be 120 euros for a batch size of 20 products (appendix V: Costs on page 182). To estimate the cost price manufacturing has to be taken into account as well and for the retail price profits and such are added to the price.

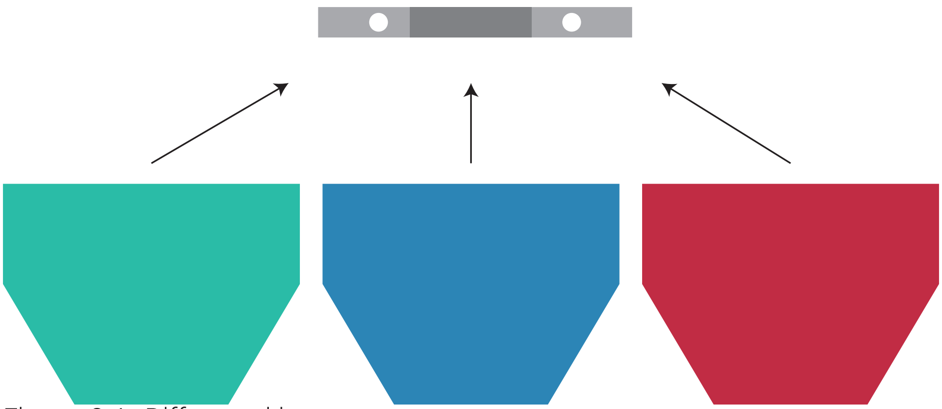


Figure 3.4: Different skins

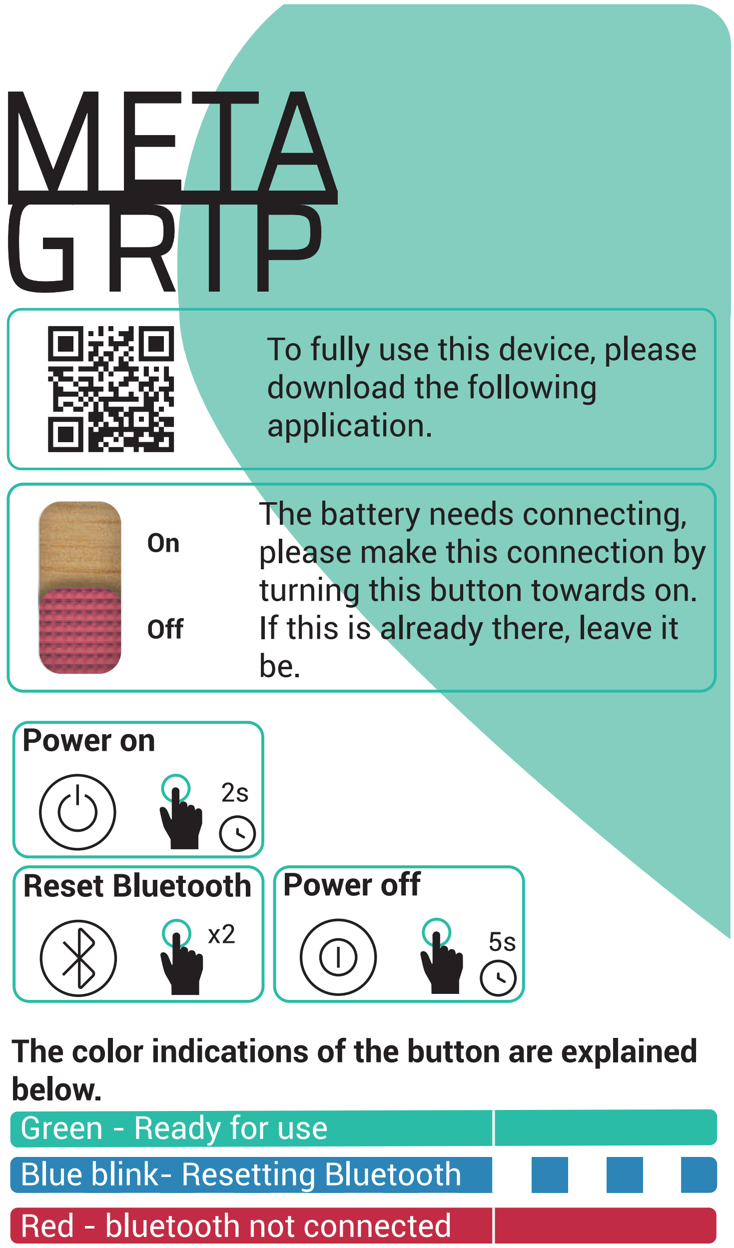


Figure 3.5: Instructions

Figure 3.6: Button

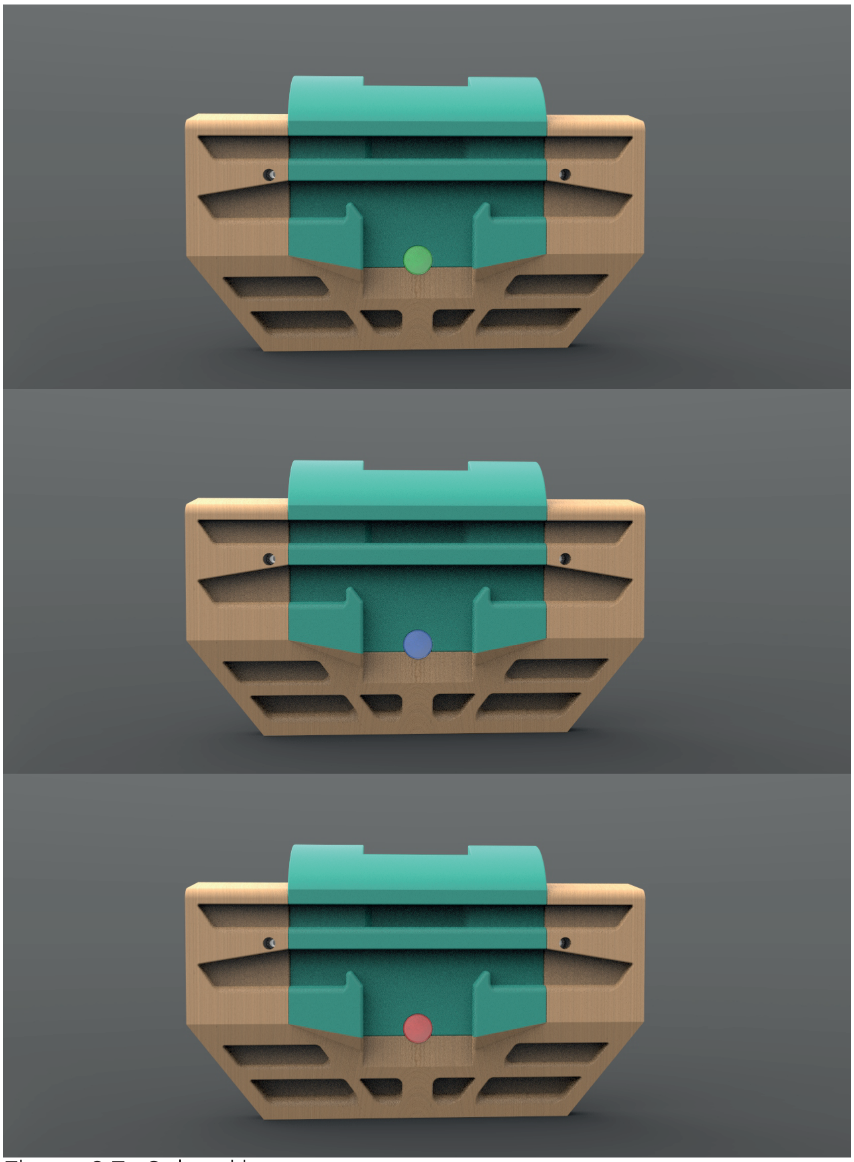


Figure 3.7: Colored button

3.3 The application

The Meta-Grip can be controlled with the mobile phone application. Via a Bluetooth connection different measurements and or trainings can be started. The Bluetooth connection allows the phone to be at a maximum distance of ten meters from the Meta-Grip. There are four basic measurements possible by the Meta-Grip which are maximum finger strength, explosiveness (figure 3.8), power endurance (figure 3.9) and critical force (figure 3.10).

Based on these measurements, feedback can be given as a percentage of bodyweight or in the form of climbing, as prior research demonstrated a relation between measurements and the climbing grade (appendix A: Introduction into climbing on page 70). Based on the difference between the desired level and the measurement of a climber, a training plan can be established to narrow the gap between the desired level and current level. The application is designed in such a way that the user can interact with the Meta-Grip unsupervised and intuitively understands the results of a measurement.

The results of the measurements will be stored in a database . This database allows over-time comparison of a climber's measurements, as well as analysis of the anonymized measurements of different climbers. With a growing number of measurements, the translation of the measurement results into a climbing grade and a training plan can be done more accurately over time with machine learning (appendix P. The Meta-Grip and machine learning on page 157). Besides the importance of the database for the climber or his/her trainer, the database can also be valuable to academics for research into the relation between hand and finger strength, injuries, climbing grades and training plans

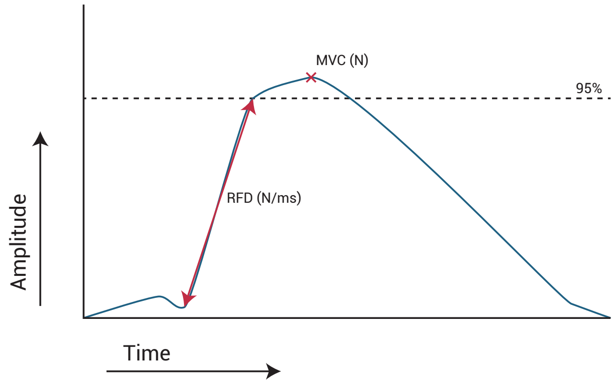


Figure 3.8: Maximum finger strength and explosiveness

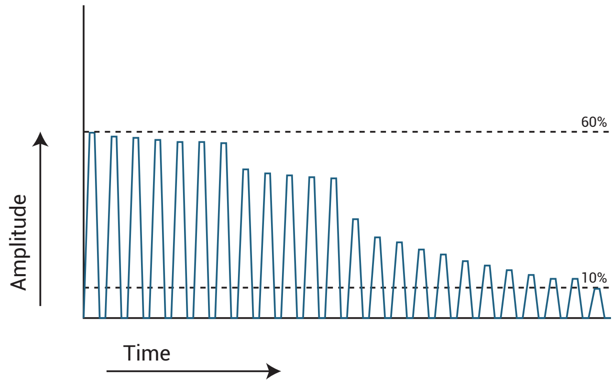


Figure 3.9: Power endurance

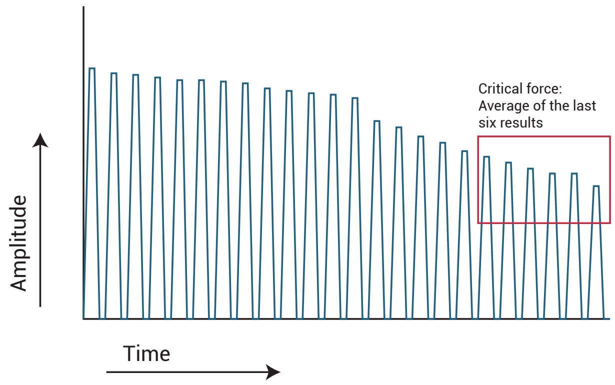
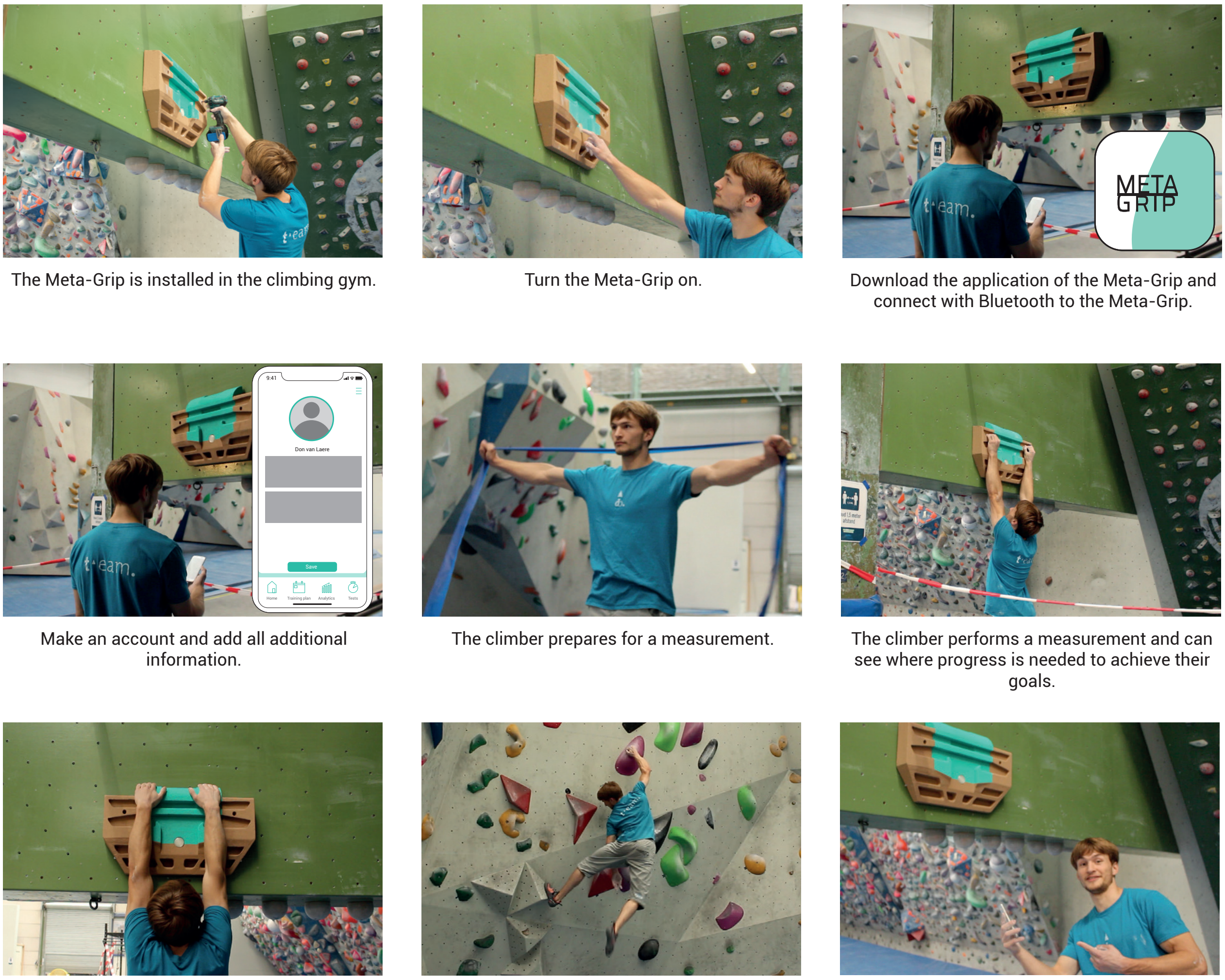


Figure 3.10: Critical force

3.4 Use scenario

In figure 3.11, the use scenario of the redesigned Meta-Grip is shown.



The Meta-Grip is installed in the climbing gym.

Turn the Meta-Grip on.

Download the application of the Meta-Grip and connect with Bluetooth to the Meta-Grip.

Make an account and add all additional information.

The climber prepares for a measurement.

The climber performs a measurement and can see where progress is needed to achieve their goals.

The climber performs exercises to reduce the gap between their actual climbing and their goals.

The climber can see the progress made towards their goals.

The climber continues training with the Meta-Grip to improve even further.

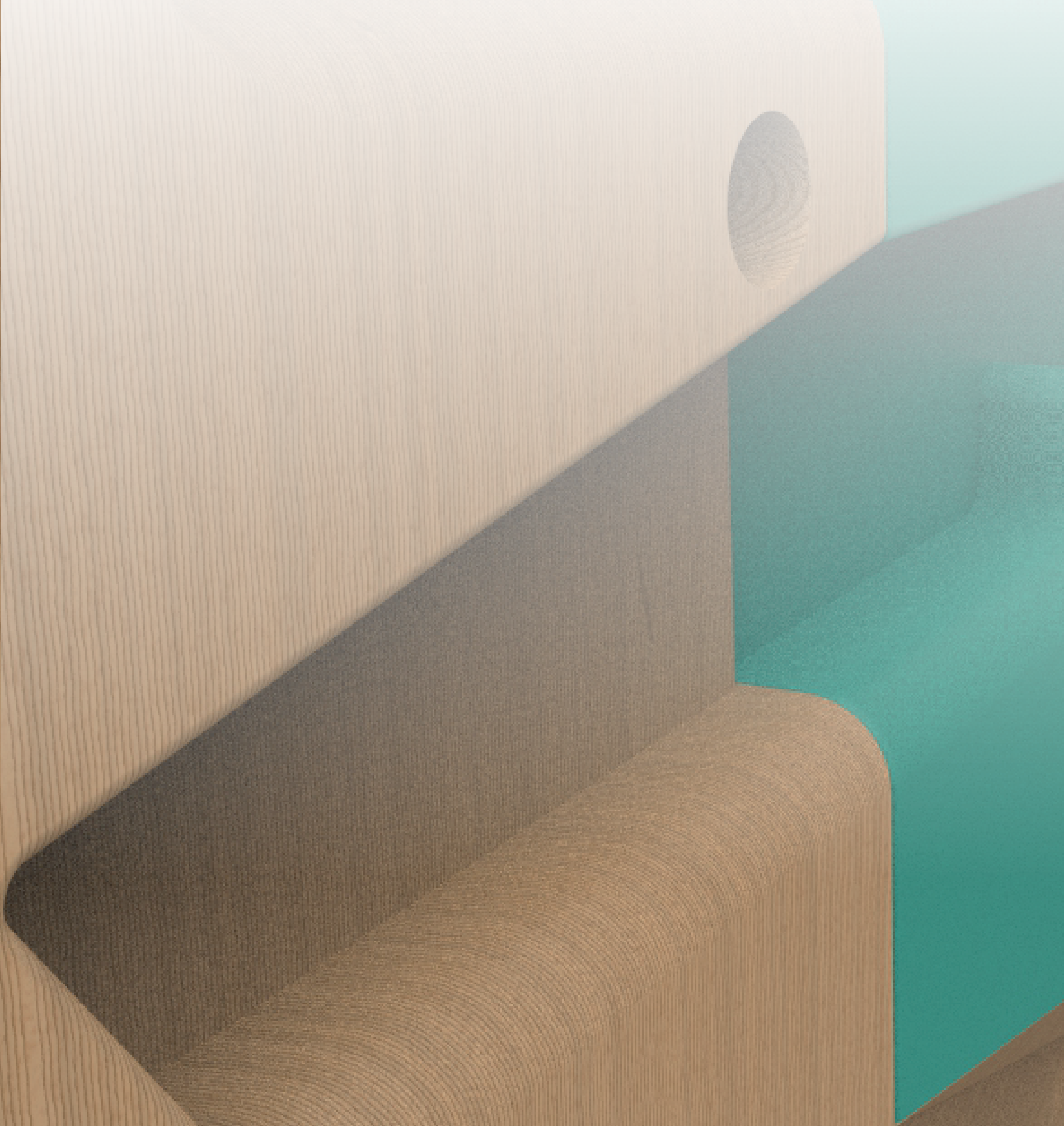
Figure 3.11: Use scenario

3.5 Conclusion

Three key challenges were defined for this research project in the previous chapter: a cost reduction, unsupervised use and improved embodiment. With regard to the costs, a large reduction has been realized, from 2520 euros to an estimated 120 euros. Unsupervised use has been made possible by the design of a user-friendly smartphone application. The embodiment is improved in several ways. The Meta-Grip has been transformed from a scientific measuring device into a well-known training device for climbers, a hangboard. It allows for easy use of different hold types and sizes. A more detailed explanation and argumentation on how the key challenges are met is presented in the next part of this report: ‘Details and choices’.

Part 2: Details and choices

This part provides more in-depth information about the different elements of the Meta-Grip. According to the Pyramid Principle, choices regarding the product and application will be substantiated. The product is described in chapter 4 and the application in chapter 5. Chapter 6 describes the assembly and production of the Meta-Grip.



Chapter 4

The product

In this chapter, the design of the physical part of the Meta-Grip will be discussed in more depth. The physical part consists of hardware and a skin. The skin is detailed in the first section, the hardware in the second section. This chapter concludes with an explanation of the installation.

4.1 The skin

The design of the Meta-Grip has the looks and functionality of a hangboard (figure 4.1). The design evolved from a process of iterations (appendix T: The Meta-Grip redesigned on page 167) and a creative session with four climbers (appendix J: Creative session at the Campus on page 124). The most important outcomes of the creative session are that all holds should be accessible at all times and the hardware is not visible to the user. There are two materials used in the Meta-Grip to get the best possible performance during a measurement and protect climbers from injuries while training, being Alder wood and polyurethane (PU) (appendix K: Materials on page 127). There is a total of eleven holds (of which 9 are mirrored for both the left and right hand) on the Meta-Grip, all differing in size and for either a full hand or two fingers. There is a DIP (distal interphalangeal joint) guard included to protect the climber when training in a full crimp with thumb position (figure 4.2) (appendix I: Climbing holds on page 114). In the center of the Meta-Grip, a button is added with which the user interacts when using the Meta-Grip. The button is (semi) translucent in order to give feedback in the form of a colored LED to the user (figure 4.3). On the side of the Meta-Grip, a switch for turning on and off the power and instructions on how to use the Meta-Grip are added (figure 3.5 on page 40).

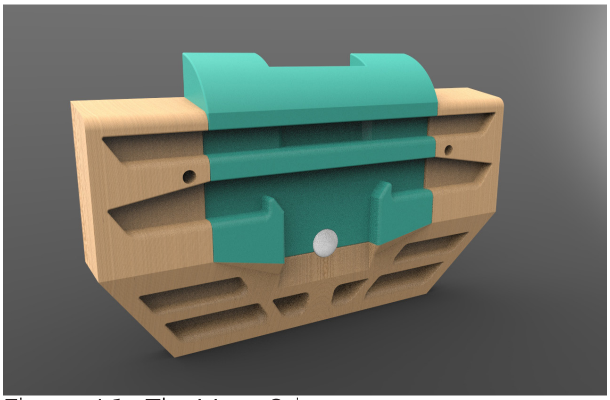


Figure 4.1: The Meta-Grip

Figure 4.2: DIP guard

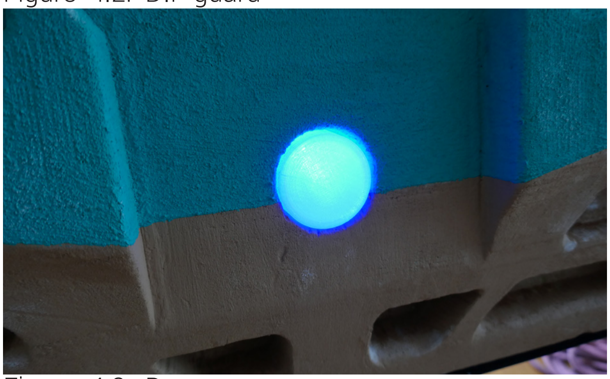


Figure 4.3: Button

4.1.1 Aesthetics

The holds of the Meta-Grip are placed left and right of the central axis, creating a symmetrical and horizontal balance (figure 4.4). The tapered bottom creates movement in the Meta-Grip (figure 4.5). This movement continues in the holds of the Meta-Grip, creating a movement both at the outer and inner edges of the Meta-Grip.

Two different materials have been selected for the Meta-Grip: alder wood (figure 4.6) and polyurethane. The balance created by both using natural and non-natural materials reflects the balance in climbing where originally non-natural tools are used to climb a natural rock wall. The PU part is a Puerto Rico green (figure 4.7) to contrast with the wood. This contrast with the colors makes the Meta-Grip more recognizable as being a special training tool. The color used for the Meta-Grip (and the colors used in the application) was based on preferences of and verified with climbers (appendix L: Color study on page 136). A color palette was defined based on the climbers' lifestyle and participants were asked to rank this and three other color palettes from most to least favorable. The predefined color palette was preferred by the participants in three instances. In one instance, where a complementary color contrast was used, this was not preferred.

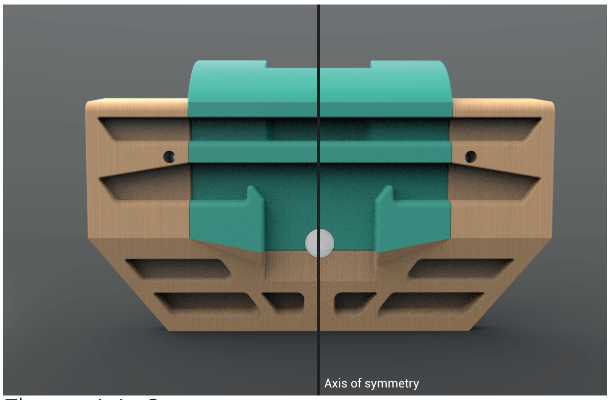


Figure 4.4: Symmetry

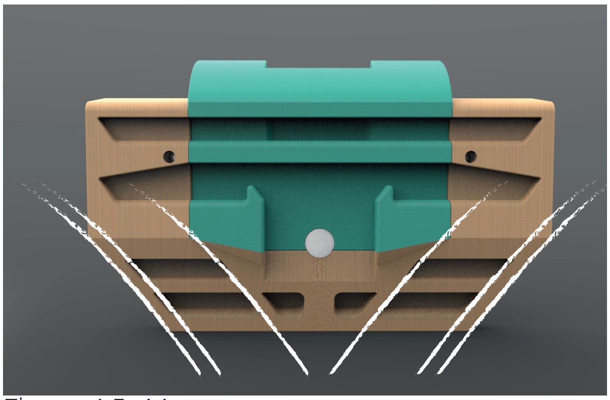


Figure 4.5: Movement


Figure 4.6: Alder wood


Figure 4.7: Polyurethane

In the center of the Meta-Grip, a big button is placed for interaction with the device. This button gives the suggestion that the device is more than a regular hangboard. The button is placed off-center between the plastic and wooden part, creating a connection between the two and guiding the eyes of the climber to the button. Since the button is also used to give feedback to the climber, a (semi) transparent material is needed. A semitransparent milk white color is chosen for the button (figure 4.8) to allow feedback to be given while at the same time hiding the hardware behind the button. Milk white is in contrast with the other colors of the Meta-Grip and catches the eye of the climber, making them even more aware of the Meta-Grip.

4.1.2 Materials

In the Meta-Grip, three different materials are visible to the user, wood and polyurethane for the holds and a button for the interaction. A study was done to determine where wood and polyurethane were desired (appendix K: Materials on page 127). This study was done with 13 participants with all prior experiences with hangboarding regularly. In the questionnaire participants had to decide what type of material (wood or PU) they would prefer for a training and a measurement on different holds. Users prefer measurements on PU for the sloper (73%), pinch (55%) and 1-phalanx crimp (64%). However, wood is preferred for measurements on the 2-finger pocket (64%) and ½ phalanx (64%). For training purposes, wood is preferred over PU for all hold types. The wooden part is made of alder wood (figure 4.9). Alder wood is chosen because of the balance between the openness of the grain, the uniformity of the grain and the grain size (appendix K: Materials on page 127). The plastic part is made out of PU which is coated with a paint mixed with quartz sand to create friction (figure 4.7 on page 40). Lastly, the button is made from polylactic acid (PLA) in a milk white color to ensure light can be let through and feedback can be seen (appendix K: Materials on page 127).

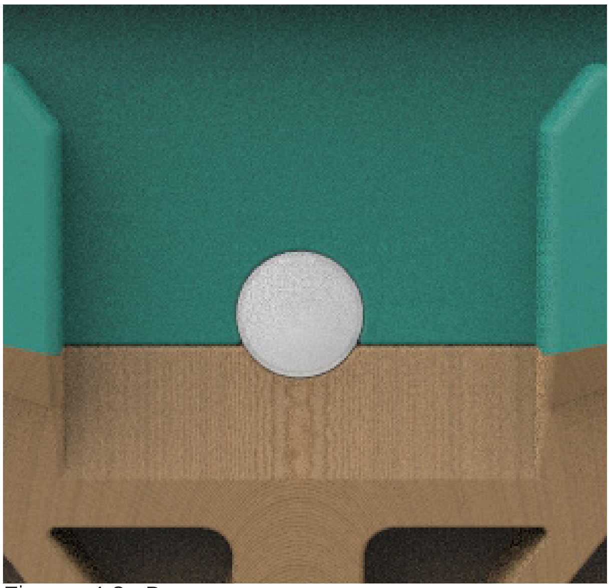


Figure 4.8: Button

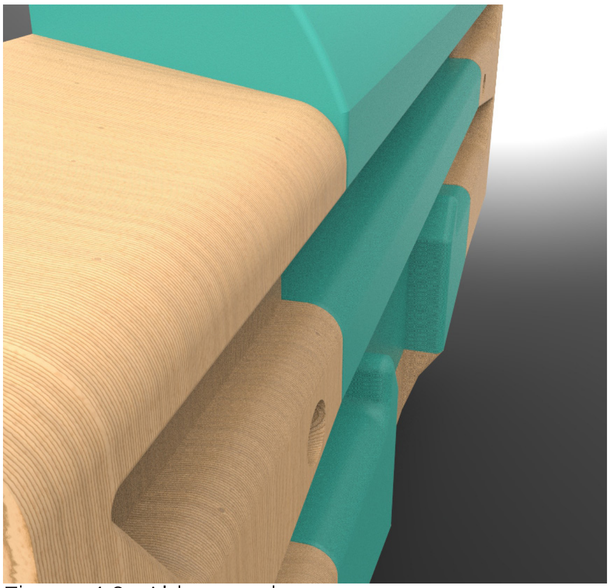


Figure 4.9: Alder wood

4.1.3 Dimensions

Hangboarding is mostly purely hanging with your fingers and hands, without the support of the feet. This puts a lot of strain on the fingers, making hangboarding prone to injury. To prevent injuries, a proper posture while hangboarding is needed which can be stimulated by correct dimensions in the Meta-Grip. A proper posture depends on the height of the hold, the distance between holds and the size of the hold (appendix I: Climbing holds on page 114). This means that the Meta-Grip should at least provide the user with a hangboard which they can use at shoulder width. With a width of 620 millimeters, the Meta-Grip is even accessible for P95 users (Dined, sd) (appendix I: Climbing holds on page 114). The depth of the Meta-Grip is dependent on the hardware that needs to fit in and the necessary material thickness. The Meta-Grip is 80 millimeters at its deepest and 31 millimeters at its smallest. Since the bottom part is not used for hardware, this is tapered in both the front and right plane (figure 4.10 and figure 4.11). This also allows the less tall users of the Meta-Grip to easily view and access the holds. The Meta-Grip is installed at a fixed height which potentially could be too high or too low for some users. However, hangboarding can also be done by adding an extra block to stand on or starting from the knees. For more measurements isee appendix T: The Meta-Grip redesigned on page 167.

Hold types and hold sizes to use in the Meta-Grip are defined by looking at previous research and existing hangboards, (appendix I: Climbing holds on page 114). This skin of the Meta-Grip is designed for the fanatic climber because in an interview with Frank Loeve, owner of climbing gym “De Campus”, it became clear that the fanatic climbers are by far the largest climbing group and if they are enthusiastic about the Meta-Grip, more are likely to follow (appendix G: Interviews on page 110). For the fanatic climber, the holds should be beginner hangboard hold sizes. There are four crimps with the sizes between 14 and 20 millimeters which will likely be used with a proper crimp grip (figure 4.12) (appendix I: Climbing holds on page 114). The edge of the crimps have a 10 millimeter radius. The edge radius influences the comfort and difficulty; the wider the radius the more comfortable and the more difficult it gets to hold it, and vice versa. To find

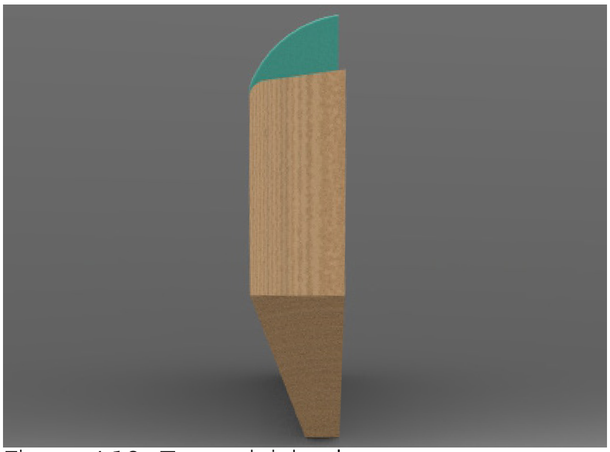


Figure 4.10: Tapered right plane

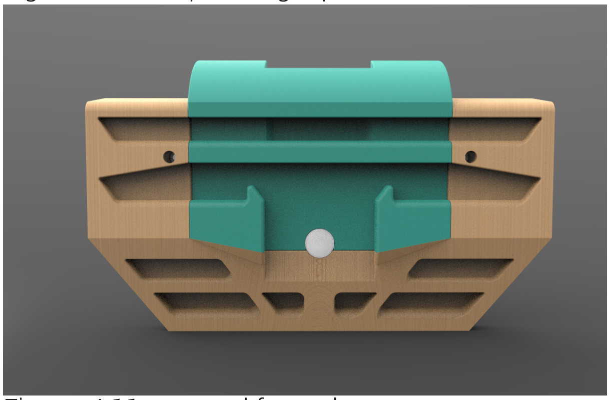


Figure 4.11: tapered front plane


Figure 4.12: Proper crimp grip on 14 mm crimp

the perfect balance between comfort and difficulty, a user test is done with four participants (appendix I: Climbing holds on page 114). In this user test a 5-points Likert scale is used to rate the difficulty and the comfort of holding a crimp. Users tested three different crimps, with an edge radius of 5, 10mm and 15 mm. From this user test, a 10 millimeter radius emerged as the best balance between comfort and difficulty (figure 4.14). The 24-millimeter hold will be used more with an open grip (figure 4.13) (appendix I: Climbing holds on page 114), depending on the expertise and strength of the climber. The 2-finger pockets are 26 millimeter deep to ensure that an injury is less likely to occur. To train in the full crimp with thump position a 22 millimeters edge with DIP guard is provided. There is one big jug at the top center of the Meta-Grip with just below a 30-millimeter edge. There are two slopers, an easy one with only a 10-degree angle and a difficult one, copying the sloper of the current Meta-Grip, with a 106,39-millimeter radius. All holds are illustrated in figure 4.15.


Figure 4.13: Open grip on 24 mm crimp

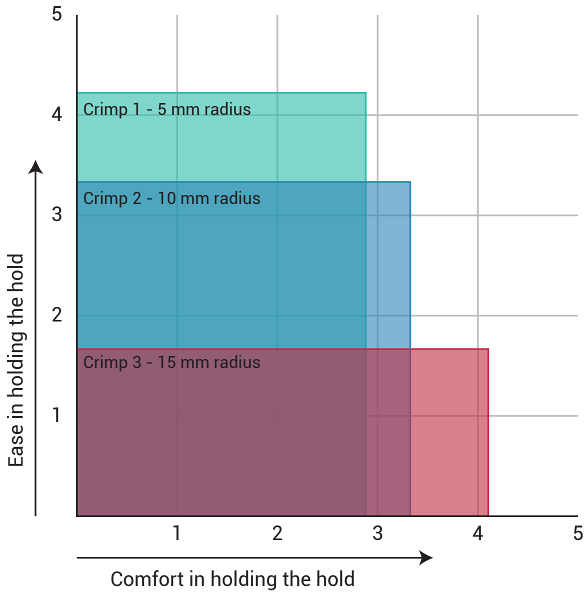


Figure 4.14: Radius size

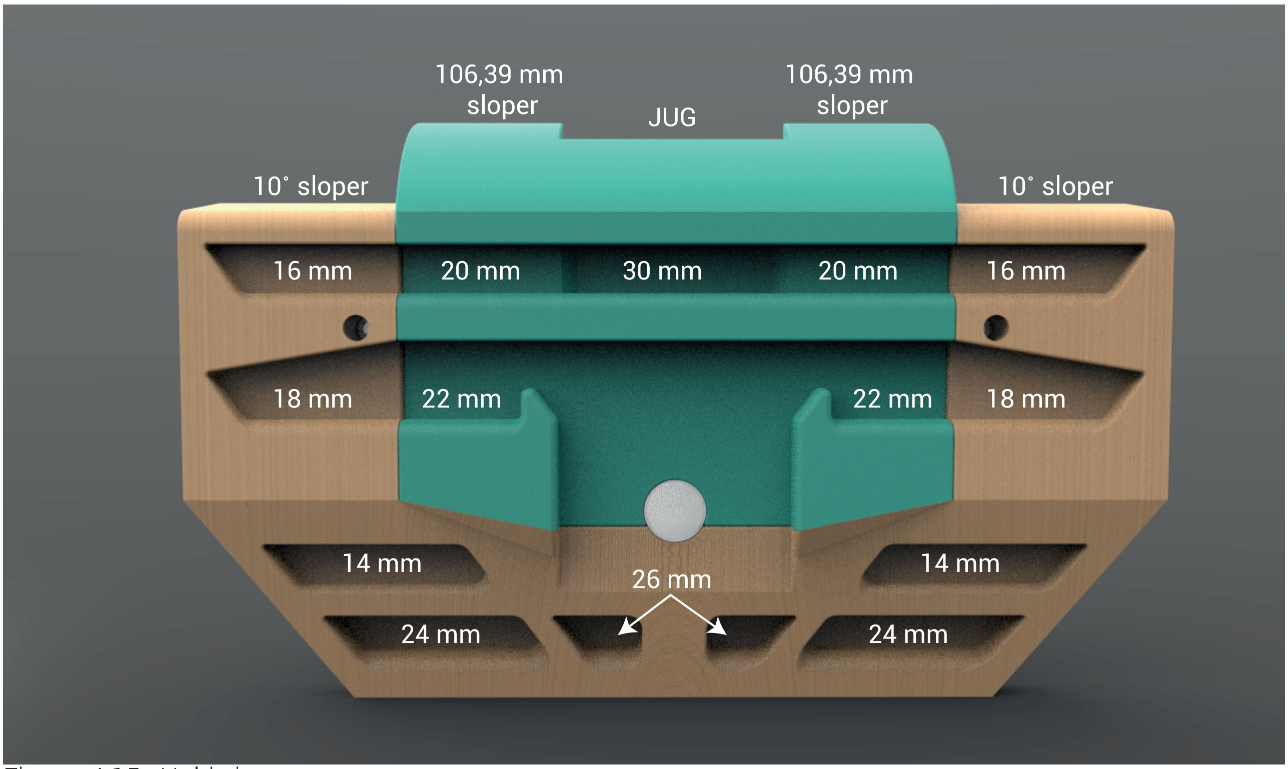


Figure 4.15: Hold sizes

Contradictory to the current Meta-Grip, the redesigned Meta-Grip is designed as a beginner hangboard. The current Meta-Grip could serve all users in one device since the difficulty of the holds could be changed by changing the angle. However, this versatility caused the device to be unattractive to the user and switching between holds is strenuous and unwanted. Disregarding the versatility allows to use different holds in one training.

Besides fanatic climbers, the amateur athlete and pro athlete climbers are also interested in a device like the Meta-Grip. Compared to the fanatic climber, these athletes are highly improvement centered and spend a fair amount of time training for their climbing goals. The current set of holds on the skin are for the beginning hangboard climber and different skins should be available for the more advanced climber, for example adding a 1-finger pocket (mono) or a pinch. To keep some consistency in holds in the Meta-Grip, the 106.39 mm radius and the 20-millimeter crimp is kept similar over all Meta-Grip skins. Consistency in the holds is important for comparing data and performance over multiple climbers and longer period of time, as will be explained in the next chapter.

4.1.4 Button

Most interaction with the Meta-Grip will be via the mobile phone of the user. The button on the Meta-Grip is used for the interaction that concerns turning the device on and off and resetting the Bluetooth. This is similar for the feedback; feedback will mostly be given via the mobile phone of the user, but feedback concerning the Bluetooth connection and whether the Meta-Grip is turned on or off will be given via a common cathode LED through the button. To determine the interactions with the button, a user test was done (appendix X: User test button feedback on page 189). In this user test, twenty participants were asked about interaction and. Most participants (80%) associated a single push with turning the Meta-Grip on. Pushing twice quickly was associated with resetting Bluetooth by 65% of the participants. More than half of the participants (55%) associated a three second long push with turning the Meta-Grip off. The interaction one single push was associated with the Meta-Grip being on (80%), resetting the Bluetooth was associated with pushing twice quickly (65%) and a long push for three seconds was associated with the Meta-Grip being turned off (55%). Regarding the light feedback, 18 out of 20 participants (90%) associated green light with the Meta-Grip being on. The participants were more divided over the other feedback options. A slight preference is visible for a red light to be associated with the Bluetooth being not connected (40%) and a blue fast blinking light with resetting the Bluetooth (50%).

4.1.5 Instructions

To make the interaction with the Meta-Grip without any problems, brief printed instructions are provided on the side of the Meta-Grip (figure 3.5 on page 31). These instructions include how to interact with the front button and what feedback it can give, instructions on how to download the app and instructions on turning the power to the hardware on and off. The instructions are printed on a sticker and put on a transparent poly (methyl methacrylate) (a.k.a. Perspex) plate which is connected with four screws to the Meta-Grip. This plate is slightly angled downwards since the Meta-Grip will be above eye height. The on and off switch for the battery sticks through the Perspex plate.

4.2 Hardware

The hardware in the Meta-Grip makes it possible to measure the force applied by the user to the Meta-Grip and to transfer this data to the smartphone application (appendix W: Electronics in the Meta-Grip on page 184). All the hardware fits inside the embodiment of the Meta-Grip (figure 4.16), making it invisible for the user. A complete overview of the electronics used in the Meta-Grip can be seen in the bill of materials in appendix U: Bill of materials on page 181.

4.2.1 Hardware for measurement

For measurement purposes, two load cells are used that each can measure safely up to 200 kg through strain gauges (appendix AE: Load cell specifications on page 220). Two, instead of one, load cells are used symmetrically for the stability of the Meta-Grip; this will prevent horizontal movement (figure 4.17). To prevent vertical movement, the Meta-Grip fits flush to the wall. The load cells that are currently sold need to be adapted (appendix T: The Meta-Grip redesigned on page 167 and appendix R: Load cell research on page 162) in order to properly attach the Meta-Grip to the climbing wall. Instead of four M6 holes at the top on one side, a big M10 hole is needed at the side of the load cell (figure 4.18).

4.2.2 Hardware for transferring data

For transferring data to the smartphone application, the loadcells are connected to an Arduino. An amplifier is added to make the data readable and a Bluetooth module is included for the mobile phone connection. To be able to use the device, a switch, on the side of the Meta-Grip needs to be turned on so that the battery (9V) is powering the Arduino. When the switch is turned on the Arduino is still in sleeping mode. This mode is an energy saving mode so the battery will last longer. To toggle the Arduino out of the sleeping mode, the front button is

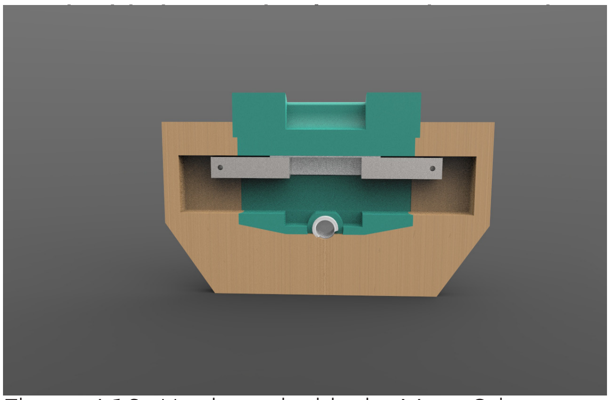


Figure 4.16: Hardware inside the Meta-Grip

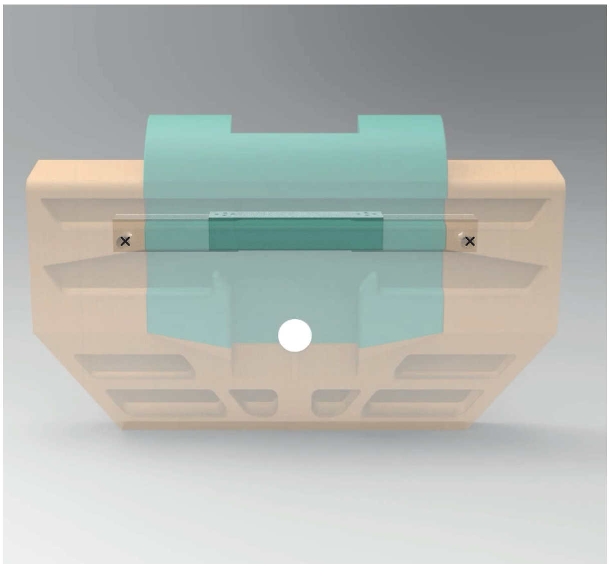


Figure 4.17: Preventing horizontal movement

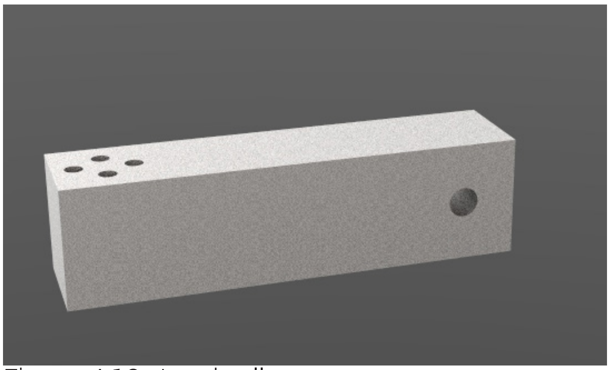


Figure 4.18: Load cell

4.3 Installation

The installation of the Meta-Grip is done easily by attaching two M10 bolts through the Meta-Grip into the climbing wall. The holes are distanced 40 millimeters apart allowing it to be put on all normal climbing walls (appendix AB: Climbing gym on page 208). Since the M10 bolt heads have to go deep in a shaft, an extended drill bit is essential. These M10 bolts, including the head, go completely through the skin (blue line) and tighten only the load cell onto the wall (white line) while the Meta-Grip is applying force on the other side of the load cells (figure 4.19). A washer of one millimeter creates space between the wall and the load cell to prevent friction from obstructing a measurement. This is all explained in the installation manual when setting up the Meta-Grip. The M10 bolts should be tightened properly, preferably with an 18 Volt impact driver which is a common tool within climbing gyms. After installing the Meta-Grip onto the wall, it needs to be calibrated. This is done by hanging a known weight on the Meta-Grip, calibrating it till it reaches that exact weight (appendix AD: Software Arduino on page 212).

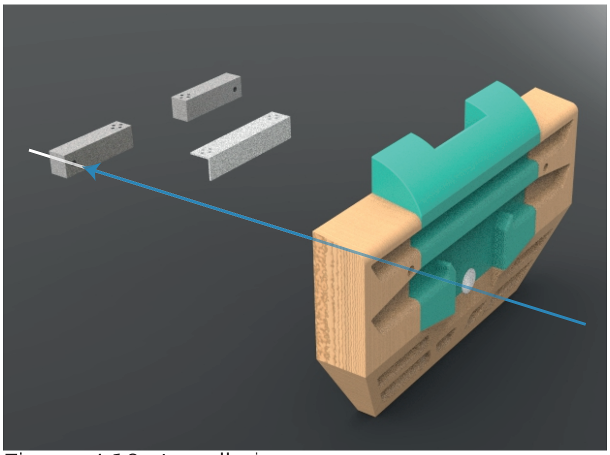


Figure 4.19: Installation

Chapter 5

The application

In this chapter, the application offered as a service with the Meta-Grip will be further detailed. There are three important parts concerning the application, namely the connection between the hardware and the application, the connection to the database and the application itself.

5.1 The application

The application design has to be intuitive and informative; it should enable unsupervised use.

Eight main screens make up the structure in the application (appendix M: The application on page 142):

1. Login/sign up. This screen allows the user to either create an account or log onto an already existing account.
2. Home (figure 5.1). In this screen, an overview is given on the current status of the training plan, previous measurements and upcoming trainings or measurements.
3. Menu (figure 5.2 on page 48. This drop-down menu is the main navigation between the different pages.
4. Training plan (figure 5.3 on page 48). In this screen, it is possible to see previous and upcoming trainings and the progress as well as importing trainings that were executed without guidance from the application.
5. Analytics. This screen shows results of measurements, with more in-depth information.
6. Tests. In this screen, a measurement can be started and executed.
7. Profile. This screen shows the user profile and the set goals and gives the ability to edit this.
8. Settings. Here, the settings of the app can be changed, like settings for notifications.

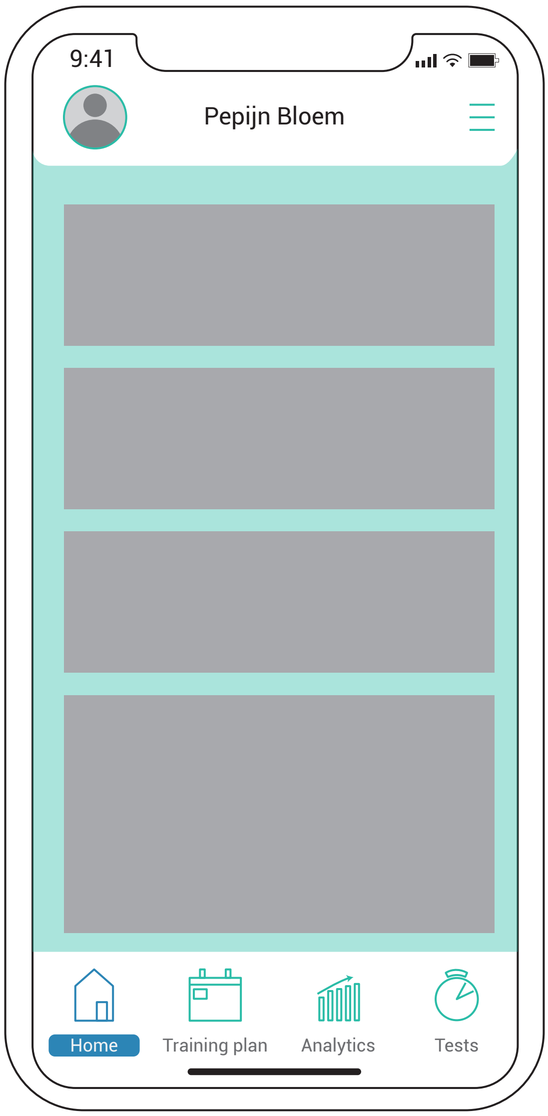


Figure 5.1: Home screen

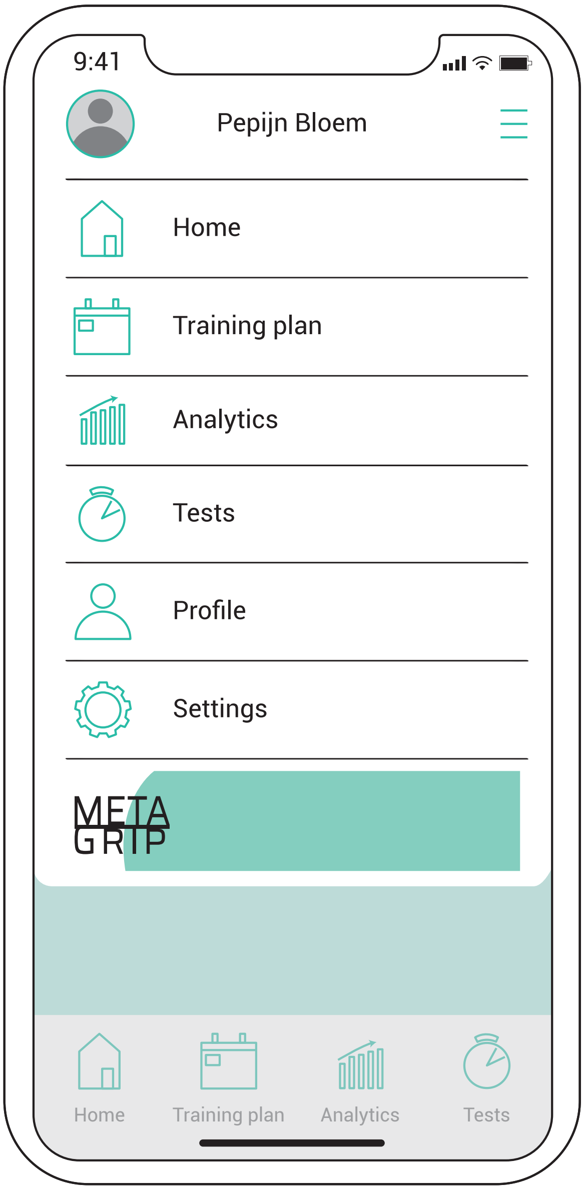


Figure 5.2: Menu

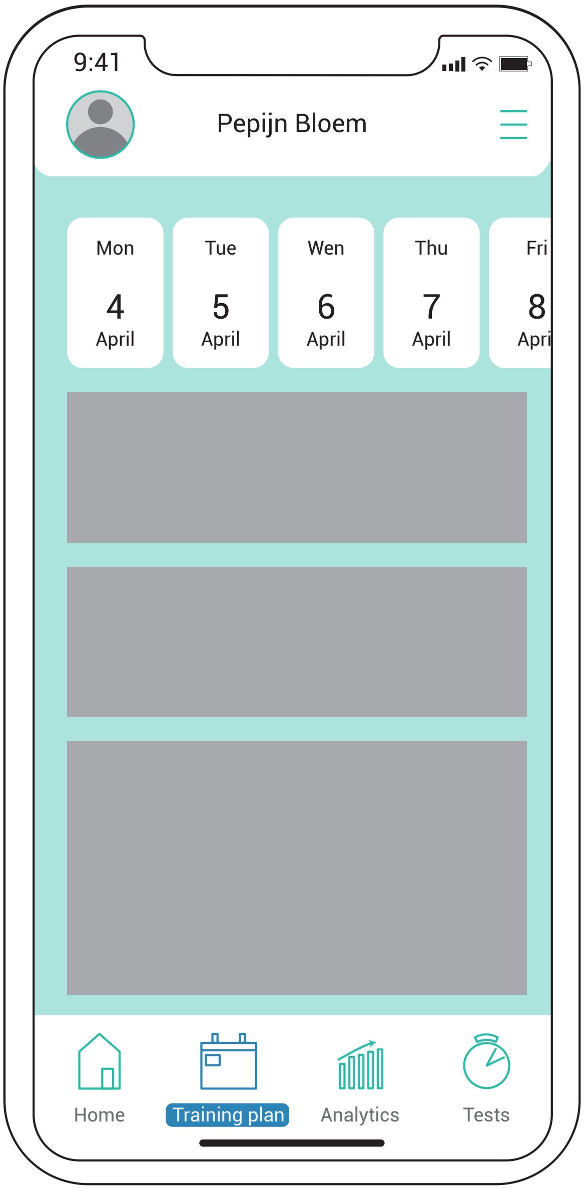


Figure 5.3: Training plan

In the application, the user can do measurements, store the data and other training plans and perform training plans or exercises. The application gives suggestions on exercises with which desired improvements can be made. Developing a proper training plan, asks for a personalized approach for each individual climber. To simplify this, three basic training plans are provided with an increasing intensity: low, medium or high. The intensity required for a climber is determined by four factors (appendix O: Determining a training plan on page 155), as suggested by Jelle Schouten, physiotherapist with a lot of experience with hand and finger injuries among climbers:

1. Climbing level
2. Years of climbing experience
3. Amount of trainings per week
4. Relation between climbing years and climbing level (speed of growth in climbing)

After establishing these four factors, an intensity of finger and hand training can be established (low, medium or high) and a proper training plan or exercise suggestion is made. In some cases, a complete training plan is not required since one is already executing an existing training plan. In that case, only specific suggestions on exercises and results should be given.

Feedback to the climber is given in terms that are easily understandable by the climber like climbing grades or a percentage of bodyweight (appendix Q: Feedback analysis on page 160). However, for trainers and physiotherapists it can be interesting to see more detailed results to accurately pinpoint where improvement is necessary.

The application is still in its early design phase and needs a lot of development to become fully functioning. In order to make the best design fitting to the climber, a creative session with five participants was hosted with the goal to find what the user would prefer (appendix N: Creative session for app design on page 149). From this creative session, specific guidelines emerged for the design of the application:

1. Do not show how many repetitions there are left exactly during a training or measurement, but give an indication of the progress (e.g. a color gradient).
2. Bright color contrasts can help get the attention of the climber even when they are tired.
3. Feedback should be given on a general level (e.g. climbing grades), but allowing to get more specific details about results.
4. Comparisons should be possible with previous measurements, but also with training plans.

There are more general design guidelines for designing an application which are described in appendix M: The application on page 142.

To establish a good link with the Meta-Grip, a color match is established between the Meta-Grip and the application. Within the application, multiple colors (figure 5.4) are used as primary color, secondary color and activation color. These colors were positively valued and accepted by a sample of the climbing population (appendix L: Color study on page 136).

Figure 5.4: Colors

5.2 The connection to the hardware

In order for the user to control the Meta-Grip, a connection between the hardware and the application is needed. The connection with the Meta-Grip needs to be two-directional: the climber wants to receive data from measurements, but also wants to send commands to the Meta-Grip. This is established by a Bluetooth module (HC-05) connected to the Arduino. This Bluetooth module has a range of ten meters. With the button on the front of the Meta-Grip, a previous connection can be disabled and the Meta-Grip then becomes visible for the new climber to connect with. After finishing a measurement, the data first has to be analyzed in the database, before the results can be presented to the user. The database is placed on a company owned independent server.

5.3 The connection to the database

The database is an important element of the Meta-Grip application. Very little research is yet available on the influence of finger and hand strength on climbing performance. The little research that is available and the data that already has been collected by earlier research with the Meta-Grip is used by an expert to transform measurements into a training plan and give feedback to the user. The next step is to be able to give feedback without the need of an expert which can be done via machine learning (appendix P. The Meta-Grip and machine learning on page 157). This can be achieved and become more accurate with a growing database. Eventually, the training plans can also be based on machine learning, without the involvement of an expert in the process. To allow for this all data should be stored and owned by Meta-Grip. Experts at Meta-Grip are then able to continuously analyze this data and improve the algorithms to transform measurements into training plans. In the end, machine learning can be used to continuously improve the training plans.

For the analysis of data and machine learning it is important that data is comparable. You cannot compare apples with oranges: the same type of measurements on the same holds should be compared. This is why it was chosen to include the 20 millimeter crimp and the 106.39 millimeter sloper that is used in the current Meta-Grip since data is already available on these hold types This is also why in each different skin of the Meta-Grip the two holds are kept constant.

Having a database owned by Meta-Grip requires an internet connection; the connection to the database is established by using

Chapter 6

Assembly and production

In this chapter, the Meta-Grip production and assembly will be discussed (appendix T: The Meta-Grip redesigned on page 167), as well as the cost price of the Meta-Grip (appendix V: Costs on page 182). We assume the Netherlands is the first market, since the initial production and research is done in the Netherlands. The market of dynamic training devices is small and international with only five other companies that produce products in this market all located outside of the Netherlands (appendix D: Involved parties with the Meta-Grip on page 80). In other sports, objective measurements have become increasingly important. It is likely that this is to transfer to climbing as well, especially now climbing has been added to the list of Olympic sports (Sport Climbing, sd). Hence, the dynamic training devices market will start growing. The amount of climbing gyms has rapidly increased and with the climbing gyms, the number of climbers has increased. Based on these developments, we assume the Meta-Grip has potential.

In the beginning, it is important to gain exposure. Therefore, we aim for climbing gyms in the Netherlands as our first clients, and secondly on physiotherapist and trainers. Currently, the Netherlands counts 39 climbing gyms and there are 43 climbing associations (Klimhallen en verenigingen in Nederland, sd). We aim at a coverage of 50%, requiring the first batch to contain 20 Meta-Grips. Through climbing gyms and trainers, many climbers will learn about the existence of the Meta-Grip and gain interest in using it and potentially buying it.

Since most competitors are international, it is likely that the Meta-Grip will quickly gain awareness on the international market and if shown that the Meta-Grip is an addition to climbing gyms and training effectivity and efficiency of climbers increases, the Meta-Grip will have an international market potential.

The next sections describe how these 20 Meta-Grips will be produced and assembled.

6.1 Wooden part

The wooden part of the Meta-Grip is made using a CNC milling machine. The front face of the Meta-Grip needs a high precision milling, whereas the back needs less precision and finesse since this is not used by climbers or seen by climbers. The wooden part will be milled out of a block alder wood with the following dimensions: 80 x 620 x 340mm.
After the wood is milled in the proper shape, some sanding may be necessary to make the surface even.

6.2 Polyurethane part

After the wooden part is finished with milling, the polyurethane part can be made. The wooden part is used as a mold and finished off with silicon to make it an enclosed shape. There is a second mold inside to be able to create a hollow space where the load cell is attached and for less material use. Directly making the polyurethane part in the wooden part ensures a connection already when the plastic is curing. This connection is than strengthened by adding screws at four locations.

6.3 Button

The button is made out of PLA and this is done initially by 3D printing. Although the price of 3D printing is higher than with other production methods, it enables changes to be easily implemented and prototypes can be easily produced . The other viable option would be injection molding. However, injection molding becomes cost-effective for much higher numbers of products which would make the mold quite expensive for only a few products and thus undesirable (Guide to Manufacturing Processes for Plastics, sd).

6.4 Hardware

The hardware will mostly be purchased from wholesalers. However, some parts need to be designed specifically for the Meta-Grip. This concerns the Printed Circuit Board (PCB). The Arduino currently used will be replaced by this PCB, being able to fulfill the needs of the Meta-Grip without having the extra, unnecessary features of an Arduino and reducing the clutter of wires. This is done by an external company since they have the expertise and equipment. Furthermore, to attach the electronics to the Meta-Grip, screws are necessary. For the load cells, a L-beam is needed and screws and insert nuts to attach both the load cell to the climbing wall as well as the load cell to the Meta-Grip (appendix T: The Meta-Grip redesigned on page 167 and appendix AA: Accuracy test load cell on page 206).

Software, database and application
The software (the code on the Arduino), database and application still need to be developed and improved. A proof of concept is given and a possible design for the application is shown briefly (appendix W: Electronics in the Meta-Grip on page 173 and appendix M: The application on page 142), but further development is necessary. Furthermore, the application, database and software need to be connected with each other for full use of the Meta-Grip.

6.5 Cost analysis

In the proposal of the future of the Meta-Grip, the cost price was preferred at a maximum of 800 euros (Orth, 2019). The cost price of the redesigned Meta-Grip is estimated on 120 euros (appendix V: Costs on page 182), being a large reduction from the preferred maximum cost price. The wood part is approximately 11 euros, the PU part approximately 20 euros and the hardware and mounting hardware is the remaining 89 euros. The price mentioned is solely based on the material costs, the manufacturing costs are not yet integrated. This will add a certain percentage on each Meta-Grip, depending on how many Meta-Grips there will be sold. The manufacturing that will have an impact on the cost price is the milling of the wood, the pouring of the PU and the 3D printing since investments in instruments need to be made.

To define the price the Meta-Grip for the buyers, more factors need to be taken into account. There is an overhead factor for operating costs which will include the expenses of the process like research, prototypes and certification and is approximately 20 percent of the price of the Meta-Grip. There is a profit margin (15 percent) included in the retail price and the VAT (21 percent) needs to be included (Thomassen, 2013). If the Meta-Grip is to be sold through various stores and organizations, there is going to be an overhead and profit margin as well for these intermediaries. However, if with the established connection in the climbing world, these intermediaries would be redundant and the price of the Meta-Grip can be lower. The total factor that needs to be added to the cost price in this case (no intermediaries required) is calculated ((overhead factor+1)*(profit margin+1)-1=total factor) which is 38 percent (Thomassen, 2013).

The organizations that are most likely to purchase the Meta-Grip are trainers, climbing gyms and physiotherapists since they will likely have more money to spend than individual climbers. In an interview with a climbing gym owner, it became apparent that a retail price below 500 euros would be an easy expenditure (appendix G: Interviews on page 110 and appendix Y: Final evaluation on page 196). Since approximately 38 percent has to be added to the cost price and the manufacturing costs have to be included (estimated to be around 30 %), the retail price of the redesigned Meta-Grip, being around 215 euros exclusive VAT, is still by far within the price range for buyers.

Part 3: The next step

This part compares the result of the project with the assignment that was set at the start of the project. From this comparison, multiple recommendations can be made.

Chapter 7

Conclusion

The goal of this project was to redesign the Meta-Grip to make it more fit towards the need of potential users. For this project, the formulated assignment was as follows:

"Redesign the Meta-Grip in such a way that it becomes an affordable and recognizable tool that measures finger and hand strength and provides immediate and understandable feedback to the climber, that can be used unsupervised by climbers and is an addition to the currently available training tools."

The assignment is met in the redesign of the Meta-Grip with the following aspects:

- The cost price estimate for the Meta-Grip is 120 euros which is less than ten percent of the cost price of the current Meta-Grip.
- With the load cell, Bluetooth module, the corresponding hardware and software, climbers are able to control the Meta-Grip through the application on their phone, and do measurements and perform trainings unsupervised by an expert.
- In the application, it is possible to get immediate and understandable feedback in climbing grades, which is something that is used and understood by all climbers.
- The redesigned Meta-Grip is equipped with a color palette, chosen and verified with climbers. This color palette is also used in the application. Furthermore, the contrast between the materials used in the Meta-Grip will likely make the Meta-Grip recognizable.
- The Meta-Grip is a dynamic hangboard, recognizable for climbers, and through the possibility of measurements and feedback an addition to currently available training tools, which are mostly static.

Satisfying the key challenges and requirements (appendix Z: Requirements and wishes on page 202), the redesigned Meta-Grip fits the assignment. Improvements and iterations still have to be made before the Meta-Grip can be marketed (see chapter 8: recommendations & discussion on page 59), however, the outcome of this project is the perfect stepping stone to a salable product.

Chapter 8

Recommendations & discussion

In this chapter, recommendations are made for the redesigned Meta-Grip. The redesigned Meta-Grip is a concept and a good stepping stone for further development of the Meta-Grip. During the process and with the evaluation (Appendix Y: Final evaluation on page 196), recommendations and suggestions for further research and development came to the surface.

The database is an important part of the service of the Meta-Grip. With a lot of measurements on the same types of holds, machine learning can be applied to automatically translate measurements into training plans. Currently, the reliability of the hardware and software is high enough for this. However, the user is the weak point in this. It would require all users to use the exact same for example half crimp position every time and this is difficult to accomplish (evaluation interview Jelle Schouten). Writing proper protocols that the user can follow intuitively should increase the validity of the measurements. To establish this, research to the validity is needed in collaboration with physiotherapists. Furthermore, the validity and reliability will also increase when the amount of measurements in the database is large. Enlarging the database quickly should be one of the aims of the Meta-Grip when first marketed. Furthermore, a 1000 Hz sample rate is ideal for the database to collect sufficient data points. This is not yet reached with the current hardware and software.

The Meta-Grip relies on the first results of research into a correlation between hand/finger strength measured in MVC and climbing performance. More research is needed to support this correlation and to look for a possible correlation between other measurements, such as RFD/CF/Stamina and climbing performance as well. When these correlations are proven by research data, feedback on the measurements can be more reliably given in terms understandable for climbers, in climbing grades.

The database can accommodate many different functions. Measurements have to be stored in the database. For reasons of comparing different measurements over time, personal data of climbers have to be stored as well. Trainers and physiotherapists are interested in the use of the application if climbers can share their data of measurements with them, again requiring personal data of climbers and trainers/physiotherapist to be stored. Since the Meta-Grip also gives advice on trainings and the progress within a training, training data has to be stored. This enables climbers to share their trainings with other climbers. This requires a carefully designed database that protects the privacy of the users. Furthermore, a Data Protection Impact Assessment is needed to comply with European law on privacy and data.

Climbing gyms are probably the first stakeholders to buy the Meta-Grip and offer it to their climbers as a training facility. Most climbing walls are made by hand using a template to drill in the holes. This makes every climbing wall differ slightly and the distance between the holes would not be exactly 200 millimeters. The Meta-Grip attachment is currently made for exactly the distance of two holes. It is desired that the Meta-Grip fits in every climbing gym so the attachment should allow a little flexibility in distance. Furthermore, in a climbing gym, training tools and other devices are used quite often which would make the battery an impediment. A battery is eventually going to run out of power whereas a wall outlet is not. Both these powering options should be available for the Meta-Grip at an easily accessible place without having to detach the complete Meta-Grip.

The Meta-Grip is vary spacious making the Meta-Grip quite large in size. According to climbers and climbing gym owners, the extra space on the Meta-Grip can be used for additional holds. The holds currently are chosen based on internet research. The interviews for evaluation already resulted in suggestions for different holds: more variation in the crimps by changing the angle across the horizontal surface, varying the size of the crimps by adding an insert, three-finger pocket over a two-finger pocket. User tests should be executed to establish what holds and materials are to their liking. Equally important is to know training on what holds contributes best to recovering from certain injuries or to improving the climbing performance. Research is needed to indicate training on which holds contributes best to increasing MVC, RFD, CF or power endurance.

Production wise, the Meta-Grip can still be improved, especially with regard to durability and sustainability. In the redesigned Meta-Grip a large block of wood is necessary for milling out the shape but a lot of the wood will be discarded. The backside of the Meta-Grip should be made that as much as wood and PU as possible is be left in the Meta-Grip.

An important function of the application is to motivate climbers to go hangboarding for improvement and for revalidation. An important trigger for motivation is seeing improvement. In the evaluation interviews it was questioned whether sufficient progress is visible in a short time period. If progress is hardly visible, this is probably not motivating climbers much. In the creative session different other triggers and feedback options for motivation were given. Further research is required to see how even the smallest progress can be made visible; the hardware in the Meta-Grip allows for detailed and precise measurements, so this might be possible. Furthermore, users should be involved in the development of additional motivational systems into the application.

This research showed the potential of a redesigned Meta-Grip. The next step is to further elaborate the concept and all parts of the product-service system. Additional to that, an in-depth market analysis should be made, together with a detailed cost estimate to complete the business case. The Meta-Grip has potential to grow into a product that is sold worldwide.

Chapter 9

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Appendices

In the appendices, extra information is given to support the main report.

Appendix A

Introduction to climbing

As in any sport, there are of lot of different branches within climbing. Climbing is divided into a couple of branches, with the most popular being bouldering and sport climbing. A quick overview is given of the different branches within climbing. Furthermore, the grade system is explained and different artificial holds and grips are highlighted.

A.1 Climbing disciplines

The oldest form of climbing is aid-climbing (figure A.1) where a rope, protective and pre-fixed equipment is used to aid the ascent. The purists among climbing thought that aid-climbing was cheating, from where traditional climbing (figure A.2) originated. Here, a rope and protective gear is used to climb a surface. It is different from aid-climbing because the climber is solely climbing the ascent without any help of equipment such as ladders. The equipment is used for protection only. Lead climbing is similar to traditional climbing but the difference is that the protection is already placed in the wall. Sport climbing (figure A.3 on page 71) is climbing a route on belay so there is no risk of having a lead fall, which could be dangerous. The last sort of climbing is bouldering (figure A.4 on page 71) where no rope is used and the low-height movements are protected by a crash pad. If you eliminate all the gear, the climb becomes a solo climb (figure A.5 on page 71) where no protection is used during the climb (De discipline klimsport, sd).

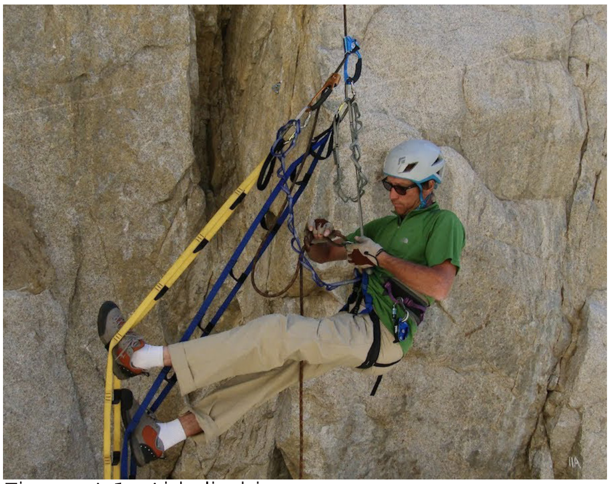


Figure A.1: Aid climbing

Figure A.2: Trad climbing

A.2 Grading system

Every climbing discipline uses the same grading system, however grades across the different branches can be interpreted differently. For example, a 8A boulder (Font) has three very difficult moves, but the moves of an 8A sport climb (French/sport) route are less difficult. However, linking all the moves together is as hard as three difficult 8A boulder moves. The difficulty of a route or boulder comes from the length, difficulty of the moves, but also the mental game. If it is a high risk route or boulder, the mental game of the climber needs to be very strong to be able to climb it, even though it could be a grade easily climbed by the climber. To be able to compare grades for boulder with grades for sport climbing, the IRCRA scale (Draper & Giles, 2016) (figure A.6 on page 72) exists.

Besides the French/sport grade and the Font grade, there are many other grades used. The most common grade in America is the Yosemite Decimal System (YDS) and the Vermin scale. The British Tech system grades the hardest move in a route making it unsuitable to grade complete routes and is thus not used often. The Ewbank system originated in Australia and is very similar to the Vermin scale. The BRZ known as the Brazilian grading system is part of a larger structure of grading routes in very high detail. This system can give a lot of information about the route beforehand on for example the hardest move, protection and duration. The Internationale des Association d'Alpinisme (UIAA) scale uses Roman numerals to grade routes and is mostly used in long climbs in the alps and short climbs in some European countries. All these grades correspondent with each other in a specific way which is displayed in figure A.6 on page 72.

Figure A.3: Sport climbing

Figure A.4: Bouldering

Figure A.5: Soloing

Climbing Group		Vermin	Font	**IRCRA Reporting Scale**	YDS	French/sport	British Tech	Ewbank	BRZ	UIAA	Metric UIAA	Watts
				1	5.1	1	2	4	I sup	I	1.00	
				2	5.2	2		6	II	II	2.00	
				3	5.3	2+		8	II sup	III	3.00	
				4	5.4	3-	3		III	III+	3.50	
Lower Grade (Level 1) Male & Female				**5**	5.5	3		10	IV	IV	4.00	
				6	5.6	3+	4	12	V	IV+ V-	4.33 4.66	0.00
				7	5.7	4		14		V	5.00	0.25
				8	5.8	4+				V+	5.33	0.50
		VB	< 2	**9**	5.9	5	5a	16	V sup	VI-	5.66	0.75
				10	5.10a	5+		18		VI	6.00	1.00
		V0-	3	**11**	5.10b	6a	5b	19	VI	VI+	6.33	1.25
	Intermediate (Level 2) Female	V0	4	**12**	5.10c	6a+	5c		VI sup	VII-	6.66	1.50
Intermediate (Level 2) Male		V0+	4+	**13**	5.10d	6b		20		VII	7.00	1.75
		V1	5	**14**	5.11a	6b+		21	7a			2.00
			5+	**15**	5.11b	6c	6a		7b	VII+	7.33	2.25
		V2	6A	**16**	5.11c	6c+		22		VIII-	7.66	2.50
		V3	6A+ 6B	**17**	5.11d	7a		23	7c	VIII	8.00	2.75
	Advanced (Level 3) Female	V4	6B+	**18**	5.12a	7a+	6b	24	8a	VIII+	8.33	3.00
		V5	6C 6C+	**19**	5.12b	7b		25	8b			3.25
Advanced (Level 3) Male		V6	7A	**20**	5.12c	7b+		26	8c	IX-	8.66	3.50
		V7	7A+	**21**	5.12d	7c	6c	27	9a	IX	9.00	3.75
			7B	**22**	5.13a	7c+		28	9b	IX+	9.33	4.00
	Elite (Level 4) Female	V8	7B+	**23**	5.13b	8a		29	9c	X-	9.66	4.25
		V9	7C	**24**	5.13c	8a+		30	10a			4.50
Elite (Level 4) Male		V10	7C+	**25**	5.13d	8b	7a	31	10b	X	10.00	4.75
		V11	8A	**26**	5.14a	8b+		32	10c	X+	10.33	5.00
		V12	8A+	**27**	5.14b	8c		33	11a	XI-	10.66	5.25
		V13	8B	**28**	5.14c	8c+		34	11b	XI	11.00	5.50
	Higher Elite (Level 5) Female			**29**	5.14d	9a	7b	35	11c			5.75
Higher Elite (Level 5) Male		V14	8B+	**30**	5.15a	9a+		36	12a	XI+	11.33	6.00
		V15	8C	**31**	5.15b	9b		37	12b	XII-	11.66	6.25
		V16	8C+	**32**	5.15c	9b+		38	12c	XII	12.00	6.50

Figure A.6: IRCRA scale (Draper & Giles, 2016)

A.3 Accomplishment classifications

In climbing, an accomplishment is put in a climbing grade but there are multiple ways to finish climbing routes that may affect the grade someone is able to climb. The four commonly used terms are a flash, a redpoint, a freepoint and an onsight.

Flashing a route is when you finish a route first try without studying the holds from the route. It is possible to prepare by watching other people climb and looking at the route with a coach (Onsight / Flash / Redpoint and Freepoint, 2008).
Redpointing a route is to finish a route without straining the rope at all. This means that there are no pre-clipped carabiners and the climb is done while lead-climbing. (Onsight / Flash / Redpoint and Freepoint, 2008)
Freepointing a route is still without straining the rope, but performing the climb while sport climbing. This is a lot safer then lead climbing, it can prevent injury and even deaths. In bouldering, there is no difference between redpointing and freepointing a route (Onsight / Flash / Redpoint and Freepoint, 2008).
Onsighting a route is when you finish a climb without having information before hand of the route or have anyone else seen it climb as well. (Onsight / Flash / Redpoint and Freepoint, 2008)

The redpoint grade is the grade that most easily compares with other climbers. Onsighting and flashing a route can be more difficult since it requires the route to be climbed either without having any information or wihtout studying the route. Freepointing a route eliminates a large part of the mental aspect in climbing which is part of the climbing grade.

A.4 Aspects in climbing

With campus and hangboards, the focus shifted more towards physical training, since this is relatively easy to train and progress is clearly visible. Also, novice climbers pay more attention to the physical aspect of climbing and forget that the technical and mental aspect are equally important (figure A.7) (Climbing Your Best: Training to Maximize Your Performance, 2001). This means that only one third of climbing is physical and the hand and fingers are just one part of the physical aspect. This decreases the overall influence of the fingers since there are a lot of physical aspects in climbing. However, hand and fingers are the primary connection between the rock and the climber next to the feet and can be the physical limiter in a climbing performance (Anderson & Anderson, 2015).

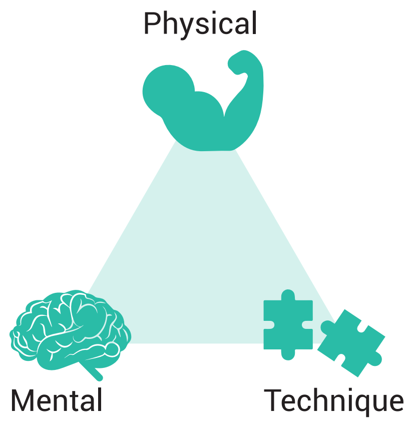


Figure A.7: Aspects in climbing

A.5 Finger force and climbing

For climbers, beside their feet, their hands are the sole connection to the wall. It is important that a climber can trust their hands and fingers to be strong enough to hold on. Climbing and finger force go hand in hand together. Climbers have a higher maximum voluntary contraction than non-climbers and a greater ability of recovery of the muscles in the hand and forearm (Macleod, et al., 2007). While climbing it is even more important that climbers are able to release the power in their hand and fingers at the exact right moment (Ozimek, Staszkiewicz, Rokowski, & Stanula, 2016).

A.6 History of finger training

In the early days, climbers trained by climbing a lot of hours, extended with some easy power exercises. The first time tools to specifically train fingers and hands were used to achieve higher results was in 1988 by Wolfgang Güllich (figure A.8). He was training for Action Directe in the Frankenjura; the first 29 ever climbed. This route required an immense dynamic finger strength and in order to gain this effectively, the first campus board was built in Nürnberg (Campus Board Brochure, sd). From this moment on, climbing levels would gradually go up and training finger and hand strength is now indispensable in training of amateur and pro climbers.

Nowadays, almost every gym has one or more campus and hangboards available for their climbers. For example, at boulder gym De Campus in The Hague, they provide climbers with a variety of holds at the campus board and multiple hangboards (figure A.9 and figure A.10). Campus board exercises can be used to train coordination in climbing and to develop muscular power (Anderson, Anderson, & Sanders, An innovative hangboard design to improve finger strength in rock climbers, 2016). Hangboards enable climbers to statically use a hold for a certain period of time. In order to train muscle strength, a hangboard training is the best targeted exercise (Anderson, Anderson, & Sanders, An innovative hangboard design to improve finger strength in rock climbers, 2016).

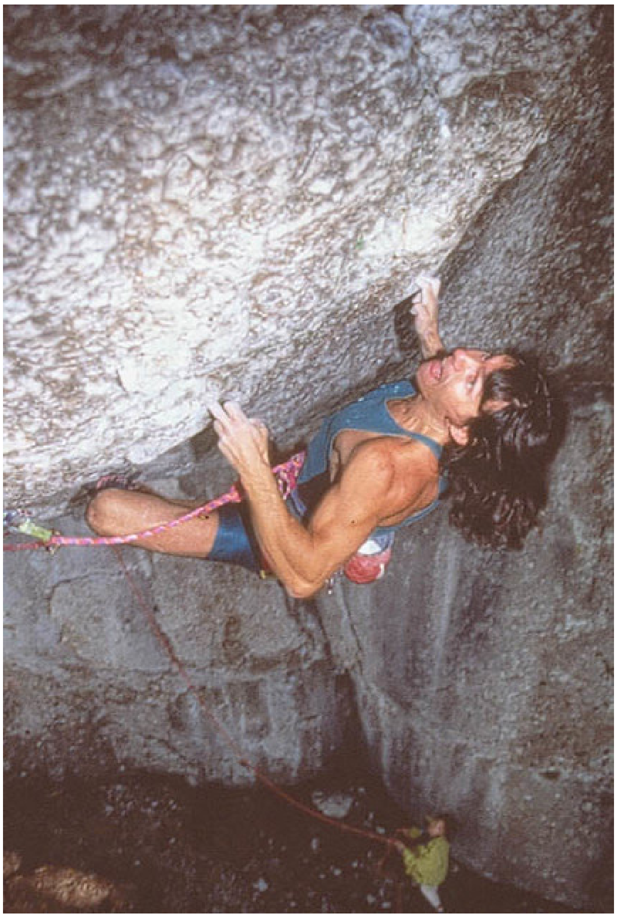


Figure A.8: Wolfgang Güllich

Figure A.9: Campus board

Figure A.10: Hangboard

In a study it was found that hangboard practice improves finger strength by 32 % and rock climbing performance (Anderson, Anderson, & Sanders, An innovative hangboard design to improve finger strength in rock climbers, 2016). However, hangboard training should be executed with precautions because it can cause injuries in the shoulder, elbow, wrists and fingers. Interestingly, the most common hangboard injury are finger pad skin injuries (figure A.11) which are caused by the friction by high shear and normal stress applied to the skin. If finger pad skin injuries occur, the skin needs to heal which will take about 5 to 15 days before a climber can continue with (Anderson, Anderson, & Sanders, An innovative hangboard design to improve finger strength in rock climbers, 2016).

Figure A.11: Finger pad injury

Appendix B

Hand anatomy, physiology and biomechanics

In this chapter, the anatomy, physiology and biomechanics of the hand are explained and the importance of the hand and fingers for climbing becomes apparent.

For understanding the hand anatomy and the importance of the hand with climbing, it is important to understand what happens in the body when climbing. While climbing, a constant energy is required because when a climber is not moving, he or she is still hanging on the wall. In order to move on the wall, the muscles need to create movement via three types of contractions (figure B.1):

1. Concentric
2. Eccentric
3. Isometric

Hands are an important factor in climbing since these are the sole connection to the wall next to the feet. In climbing, hands are mostly used in fixed joint positions, making them isometric contractions. The isometric contractions in the forearms, when the muscle length remains fixed, are used to hold handholds. The isometric strength and endurance is often a limiting factor for climbers (Anderson & Anderson, The Rock Climber's Training Manual: A Guide to Continuous Improvement, 2015). Training can help to strengthen the fingers.

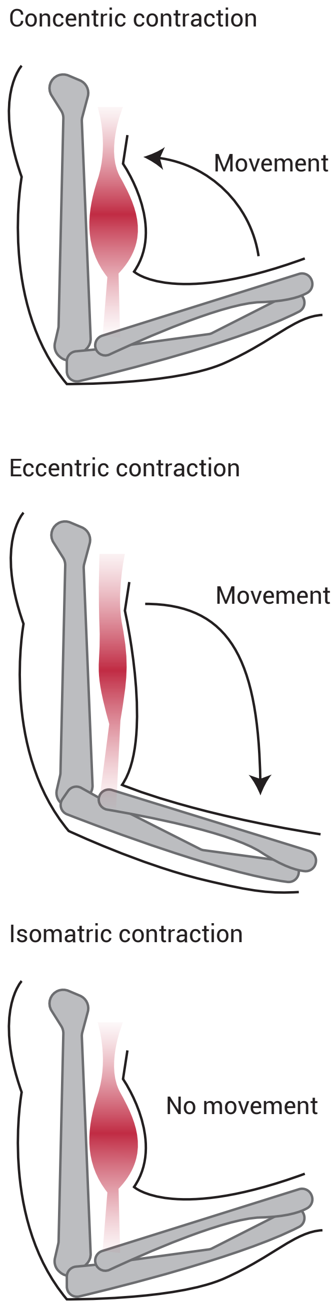


Figure B.1: Contractions

Hands are made of bones, joints, tendons, ligaments, muscles, nerves, blood vessels and connective tissue. To increase strength and to build up resistance for high tensions, all different elements in the hand need to adjust to the load. Skin, bones, ligaments and cartilage mostly exist out of collagen. Collagen is the main structural protein which is a very important part in the connective tissues. The half-life of collagen is 300 to 500 days meaning that it takes almost two years in some cases to replace half of the connective tissue (de Morree, 2008). There has not been research to test whether two years is enough to adjust to the climbing load, but according to Jelle Schouten, this is good guideline. A muscle is already resistant to the load after three weeks, a bone is resistant after one year, tendons after one to two years, ligaments approximately after two years and cartilage after three to five years of training (Schoefffl, Hochholzner, & Lightner Jr., 2003).

When a climber is used to the climbing load, a change can occur in their hands; the size of the fingers can increase. This increase in size is due to the response components have to the climbing load. This growth appears in the cortical bones of the fingers which can grow up to 25 %. The medullary canal will narrow with climbers, up to 20 % (Hahn, Schweizer, Erschbaumer, Allenspach, & Rufibauch, 2012). This growth normally appears after more than ten years of regular, high-level climbing. Also, the flexor tendons, which are only approximately five millimeter in diameter, can be twice as strong compared to non-climbers. This is a significant growth since the tendons are quite small.

When grabbing a hold with your fingers, the finger flexors are responsible for the flexing of the fingers. The superficial flexor muscle suffers from functional insufficiency. This means that in the flex position (figure B.2), it is hard to give a lot of finger power, however in the extended position (figure B.2), it creates a pre-tension of the fingers making it easier to give finger power (Schoefffl, Hochholzner, & Lightner Jr., 2003). If a climber gets tired, they feel the pump in the finger flexors, but the extensors are crucial when power is needed. Extensors get tired and the hand moves from the optimum power position to a position which is less ideal to execute a lot of power, making the move requiring even more power. When a climber is close to letting go of the hold, the elbows move in to 'chicken wing' position (figure B.3 on page 78). This creates an even more flexed position making it harder to find enough power and the climber has to let go (Schoefffl, Hochholzner, & Lightner Jr., 2003).

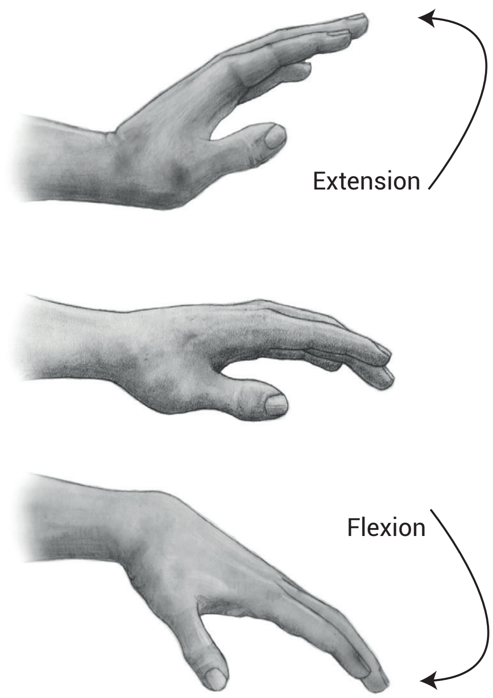


Figure B.2: Extension and Flexion (Extension and Flexion, 2019)

When the fingers are used in a crimp position (appendix I: Climbing holds on page 114), a lot of force is necessary. Since the fingers have close to no muscles, the power needs to be transported from the wrist and hand. This is done by the flexor tendons. To ensure the flexor tendons stay close to the finger bones, they are attached with five annular pulleys and three cruciate pulleys (figure B.4). When putting a lot of force on the different phalanges when holding a hold, tension is built up in the pulleys. In the crimp position, the friction and tension on the pulleys is very high which can lead to (partial) rupture of certain pulleys. The most high risk holds are small edges with over extension of the interphalangeal joint (PIP) (figure B.5) (Schoefffl, Hochholzner, & Lightner Jr., 2003). Pulley injuries happen to approximately 20 percent of the climbers (Kubiak, Klugman, & Bosco, 2006). The A2 pulley of the ring finger is most likely to be injured since in the closed crimp position the thenar muscles in the thumb create a very high load on the PIP joint of the index finger (Schoefffl, Hochholzner, & Lightner Jr., 2003).

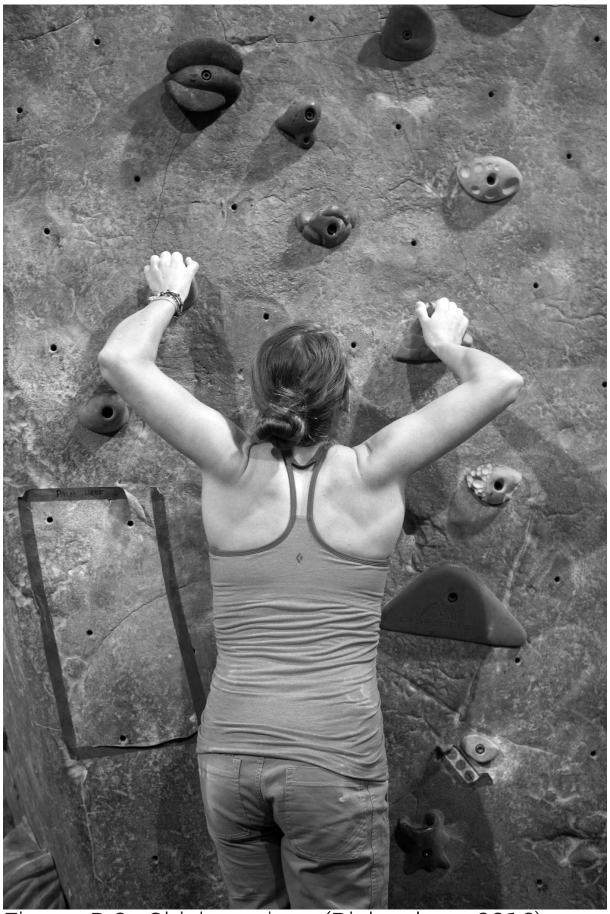


Figure B.3: Chicken wings (Richardson, 2016)

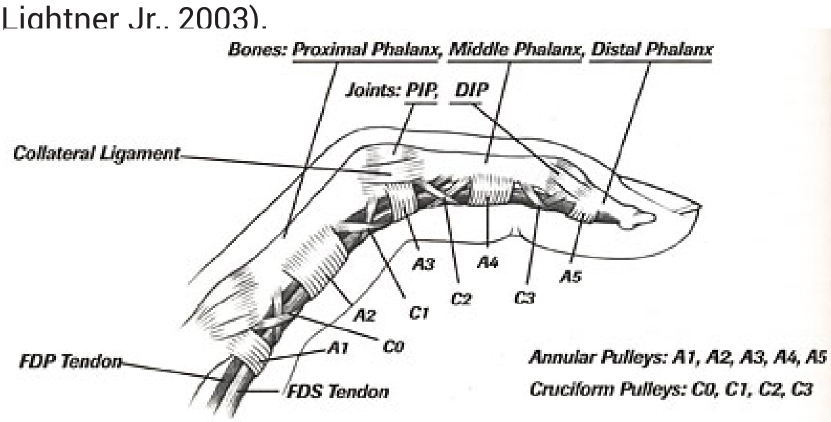


Figure B.4: Finger anatomy (Horst, 2008)

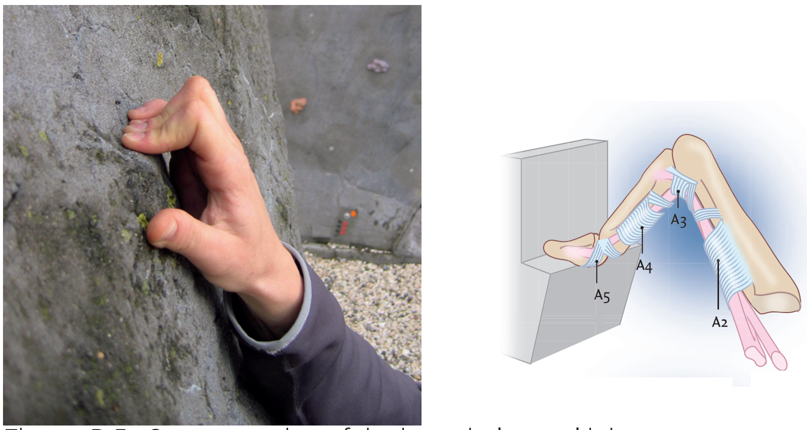


Figure B.5: Over extension of the interphalangeal joint

Appendix C

Hangboard routine

There are a lot of variations available for a training plan for climbing. The Rock Prodigy Training Method (Anderson & Anderson, The Rock Climber's Training Manual: A Guide to Continuous Improvement, 2015) is one example available and has six different training phases: base fitness, strength, power, power endurance, performance and rest. A hangboard is often introduced when doing strength training. On a hangboard, both the anaerobic and aerobic system can be trained with the same exercises but with different hang and rest time and repetitions. An example of a training is given in table C.1. Most exercises are static, called deadhangs (figure C.1). Deadhangs can be performed on a variety of holds and hold sizes.

Repetitions	Time	Activity	Hold
6	10 seconds	Deadhang	Warm-up jug
	5 seconds	Rest	
6	10 seconds	Deadhang	Medium edge
	5 seconds	Rest	
6	10 seconds	Deadhang	Sloper
	5 seconds	Rest	
6	10 seconds	Deadhang	2-finger pocket
	5 seconds	Rest	
6	10 seconds	Deadhang	Large open-hand edge
	5 seconds	Rest	

Table C.1: Hangboard routine (Anderson & Anderson, The Rock Climber's Training Manual: A Guide to Continuous Improvement, 2015)

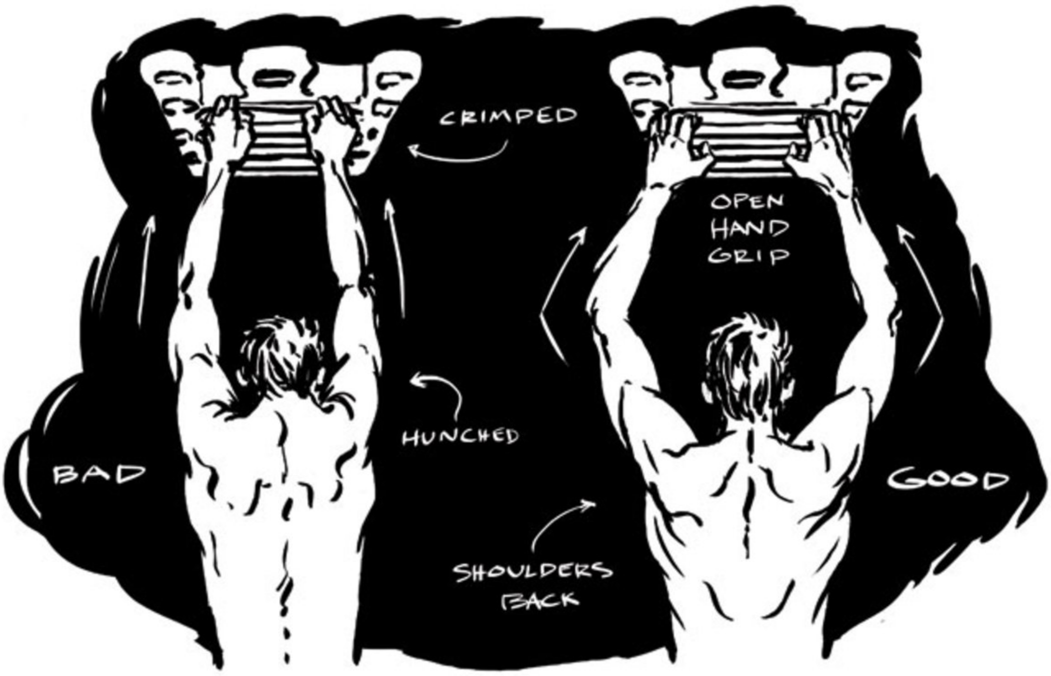


Figure C.1: Deadhangs (Givens)

Appendix D

Involved parties with the Meta-Grip

There are multiple people involved with the current Meta-Grip and this will grow with making the Meta-Grip unsupervised. For the redesigned Meta-Grip, more stakeholders appear then initially in the Meta-Grip because of the shifting focus of the Meta-Grip from research orientated towards consumer orientated. In this chapter, different stakeholders will be discussed. After that, the competitors and users will be reviewed in more depth.

D.1 Stakeholders

The six main stakeholders for the Meta-Grip are suppliers, the Vrije Universiteit, physiotherapists, trainers, climbing gyms and competitors (figure D.1 on page 81). To understand the influence of different stakeholders better, the stakeholders are mapped in the stakeholder circle (figure D.2 on page 82) (Weaver & Bourne, 2002). Here, the radial depth represents the power of the stakeholder, the width of the segment the influence of stakeholders and the distance from center is the proximity of the stakeholder to the project. In the enumeration below, the influence stakeholders have will be described.

- Suppliers provide the materials and parts needed to embody the Meta-Grip. Most of the items are assembled and made at the Vrije Universiteit by Daniël Koops at the Amsterdam UMC. However, for the 3D-printing of the polyamide 12, Oceanz is used. They offer high quality polyamide parts, for material properties, see appendix H: Polyamide-12 on page 113). Furthermore, the aluminum is bought from a supplier as well as the standardized parts used in the Meta-Grip (e.g. bolts and screws).
- The Vrije Universiteit in Amterdam is still the owner of the idea so if anything would be realized after this, in terms of a start-up, the Vrije Universiteit will play a crucial role in releasing information and patents. Within the Vrije Universiteit, there are multiple departments working on the Meta-Grip since multiple expertise areas were necessary to develop the Meta-Grip. There are multiple researchers, technicians and valorization groups (D-lab and IXA) working on the Meta-Grip.
- Physiotherapists already use tools to make an objective measurement of someone's grip, but with the Meta-Grip the measurements can be more climbing specific which can better facilitate recovery.
- Trainers can use this tool to improve trainees in climbing by being able to exactly identify what needs improvement and target this in the training.
- Climbing gyms provide climbers with tools to train and get better and the Meta-Grip will be a good addition to the already available training tools.
- Competitors can force the Meta-Grip to compete with them, otherwise people will not choose for the Meta-Grip. Important is to identify the features and price of competitors to adapt the Meta-Grip accordingly.
- The faculty Industrial Design Engineering (IDE) has the power to

pull the plug on the project since it is a graduation project but has very little influence.

- The project team is really close to the project, but does not have significant influence.

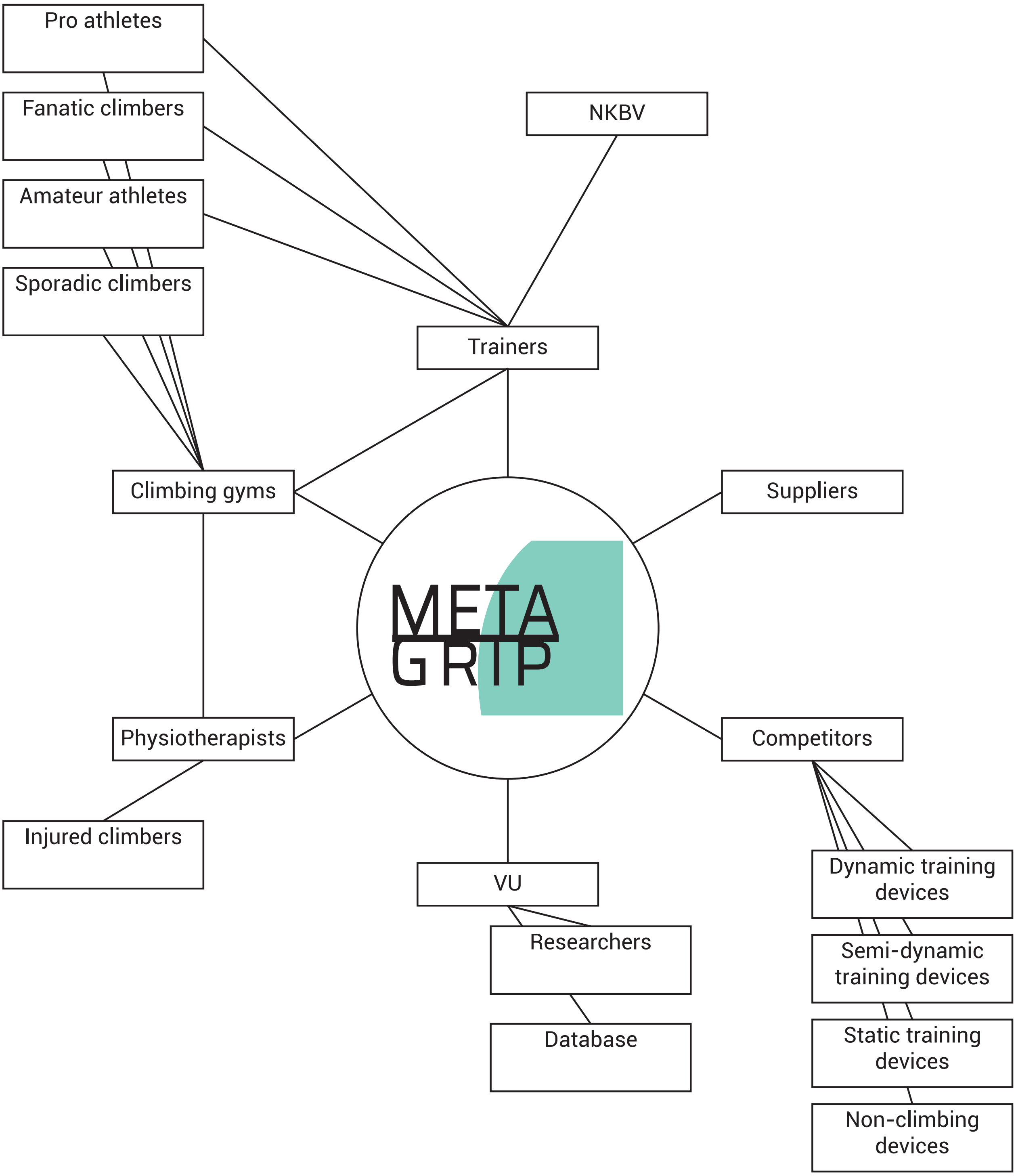


Figure D.1: Stakeholders

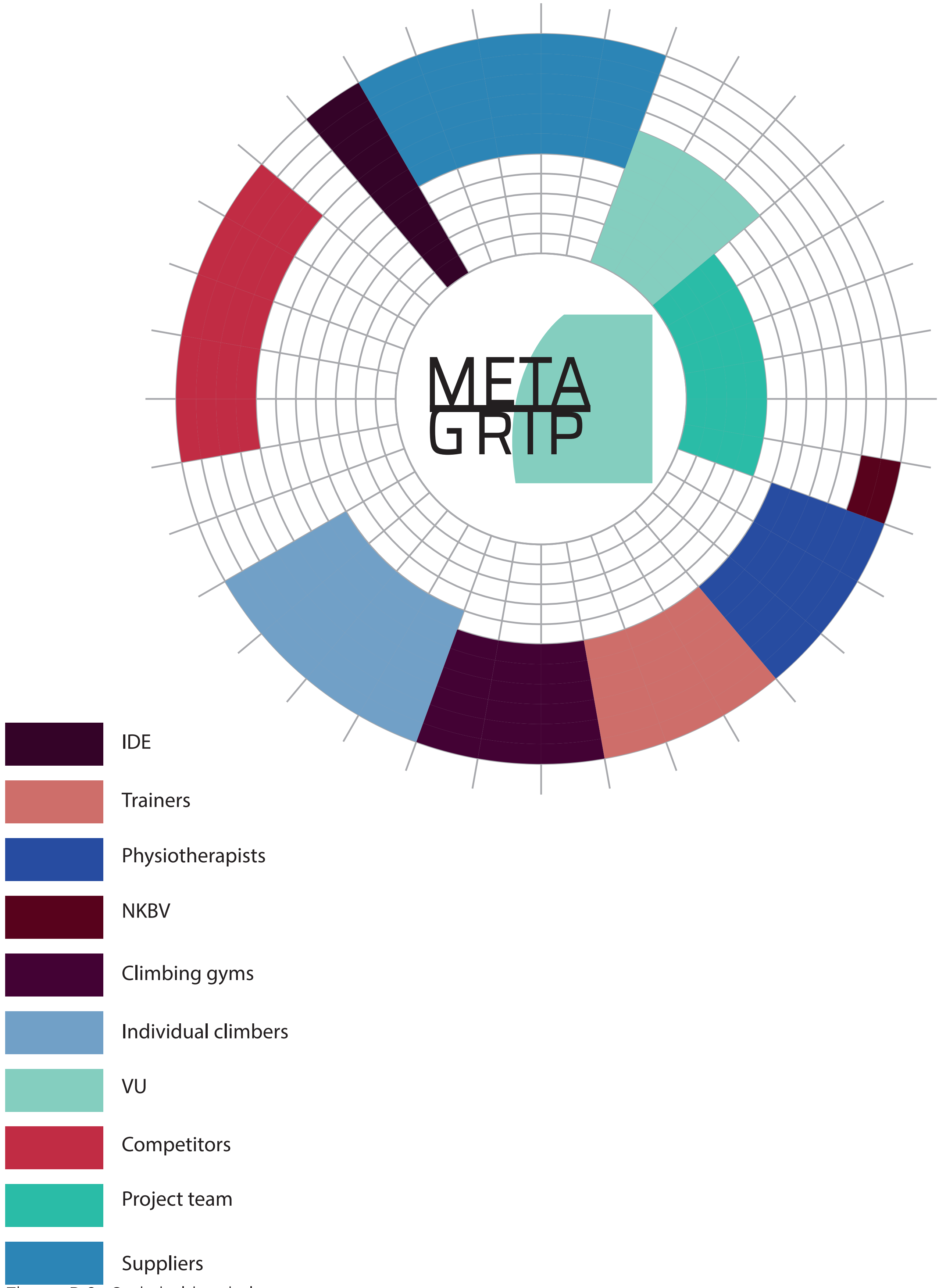


Figure D.2: Stakeholder circle

D.2 Competitors

There are four types of competitors for the Meta-Grip of which three are climbing specific and one is not. The climbing specific competitors are classified in three groups, from dynamic to static. Dynamic means direct and objective feedback where static means no feedback at all. An overview of all the competitors is given in figure D.3 and a detailed description of the competitors is given in the subsequent section.

1. Dynamic training devices: Training devices that measure accurately and objectively (with help of a load cell) the hand and finger strength.
2. Semi-dynamic training devices: Training devices that provide a form of feedback regarding the performance of the climber but do so without any objective force measurement.
3. Static training devices: Training devices that do not give feedback on the user's performance.
4. Devices not specific for climbing that can only measure certain aspects of hand and finger strength.

The Meta-Grip currently falls under the group dynamic training devices. However, the Meta-Grip does not yet offer the possibility to perform a training on the device which is possible by competitors in the group dynamic training device.

Figure D.3: Competitors

D.2.1 Dynamic training devices

Smartboard

Smartboard (figure D.4) (Smartboard, sd) is a measurement device with a large range in hold sizes and sorts. This hangboard is mounted to a frame on the wall with which they perform the measurements. Via Bluetooth, the data is transmitted to an app. The Smartboard is sold for approximately 3000 euros. First an evaluation test is done after which exercises are given to improve based on the evaluation results. To track progress of the climbers, tests are performed on a regular basis.

Figure D.4: Smartboard

Entralpi

Entralpi (figure D.5) (Entralpi, sd) is a smart scale with which you can measure hand and finger strength with every hang board. The scale is simply placed on the floor and connected with the app where you can see and store the data. The sample rate of the scale is 80 Hz and it can measure among other things MVC and RFD. However, in most climbing gyms, you can find a big mat underneath the training devices which makes a measurement not accurate at al. It is also the question if you really test finger strength or the ability to lift yourself off from the scale. It is sold for 199 Canadian dollars, being approximately 133 euros.

Figure D.5: Entralpi

D.2.1.3 Tindeq

Tindeq (figure D.5) (Progressor, sd) developed a small load sensor of only 150 grams that can be used with any free hanging training grip. It can measure endurance, MVC or RFD with a sample rate of 80 Hz. The system can hold up to 150 kg. Because you can use this device only with free hanging training grips, besides finger and hand strength, the factor wrist stability will also influence the results. The precision of the results is also lower because the load is transferred via a rope or carabiners. But with a price of 150 US dollars, the decrease in accuracy is exceptable. On the app, you can see the results of the measurements live and it is possible to save them, but no training plan is given.

Figure D.5: Tindeq

Climbro

The Climbro (figure D.6) (Climbro, sd) is a hangboard which is able to do objective measurements of climbers hand and finger strength. It comes with an app on which the results can be viewed and on which a trainings scheme based on the results will be made. The Climbro transmits the data from the test via Bluetooth to the phone of the user. When starting the Climbro up, a calibration is needed to get a correct measurement. The holds can be made smaller by adding magnetic plates that decrease the depth of the hold. The Climbro is sold for approximately 800 euros.

Figure D.6: Climbro

Lattice Digital Training Rung

The Lattice Digital Training Rung (figure D.7) (Lattice training, sd) can measure maximum finger flexor force, rate of force development and do continuous and intermittent tests of force output with a certain load. It can perform the measurements on three different hold sizes; 40 mm, 20 mm and 10 mm. The measurement is done with a single load cell with a maximum load of 200 kilograms. The user of this device as defined by Lattice are sport scientists since in-depth knowledge is necessary to interpret the data. In order for users to have a correct set-up and sufficient knowledge to use the product, a remote introductory training is necessary where, in 1,5 hours, the setup and interpretation of key data is explained.

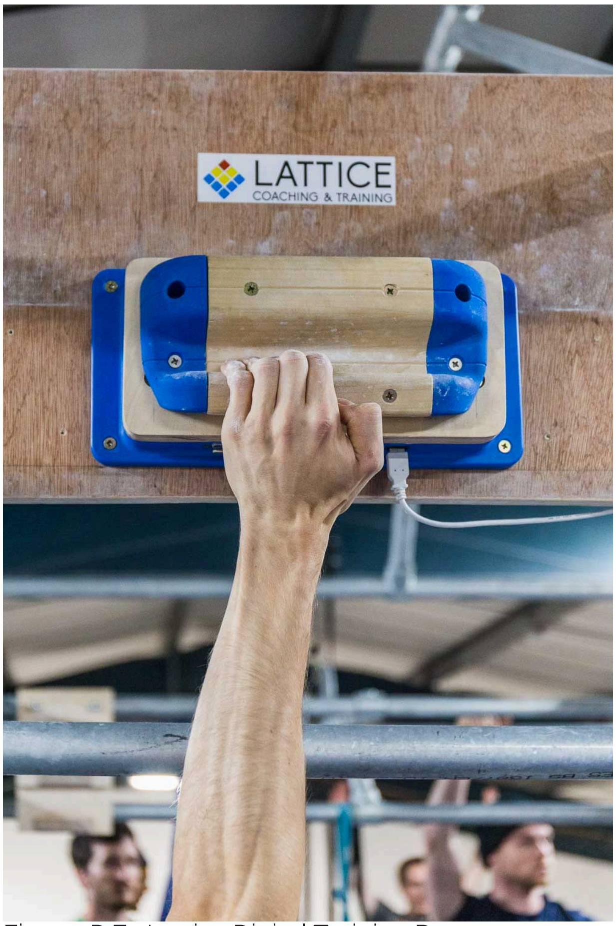


Figure D.7: Lattice Digital Training Rung

The current product is sold for 960 British pounds, approximately 1112 euros, excluding a computer with windows or Linux and a recommended separate amplifier. The output of the data can be to either a program that is able to capture serial data (e.g. MATLAB) or the direct data from the load cell which then needs to be converted through a bridge amplifier and an AD-converter. In the last case, a bridge amplifier and an AD-converter is still necessary to purchase since it is not included in the product. The sample frequency of this product is 80 Hz. The data is delivered as a text file and the users have to analyze it themselves. They offer an excel file, but users did not have a positive working experience with it.

D.2.2 Semi-dynamic devices

Zlagboard

The Zlagboard (figure D.8) is a hangboard made in such a way that with the accelerometer and the gyroscope in the phone it is possible to measure when someone is starting and stopping with hanging on the board. When a weight is put on the Zlagboard, the phone holder tilts forwards making it easier visible while hanging and activating the exercise. This helps in having a proper training and giving active feedback on time duration, but does not give objective feedback on the performance of the climber. The variety of holds and hold sizes is quite large on the Zlagboard since a relative general hangboard type can be used (Hangboards, sd). The price of the Zlagboards range between the 200 and 250 euros (Training, sd).

Figure D.8: Zlagboard

D.2.3 Static training devices

Campus board
A campus board (figure D.9) is a great way to train finger and hand strength since it comes in a large variety of sizes and shapes. There is the possibility for half spheres or elongated wooden holds from slopers to crimps. On a campus board, most climbers move upwards to train. There is no feedback system integrated in a campus board so achieving the correct training depends solely on the user.

Hangboard
Hangboards (figure D.10) are a different way to train finger and hand strength. These come in dense boards with a lot of different holds and hold sizes on them. Holds on a hangboard can vary to jugs, slopers and edges. On a hangboard it is not possible to move upwards like on a hangboard so a different training is performed here. Most hangboards are static and do not provide any feedback to the user.


Figure D.9: Campus board

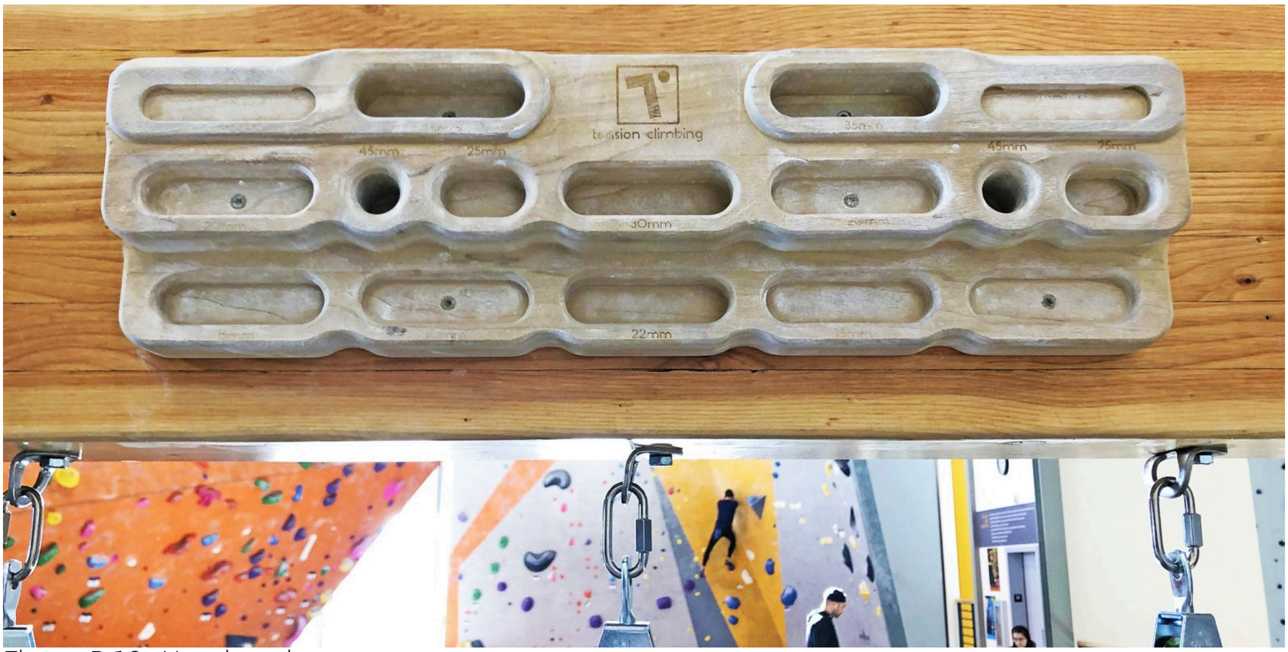


Figure D.10: Hangboard

D.2.4 Non-climbing devices

E-cone

The E-Cone (figure D.11) is a device that is originally used to measure pressure distribution with rheumatoid arthritis and hand osteoarthritis (van Alebeek, Hoeksma, & van Merend, 2012). However, this device can also be used for climbers to measure their pressure distribution among their hand. It gives direct and accurate feedback, but cannot measure any other climbing related finger and hand strengths. It is also not possible to measure the amount of power supplied by the test person.

Jamar

A Jamar (figure D.12) can measure the pinch force delivered by a person. It is mostly used by medical professionals such as physiotherapists. For climbers it still misses the possibility to measure multiple finger and hand strengths the Meta-Grip is able to do.

Figure D.11: E-cone

Figure D.12: Jamar

D.2.5 Overview closest competitors

In figure D.13, an overview is given of the closest competitors of the Meta-Grip in the group dynamic training devices. In table D.1 can be seen what they can measure compared to the Meta-Grip. Entralpi as a competitor is left out of this scope since the measurement is done completely different compared to the Meta-Grip and other dynamic training devices. Given the different terminology for measurements used by the different devices, it is hard to determine the degree of similarity in measurements. One of the differences between the measurements of multiple competitors is executing it with one or either both arms. If executed with both arms, it is not possible to determine a difference between left or right whereas this is possible if the tests are executed with only one arm.

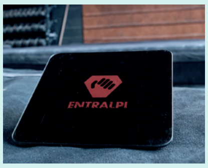
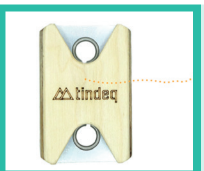
					
Brand	Smartboard	Entralpi	Tindeq	Climbro	Lattice
Transmission	Bluetooth	Bluetooth	Bluetooth	Bluetooth	Wire
Sample rate	-	80 Hz	80 Hz	-	80 Hz
Prize	€ 3000	€ 133	€ 135	€ 800	€ 1112
Feedback	Training plan	Training plan	Values	Training plan	Values
View history	Yes	Yes	Yes	Yes	Yes

Figure D.13: Closest competitors

Meta-Grip	*Smartboard*	*Tindeq*	*Climbro*	*Lattice*
Maximum finger strength	Maximum finger strength	Peak force	Maximum finger strength	Max finger flexor force
Explosiveness		Explosiveness		Explosiveness
Power endurance	Power endurance	Endurance		
Stamina	Stamina			Critical force
	Power to weight ratio			
	Arm's max power			
	Arm's energetical capacity			
			Forearm strength and endurance (finger hang)	
			Forearms anaerobic capacity (continuous finger hang)	
			Forearms aerobic capacity (intermittent finger hang)	
				Continuous and intermittent tests of force output at maximal or sub-maximal loads

Table D.1: Measuring units

D.3 User group

The three main stakeholders who represent the users of this product are climbing gyms (figure D.14), trainers (figure D.15) and physiotherapists (figure D.16) (Orth, 2019). These people will not directly use the Meta-Grip themselves, but will provide their clients with the possibility to perform a measurement with or without guidance. Based on an interview with Sander ter Steege, owner of the climbing gym Delft's Bleau, the needs and wishes for climbing gyms were established. The interview took approximately 30 minutes and was semi-structured. After an introduction of the Meta-Grip, the needs and wishes as well as the responsibilities and goals of a climbing gym were discussed and defined (appendix H: Interviews on page 110). The needs and wishes of the trainers and climbing gyms were established with previous research and informal conversations with trainers at the Ayers Rookies and Jelle Schouten.

Figure D.14: Climbing gyms

Climbing gyms

Needs and wishes

Feedback should be given in form of a trainingsplan instead of numbers.
The other aspects of climbing should not be forgotten.
Tool should be safe to use for everyone.
Different levels of involvement in training intensity are interesting.

"Climbing is not solely for exhaustion; it is much more solving a puzzle and having a challenge."

Major responsibilities and goals

To provide climbers with facilities so they can keep developing. Training tools can help a lot with underdeveloped muscle groups or coming back from an injury.

Figure D.15: Trainers

Trainers

Needs and wishes

Discussing and reviewing results of the trainees should be possible.
Unedited results should be able to view to pinpoint very detailed where improvement is necessary.
Trainees and trainers should be able to see different things since the trainee does not know how to implement detailed results.

"Trainees completely trust the trainer with them finding the best fitting trainingsplan. To have a tool to do this objective would help a lot."

Major responsibilities and goals

Trainers structure the training of their trainees and play a key role in their progress. It is important to notice where improvement is necessary and an objective measurement can help with that.

Figure D.16: Physiotherapists

Physiotherapists

Needs and wishes

Unedited results needs to be available in order to correctly assess the climber.
The climber needs to understand the data as well.
The physiotherapist needs to be able to track progres of the climber as well as the climber.

"I was climbing outdoors and I went to go for a move and it went bang! Actually, it was more of a pop; a really loud, satisfying pop. Everyone heard it go."

Major responsibilities and goals

Physiotherapists need to restore someone's physical state to normal again after an injury. The climber normally wants this as fast as possible and the physiotherapist has to give proper exercises and assessment in order to achieve this.

The climbers that will use the Meta-Grip through either the climbing gym, physiotherapist or trainer, can be separated using a framework with two axis: leisure towards improvement centered and occasional towards structured training. The user groups were established with a questionnaire among climbers (n=21, age 36 stdev 15) (appendix G: Defining the user group climbers on page 104). First, the climbers answered questions to determine the type of climber. Second, the climber answered open questions about the use of the Meta-Grip. The five different groups can be found in figure D.17 and are listed below:

1. Sporadic climbers: These type of climbers visit the climbing gym not on a regular basis and are climbing because of the pleasure they get from climbing.
2. Fanatic climbers: Fanatic climbers do not have an improvement centered training program, but are more regularly in a gym and are able to see progress due to this.
3. Amateur athletes: Amateur athletes follow a training program and because of this have a structured schedule.
4. Pro athletes: Pro athletes spend a large portion of their time training to try to improve themselves to achieve certain goals. To achieve this, structure is needed in their training program.
5. Injured climbers: Injured climbers need to improve and have structure to recover from an injury. Injured climbers are strictly not a seperate user group since it will always be a climber from one of the four other groups, being injured. However, we do distinguish this as a serpate group since injured climbers need to adapt their habits. Injured sporadic climbers need to bring more structure and focus on recovery (which can be seen as an improvement). Injured fanatic climbers need to be more improvement centered in order for the recovery to be successful as fast as possible. Injured amateur and pro athletes probably need to adjust their training plan, focus on recovery more than on impovement.

As can be seen in figure D.17, there is no user group present in the segment occasional climbing and improvement centered. the reason for this is that if a climber is or becomes improvement centered, a structured training is necessary so they move quite fast to the other segment.

Every user group has their own wishes and needs and are driven by different factors. To distinguish these user groups, a persona is made for each group (figure D.18 up to and including figure D.22 on page 81, 82 and 83).

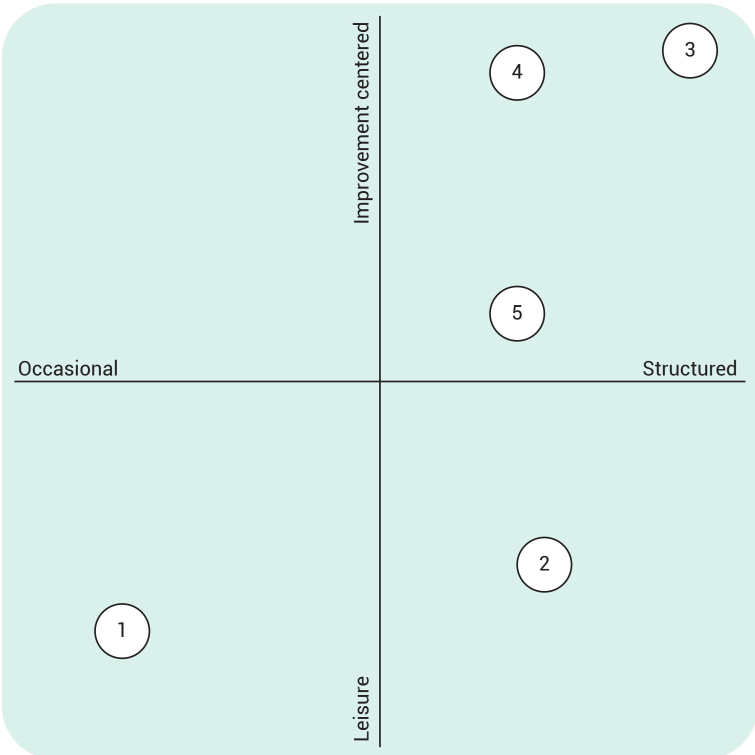


Figure D.17: User groups

Sporadic climbers

Qualities

No structure in when and how often they go climbing.
Climb solely for the joy.
Do not improve drastically.

"To have use of a device like the Meta-Grip, I have to climb at a more advanced level."

Major responsibilities and goals

A measurement could be done out of curiosity, but mostly these climbers would have no use from a measurement.

Needs and wishes

N The only result they need is the results in 'climbing terms'.
W A measurement can be conducted out of curiosity.

Figure D.18: Sporadic climbers

Fanatic climbers

Qualities

Climb because of the joy it gives them.
Does not have a set goal.
Can measure progress in terms of grades climbed.

"I would use the Meta-Grip out of curiosity, to know what the limiting factor in my climbing is."

Major responsibilities and goals

The most important thing is the pleasure received from climbing. Because of the joy for climbing and the structure that originates from this joy, progress can be made. This can be tracked and more improvements can even be made.

Needs and wishes

N Suggestions on exercises.
N The results have to be in 'climbing terms' for clarity.
N There should be the possibility to compare results of older measurements.
W Use should be intuitive to make it attractive to perform a measurement.
W There should be guidance on how to perform a measurement.
W A trainingsplan can be helpful to get these clibmers to a new level.

Figure D.19: Fanatic climbers

Amateur athletes

Qualities

Working towards a set goal.
Follow a trainingsplan.
Structure in training.

"It would be nice if there is an app that stores my data locally ... and the app communicates with my sportwatch."

Major responsibilities and goals

It is important that the structure in training is kept to ensure improvement over the long term. With doing this, reaching a certain goal is more likely and can be done with more ease than otherwise.

Needs and wishes

N Regular measurements to track their progress.
N The results should be available in 'climber terms'.
N Storing data should be possible and a comparison should be easy between different sessions over time.
N A measurement should be possible at all possible times without supervision.
N There should be an explanation on what is measured exactly.
W Suggestions on how to improve and how to translate the results to a training plan.
W Unedited results should be available.
W Use should be intuitive to make it attractive to perform.

Figure D.20: Amateur athletes

Pro athletes

Qualities

Spend a lot of their time training.
Working towards one or multiple goals.
Structured trainingsplan.
Training under professional supervision.

"That's always my goal. I never want to come back and just be as good as I was – I want to come back better. And now I am."

Major responsibilities and goals

Having multiple goals in one climbing season asks for advanced training plans and a high fitness level overall. To ensure this, objective measurements of smaller parts of the body can focus training plans even more.

Needs and wishes

N Detailed results are necessary to exactly pinpoint where improvements can be made.
N Unedited results are desired as well as in depth training plan suggestions.
N Measurements should be possible frequently to closely track progress.
N Tracking progress through comparing results over time should be easy.
W Training suggestions should only focus on specific suggestions since they have to fit within the already existing training plan of the athletes.

Figure D.21: Pro athletes

Injured climbers

Figure D.22: Injured climbers

Qualities

Having an injury in the upper extremities (hand, finger, arm, shoulder).
Are involved with a physiotherapist and have a diagnoses.
They know what to do to improve.

"Injuries are always a blessing in disguise, they give you an opportunity to work on something you wouldn't otherwise have time for."

Major responsibilities and goals

Injured climbers need structure to get injury free again. They also need specific exercises targeted to train at a certain level to improve on the injury.

Needs and wishes

N Detailed results are needed to exactly pinpoint the injury and later in the process the improvement.
N Detailed and accurate feedback should be given on how the injured ligament performs compared to the other hand or previous measurements.
N Often and structured measurements are needed to track progress.
W Proper guidance should be available to implement the results correctly in a trainingsplan.

Appendix E

The current Meta-Grip

In this chapter, the current Meta-Grip will be discussed and reviewed on multiple aspects. Existing research and literature on the current Meta-Grip will be presented. Furthermore, the embodiment, feedback system and the software will be reviewed.

The current Meta-Grip (figure E.1) was developed by a team at the Vrije Universiteit in Amsterdam to support and confirm assumptions made for the paper: "Functional variability in grasping strength supports performance across variation in route design in experienced climbers" (Van Bergen, Kasper, Orth, & Geerte). With the Meta-Grip they wanted to confirm that maximal isometric force on different types of holds can predict climbing performance on routes composed of the same type of holds. In the study, they found a significant positive correlation between forces on the sloper and crimp and the climbing distance in a route with slopers and crimps.

This correlation makes it likely that using such measurements enables climbers to improve their climbing performances, since they can exactly pinpoint where they need improvement. The next step for the Meta-Grip, therefore, was to transform it to a product that is usable for climbers in general and not only for the researchers from the VU.

For the Meta-Grip, a business plan was developed for the application of the National Sportinnovator price in 2017. This grant was assigned to the team in 2017 enabling a lot of development (META GRIP HELPT NEDERLANDSE KLIMMERS IN AANLOOP NAAR KWALIFICATIE TOKIO, 2019). Besides this, a NWO subsidy was granted to "Build tools for individuals to improve themselves and their sport" ('Meta-grip': monitoring grip force to minimize hand injuries and improve climbing performance).

The three different user groups as defined in the grant application are physiotherapists, individual climbers and commercial gyms. With these three groups a differentiation can be made

Figure E.1: Overview Meta-Grip

in complexity and functionalities of the product and the price. Physiotherapists require more complexity and functionalities which will consequently make the price of the product higher. Individual climbers and commercial gyms require the same complexity and functionalities since it is evidently used by the same end-user (individual climbers). In the proposal for the National Sportinnovator price, the desired costs for the Meta-Grip for individual users is estimated at 800 euros which will be used as a directive in this study. However, the current Meta-Grip has a cost price of 2520 euro excluding any selling margins. Table E.1 presents how the costs are divided over the different elemens of the Meta-Grip.

Frame materials including assembly	€ 100,00
Computer	€ 600,00
Single-point load cell	€ 100,00
Bridge amplifier	€ 414,00
AD-converter	€ 806,00
3D components	€ 500,00
Total	**€ 2520,00**

Table E.1: Current Meta-Grip price

E.1 The construction

The Meta-Grip (figure E.2) consists of multiple parts that together make the system. The user interacts with the hold on the Meta-Grip. Only one hold can be used at a time, but by changing the side and top turning wheels, the Meta-Grip can be adjusted to different holds and difficulties of holds. The load cell is then attached to the top of the Meta-Grip which transfers the load through an I-profile aluminum rod to an aluminum frame which is attached to the wall. The load cell measures the power applied by the user. The aluminum frame attached to the wall is used to adjust the height of the Meta-Grip.

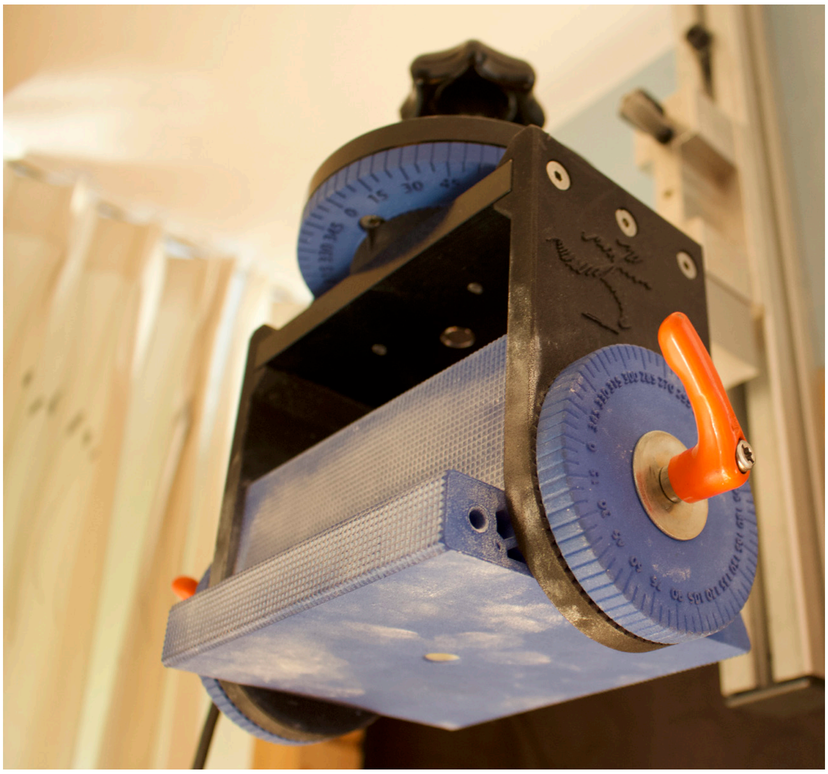


Figure E.2: Close-up Meta-Grip

E.2 Working principle

When the climber is pulling on the Meta-Grip, a slight movement is made in the load cell. The load cell has two strain gauges in the length and is able to measure the deflection as a change in resistance. From the load cell the data will go through a bridge amplifier which enlarges the data so it is easier to analyze. After that, using an AD-converter, the data is transformed from analogue to digital and can be analyzed using LABview (figure E.3 and figure E.4). The data that is used in the analysis is the force in Newton that a climber is exercising on the Meta-Grip. This force needs to be corrected by bodyweight to give meaningful feedback.

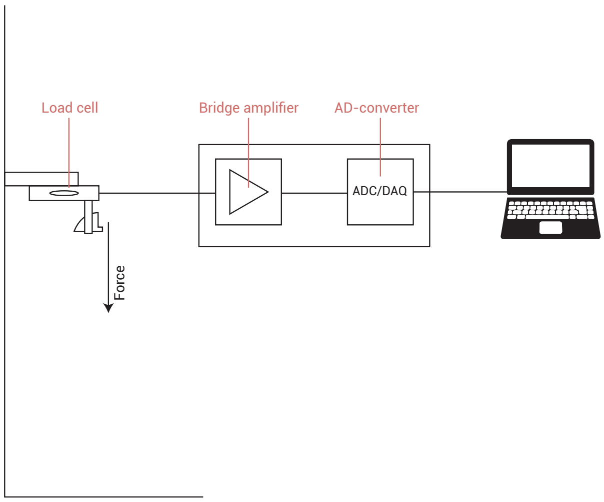


Figure E.3: Current Meta-Grip System

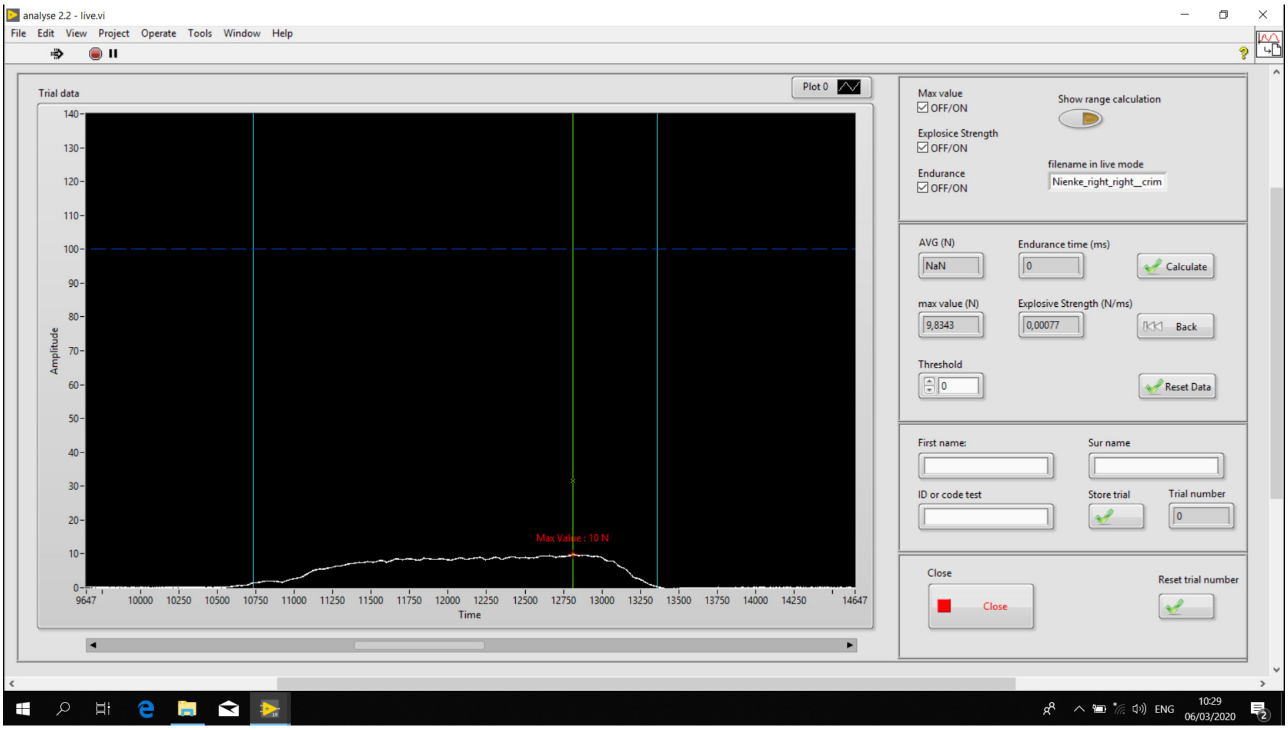


Figure E.4: LABview analysing

E.3 Use scenario

The current use scenario can be found in figure E.5 on page 99 and figure E.6 on page 100. It is critical to see that in this scenario the Meta-Grip cannot be operated without an expert saying what the climber has to do and afterwards interpreting the data and reporting this back in a way that the climber understands. Furthermore, installation of the Meta-Grip takes quite long and it would be better if the Meta-Grip would be fixed in a climbing gym. This is currently not possible due to the device not being foolproof and people cannot operate it on their own.

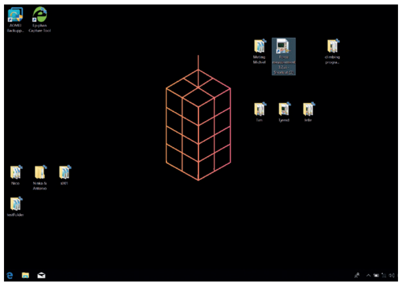
Attach the rail to the climbing wall.

Attach the Meta-Grip to the rail.

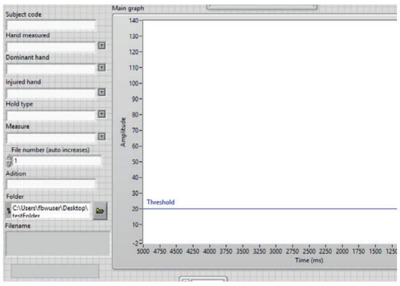
Adjust the Meta-Grip to the correct height.

Turn the Meta-Grip in the correct angle for the measurement.

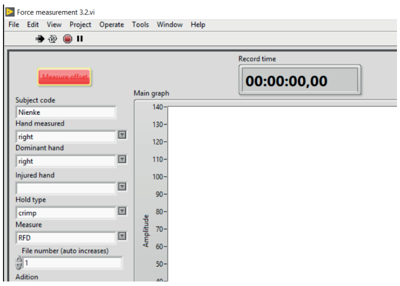
Connect the AD-converter and laptop to the Meta-Grip.



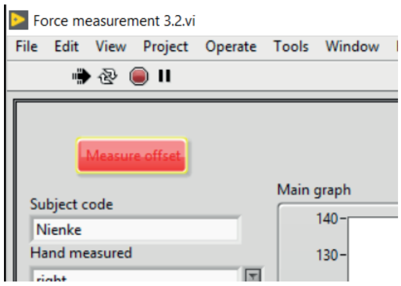
Boot up the laptop and start the programm “Force measurement 3.2”.



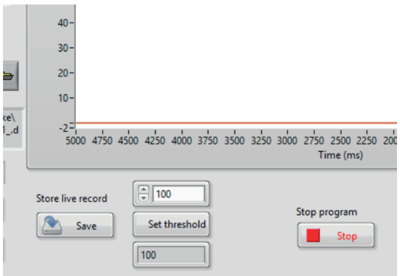
Insert the necessary data from the climber.



“Run” the program.



Measure the offset.

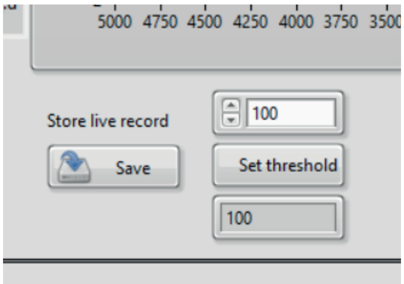


Change the amplitude towards 100 kg.

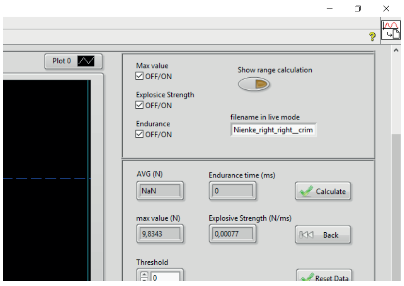
Start the measurement by clicking on “record with CD”.

After the measurement is finished, click again on “record with CD”.

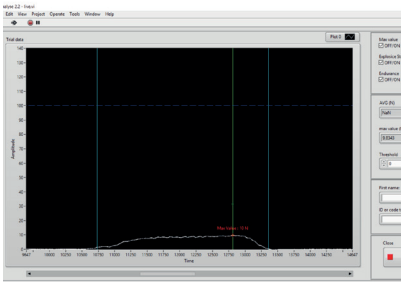
Figure E.5: Current use scenario part 1



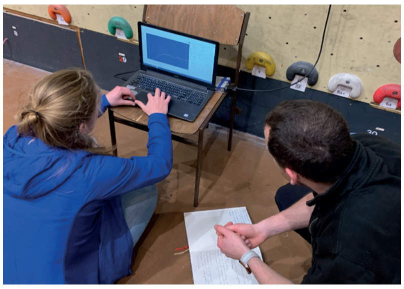
Press the “save" button.



Analyze the results in the program by checking what you want to know.



Move the blue lines around the part you want to measure.



Communicate the results with the climber.

Determine a next step based on these results with the climber.

Figure E.6: Current use scenario part 2

E.4 Meta-Grip data

The Meta-Grip is able to measure four different values which are extracted from the testing protocol for the Dutch national climbing team.

E.4.1 Maximum Voluntary Contraction (MVC)

The MVC or maximum finger strength (figure E.7) measures the peak force of the user. To achieve this, the climber pulls as hard as possible on the hold, with extra weight if they can pull more than their own bodyweight. The MVC is corrected by the bodyweight of the climber and expressed in Newton or kilograms. The MVC can also be expressed in a percentage of the bodyweight of the climber. To measure the MVC, the measurement is started with the dominant hand. If the climber is able to do a one-arm hang quite easily, extra weight is required. The measurement is carried out for both hands, first completely for the dominant hand, than for the non-dominant hand. Each measurement is build up with a ten second measurement and a two minute rest, repeating three times. The highest measured value is the outcome of the measurement.

E.4.2 Rate of Force Development (RFD)

The RFD or explosiveness (figure E.7) measures the time needed to reach 95 % of the MVC. This value shows the explosion rate of the muscles of the climber. The RFD is expressed in [N/ms] or just in milliseconds (Lattice training, sd). Measuring Rate of Force Development accurately is quite difficult and the best procedure still needs to be found. Two different ways exist, both having some advantages relative to the other. The first procedure is asking the climber to jump towards the hold, therefore making it necessary to place the hold slightly higher. This procedure makes it easier for climbers to get as fast as possible to peak power. However, with jumping, the posture cannot be controlled easily and can lead to injury if a person is not able to support their weight with one arm. The second procedure is more static where the climber is asked to pull as hard and as fast as possible on the hold without any dynamic movement beforehand. This procedure makes it more difficult to show the best explosiveness in the measurement but is relatively more safe.

The measurement with the Meta-Grip is done with the dominant hand first and afterwards the other hand. The climber is asked to pull as hard and as fast as possible for ten seconds with 90 seconds rest in between. This is repeated five times. The highest value is the outcome of the measurement.

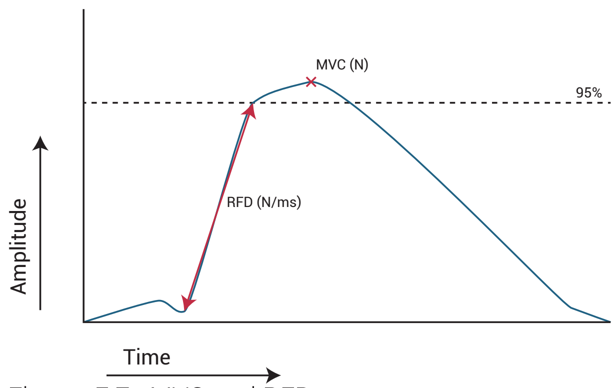


Figure E.7: MVC and RFD

E.4.3 Critical force

The critical force or stamina (figure E.8) measures the endurance of the climber. Again, first the dominant hand is tested. The climber has to pull with full power for seven seconds with a three seconds rest period and repeating this 24 times. The outcome of the measurement is the average of the last six peaks expressed in Newton or Kilograms.

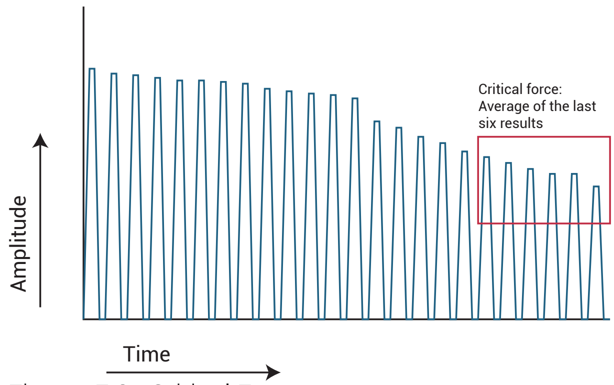


Figure E.8: Critical Force

E.4.4 Power endurance

The power endurance (figure E.9) measures the recovery ability of the climber. It is the ability of the muscle to exert power at a certain level for an extended period of time. The threshold of the measurement is at 60 percent of the MVC, the climber should not reach above this in order to activate the aerobic system and not the anaerobic system. The measurement is first done with the dominant hand and afterwards with the other hand. A measurement is holding the hold for seven seconds and resting for three seconds and repeating this until the power reaches below ten percent of the MVC. The outcome of the measurement are the number of repetitions done by the climber.

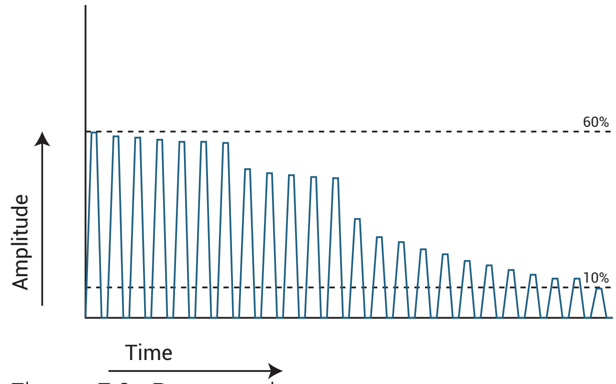


Figure E.9: Power endurance

E.4.5 Testing time

Combining all measurements together gives a total testing time of 75 minutes (table E.2). After each measurement type and hand, a proper rest of two minutes is needed. This is already in the measurement for the maximum finger strength. For the explosiveness measurement, the rest in between is 90 seconds so for the final rest, 30 seconds is added for both hands. For the power endurance and stamina, a rest is added at the end of each hand measurement.

Warming-up	900 s
Maximum finger strength	((10+120)*3)*2=780 s
Explosiveness	((10+90)*5)*2 + 60=1060 s
Power endurance	((7+3)*40)*2 + 240 = 1040 s
Stamina	((7+3)*24)*2+240 = 720 s
Total time	4500 s = 75 minutes

Table E.2: Testing time

E.4.6 Remarks

Currently, four measurements are done with the Meta-Grip on only two different holds. However, measurements and hold types can be added to this series if desired by the climber. When more measurements are added to the protocol, one has to take into account the influence of muscle fatigue. While climbing, holding on to small holds, a fatigue in the forearms can appear, also called the pump (Schoefffl, Hochholzner, & Lightner Jr., 2003) making it harder for climbers to hold on and thus decreasing the results. Before starting one or multiple measurements, a proper warm-up of at least fifteen minutes is necessary. For the measurements, similar postures among climbers is very important.

Appendix F

Defining the climber user groups

This questionnaire was conducted to find out the opinion of climbers about the current Meta-Grip and how they would use it.

F.1 Research questions

1. What type of climber is interested in using the Meta-Grip and would they implement it in their training?
2. How often would climbers like a measurement?
3. Would climbers want to compare their data?

F.2 Hypothesis

It is expected that more advanced climbers (in level or years climbing) can see more advantages of the device than novice and unexperienced climbers. People who are making their own training plan value the Meta-Grip more and are keener on implementing it. It is also expected that people would like to compare their results with fellow climbers since this can be a motivational factor.

F.3 Method

The questionnaire is spread through a Google Form among climbers. Climbers in the network of the researcher (the researcher has access to fellow climbers with considerable years of experience, to a climbing gym, to adult training teams, youth training teams and climbers with a high level in climbing) were invited to participate.

F.3.1 Participants

21 climbers answered the questions with an age between 17 and 74 years old age (an average of 36 and stdev of 15).

F.3.2 Stimuli

Google Form

F.3.3 Apparatus

Laptops or mobile phones to access the questionnaire.

F.3.4 Procedure

1. The participants are asked to sign the consent form.
2. They perform the questionnaire on their own device without any supervision.
3. After they are finished, they send the questionnaire.

F.3.5 Measures

The research questions will be answered by analyzing the answers of the participants.

F.4 Results

In the questionnaire there was a lot of difference between age (figure F.1 on page 105) and years of climbing experience. The years of climbing experience ranged from one till thirty years, meaning that some climbers started already climbing when specifically training finger strength was not common yet. For the full results, see table F.3 on page 107, table F.4 on page 108 and table F.5 on page 109.

The answer on whether climbers want to use the Meta-Grip is closely related to how they train (figure F.2). Climbers who have a trainer or coach mostly say no; they realy on their tariner, are probably not aware of how they train or how to adjust their training. If they mentioned that they would use it (n=5 (yes and maybe)), they want their trainer or coach to be able to implement it. People who make their own training plan are aware of how the Meta-Grip could positively influence their strength and are more eager to implement it (n=3). In total 13 out of 21 participants would (probably) use the Meta-Grip. 16 participants would adjust their training on the basis of the results of a measurement with the Meta-Grip. There were some remarks that they would need professional assistance on how to implement it.

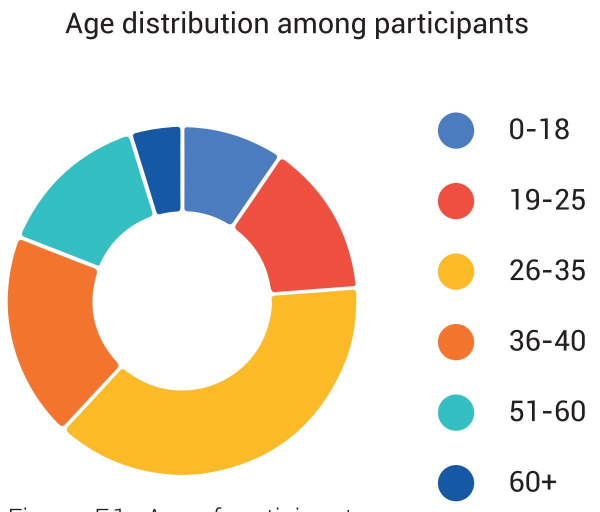


Figure F.1: Age of participants

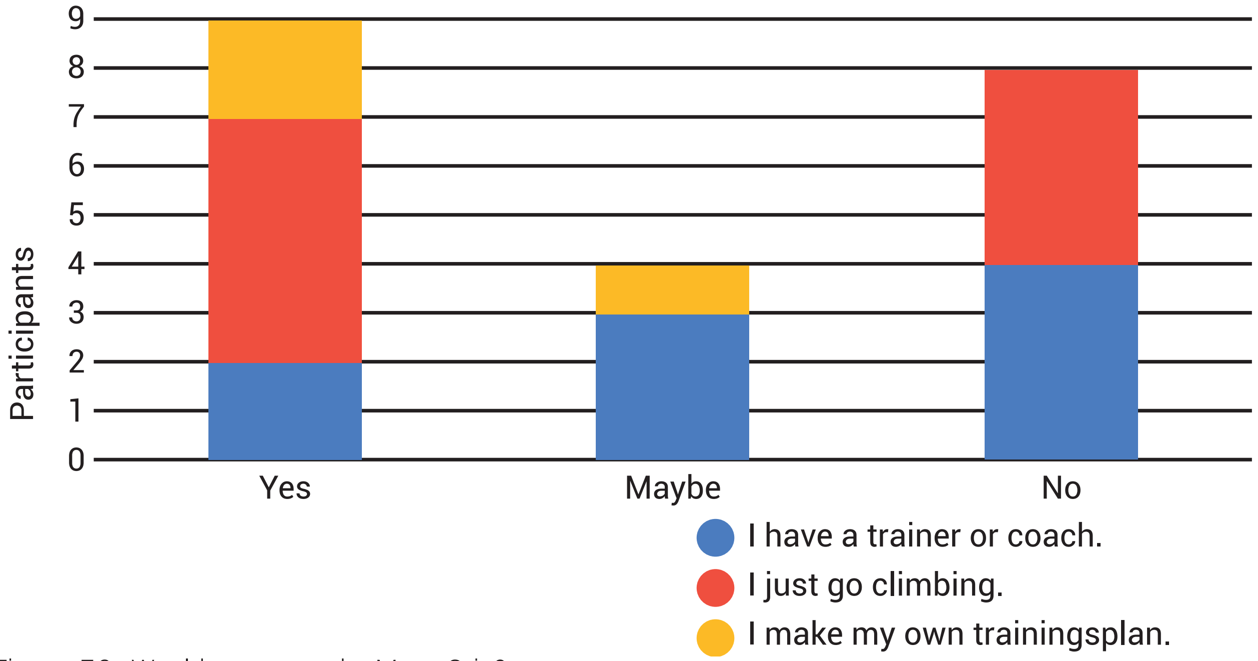


Figure F.2: Would users use the Meta-Grip?

Climbers mentioned that they would like a measurement every 2 month on average to track progress. Most of them (n=12) mentioned the need of guidance of a professional and a possibility to measure progression which than is linked to training advice. This could be done by either a professional or an app. One participant mentioned that a communication with a sport watch would be nice. The participants would use the Meta-Grip to measure progress and being able to train more effective (n=15), to recover from an injury (n=3) and out of curiosity (n=1).

None of the climbers mentioned that they want to compare their results with that of fellow climbers, which is something that was mentioned by Sander, the owner of Delft's Bleau. Being competitive towards other climbers is maybe something that subconsciously interests us. Most climbers only mentioned the need to compare to their own data or have their results as a training plan (without ever seeing their data).

F.5 Conclusion

The climbers most interested in using the Meat-Grip are the climbers who make their own training plan and based on the results of the Meta-Grip, would implement and change their training plan. Climbers want a measurement every two months with guidance from either a professional or an application. They want to be able to compare their results over time.

F.6 Limitation

This user test was done fully online due to the corona virus. This made it impossible to ask for more information and details in their answers. Furthermore, the Meta-Grip was explained as good as possible, but it was not possible for the participants to actually see the Meta-Grip and ask questions about it. Maybe the product was not clear to everyone. In order to get better results and more detailed answers, a semi-structured interview as research method is desired.

Participant	What is your age?	What is your climbing level?	How many times do you climb in a week?	How many years do you already climb?	How do you train?	Would you use the Meta-Grip in your training and if yes, how?
Participant 1	17	6c	2	9	I have a trainer or coach.	Kijken hoe het werkt
Participant 2	27	7a	2	4	I have a trainer or coach.	No
Participant 3	24	6a	2	2	I just go climbing.	Not really, but maybe later if I am at a more advanced level. Then it might become more relevant.
Participant 4	19	6b	3	4	I make my own trainingsplan.	To see progress and compare grip strenght on different holds
Participant 5	21	7b	3	10	I make my own trainingsplan.	Yes for assesments
Participant 6	48	5c	2	28 years	I just go climbing.	I would use Meta-Grip once in a while, say every two months or so, to see how I am doing and if I am still improving or not
Participant 7	33	6a	3	10	I have a trainer or coach.	Maybe
Participant 8	33	6c	1	20	I just go climbing.	No
Participant 9	29	6a	3	2	I just go climbing.	To calculate my current strength
Participant 10	17	6c	2	7	I have a trainer or coach.	Yes, I would use it to find out what types of grips I struggle with and what position to use to exert most possible pressure
Participant 11	42	5b	1	2	I train in a group	I would use it but with guidance from a professional that can understand the outcomes. And give advice on the basis of that.
Participant 12	30	6b	2	2	I have a trainer or coach.	No first time i heard of it
Participant 13	51	6c	3	15	I just go climbing.	To measure my progress in time of year and seeking my limits
Participant 14	27	5c	2	5	I just go climbing.	ja
Participant 15	34	6a	1	6	I have a trainer or coach.	Likely not
Participant 16	43	6a	2	1	First 2 options	No
Participant 17	26	6c	3	05-jun	I make my own trainingsplan.	Hang on it?
Participant 18	47	5c	1	1.5	I have a trainer or coach.	I dont know
Participant 19	53	6c	2	30	I just go climbing.	Ja, wanneer aan de meting ook een specifiek trainingsadvies wordt gekoppeld. Dus dat je daarna weet wat je moet doen.
Participant 20	60	5c	1	3 years	I have a trainer or coach.	Not yet. But it is nice to know your grip force
Participant 21	74	5c	1	30	I just go climbing.	Nee

Table F.3: Results 1

Why would you use the Meta-Grip and for what purpose?	Would you adjust your training on the basis of results of a measurement with the Meta-Grip and if yes, how?
Sterker worden	Ja, in overleg met mn trainer
Knowing if I have to train my finger strength	Yes , training strength of my grip
Either to train in a more specific way (e.g. if I want to focus on certain grips) or to recover better from an injury (I broke my little finger during climbing two years ago).	Yes, if it shows obvious improvements and easy to grasp tips.
To have more insight in current level and progress	Yes i would know which kind of holds i need to train more on
For strength assesments	No
I would use the Meta-Grip to prevent injuries, to see how I can still use a hold but with less strength, so the risk for injuries diminishes	yes, I would try to focus on different ways to reduce the strength I need to use a certain type of hold
To target specific hand strength and endurance	Yes because based on measurements you can train more specific
Not use it for my own training. Maybe should use it when I would give training on a high level. But depents off the return on investment	Yes, depending on the result
To see if my measured strength could be improved	No
^	Yes, I would train specific types of gripping
Everything to improve my technique and strength.	Yes, but i need someone to tell me how.
Probably to use for measuring strength. And monitoring progression in training. To have better insights and create more effective training methods.	Same answer as above. I would adjust. When there is barely progression in strength it could be sign of overtraining or under training When there is progression in your climbing but there is no improvement in grip strength. You can say grip strength isn't as important or at the moment not an limiting factor. So you can switch your focus point.
To climb injury free at all times	Yes and how depends on the results
Om kracht ontwikkeling te meten en te zien of er vooruitgang is.	Ja
Once in a while to check status	No
Curiosity	If there would be an indication that I'm using my fingers/hands incorrectly
To see is finger strength exercises actually improve my finger strength	Maybe
I'd like to see my strength.	If I knew how i would try
Nieuwschierigheid. Weten wat de beperkende factor is in het beter kunnen klimmen (kracht, techniek, durf, etc.)	Mogelijk
If we use a meta grip it's nice to know your improvements	Yes
?	Nee

Table F.4: Results 2

How often would you like to do a measurement?	How would you like to receive the results of a measurement?	Do you have any remarks?	What is your gender
1 keer per kwartaal	Meteen	Nope	
One a year	01-okt		
once in 6 months maybe?	Together with face-to-face feedback from a coach, to maybe clarify some of the technical results.	Nice research, good luck!:)	
Every 2 months	In a Nice graph and or sheet So that iT is easy to see how far along i am		Female
Onces every few months	Email		Male
once every two months	digitally, so I can easily save it and compare results of different measurements over time		Female
Monthly	Email		Male
After each cyclus	App		Male
Every 3-6 months	During measuring		Male
Once every so many weeks	Digitally	No	Male
Monthly	In an app so I can see the improvement		Female
Depends on your training and periodisation i would measure every 4 weeks.	Directly	I never used the meta grip	Male
Once a week	By a app	It would be nice if there is a app that stores my data locally en kept it in a nice graphic and the app communicates with my sportswatch	Male
1x per maand	Grafiek		Female
2 times a year	As email for easy archiving	Cables, laptops and climbing don't go wel together. A device should be very rugged	Male
I wouldn't	Direct reading		Female
Once per week	On my phone, In an app or per mail (per mail also all previous results, not just the last result)		Male
3 months	email or app		Male
Hangt af van de ontwikkeling. Wanneer metingen constant blijven heeft het geen zin om opnieuw te meten.	In een app met je eerdere metingen en eventueel gekoppeld een trainingsplan.		Male
Once a month	By mail	No	Male
?	?	Nee	Male

Table F.5: Results 3

Appendix G

Interviews

In this appendix, the interviews done with climbing gym owners are discussed. First, the interview with Frank Loeve will be discussed. Second, the interview with Sander ter Steege will be discussed.

G.1 Interview with climbing gym owner Frank Loeve

In this semi-structured interview, the following questions are prepared, as a guideline for discussion. The semi-structured character of the interview allowed for more indepth discussions on these topics and for other topics to be adressed by the interviewee.

- As climbing gym owner, in what price range should the Meta-Grip be for you to be interested in buying the Meta-Grip.
- What is the added value of the Meta-Grip for your climbing gym?
- What are the most important requirements the Meta-Grip has to fulfill for a climbing gym?
- What is your opinion in using an application for and during trainings?
- Which group of climbers will mostly use the Meta-Grip?
- Do you think it is a good thing if multiple climbing gyms offer the same training facilities?
- Do you think this product will eventually be bought by individual climbers?
- Would you buy the Meta-Grip as a climbing gym owners?

Frank Loeve, from de Campus, has as a philosophy that if some people are interested, buying tools makes sense. Frank Loeve would be interested in buying the Meta-Grip if the price is below 500 euros. This is such a small investment for a climbing gym that buying it is easy. If the Meta-Grip will cost more than 1000 euros, serious research into the necessity of it for the climbing gym is needed. When trainers think it is an addition, this might be a reason for investing in the Meta-Grip. Furthermore, as a climbing gym, you want to offer a complete training facility so the product should be useful, functional and an addition to the training facility. The wider the functionality of the product, the more useful it is. Frank believes that if fanatic climbers are convinced that the product will help them get better, the user group will be very large.
There are a lot of climbers that already use an application for their training, but also a lot who do not. The Meta-Grip should both be useable with and without application. The application can give guidance since most people do not know what they should do with a training facility.

G.2 Interview with climbing gym owner Sander ter Steege

In this semi-structured interview, the following questions were prepared, as a guideline for discussion. The semi-structured character of the interview allowed for more indepth discussions on these topics and for other topics to be adressed by the interviewee.

- What are the most important responsibilities concerning training facilities of a climbing gym owner?
- What are your goals concerning training facilities as a climbing gym owner?
- What is a necessity in a climbing gym and what is desirable?
- Would you buy a product if competitive climbing gyms are already using it?
- How do you determine the needs of clients concerning training facilities?
- Are there any requirements for training facilities for the climbing gym? (appearances, functionality, price)
- How do you feel about the appearances of a product and how that would fit within the climbing gym?
- How do you feel about a high price and potentially a lease contract?
- With a complex product, would you like a service system from the company to safeguard the quality of the product?
- How important is the possibility for everyone to use this product?
- Would you purchase a product that can only be used by a select group of climbers?
- What type of climbers do you have in your climbing gym? (e.g. pro athletes, fanatic climbers, sporadic climbers, amateur athletes, injured climbers)
- Have you ever considered buying a product which is able to execute an objective measurement for hand and finger force? If yes, which product?
- How much money would you be willing to pay for such a product?
- Which functions would such a product have minimally?
- How would you, as a climbing gym owner, like to receive feedback? (with a screen, via mobile phone, via a television screen, via an iPad like product)

Sander ter Steege from Delfts Bleau, has as a philosophy that the product should be perfect, no injury risk and fit within the gym. Sport climbing and especially bouldering is rapidly growing these last few years with which logically a growth in climbing gyms evokes. Sander believes that as a climbing gym, you have to supply the possibility that people can keep on improving. This does not necessarily mean helping people to get stronger. Sander believes that climbers nowadays are too strong for the level they climb. A lot of climbers neglect the mental and technique part of climbing. Some people replace fitness with climbing gyms since it is a full body workout and progression is really good measurable. Important is that climbing is not solely for exhaustion, but it is more like solving puzzles and having a challenge.

Sander's vision in responsibilities of the hall is to make sure people cannot completely wreck themselves while climbing. He offers specific training facilities for advanced athletes. They require a high base line in all aspects of climbing as well as a lot of control. If used properly, these tools (hangboards, campus boards, rings, e.g.) can help a lot if someone has an underdeveloped muscle group or is recovering from an injury.

Sander has the opinion that being able to get a number linked to your performance and being able to compare it with peers is going beyond the purpose of the device. If feedback is given this way, it can only be used under accompaniment of professionals (physiotherapists or trainers). When a device is able to translate the numbers to a training plan, it could be considered for use without any guidance. If any numbers should be given, it should be ratio numbers, Sander believes. Sander certainly has an interest in buying such a product, but it has to contribute to the quality of Delfts Bleau.

Sander has some doubt regarding structural measurements with the Meta-Grip. He notices that most climbers do not train in a structured manner. When structure is lacking, it is hard to see progression and useful measurements are difficult.

Appendix H

Polyamide-12

OCEANZ PA12

Datasheet for polyamide parts produced by Selective Laser Sintering

This whitish fine powder on the basis of polyamide 12 serves with its very well-balanced property profile a wide variety of applications. Laser-sintered parts made from Oceanz PA12 possess excellent material properties:

- high strength and stiffness
- good chemical resistance and excellent long-term constant behaviour
- bio compatible according to EN ISO 10993-1 and EU regulation No 10/2011
- approved for food contact in compliance with exception high alcoholic foodstuff

Typical applications of the material are fully functional plastic parts of highest quality. Due to the excellent mechanical properties the material is often used to substitute typical injection moulding plastics. The biocompatibility allows its use for various medical applications (e.g. surgical guides, protheses) and food contact applications.

Oceanz PA12 which is processed in our ISO9001 can be polished, coloured and coated. Oceanz PA12 can also be processed in our ISO13485 certified production environment. Products processed in ISO13485 cannot be polished, coloured and coated.

Part properties	Value	Unit
Part colour	White	-
Part density	0.93	g/cm^3
Minimum wall thickness	0.7	mm
Layer thickness	0.1 – 0.12	mm
Max. product size	675 x 366 x 545	mm
Tensile modulus	1650	MPa
Tensile strength XY	48	MPa
Tensile strength Z	42	MPa
Strain at break XY	18	%
Strain at break Z	4	%
Shore hardness	75	Shore D
Melting temperature	185 - 189	°C

Please note that all mentioned mechanical properties are optimum values according to manufacturer. Due to the layer by layer production process and the specific design of each individual product values may differ. *If specific properties and/or dimensions are critical, always contact us so we can inform you how to obtain required specifications!*

All information in this data sheet is based on appropriate testing further details of which are available on request and is stated to the best of our knowledge and belief at the time of publication. It is presented apart from contractual obligations and does not constitute any guarantee or warranty express or implied of properties or of process or application possibilities in individual cases. The data are subject to change without notice as part of our continuous development and improvement processes.

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Revision date: January 2020

Appendix I

Climbing holds

There are many types of climbing holds available nowadays. At first, climbing holds were trying to copy rock structures known to people, but now the most impressive shapes are available. In this chapter, the different holds, grips on the holds and materials will be discussed. Furthermore, the various holds can have a large variety of dimensions which will be discussed as well.

I.1 Hold types

Artificial climbing holds vary a lot in difficulty and form. There are in general five types of holds (figure I.1):

1. The most easy hold is a jug which enables the climber to secure their fingers behind.
2. A sloper is a big hold which you can hold onto with friction. It is not possible to wrap your hand around it since it is too big.
3. A pinch is a hold which you are able to hold if you squeeze your hand and fingers together.
4. A crimp is a tiny edge on which you hold on with the tips of your fingers.
5. A pocket is a hold where not all fingers fit in, and thus make it difficult because weight has to be hold with less fingers.

Pinch | Sloper | Crimp | Jug | Pocket

Figure I.1: type of climbing holds

On these holds, the hand can be used in various positions, from an open crimp to a closed crimp (Hangboarding a way, sd). These can be seen in figure I.2 till figure I.5. The different crimp positions can be separated by the position of the first finger. In the open crimp, the PIP joint of the first finger(figure I.2) is straight. In the half crimp, the PIP joint of the first finger is approximately 90 degrees (figure I.3). In the full crimp, the PIP joint of the first finger is bend further than 90 degrees (figure I.4). In the full crimp with thumb, the position is similar to the full crimp without thumb for the fingers. The thumb is then put on top of the first finger to reduce load on the first finger (figure I.5).


Figure I.2: Open crimp

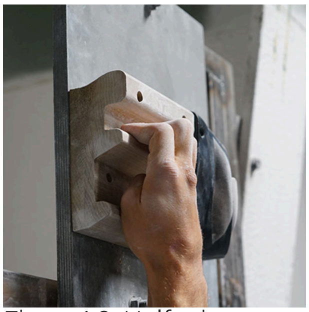


Figure I.3: Half crimp


Figure I.4: Full crimp


fFigure I.5 Full crimp with thumb

I.2 Materials

Most of the climbing holds are made of polyethylene (PE) (figure I.6) with a filler of quartz sand or aluminum oxide. Polyurethane (PU) (figure I.6) and wood (figure I.6) are also used for climbing holds but are not as common as PE holds. Wood is mostly used for training since it safes the skin much more then PE or PU. The disadvantages of wood are that it takes time to have a little bit of resistance because the grain of the wood needs to open up. The resistance will however never be as good as on PE or PU holds.

PE is three times more heavy than PU and fractures easily when dropped or bumped into something. Also, because of the filler, the holds are not recyclable. These are the main reasons PU was developed as a hold material, however, PU also has some disadvantages. PU is without any filler which makes it wear out faster. This is because the rubber in climbing shoes can reach a local temperature of 80˚C which makes the PU melt and the structure will wear out really fast. After the first layer of structure is completely worn away, a new coating can be applied consisting of sand and paint which makes the hold good for another five years. The coating can in theory be removed and reapplied every time the structure of the holds is worn away but this is quite expensive. PU can be recycled quite good, but first the coating needs to be taken off before it can be recycled. Because PU is not porous like PE, much more different shapes can be made as well as hollow shapes (figure I.7) which is not possible with PE.

PE hold | PU hold | Wooden hold

Figure I.6: Different materials

Figure I.7: PU mold

I.3 Dimensions

I.3.1 Crimps

There is a very wide range of hold sizes used in hangboards. The crimps smaller then 10 mm are also called micro crimps (figure I.8). In a study testing on 2.8, 4.3, 5.8, 7.3 and 12.5 mm crimps (Bourne , Halaki, Vanwanseele, & Clarke, 2011) it was found that on the 5.8 and 7.3 mm crimp, climbers above level 22 (IRCRA scale) performed significantly better then climbers below level 22 (IRCRA scale). On the smaller crimps, no significant difference in performance is found which can indicate that those are too small (Sanderson, 2018). In a study done on holds with a depth ranging from one, two, three and four centimeters, it was found that participants preferred a half crimp grip on the one and two centimeters and on the other depths an open grip was preferred (Amca & Aritan, 2012).

From both studies it can be concluded that a crimp should not exceed the two centimeters to ensure a proper crimp grip. A crimp should also not be smaller than 5.8 mm since that is considered too small. The crimps used in the Meta-Grip should be within the 20 – 5.8 mm range.

For crimps, it is also important that every user can fit the same amount of phalanges on the crimp. This is difficult to ensure since this varies a lot between climbers. In research, they used radiographs to measure the distal phalanges on 200 persons. In table I.1 it can be seen that there is a difference in phalanx size which can be up to 9 millimeters (Darowish, Brenneman, & Bigger, 2015). A versatile hold size could be the solution for ensuring the same amount of phalanx on the crimp. A crimp can also be used in multiple ways. The full crimp with thumb support is a critical position in climbing, but due to high loads also injury prone (Anerson, Anderson, & Sanders, 2016). To be able to train this position without the high load, a support can be used that separates the thumb from the index finger, called a DIP guard (figure I.9) (Anerson, Anderson, & Sanders, 2016).

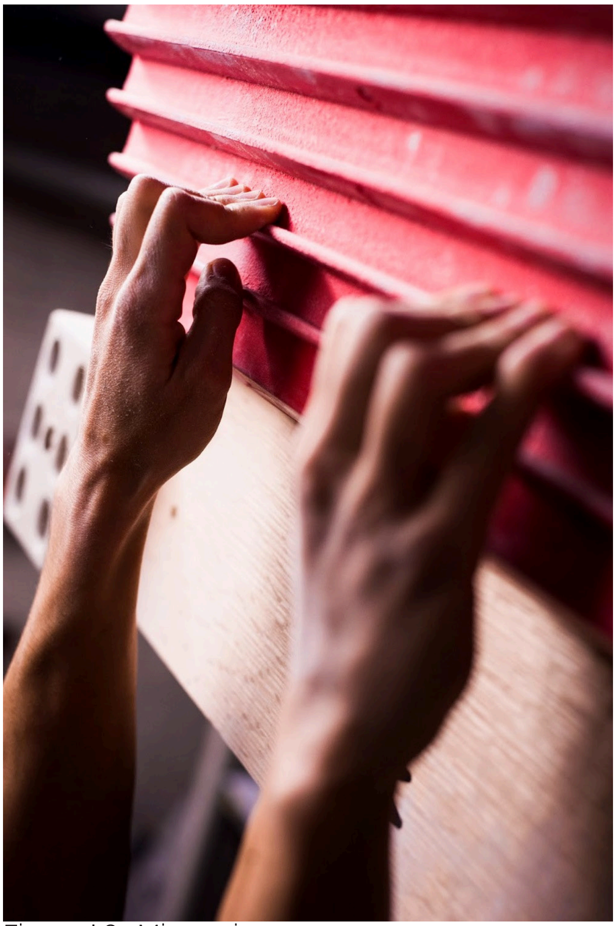


Figure I.8: Micro crimp

Finger	Measurement	Gender	Dimension (mm)
Index	Width	Female	4.4
		Male	5.3
Index	Height	Female	3.2
		Male	3.8
Long	Width	Female	4.9
		Male	5.8
Long	Height	Female	3.4
		Male	3.9
Ring	Width	Female	4.5
		Male	5.3
Ring	Height	Female	3.1
		Male	3.6
Small	Width	Female	3.4
		Male	4.1
Small	Height	Female	2.7
		Male	3.2

Table I.1: Phalanx sizes (Darowish, Brenneman, & Bigger, 2015)

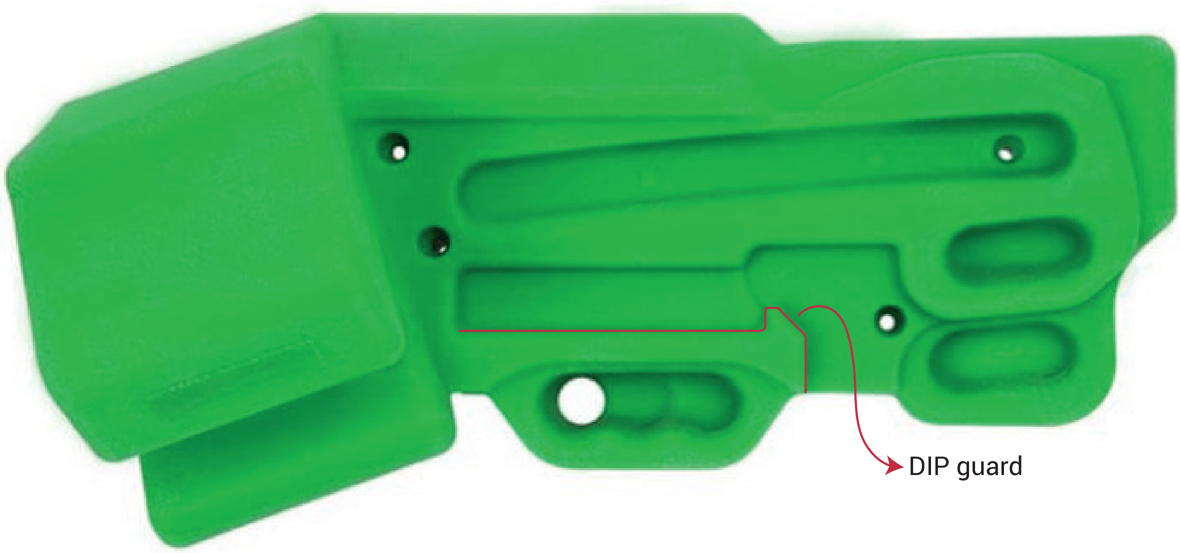


Figure I.9: DIP guard

A crimp can change in difficulty if the radius is changed at the intersection of the horizontal and vertical surfaces (red dotted line in figure I.10). Making the radius too large results in a very slopey crimp and making the radius too small results in an uncomfortable crimp since it will cut in the fingers of the climber. To test which radius is the most pleasant, three crimps will be tested with a radius of 5 mm, 10 mm and 15 mm. The participants test the radius hanging 10 seconds on how hard it is to hold the crimp and how uncomfortable it is to hold the crimp. To determine then what the best radius is to use in crimps, the difficulty to hold the crimp and the comfortability of holding the crimp needs to be plotted opposite to each other.

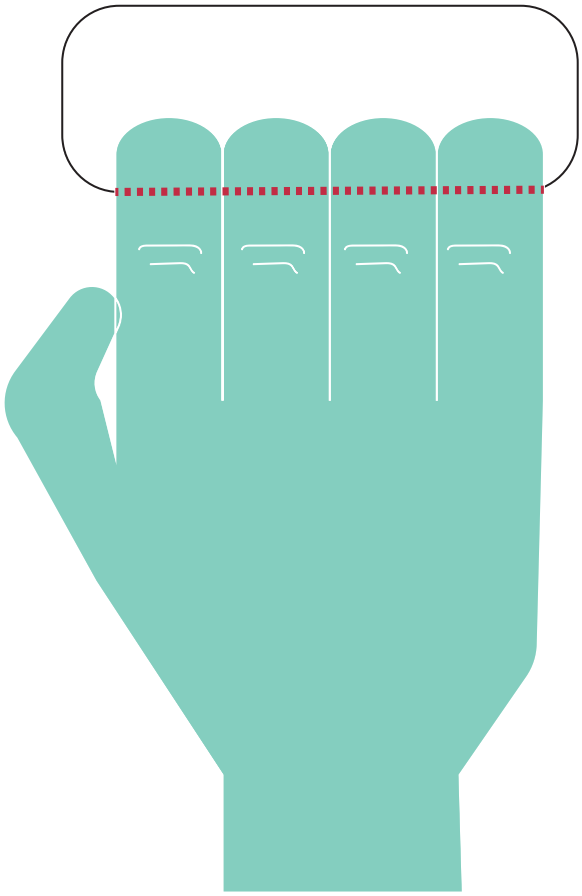


Figure I.10: Radius edge

Figure I.11: 3D-printed crimps

Research questions

1. Which radius gives the highest comfort?
2. Which radius gives the best performance?

Hypothesis

It is expected that a smaller radius goes with a better performance whereas comfort is achieved by a larger radius.

Method

Participants

There are four participants in this user test, with varying experience in climbing (average is 20 years). The participants were selected on being in one houshold during the Corona lockdown.

Stimuli

Three different 3D-printed crimps (figure I.11) with different radiuses and a google form.

Apparatus

A hangboard stand with three different crimps and a mobile phone.

Procedure

Participants were explained what the purpose of the user test was. After the general information, participants had to execute as much force as possible on the first crimp for ten seconds, first with their right hand, then with their left hand. This was repeated for the second and third crimp. After executing force with a hand on a crimp, two questions were asked:

1. How hard is it to hold the crimp?
2. How uncomfortable is it to hold the crimp?

The Likert scale was used for these questions. For the first question, the range was from very hard to very easy and for the second question from very comfortable to very uncomfortable.

Results

The results were as expected. The smallest radius (5 mm) was not high in comfort, but gives the participants a feeling they can perform well. The medium radius (10 mm) was almost equal high in comfort as it was in being able to perform well. The last and large radius (15 mm) was high in comfort, but participants did not feel like they were able to perform well. This is visualized in figure I.12. For the full results, see table I.2 on page 121.

Conclusion

To find the optimal radius, both comfort and performance are important. Therefore, the 10 mm, medium, radius is ideal.

Discussion

The crimps were only tested with a crimp of 20 mm deep. If the crimp depth changes, it is likely that the radius needs to change as well. For a smaller crimp, if the radius is 10 mm, it can be too hard to hold on.

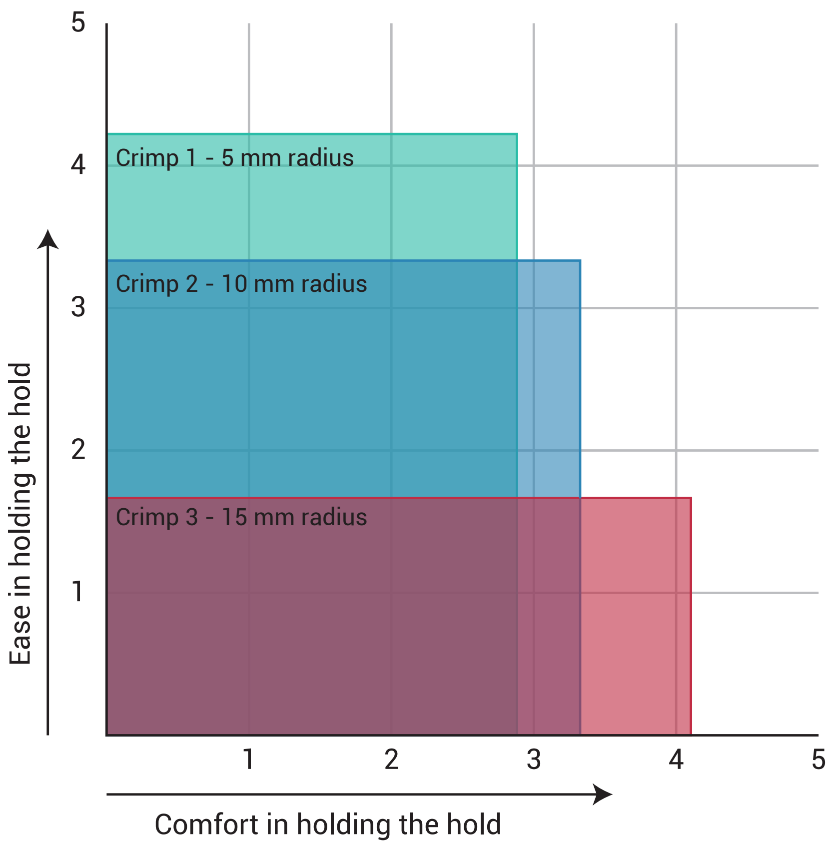


Figure I.12: Radius size

	Participant 1	Participant 2	Participant 3	Participant 4
What is your redpoint level bouldering?	18	15	15	16
What is your redpoint level lead?	16	12	10	11
Climbing experience in years	14	30	6	30
How hard is it to hold the crimp? [5 mm] [Right]	4	4	4	4
How uncomfortable is it to hold the crimp? [5 mm] [Right]	2	3	4	2
How hard is it to hold the crimp? [5 mm] [Left]	4	4	5	5
How uncomfortable is it to hold the crimp? [5 mm] [Left]	2	3	4	3
How hard is it to hold the crimp? [10 mm] [Right]	3	4	3	3
How uncomfortable is it to hold the crimp? [10 mm] [Right]	4	3	4	3
How hard is it to hold the crimp? [10 mm] [Left]	3	4	4	3
How uncomfortable is it to hold the crimp? [10 mm] [Left]	4	4	4	3
How hard is it to hold the crimp? [15 mm] [Right]	1	3	1	2
How uncomfortable is it to hold the crimp? [15 mm] [Right]	5	4	3	4
How hard is it to hold the crimp? [15 mm] [Left]	1	2	2	2
How uncomfortable is it to hold the crimp? [15 mm] [Left]	5	4	5	3

Table I.2: Results radius size

I.3.2 Sloper

Slopers exist in various shapes and sizes across different hangboards. A sloper can either be a flat surface at a certain angle making it easier or harder (figure I.13) or it can be a rounded shape which can change in difficulty by having a larger or smaller radius (figure I.14). The current Meta-Grip sloper is rounded and has a radius of 106,39 mm. For the flat surface sloper, a 10˚ sloper is considered easy where with a 30˚ sloper the effect of the angle is significant (Amca & Aritan, 2012). On a sloper, an open grip is desired and to ensure this, the depth of the sloper should be larger than 20 millimeters (Amca & Aritan, 2012). The sloper should also be wide enough for every user. According to Dined, the hand width of a P95 user is 97 mm, therefore the sloper on the Meta-Grip should be at least a width of 100 mm (Dined, sd).

Figure I.13: Flat surface sloper

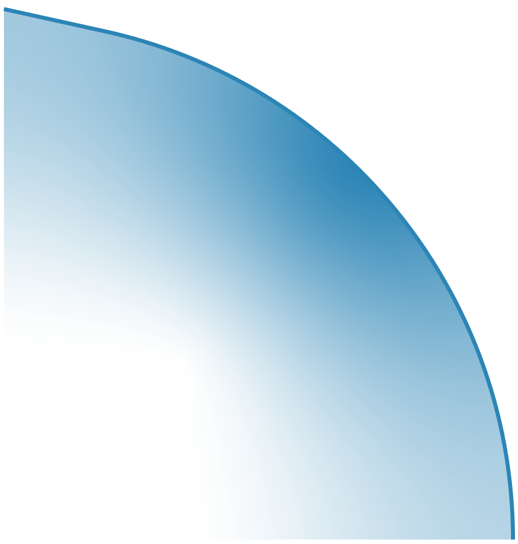


Figure I.14: Round surface sloper

I.3.3 Pinch

The pinch size is very much related to hand size. Pinches are considered shallow and narrow if they are less than five centimeters and wide if they are more than eight centimeters. For training purposes narrow and wide pinches are more effective than one in between. With two different pinch sizes together, a third can be created (figure I.15), which can help in saving space on the hangboard. The posture is very important to prevent injury using a pinch and different from the posture when using a crimp, pocket or sloper which should also be taken into account when assembling the shape of the hangboard. Using a pinch, the wrists should be in a natural position (15˚ - 30 ˚ extension), the thumbs should be pointed upwards and the shoulders flexion should be 45˚ - 135˚. This brings our arms slightly in front of the body (López, 2013) (figure I.16). Taking into account this posture, the pinches should be situated as such that the user can easily grab the pinches from underneath and that it is possible to hang underneath them.

Figure I.15: Pinch combination

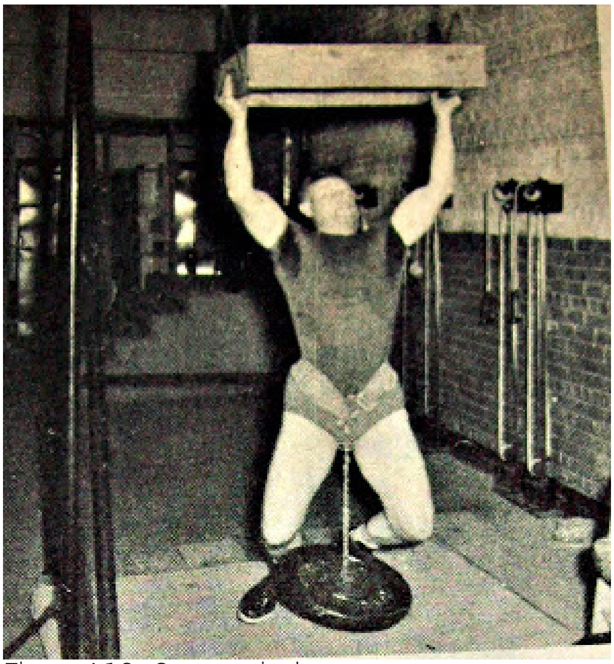


Figure I.16: Correct pinch posture

I.3.4 Pocket

Pockets can be made for three, two and one finger. The one finger pocket is not often used because of the risk of injury (Schweizer, 2003). Two-finger pockets should fit only two fingers. The forefinger breadth for P5 is 14 mm and for P95 it is 20 mm (Dined, sd). This is quite a large difference but holds should be usable for P95 users also. This results in a two-finger pocket being at least 40 mm wide. The pocket should ideally fit one phalanx.

I.4 Grip selection

Climbers can be divided into five different user groups (appendix D: Involved parties with the Meta-Grip on page 80). These five different groups have different preferences regarding the hold types and sizes. In the Rock Prodigy Training Method they selected different holds for beginner, intermediate and advanced hangboard (Anderson & Anderson, 2015). The Rock Prodigy Training Method is a training program specifically developed for climbers and based on research with climbers instead of based on different sports (dancing, powerlifting). This program has different training phases leading up to a predictable performance peak. For the beginner hangboard, the holds should at least include:

- Jug
- Large crimp
- Medium crimp
- Wide pinch
- Medium pinch
- Sloper
- Deep 3-finger pocket
- Deep 2-finger pocket

For the intermediate hangboard, the large crimp should be replaced by a small crimp and the deep 2-finger pocket should be replaced by a shallow 2-finger pocket. For the advanced hangboard, a 1-finger pocket is advised (Anderson & Anderson, 2015). However, other research shows a 1-finger pocket leads quickly to injury (Schweizer, 2003) (Kubiak, Klugman, & Bosco, 2006) and is not ideal to train regularly. However, when training for a specific route where this hold and size appears, it can be desired to train this specific hold (Anderson & Anderson, 2015).

I.5 Conclusion

All holds have a range of sizes that allows implementation in the hangboard. For the crimp to be used in the correct position and have an effect on training, it should range between 20 and 5.8 millimeters. Ideally for a measurement, every user can fit one phalanx on the hold which can be achieved by a versatile hold depth.
To protect the climber in the closed crimp with thumb posture, the DIP guard can be implemented in the hangboard. Furthermore, the radius of the crimps should be ten millimeters.
A sloper should have a depth larger than 20 millimeters to ensure an open grip. The sloper can range between 10 and 30 degrees, depending on the desired difficulty. The sloper should be at least a 100 millimeter wide for all users to fit their whole hand on the sloper.
A small pinch is less than five centimeters and a large pinch is larger than eight centimeters. Combining two pinches, a third one can be created, saving space on the hangboard.
Pockets can also be included on the hangboard, however a 1-finger pocket has a too high risk for injury. Two and three finger pockets are helping climbers in getting better. Since every user should be able to use the holds, the two-finger pocket should at least have a width of 40 millimeter

For different climbers, different holds are desired on a hangboard. To accommodate all climbers, multiple hangboards are necessary.

Appendix J

Creative session at the Campus

This creative session is organized to get feedback on the embodiment of the redesigned Meta-Grip. The participants are all climbers, with different climbing levels and experiences.

J.1 The session

The session was executed with four participants (figure J.1 on page 125). The participants have an average age of 26 years old and an average climbing experience of 3,5 years. Three of the climbers have experiences with specific strength training for climbing. The participants are asked for consent, since pictures taken during the session will be used in the report. In the first part of the session, the concept of the Meta-Grip and the first exercise was explained. The basic functions of the Meta-Grip were explained (measurement and training) and the redesigned skin was introduced. The shape of the wood part and the PU part is given to the participants. They are not allowed to change this. They are asked to draw multiple posibilities on how they want the holds to be arranged and what holds they want. After making multiple possibilities, they are to describe why those possibilities seem ideal to them. Some interesting results can be seen in figure J.2, figure J.3 and figure J.4 on page 125 and are listed below;

- The crimps can be angled to make the crimps more diverse in posture.
- The sides of the Meta-Grip can be used for crimps as well.
- The bottom of the Meta-Grip can be used to hang ball slopers (figure J.4 on page 125).
- The participants also drew slopers on the front face of the Meta-Grip.
- People added a pinch as well on the Meta-Grip.

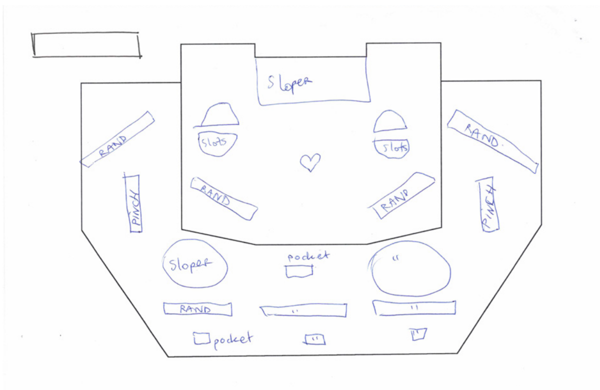


Figure J.2: Result 1

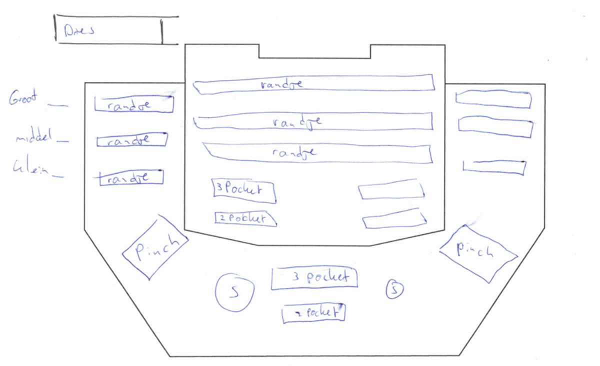


Figure J.3: Result 2

Figure J.1: Participants working on their design

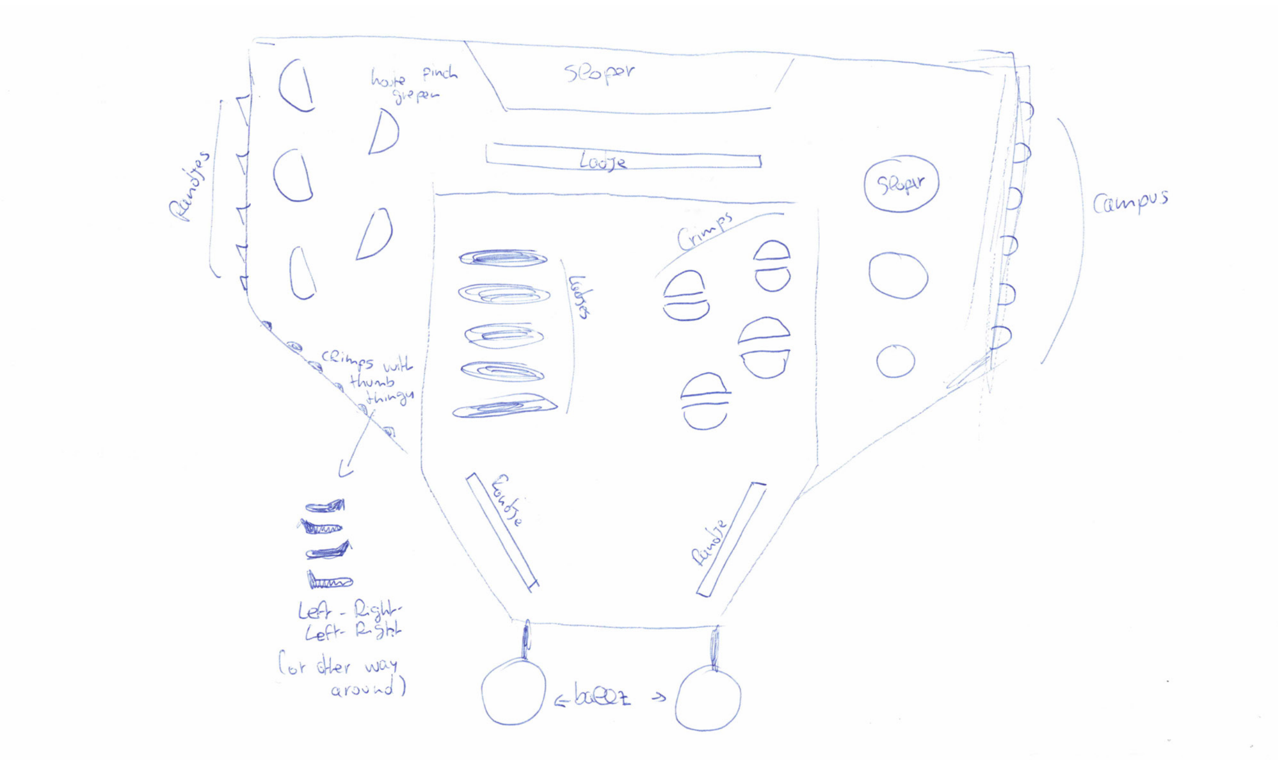


Figure J.4: Ball slopers

After this, the design at that moment of the Meta-Grip was shown through pictures made in Keyshot (figure J.5). The participants had to evaluate this design on several points; a sheet with some questions was provided to the participants. In general, the participants really liked that risk of injury is taken into account by adding the DIP guard and the combination of PU and wood. However, the design can still make some improvements according to the participants: more surface of the Meta-Grip can be used (the sides and a higher density of holds). The two finger pockets cannot be used at the same time since they are positioned to close together. This also applies to the jug. The participants also would have preferred more different finger pockets.

After these two parts, the participants were allowed to draw any ideas they still had or thought about; they might have been sparked by listening to others, however, no changes were made.

J.2 Conclusion

From this session it can be concluded that the current design of the Meta-Grip is already in taste with climbers. Positive changes can be made like using more of the Meta-Grip for climbing holds, adding a pinch or having more diverse holds. The jug and finger pockets in the current design are difficult to use with both hands at the same time because of the small distance between the two. It is also interesting to look into using more of the Meta-Grip for holds, like the sides.

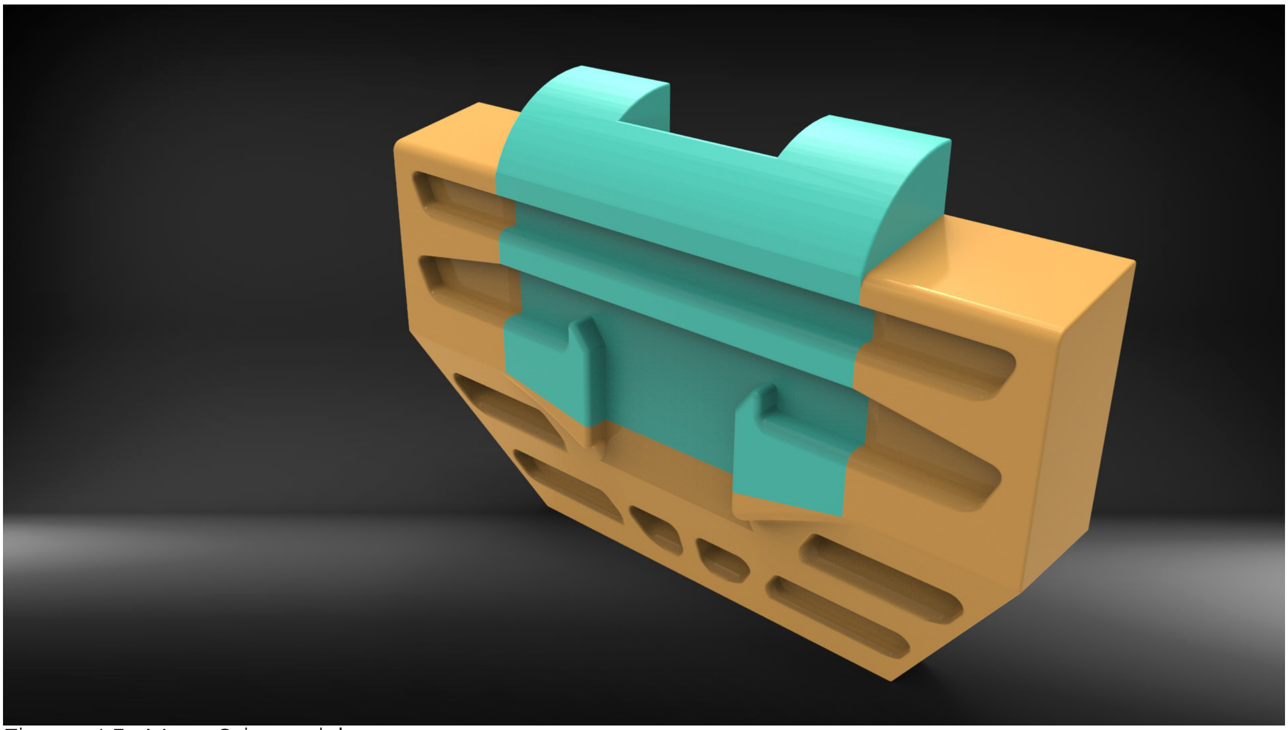


Figure J.5: Meta-Grip model

Appendix K

Materials

This chapter describes important choices concerning the material of the Meta-Grip.

K.1 The skin

In hangboards, there is a lot of variation in form, size and materials used. For example, Beastmaker uses beech and tulipwood for their hangboards. There are also hangboards made from PE combined with a filler, like normal climbing holds.

To decide if wood or PE/PU would be best for the Meta-Grip, a questionnaire was performed among climbers who regularly use a hangboard in their training. We asked them their preference for wood or common climbing holds materials (PE/PU). We distinguished two situations in which the Meta-Grip will be used;

1. The first situation is for training purposes. During a training, a climber usually uses the Meta-Grip for a longer period of time on different holds, executing multiple exercises.
2. The second situation is for measurements. For a measurement it is necessary that a climber can perform at their absolute best, with maximum strength so the materials used for a measurement have to enable this and not limit it.

K.1.1 Research question

1. What type of material is preferred for measurements on different hold types and sizes?
2. What type of materials is preferred for training on different hold types and sizes?

K.1.2 Hypothesis

The friction with polyurethane or polyethylene is much higher than with wood so it is expected that for a measurement, climbers would prefer that over wood. For training, it is less important that the friction is optimal and more important that the skin of climbers stays intact, therefore it is expected that climbers prefer wood for training.

K.1.3 Method

Participants

This user test was done with 13 participants which did 2.3 hangboard sessions per week on average. The average climbing level for lead was 22 (IRCRA scale) and for boulder 24 (IRCRA scale). The participants were climbers in the network of the researcher and some climbers from the Dutch National Climbing Team and all part of the amateur or pro athlete group.

Stimuli

Google form

Apparatus

Laptops or mobile phones to access the questionnaire.

Procedure
First, the participant was introduced to the purpose of this user test via a text description. After this, they had to fill in some general information about their climbing experience. After this, the question was asked which material they would prefer with a measurement and in a training, without specifying the holds. After this, a distinction was made between holds. The holds included in the questionnaire were:

- A sloper
- A 1-phalanx crimp
- A ½ phalanx crimp
- A pinch
- A 2-finger pocket

Measures
The research questions will be answered by analyzing the answers of the participants.

K.1.4 Results
In figure K.1 on page 129, an overview is given of the answers given by the participants. On a sloper, a 1-phalanx crimp and a pinch, climbers would prefer polyurethane or polyethylene as a material for a measurement. However, on a 2-finger pocket and a ½ phalanx crimp climbers would prefer wood since this is more strenuous on the fingers. For training purposes, climbers would prefer wood in all cases. The full results can be found in figure K.2 on page 130 and figure K.3 on page 131.

K.1.5 Conclusion
From this questionnaire, we can conclude that in most cases climbers would prefer to do a measurement on a sloper, 1 phalanx crimp and a pinch on material that is similar to most climbing holds, being PU/PE, but would prefer training on a wood type. With the more harder holds, the 2-finger pocket and the ½ phalanx crimp, climbers prefer wood in both the training and measurement.

K.1.6 Discussion

The group of participants is not representable for the whole user group since they are all amateur athletes or pro athletes. However, these climbers have by far the most experience in hangboard training and thus aware of the toll it takes on the finger. To protect less experienced climbers, this group is chosen since they can identify what is best for their hands and fingers. The less experienced climbers can take advantage of the knowledge these climbers already have and prevent injuries.

K.1.7 Manufacturing

The results of the questionnaire indicates that a combination of materials, using both PE/PU and wood for the hangboard, is best. This requires a combination of materials. A combination of materials is possible. However, PE climbing holds (most commonly used) shrink when curing and, hence, are difficult to combine with wood. PU holds do not shrink when curing and it is possible to glue them to wood, which is not possible for PE holds. To even further ensure that everything stays in place, a slat connection (figure K.4) can be used to make the structure more rigid before gluing as advised by Frank Bogerman, a professional hold builder.

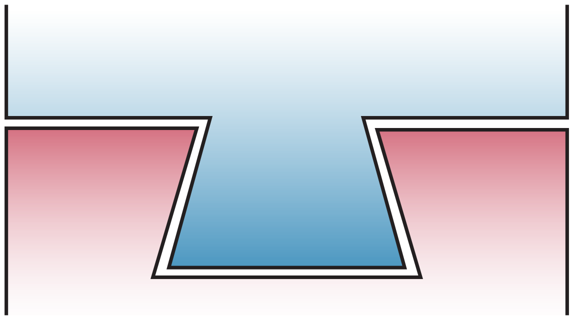


Figure K.4: Slat connection

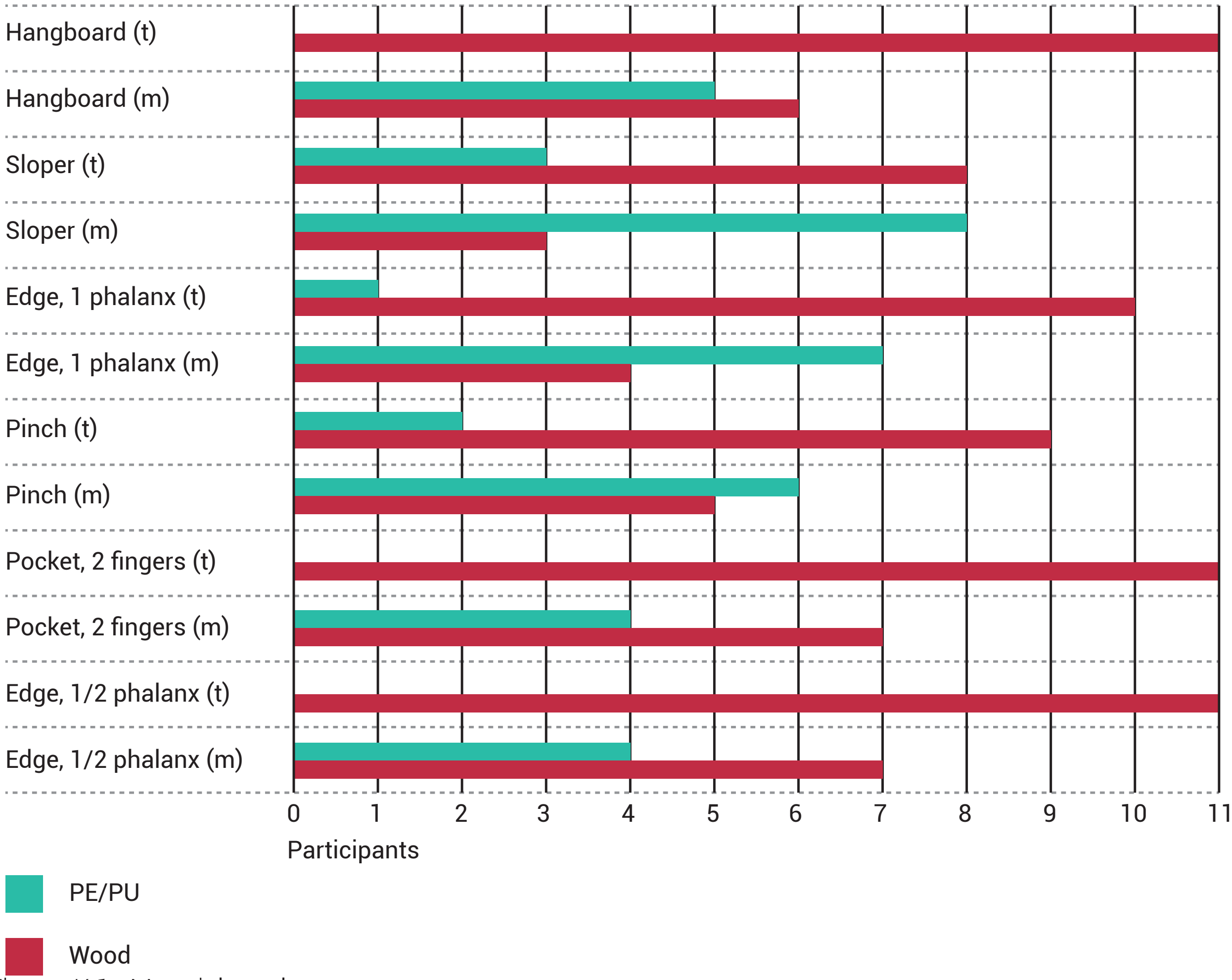


Figure K.1: Material results

Kolom1	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	Participant 7	Participant 8	Participant 9
Do you train on a hang board?	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
How many times per week do you train on a hang board?	3	2	1	0	3	2	3	1	2
What is your redpoint level bouldering?	7b	7c+	7b	6b/c	7c	7a	7c	8b+	8a
What is your redpoint level lead climbing?	Optie 1	8a+	7a+	7a	8a	7a	7c	8b	8a+
For training, which hang board would you prefer?	A wooden hang board	A wooden hang board	A wooden hang board	A wooden hang board	A wooden hang board	A wooden hang board	A wooden hang board	A wooden hang board	A wooden hang board
With a measurement, which hang board would you prefer?	A wooden hang board	A hang board made from the same materials as common climbing holds (PE)	A hang board made from the same materials as common climbing holds (PE)	A wooden hang board	A wooden hang board	A hang board made from the same materials as common climbing holds (PE)	A wooden hang board	A hang board made from the same materials as common climbing holds (PE)	A hang board made from the same materials as common climbing holds (PE)
Which material would you prefer for the following options? [A sloper (training)]	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)
Which material would you prefer for the following options? [A sloper (measurement)]	A hold made from the same materials as common climbing holds (PE)	A hold made from the same materials as common climbing holds (PE)	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A hold made from the same materials as common climbing holds (PE)
Which material would you prefer for the following options? [An edge for 1 phalanx (vingerkootje) (training)]	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A wooden hold	A wooden hold	A wooden hold	A wooden hold	A wooden hold	A wooden hold
Which material would you prefer for the following options? [An edge for 1 phalanx (vingerkootje) (measurement)]	A hold made from the same materials as common climbing holds (PE)	A hold made from the same materials as common climbing holds (PE)	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A hold made from the same materials as common climbing holds (PE)
Which material would you prefer for the following options? [A pinch (training)]	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A wooden hold	A wooden hold	A wooden hold
Which material would you prefer for the following options? [A pinch (measurement)]	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold
Which material would you prefer for the following options? [2-finger pocket (training)]	A wooden hold	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A wooden hold	A wooden hold	A wooden hold
Which material would you prefer for the following options? [2-finger pocket (measurement)]	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold
Which material would you prefer for the following options? [An edge for 1/2 phalanx (vingerkootje) (training)]	A wooden hold	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A wooden hold	A wooden hold	A wooden hold
Which material would you prefer for the following options? [An edge for 1/2 phalanx (vingerkootje) (measurement)]	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold

Figure K.2: Results 1

Participant 10	Participant 11	Participant 12	Participant 13
No	Yes	Yes	Yes
0	4	3	1
7C+	8a	8b	7B
7c+	8b	8c	7b
A wooden hang board	A wooden hang board	A wooden hang board	A wooden hang board
A wooden hang board	A wooden hang board	A wooden hang board	A wooden hang board
A wooden hold	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)
A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A hold made from the same materials as common climbing holds (PE)
A wooden hold	A wooden hold	A wooden hold	A wooden hold
A wooden hold	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)
A wooden hold	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)
A wooden hold	A hold made from the same materials as common climbing holds (PE)	A wooden hold	A hold made from the same materials as common climbing holds (PE)
A wooden hold	A wooden hold	A wooden hold	A wooden hold
A wooden hold	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)
A wooden hold	A wooden hold	A wooden hold	A wooden hold
A wooden hold	A wooden hold	A wooden hold	A hold made from the same materials as common climbing holds (PE)

Figure K.3: Results 2

K.1.7 Wood

Wood for climbing holds gets better when it ages because the grain opens up more which increases the friction. In order to have good friction, the grain needs to be uniform in the wood. Furthermore, wood should not splinter too fast or be too soft. To find the correct wood for a hangboard, the splitting strength and the hardness of wood are important to look at. The splitting strength is the force per millimeter that is needed to split a piece of wood perpendicular on the fiber direction. The hardness of wood is defined as the power that is needed to push a steel sphere with a diameter of 11,824 mm halfway in the wood, also known as the Janka-hardness (Hout, 2013). The assumption is made that the hangboard will be used only indoors; weather resistance makes it more difficult to find a fitting type of wood.

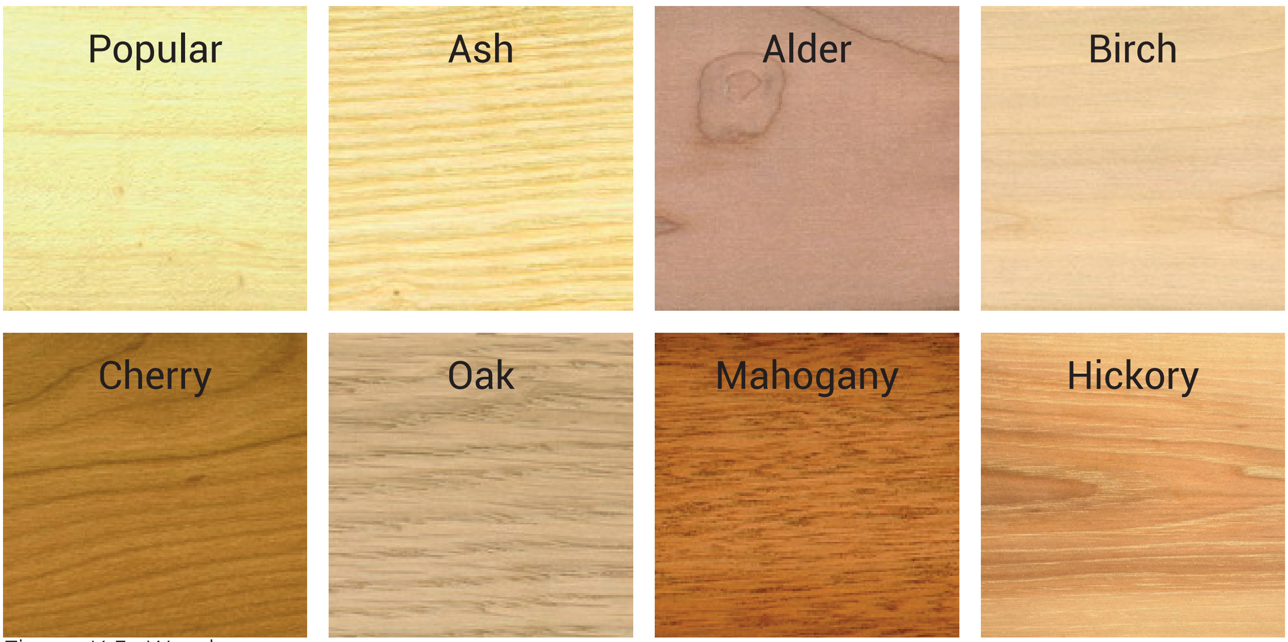


Figure K.5: Wood types

In table K.1 multiple woods (figure K.5 on page 132) are compared to each other (Hout, Houtvademecum, 2018). For finding the best wood type for the hangboard, Robert Hogenelst was consulted as an expert, with more than 30 years of experience in woodworking. From this table we can already exclude mahogany and oak since it splinters easily and can break crosshair which is the direction of the force applied on a hangboard. Furthermore, popular and cherry are less ideal wood types since they are relatively soft. That leaves birch, alder, ash and hickory which will be compared based on the purposes for which they are mostly used. Ash is used for a lot of sporting goods like sticks for hockey, polo and golf as well as bars for gymnastics. There are also garden tools which use ash wood as a handle (Houtsoort Essen, sd). Birch is less used for sporting goods and more for objects that require less interaction (Houtsoort Berken, sd). Alder is mostly used for brooms, toys but also for sculpting. However, in contact with iron, corrosion can arise which should be taken into account (Houtsoort Elzen, sd). Hickory is mostly used in applications where elastic but strong wood is necessary like in gymnastic equipment, gliders and skis (Houtsoort Hickory, sd). From these four wood types, hickory is less ideal since it is elastic which is not wanted in a hangboard.

Ash, birch and alder (figure K.6 on page 134) are all a good choice for a hangboard. The differing prices of wood types can lead to a preference for a certain wood type. The prices of ash, birch and alder are respectively 968 euros, 847 euros and 665 euros per cubic meter (m3) (Houtsoorten en prijslijst, sd).

Wood type	*Splitting strength*	*Hardness*	*Comments*
Popular	50 – 63 N/mm	2300 N	Relatively soft wood
Birch	84 – 90 N/mm	5470 N	Relatively closed grain
Alder	58 – 69 N/mm	2940 N	
Cherry	77 – 108 N/mm	4630 – 6900 N	Relatively soft and closed grain
Ash		6140 N	
Oak	73 – 97 N/mm	5740 – 7840 N	Open grain, hard, but splinters easily
Hickory	115 N/mm	10100 N	Used for gymnastic equipment
Mahogany	52 N/mm	4720 – 3560 N	Can easily break across the grain (crosshair)

Table K.1: Wood types

Using the weighted objective method (Roozenburg & Eekels, 2003) a choice is made between alder, ash and birch. The criteria are as following:

1. The openness of the grain. An open grain in the wood makes it possible for the wood to, over time, become better to hold with more friction. However, a too open grain can cause splintering and too much wearing.
2. The uniformity of the grain. It is important that the grain is straight and similar over the whole wood in order to have good strength and nice grip.
3. The grain size. Smaller and more grains means that they cannot open as wide as larger and less grains. However, having too large grains is not ideal as well because of the splintering and less grip.
4. Price. The price is important, a lower price is more preferred.
5. Splitting strength. Of all materials chosen, the splitting strength is sufficient. However, the higher the better.
6. Hardness. Of all materials chosen, the hardness is sufficient. However, the higher the better.

In table K.2, the results of the weighted objective method can be seen. Alder has the highest score and is thus the most preferred wood. Ash and birch score less in the weighted objective table.

Figure K.6: Ash, birch and alder wood

		Alder		Ash		Birch	
	Weight	Score	Weighted score	Score	Weighted score	Score	Weighted score
The openness of the grain	30	8	240	6	180	7	210
The uniformity of the grain	20	8	160	5	100	8	160
The grain size	15	9	135	6	90	7	105
Price	15	7	105	5	75	9	135
Splitting strength	10	7	70	10	100	9	90
Hardness	10	9	90	3	30	6	60
	100		**800**		**575**		**760**

Table K.2: Weighted objective method wood type

K.2 Button

The button needs to be translucent to allow light feedback to shine through and reach the user. The button will be made from plastic, either polypropylene (PP) (Polypropylene, sd), Acrylonitrile Butadiene Styrene (ABS) (ABS, sd), high-density polyethylene (HDPE) (Griffin, 2019) or polylactic acid (PLA) (PLA, sd). Since the button will likely be produced via 3D printing because of the small batch, this is also in the weighted objective method. All materials can be produced via 3D printing, only some better than others. In table K.3, the weighted objective method is used to make a decision on what material to use for the button. There are five assessment criteria which are explained below:

- Transparency. The button needs to be transparent to allow light feedback to shine through.
- Shrinkage/warping. When 3D printing, shrinkage and warping can occur. Designing with shrinkage and warping is difficult because of the uncertainty of how the object will come out at the end.
- 3D printing. This criteria assesses the ability to 3D print materials.
- Price. A lower material price causes a lower overall price which is good.
- Durability. The durability of all materials is high, but some are better than others.

From the weighted objective method PLA comes as the best option with ABS being second. PP and HDPE are less ideal because of the shrinkage/warping and 3D printing is more difficult. The durability of PLA is less than the other materials, but since the button is not a very heavily used object, this will be fine.

		PP (Polypropylene, sd)		ABS (ABS, sd)		HDPE (Griffin, 2019)		PLA (PLA, sd)	
	Weight	Score	Weighted score	Score	Weighted score	Score	Weighted score	Score	Weighted score
Transparancy	35	9	315	9	315	7	245	9	315
Shrinkage/ warping	27	4	108	4	108	4	108	9	243
3D printing	20	4	80	8	160	4	80	9	180
Price	12	4	48	9	108	3	36	9	108
Durability	6	8	48	8	48	8	48	4	24
	100		599		739		517		870

Table K.3: Button material

Appendix L

Color study

In this chapter, the chosen colors for the Meta-Grip will be substantiated. To identify the colors, research is done across already existing climbing brands and to the climbing lifestyle. Based on this, the researchers developed a color panel. This color panel was verified by climbers by means of a user test.

L.1 Climbing lifestyle

Climbing originally started out on the rocks and has developed more on artificial holds and walls over the years. In climbing there is a balance between natural materials and created materials. It is important that this balance stays intact. Furthermore, in most climbing materials there is a contrast with nature; contrasting bright colors are used for producing climbing materials. This has a functional reason since people want to be able to easily find their belongings in a natural area. This is shown in the collage in figure L.1 on page 137.

L.2 Chosen colors

Looking at colors other companies use, you almost always see a combination of natural and accentuating colors. There are also mostly some accent colors that give a good contrast. In figure L.2, the color palette created for the Meta-Grip can be seen. The two colors on the far right identify more with natural colors since they are toned down and create a rest for the eyes. The red, green and blue are bright colors that create a contrast with other natural materials and with the two right colors.

Figure L.2: Chosen colors

Figure L.1: Climbing lifestyle

L.3 User test

The goal of the user tets is to evaluate which color palette is preferred by the users, with which colors they would like to be identified as a climber.

L.3.1 Research question

1. What color palette is preferred by climbers?

L.3.2 Hypothesis

It is expected that the chosen color palette is preferred by the climbers since those colors work well together. It is also expected that users find it hard to identify their most favorable color out of the first and second color palette since the difference between them is rather small.

L.3.3 Method

Participants

There are five participants, all climbers in the network of the researcher. Their level of climbing differs from fanatic climbing to amateur athlete.

Stimuli

There are multiple palettes made from which they have to choose. The first color palette is created by picking three colors of the colors for the Meta-Grip . The second color palette is created by changing the hue 30˚ which is a small difference with the picked colors. The third color palette has a changed hue of 60˚ and the third palette has a changed hue of 180˚. This is shown for the four different questions from top to bottom in figure L.3.

Apparatus

Participants use their own phone or laptop to participate in this study.

Procedure

Participants will follow the google form where they are informed of the purpose of this user test. After that, they will see four palettes of three colors each which they have to rank from least to most favorable. The order of the four palettes was different for each repetition to prevent the chosen palette to be the first one to rank. After repeating this four times with different color panels, the final color palette is shown and they are asked to give their opinion about this.

L.3.4 Results

A point system was used for the color study. If a color was most favorable it got four points and least favorable was one point. This led to a total score which is shown in figure L.4 on page 140 and figure L.5 on page 141.
For the first color palette (color palette A till D), the participants preferred the color palette with the chosen colors the most. However, they did not like the color

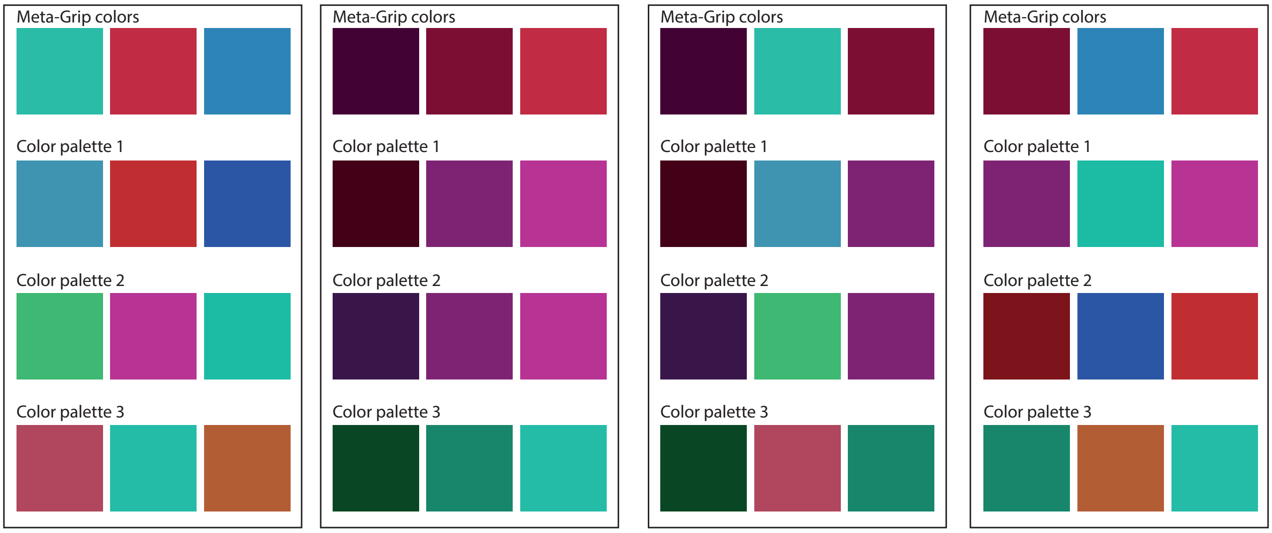


Figure L.3: User test colors

palette with a changed hue of 30˚ as second best which was expected.
For the second palette (color palette E till H), the most favorable color palette were the chosen colors. Again, the second best color palette was not the one with a changed hue of 30˚.
In the third color palette (color palette I till L), the chosen colors were ranked lowest with one other color palette. In this color palette, there was a complementary contrast which can be the reason that this color palette was ranked lowest.
In the fourth color palette (color palette M till P), the chosen palette was again the most preferred by the participants.
In the comments, the participants mentioned that these 'old-fashioned' colors fit perfectly with climbing.

L.3.5 Conclusion

It can be concluded that the participants overall liked the color palette shown in figure L.2 on page 136. When using these colors, attention should be paid to the contrast within this color palette (red and green); these should not be used next to each other with the same brightness. Furthermore, five colors are a lot for a brand image and thus primary and secondary colors need to be identified.

L.3.6 Discussion

This user test was done after the colors for the Meta-Grip were established.
If the user was involved earlier in the process, different colors might have been chosen. In this user test, a small population of the climbing community is asked to participate; it is therefore hard to generalize findings. Then again, it is difficult to mix a color palette which all climbers like, since colors are part of a personal taste.

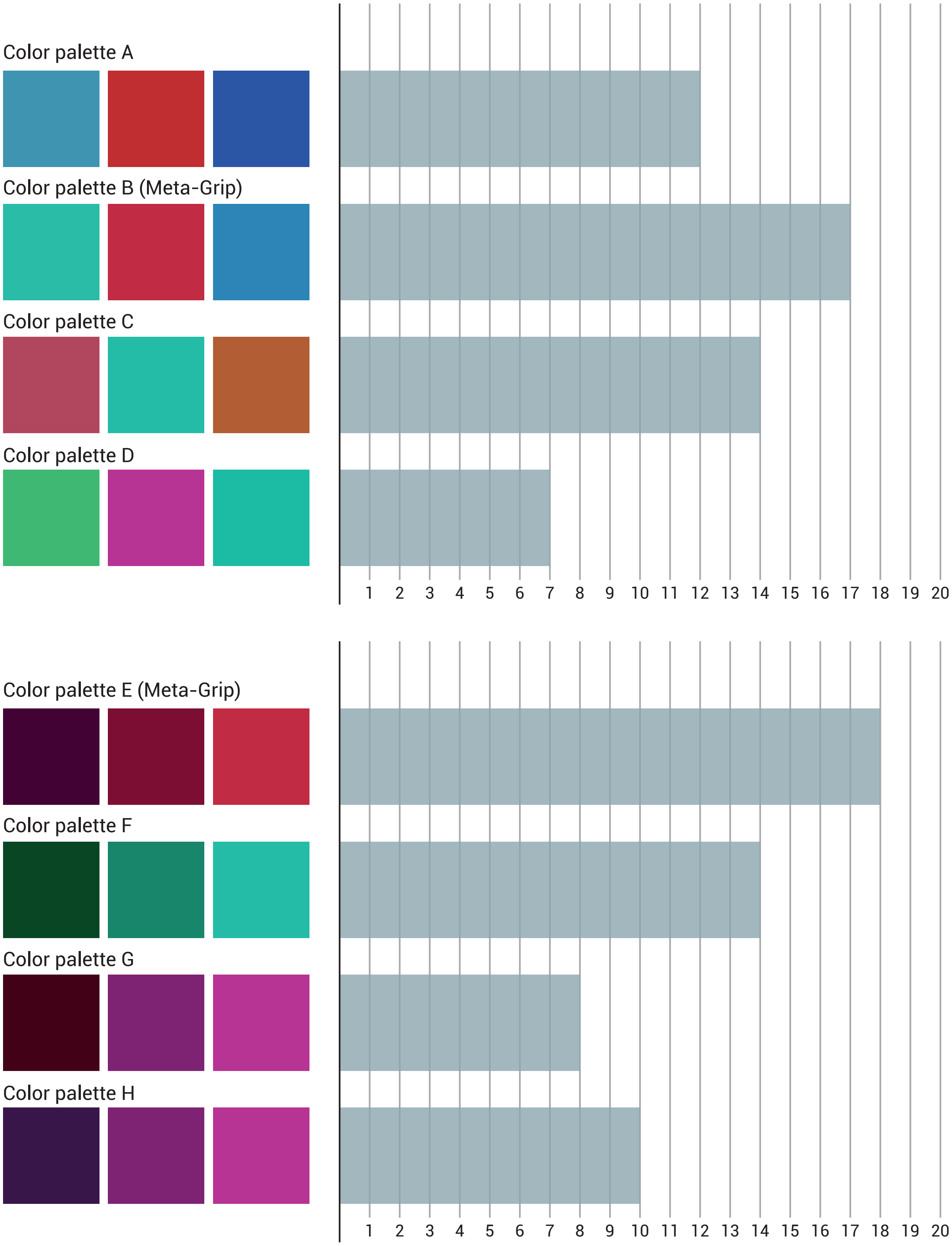


Figure L.4: Color study results 1

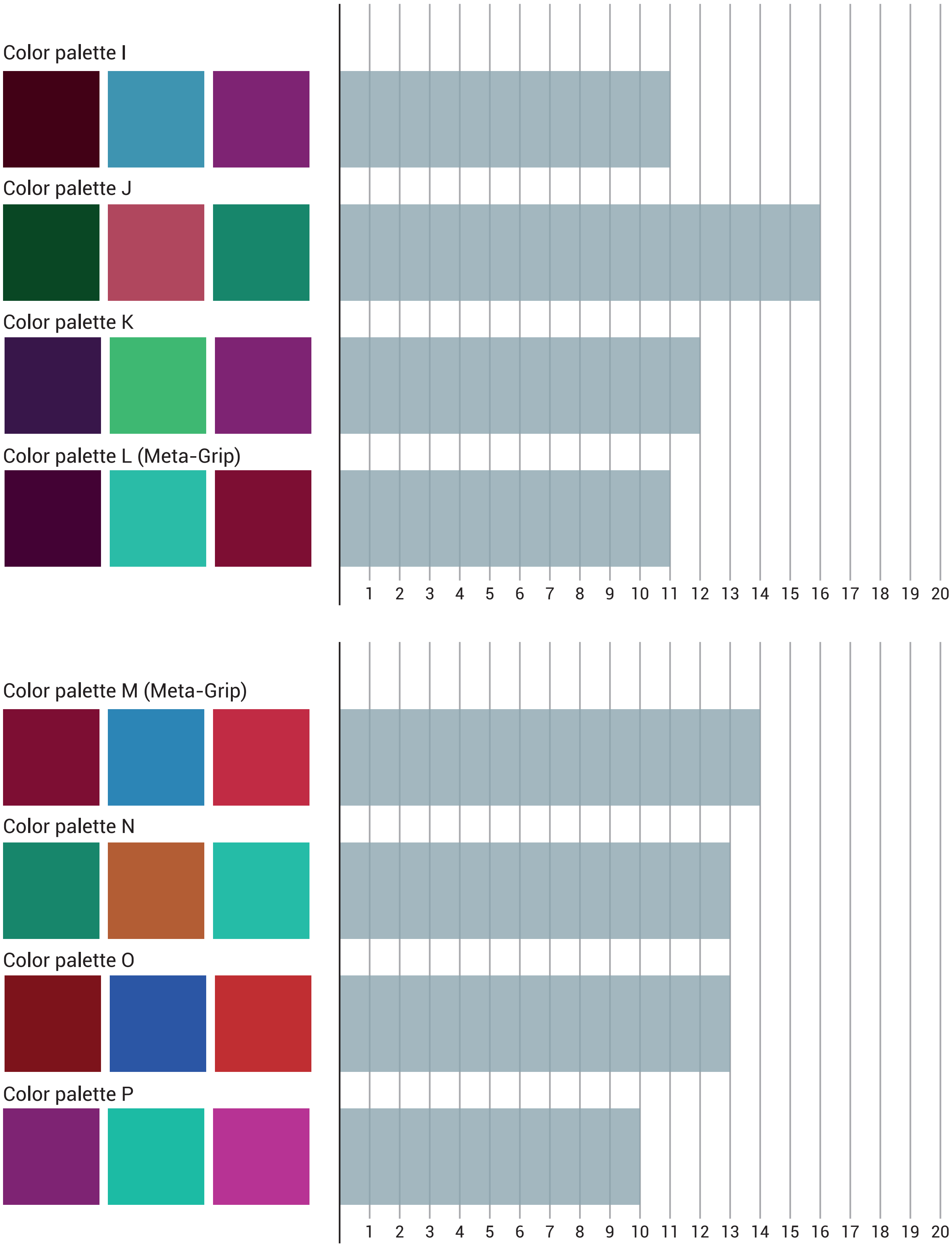


Figure L.5: Color study results 2

Appendix M

The application

In this chapter, the application supporting the Meta-Grip will be discussed. A design idea will be given as well as suggestions for improvement. Certain features in the application will be highlighted, such as the tests and analytics feature since these are an important part for climbers being able to and wanting to use the application and Meta-Grip unsupervised.

M.1 The app flow

Having the correct app flow is really important in being able to involve the users and make use with the application seem logical. The app for the Meta-Grip will consists of eight main screens:

1. Login/sign up screen (figure M.1 on page 143). In this screen it is possible to either make a new account or login to an existing account.
2. Home screen (figure M.2 on page 143). This screen provides an overview of the current training plan, goals and results of measurements.
3. Menu screen (figure M.3 on page 143). This menu will roll down over any screen that is currently viewed. Here it is possible to navigate between pages and is accessible at all times.
4. Training plan screen (figure M.4 on page 143). In this page, the current training plan will be shown with upcoming trainings and finished trainings from which the results can be reviewed.
5. Analytics screen (figure M.5 on page 144). In this screen, results of previous measurements can be viewed.
6. Tests screen (figure M.6 on page 144). In this screen, a new test can be started, both singular tests or the complete measurement.
7. Profile screen (figure M.7 on page 144). In this screen, the personal profile of the user can be viewed and changed.
8. Setting screen (figure M.8 on page 144). In this screen, general settings can be changed.

In figure M.9 on page 145, an overview of the interaction between the different screens can be seen. In figure M.10 on page 146, a more detailed app flow of doing a measurement can be seen. To best guide the user through a measurement, different steps and interactions are needed. This enables unsupervised use.

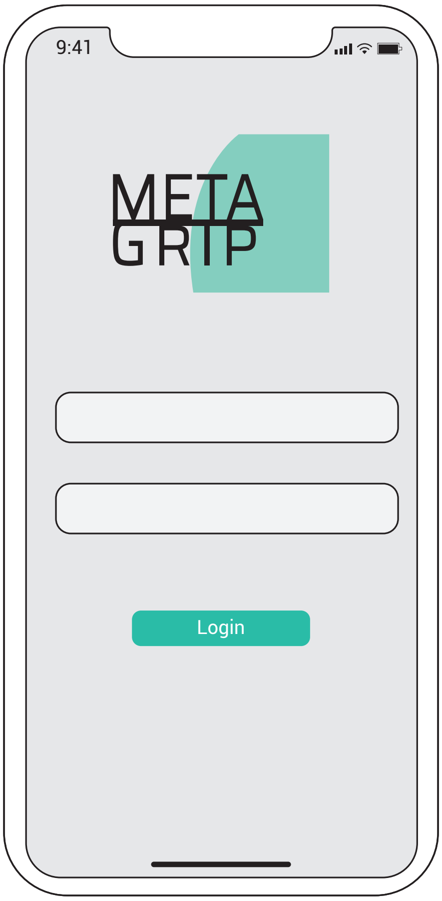


Figure M.1: Log in screen

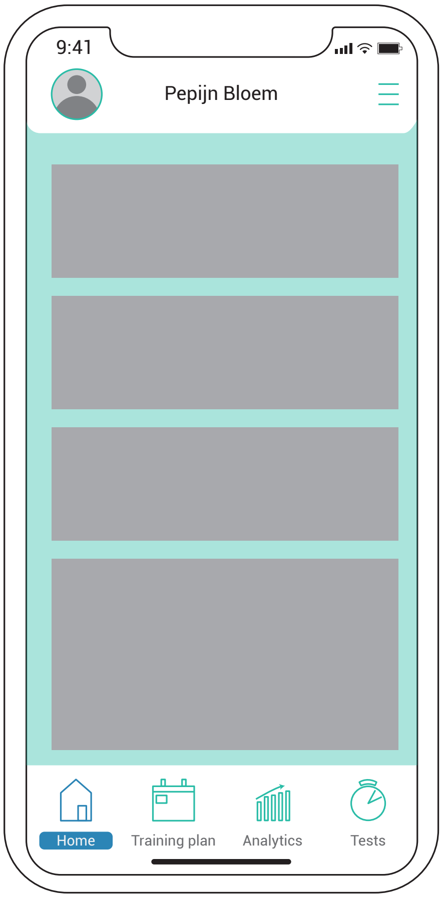


Figure M.2: Home page

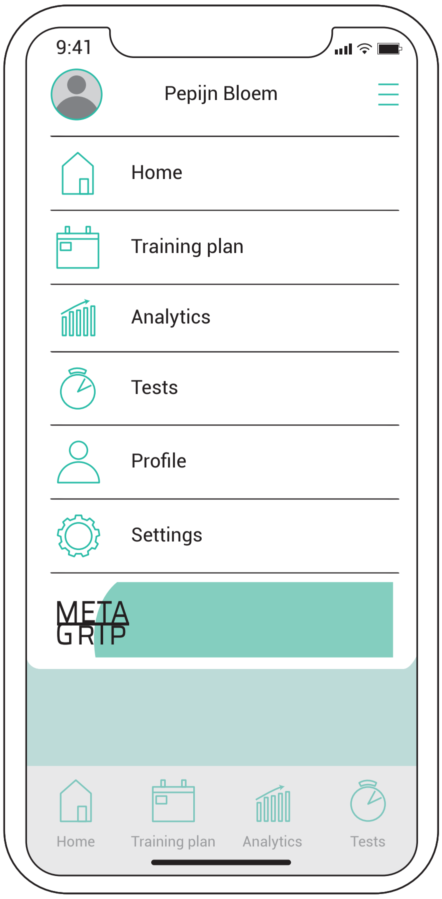


Figure M.3: Menu

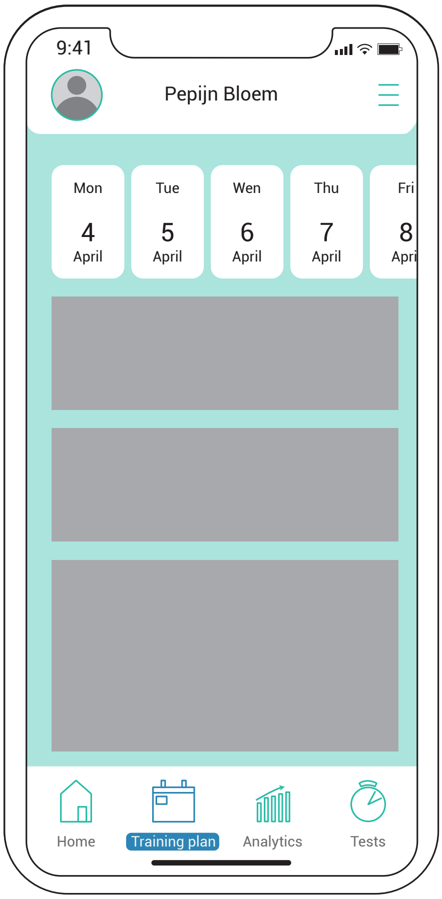


Figure M.4: Training

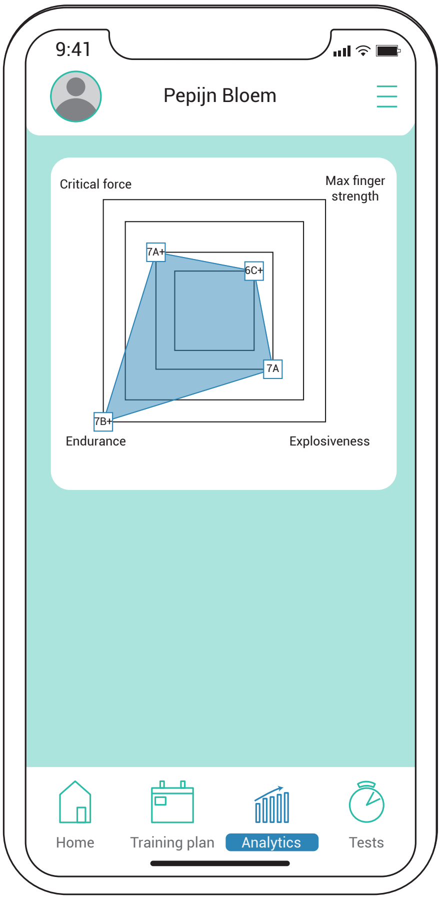


Figure M.5: Analytics

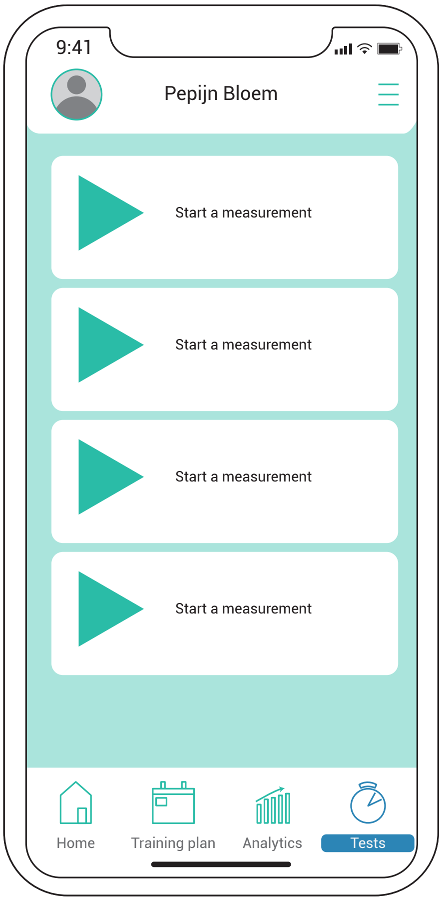


Figure M.6: Tests

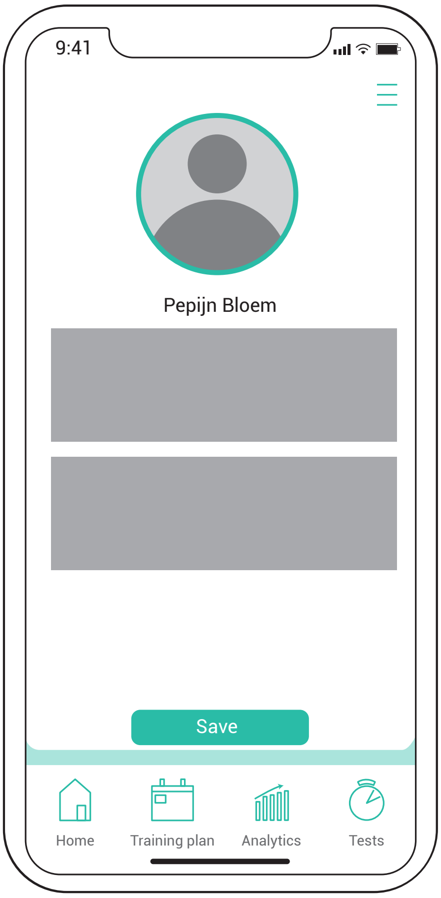


Figure M.7: Profile

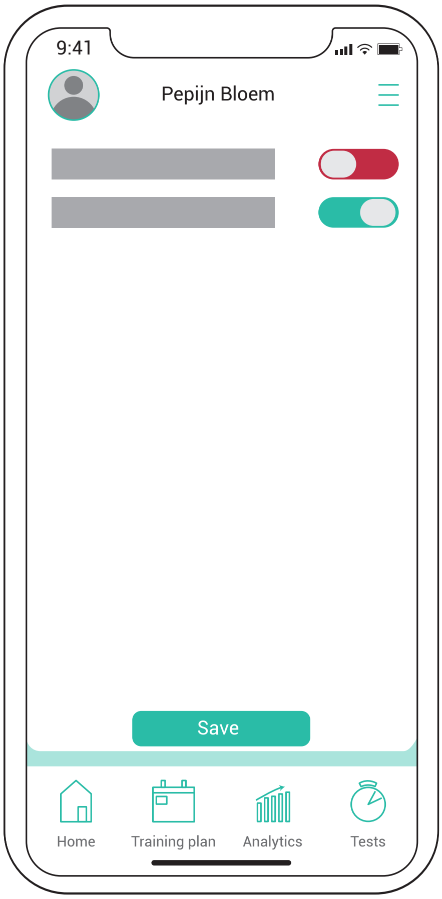


Figure M.8: Settings

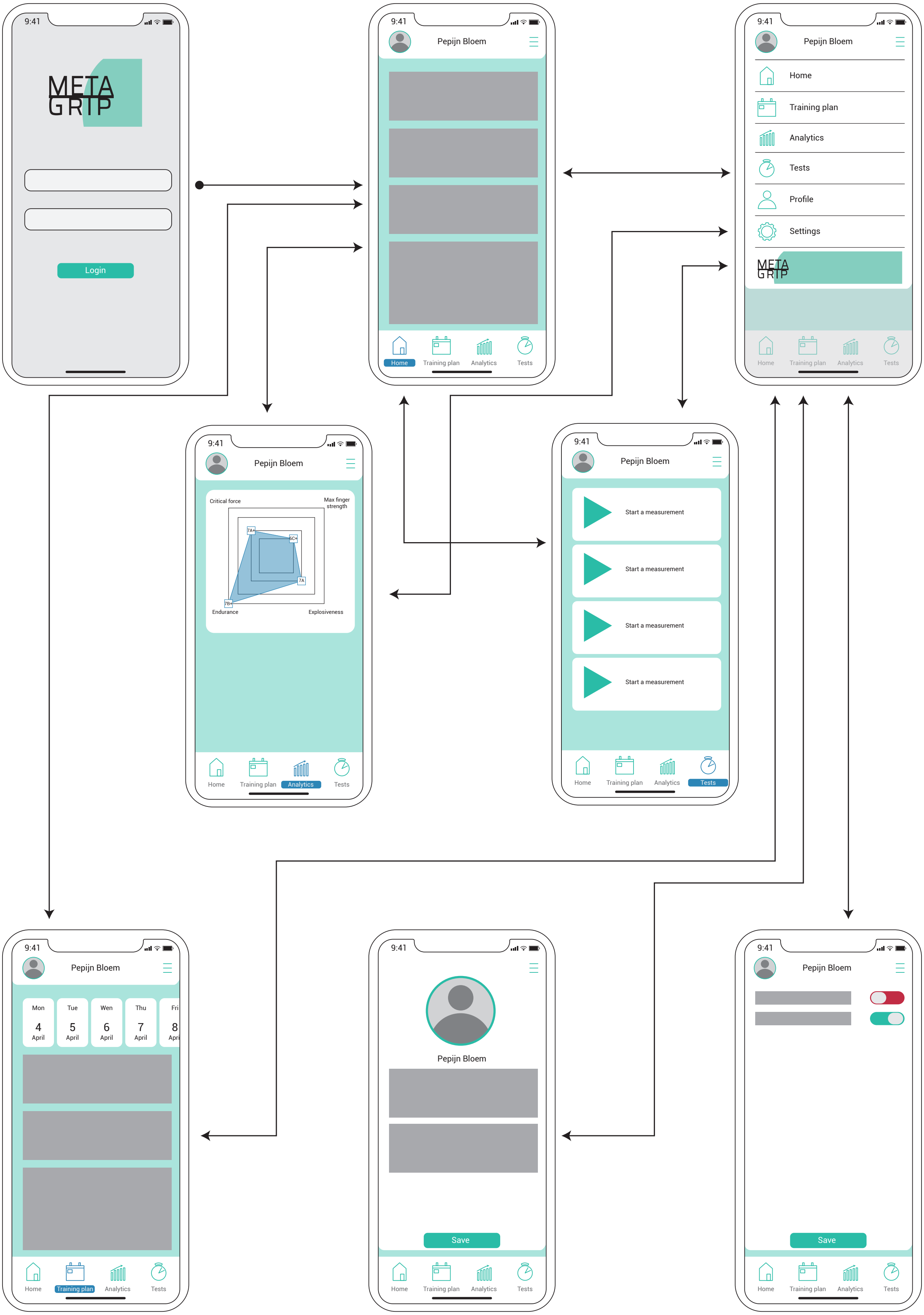


Figure M.9: Page interaction

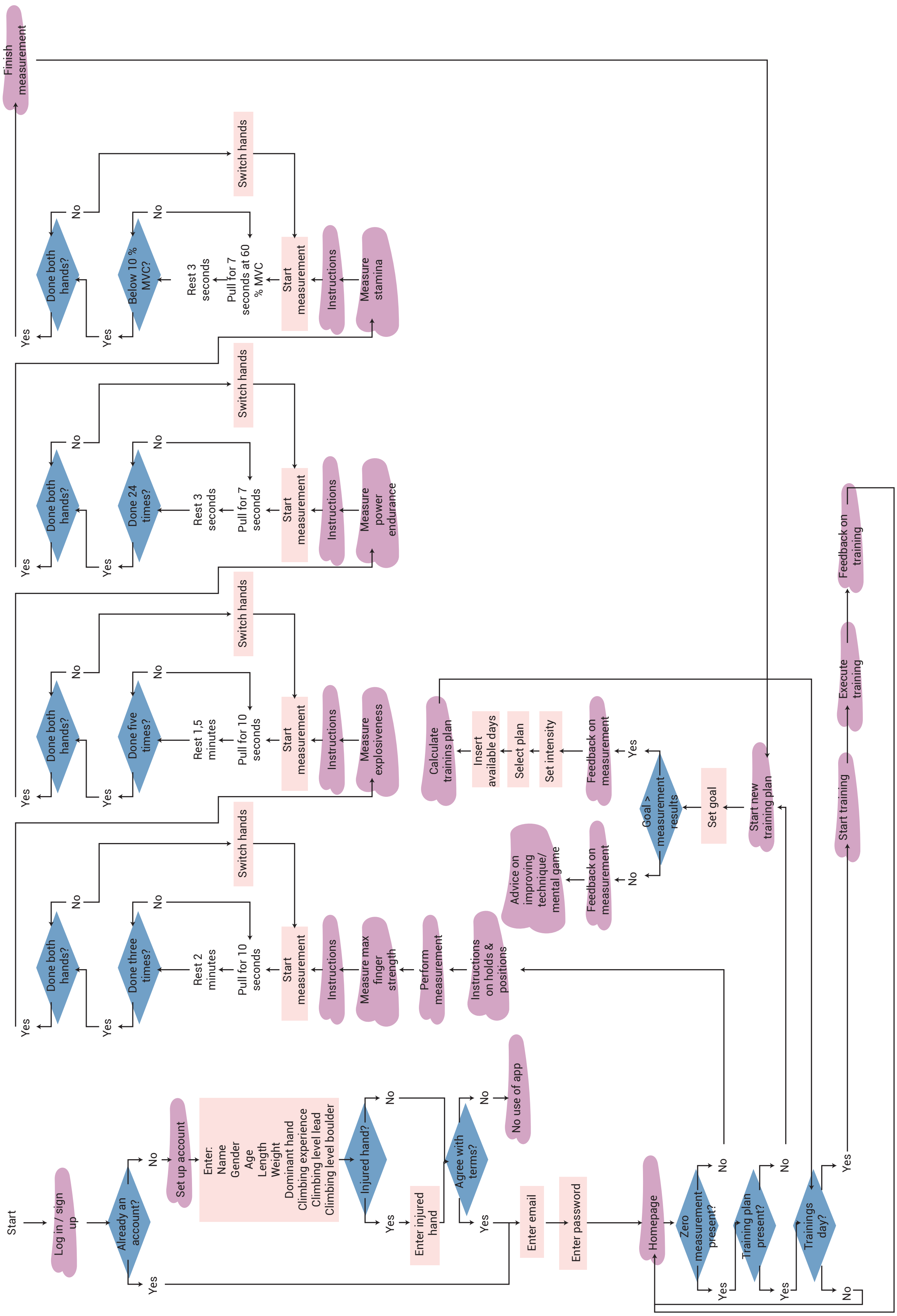


Figure M.10: App flow

M.2 Tests screen

The user executes measurements on their highest level of power which makes them tired. Therefore, the app flow for the tests screen should be very clear, explicit and intuitive. During the creative session (appendix N: Creative session for app design on page 149), this was also a point that was looked at. Some important design guidelines can be formed from the creative session:

- Do not show how many repetitions are left for power endurance and critical force, instead show a color gradient that gives an indication.
- Bright color contrasts should be used to indicate hang and rest time.
- Actual and direct feedback on how much power the climber is exerting on the Meta-Grip can be relevant with certain measures.
- A hand indication should be in the screen at all times since people tend to forget which hand is being tested due to tiredness.

M.3 Analytics screen

The measurement done by the Meta-Grip is quite technical and has a high level of detail. Regardless how interesting this can be, it can also make it unclear and confusing for the user. The feedback about a measurement given to the user should be understandable and only when asked for go into more detail.

Climbing grades are a very universal term among climbers and easy to relate to as a climber. This makes it the ideal way of giving feedback to the user. Ideally the app provides an overview of the level of the overall measurement and specific level for the separate measurements. When more detail about a specific measurement is desired, this can be viewed. Furthermore, comparing the measurements over time with each other is also adding value. If a training plan is already in progress or finished, there can also be a comparison between training plan and measurement results.

To motivate climbers to do even better or to set a certain goal, comparisons can be made as a motivation factor. This can be done with for example objects that they are able to pull, comparing with other climbers or being able to achieve badges for getting up to a certain level.

M.4 Design guidelines

Designing an application is something that requires a specific skill. Described below are some guidelines on what should be considered when designing an application. The current application design is a good start, but still needs a lot of improving to be able to roll out to users.

M.4.1 Layout grid

When designing an application, it is important to use a layout grid. A layout grid consists of columns, gutters and margins. By making a layout grid and applying that to all the application pages, a more uniform look is created. Since it is expected that most users will use their smartphone in portrait position to utilize this application, the window will be sized as extra small. For the extra small window, there are likely to be four columns with a gutter and margin size of 16 pixels (Responsive layout grid, sd).

M.4.2 Activation color

To ensure that the user can interact more intuitively with the application, a hierarchy should be applied to the color use. If an action is needed from the user, an activation color can be used. This is a color that is similar throughout the whole application that asks for an action from the user.

M.4.3 Onboarding

Onboarding essentially means that the user is guided through the application when they first use it. Onboarding can help the user get the best experience possible from the application, making it more certain they will return to using the application.

M.4.4 Breadcrumbs

Breadcrumbs can show the user where they are within the application. Using breadcrumbs makes it clearer to the user where they are at any given moment and how to go back to earlier screens or how to access that location again in a future time. Breadcrumbs are mostly used in web applications, but using them in a mobile phone application can make the application clearer to the user.

Appendix N

Creative session for app design

The goal of the creative session is to find out what flow in the application is preferred by the user and which feedback users want to receive and how. This information is obtained by hosting a creative session with both climbers and non-climbers.

N.1 Participants

This creative session will be attended by both climbers and non-climbers. The climbers are involved since they will be the end user of the application. However, involving non-climbers can lead to interesting insights that would not be acquired by only involving climbers in the creative session. The total of participants is five (2 climbers, 3 non-climbers).

N.2 Expected planning

In table N.1 there is an overview of the different steps in the creative session and how long it will take. This gives a good overview of what is expected of the creative session.

What	Time	Explanation
Rules	5 minutes	The rules of this session are as following: 1. There is no wrong answer. 2. Every idea is a good idea 3. Quantity above quality 4. Maintain a 1.5 meter distance at all time from each other. 5. Do not share stuff used during the session, there is enough to provide everyone with their own.
Introduction	15 minutes	From a deck of picture cards (Bijkerk & Loonen v, 2009) participants pick one or two cards that represent something about them personally. After five minutes, the participants have to introduce themselves to the group with the help of these cards.
Explanation	10 minutes	An introduction by the session leader is given about the Meta-Grip and its capabilities. The introduction ends by explaining the different values the Meta-Grip can measure.
Brainstorm about feedback	10 minutes	The participants write ideas on how you can give feedback on the results of a measurement on post-its, individually. This can be for all measurements and hands (eight) at once or just one. All post-its are put on a flip over.
Categorize feedback	10 minutes	After this, the participants have to categorize the ideas. The categories can be chosen by the group.
Extra ideas on feedback	10 minutes	After putting everything in categories, the participants have 10 minutes extra to think of new ideas. Looking at other ideas can provoke new ideas with the participants.
Best idea about feedback	5 minutes	Everyone chooses the best and clearest idea regarding the feedback given to the user.
Break	5 minutes	
Explanation application	5 minutes	The session leader gives an explanation on the general app flow and what it is expected to do.
Draw a measurement	10 minutes	The participants all get mock-up mobile phone screens to draw out how doing a measurement will look like in the application. The participants only need to draw an app flow for one measurement with one hand (more is always an option).
Look at ideas	5 minutes	Every idea for an app flow is placed on a flip over and everyone can take a look at them.
Group app flow	15 minutes	The participants are now going to dive into the general app flow. As a group where one person is responsible for drawing/writing, they are going to figure out the general app flow. They are allowed to use multiple flip over pages.
Motivation factors	10 minutes	Participants are going to describe motivation factors for using the app, training, doing a measurement and more scenarios individually on post-its.
Collection motivation factors	5 minutes	The motivation factors are collected at a large flip over.
Feedback	10 minutes	The session is over and the participants can now comment both on the logistics and content of the session.

Table N.1: Planning creative session

N.3 The session

The session was a success. The results are interesting and refreshing and the participants enjoyed the session. The results are presented below.

N.3.1 Actual planning

During the session, some factors were overlooked making it difficult to stick to the planning. Explaining what the Meta-Grip can do exactly is proven to be quite difficult which make it took longer than expected. After brainstorming about feedback, the categorizing was skipped since this was quite difficult while keeping a 1.5 meter distance and to keep the session within the time. Furthermore, during the session, it made more sense to skip the group app flow step as well. All the other steps were close to the measurements whereas the group app flow actually was more general. With not doing those steps, the session was finished right on time.

N.3.2 Results brainstorm about feedback

After understanding how a measurement works and what types there are, the participants wrote down ideas on how to give feedback to the user (figure N.1). The most valuable ideas are listed below

- In figure N.2 on page 152 a graph with four measurement results is presented. There is an ideal shape, respresenting the climber's goal for each measurement and the current measurement. The closer to the ideal shape, the closer the climber is to the set goal.
- In an optimum graph (figure N.3 on page 152), the previous measurements can be compared and the climber is motivated to do better than previous times.
- Every measurement could have their own icon which gets solid after finishing the measurement.
- A circle where you can see your

Figure N.1: Results of brainstorm about feedback average grade and the four measurements. Clicking on a measurement shows more data about the specific measurement (figure N.4).

- A graph that shows past, present and future goals and measurements to get a good overview of how training is going.
- Comparing maximum finger strength with weight of everyday objects, for example, a person is now able to pull a small pig.
- Having a bar chart to compare the four measurements with the goal grade and being able to compare this with previous measurements.

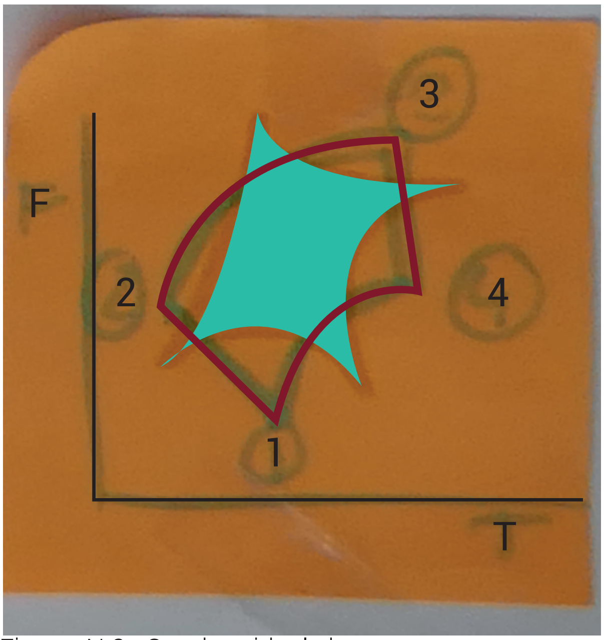


Figure N.2: Graph to ideal shape

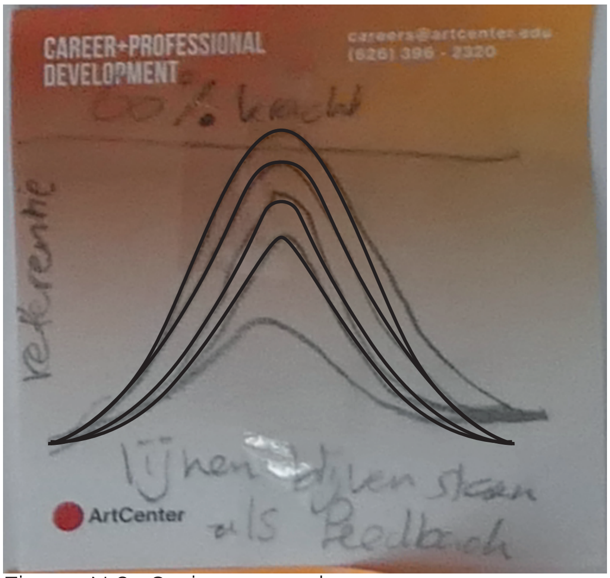


Figure N.3: Optimum graph

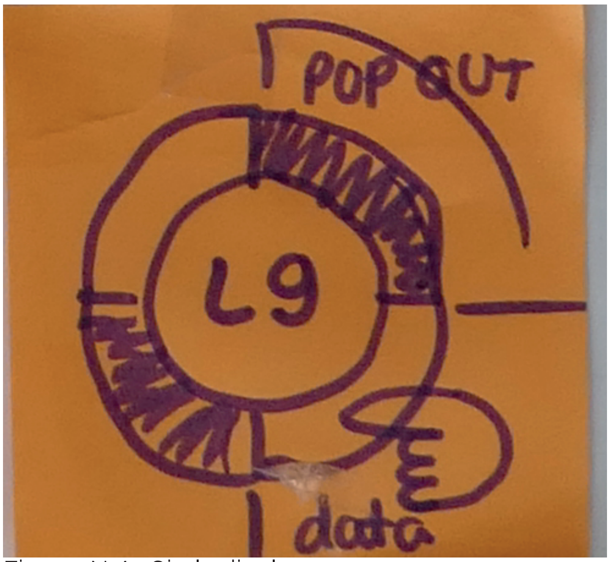


Figure N.4: Circle display

N.3.3 Results of drawing a measurement

After looking at the specific feedback, the whole measurement was looked at. This was done by asking the participants to draw a measurement app flow in phone mock-ups. The results can be seen in figure N.5. After finishing, the participants were asked to point out some good elements in all the applications. A list of the best elements is given below:

- With the critical force or endurance measurement, the participants suggested to, instead of showing how many repetitions are still left, showing a color range. This color range gives an indication of where the participant is with the repetitions, but does not define a number, making it harder for the participant to know when they are finished. This is a benefit since the participant cannot save up energy for the last couple of repetitions making the measurement more accurate.
- To make a difference in hanging and rest time, a bright color contrast was suggested. This makes it easy for the participant to spot even when just glimpsing at the screen.
- For the power endurance measurement, a screen where you can see how much of your maximum voluntary contraction you are pulling is ideal. This is actual and direct feedback from the measurement making sure the participant is giving enough power for the measurement.
- The participants mentioned that when people are getting tired, it can be likely that they forget which hand they are using. This should be shown in the screen at all times.
- The visual communication of where to hang is good since it indicates what the user needs to do and suggests which crimp to use.

Figure N.5: Results of drawing a measurement

N.3.4 Results of motivation factors

Finding motivation factors was proven to be difficult for the participants. They also mentioned that motivation factors can be annoying and should be a choice of the user. They also mentioned that the application will likely be a serious application and that certain motivation factors are too childish. The motivation factors can be found in figure N.6 and the best are listed below:

- The 'kapotknijpkaliber' is a grade on which you can see what you are able to crush with the power you have. This can be for example an orange or an apple or even a walnut.
- Being able to collect points and unlock new features or extras with it is a nice motivation.
- Comparing with other climbers and non-climbers as well.
- Just like Garmin does, it is nice to include badges and goals to achieve. This is a motivation for users to do something or try a little bit harder.
- Being able to share training data just like Strava.

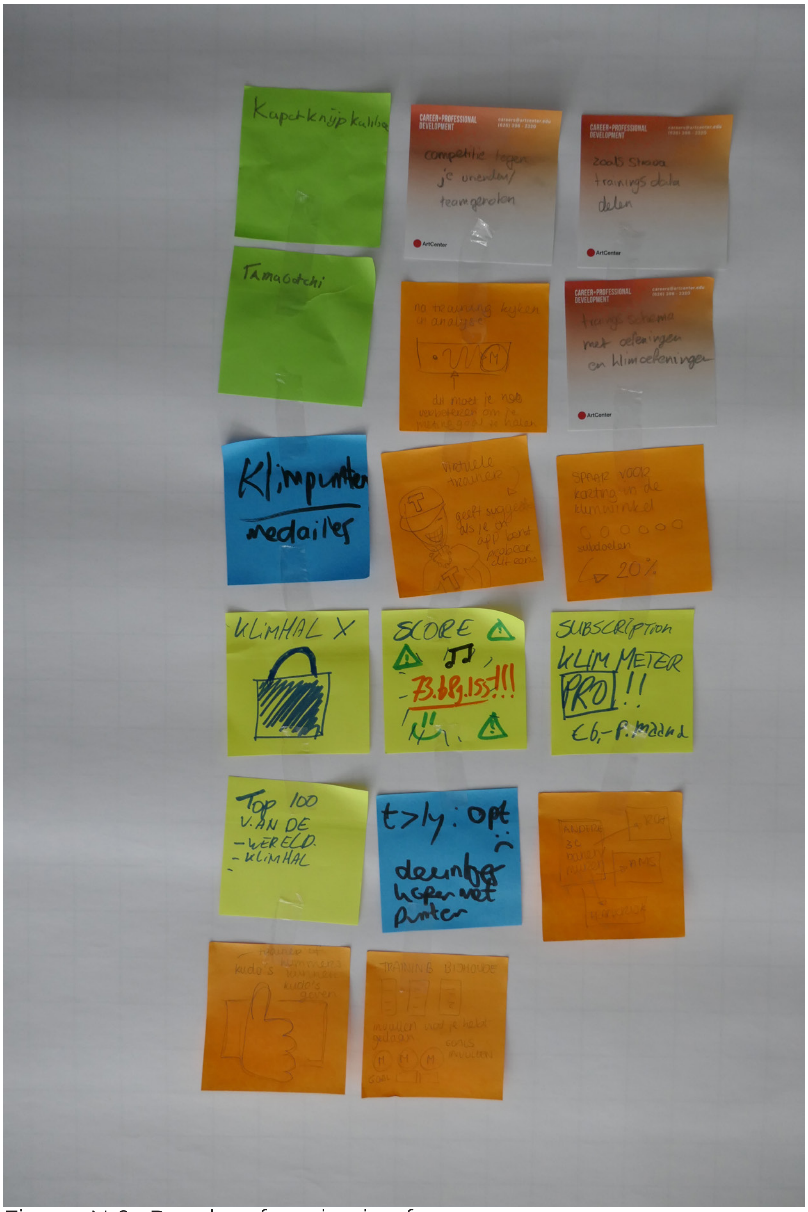


Figure N.6: Results of motivation factors

Appendix O

Determining a training plan

Determining a training plan depends on multiple factors evolving around the climber according to experts consulted for this research. The most important factor is the level they have in climbing according to the IRCRA scale. Furthermore, it is important to take into account the years of climbing experience. This is because the tendons and structures in the hand and fingers change according to the climbing load over a longer period of time. The last influence is the amount of practices a climber performs in one week.

The IRCRA scale (Draper & Giles, 2016) goes from 1 till 32 and is a good method to translate boulder and lead in one grade. The IRCRA scale is divided in levels of expertise for male and female. These will be used to determine the intensity of the training and are listed below in figure O.1. Below a certain level, specific hand and finger training is not necessary since improvements for climbing can be made on various other parts first according to a physiotherapist with experience in climbing injuries amongst which hand and finger injuries, this level is around 6B (IRCRA scale 13).

The years of climbing experience are also of influence in determining the intensity of a training plan. Fingers and hands are used differently while climbing and have to be in exceptional performance compared to non-climbers to achieve certain levels injury free ('Meta-grip': monitoring grip force to minimize hand injuries and improve climbing performance). In studies, the MVC and endurance was compared to other athletes and the MVC of climbers was on average higher than other athletes, suggesting specific adaptations in the fingers and hands of climbers (Grant, et al., 2003) (Macleod, et al., 2007). According to a physiotherapist specialized in hand and finger injuries, a climber can start specific finger and hand

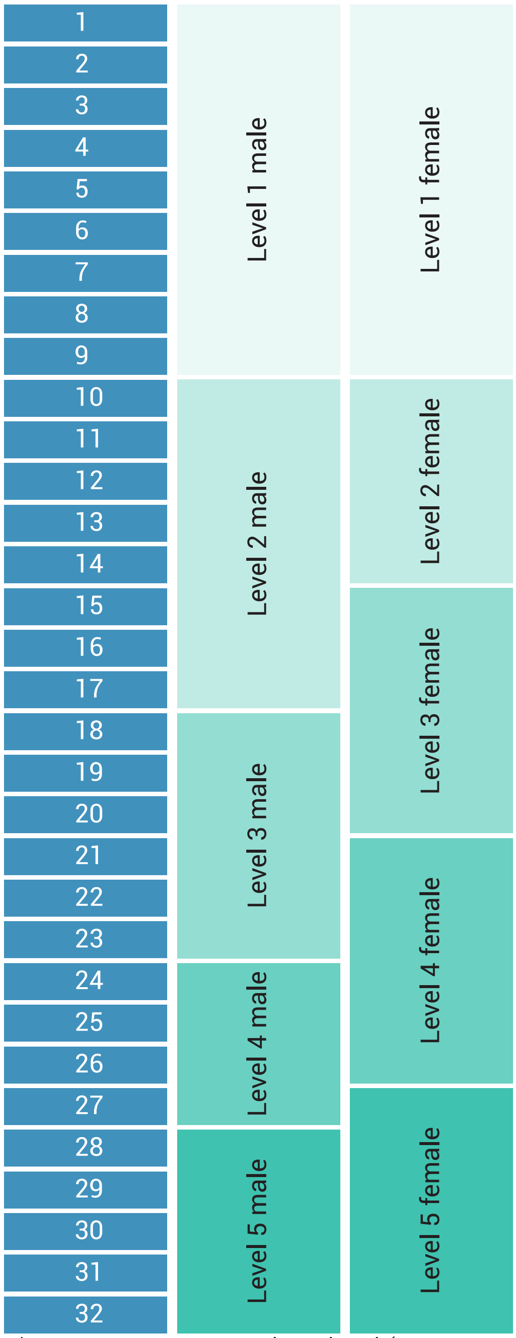


Figure O.1: IRCRA scale to level (Draper & Giles, 2016) training when they are no longer growing. As a directive 18 years and older is often maintained in climbing gyms. In research it is found that climbers younger than 16 years should not perform finger strength training (Schöffl & Morrison, 2007) However, a climber can start at a younger age but only with a lot of guidance from an expert. If a person starts with climbing, ring ligaments, tendons and other ligaments in the hand and fingers take the longest to adapt to climbing. In order for a climber to be used to the climbing load, the collagen needs to be replaced. Collagen have a half-life of approximately 300 to 500 days (de Morree, 2008). There is still no researched opinion on how many collagen needs to be replaced, but for the sake of the app, we will take 500 days as approximation. 500 days means it takes approximately two years for a climber to get used to the climbing load.

Another study indicating that climbing level and years of experience influence the strength in fingers and hence the possible training intensity is in a study among elite climbers, recreational climbers and non-climbers. There was a significant difference in finger strength among elite climbers compared to recreational climbers and non-climbers which suggests that only elite climbers are able to perform a high intensity training safely (Grant , Hynes , Whittaker, & Aitchison, 1996)

The last factor that influences the intensity of a training plan is the amount of times a climber is climbing per week. When a climber is used to climb three times a week, the intensity of the training plan can be higher than when the climber is only climbing once a week.

The relation between climbing years and climbing level are also important to take notice of. Take for example a climber who has been climbing for three years and managed to get from 5A to 5C and a climber who has also been climbing for three years but managed to get from 5A to 6C. For the second climber, a lot of progress have been made where a next step could be more specific training on hand and finger improvements. However, for the first climber, progress is minimal and doing specific training on hand and finger improvements will probably not be the best course of action.

Combining all the factors in determining the intensity of a training plan gives us the following figure O.2. The training plans can be divided into three intensity segments; low, medium and high intensity. In a training, intensity can be changed by multiple factors. A few examples are given below (Friedrich & Huch, 2016):

- The repetition within each set
- The repetition of the whole exercise
- The rest time
- The active hanging time
- The holds used
- The position in which the exercise is executed

Many more factors can influence the intensity of the training, but these are the most common once in making a training plan.

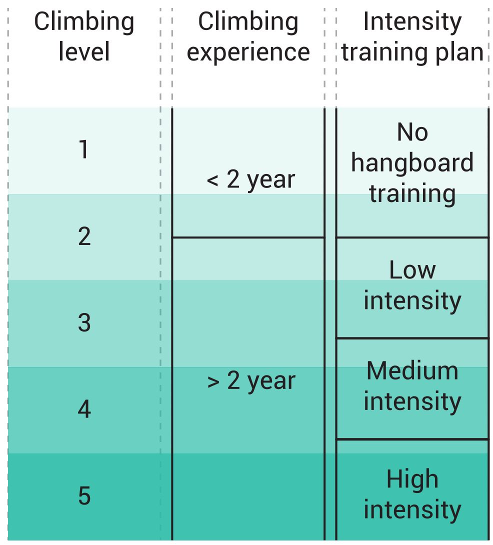


Figure O.2: Making a training plan

Appendix P

The Meta-Grip and Machine learning

The Meta-Grip will be part of a product-service system in the future. The service is not yet completely computer-based. The transformation of the measurement into a training plan requires an expert opinion. This is because insufficient research and data is available yet for this to be done automatically by algorithms. To serve a lot of users and the same time and to be able to continuously improve the service, machine learning should be part of the service system.

The definition of machine learning is as follows: "Machine learning is a subset of artificial intelligence, in which machines learn how to complete a certain task without being explicitly programmed to do so." (Fesiuk, 27). There are two models of machine learning; supervised and unsupervised learning. The Meta-Grip will be based on supervised learning. The expert will suggest different trainings which will correspond with the database. The Meta-Grip will then automatically place that user/training plan/measurement in a certain group. It will start out with a small number of groups but this will gradually grow since more measurements mean that more nuanced differences can be made and more focused training plans can be given.

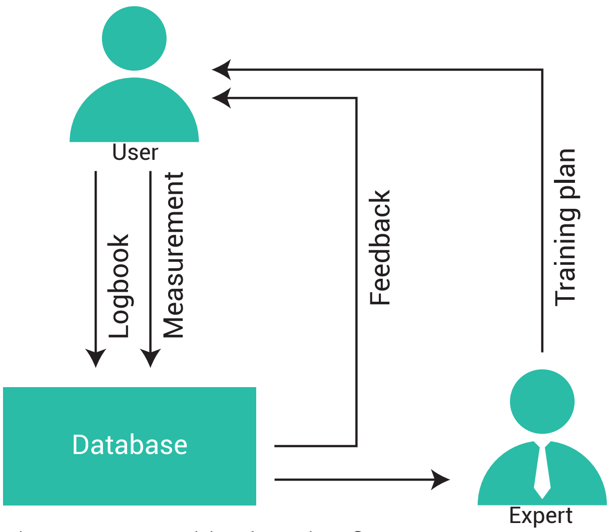


Figure P.1: Machine learning first step

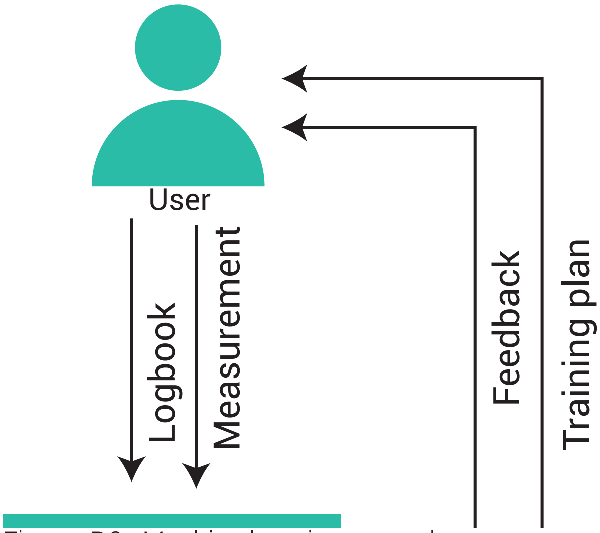


Figure P.2: Machine learning second step

P.1 Machine learning steps

The new and improved Meta-Grip will give, in the ideal situation, suggestions on training plans based on data accomplished from earlier users of the app. Currently, the expert gives both the feedback and a training plan to the user (figure P.1). However, with the database and the good correlation between climbing grade and measurements (Van Bergen, Soekarjo, Kasper, & Orth), the app can soon give feedback in climbing grade to the user with the supervision of an expert (figure P.2).

The next step is giving feedback without the supervision of an expert (figure P.3). However, making a training plan is still difficult and an expert is necessary to suggest a training plan based on the results of the measurement. Also, to make an accurate training plan, a logbook should be maintained by the climber so the expert has a proper overview of all the trainings executed and can decide accordingly. This will be stored in the database as well to make further improvements to the concept possible. Through machine learning, the Meta-Grip can learn which training plans are suggested with which results and with logbook data, the expert can over time be completely eliminated from the use cycle of the Meta-Grip (figure P.4).

In appendix D: Involved parties with the Meta-Grip on page 80, five different climber groups are identified which all have their own needs and wishes. Eliminating the expert is preferred for certain groups. Some groups will, however, still want to rely on guidance of an expert. The climber groups for which this is applicable are the injured climbers and pro athletes. These groups need such specific exercises and close guidance on their progress that it is desired for an expert to stay involved for interpreting the results and making a training plan accordingly.

In order to give a proper training plan to the climber with the app, it is necessary to know exactly which trainings climbers do, how they went and what they did within this training. This is also important to see whether someone is for example overtraining. So, besides the trainings executed with the app (mostly on the hangboard itself), trainings outside this scope need to be added as well for a complete advice. After a training is finished, the actual performance will be compared to the prognose. From this it can be seen if a training plan is too hard or too easy. If this will be compared

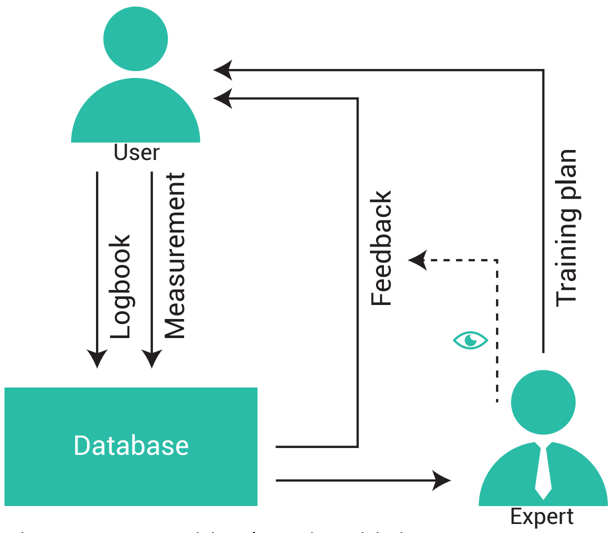


Figure P.3: Machine learning third step

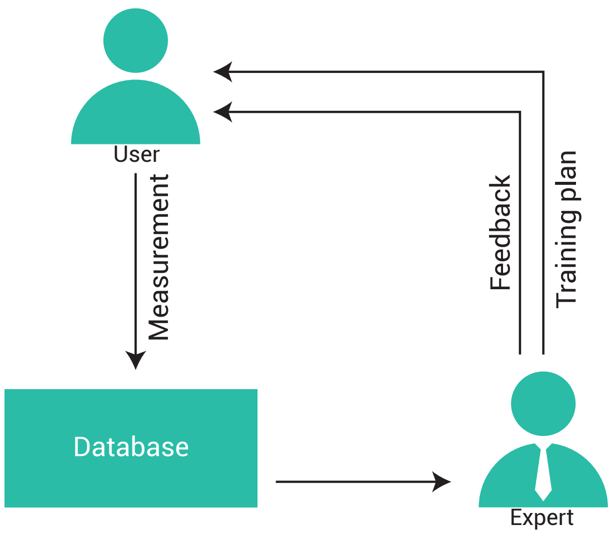


Figure P.4: Machine learning fourth step

with the subjective opinion of the user and how they think the training went (some days are better than others), the effectivity of the training can be indicated.

P.2 Timing

The timing of implementing these phases is crucial. Having a lot of users, but not an automated process yet for giving feedback or a training plan is killing for the motivation of the user to re-use the Meta-Grip. On the other hand, the steps should not be rushed since the algorithms should be reliable and provide accurate feedback and advice on training plans. The current Meta-Grip is already in the first phase; data is collected and feedback and a training plan is provided by an expert. Going to the second phase is something that can be achieved relatively easy and for sure before the first redesigned Meta-Grip is sold. This is possible because with the current Meta-Grip sufficient data is already collected for the verification of the measurement to climbing grade conversions. For the maximum finger force (corrected with bodyweight), a significant positive correlation was found with the climbing grade (Van Bergen, Soekarjo, Kasper, & Orth). The supervision of the expert on the feedback can gradually be reduced up to a point where it is none. This will take place in the first 2-month period after the Meta-Grip is taken into use. The last and fourth phase is somewhat more difficult to achieve since the Meta-Grip needs to be able to also suggest a training plan based on the feedback. For this sufficient data is needed, requiring sufficient users to use the Meta-Grip and log their experiences which will take ideally up to a year.

Appendix Q

Feedback analysis

In this chapter, the way of feedback and the necessary feedback for the app towards climbers is discussed.

Q.1 Current situation

In the current situation, the Meta-Grip shows four measurements. The expert can transform the results into a training plan. Feedback to the climber is given through the expert, since the climber cannot interpret this data correctly and translate it into an effective training. The four measurements with their corresponding units are as following:

1. Maximal finger strength in Newton
2. Explosiveness in Newton per milliseconds
3. Power endurance in Newton
4. Stamina in times it can be repeated

Q.2 Feedback in measurements

For climbers to understand the feedback given by the app, it needs to be in terms that everyone can understand, namely climbing grades. Climbing routes are graded by a number of different grading systems which all relate to each other in some way (Appendix A: Introduction into climbing on page 70). To give a clear overview, multiple types of visuals can be used to give feedback on all different points, see figure Q.1 to Q.3 and figure Q.4 to Q.6 on page 161 as an example. These are all visual ways of showing progress or the current situation which will likely be

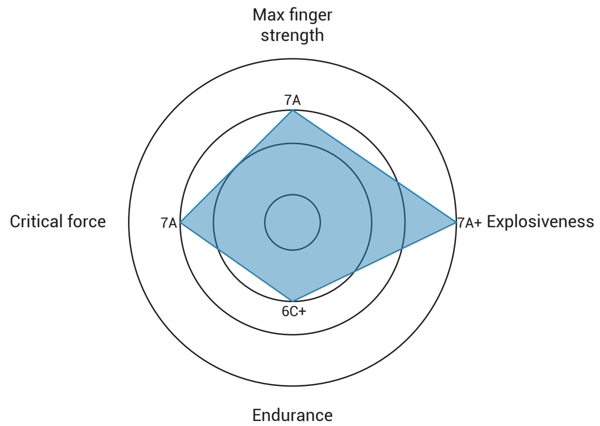


Figure Q.1: Cobweb feedback

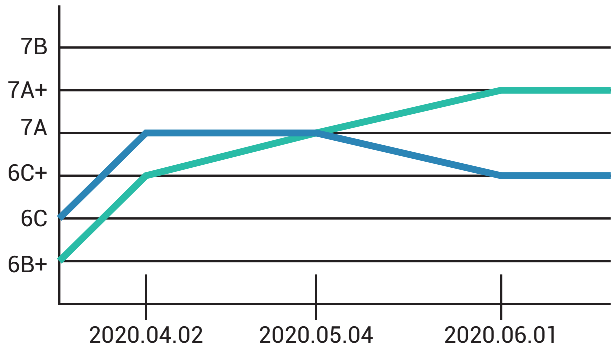


Figure Q.2: Linear feedback

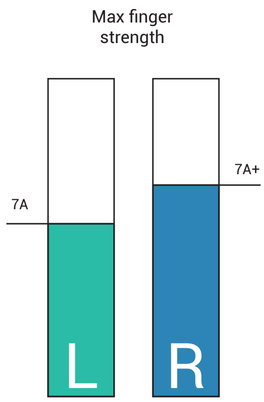


Figure Q.3: Bar feedback

more attractive to the user than a non-visual way like a text. Most of the time, climbers are aware of the grade they are climbing and can imagine the difficulty that represents a certain grade. Giving feedback in climbing grades can be the solution to let climbers interpret the data from a measurement on their own. To make feedback relevant, it should be compared to what the climber wants to achieve or the grade they currently climb. This can show where improvements need to be made by the climber.

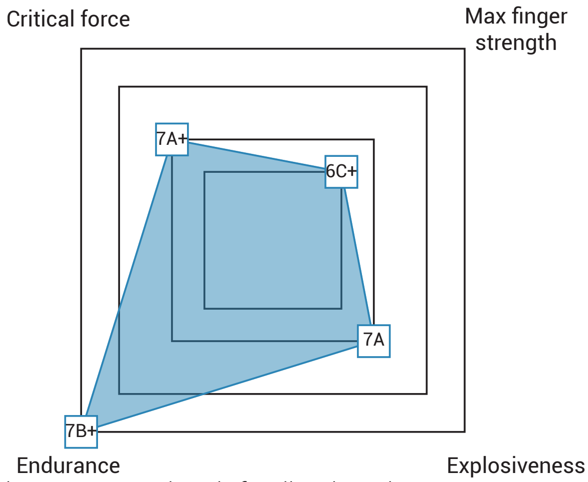


Figure Q.4: Cobweb feedback variant

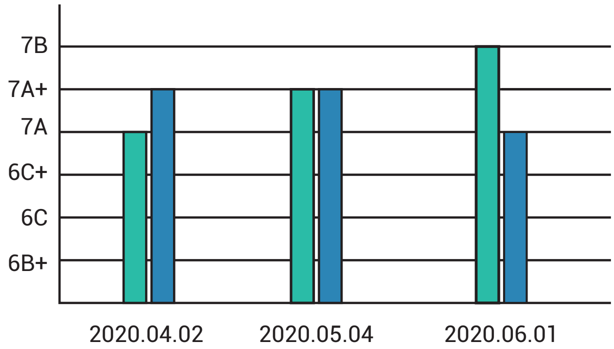


Figure Q.5: Bar feedback variant

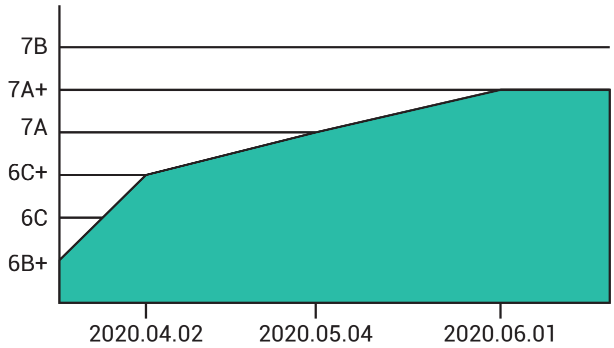


Figure Q.6: Line feedback variant

Load cell research

In the Meta-Grip, to measure the force a user is applying, a load cell is used. There are a lot of different sizes and shapes available in load cells as well as different specifications.

There are three common type of load cells available (figure R.1);

- S-beam load cells
- Button load cells
- Single point load cells

The main difference between the load cell are shape and how to align them properly in the model. The S-beam and button load cell are in one plane but the single point load cell is off centered. The single point load cell is made to measure compression. When the shape of the load cell changes, a change in electrical resistance happens as well.

In the previous model of the Meta-Grip, the researchers used an S-beam to measure the force applied by the user. However, because the force is not completely in one plane, the S-beam will not be able to measure correctly. This is why the current model of the Meta-Grip uses a single point load cell.

The current load cell used is the MT1241 Single Point Load Cell from Mettler Toledo. This load cell has a rated capacity up to 250 kg. The model is a straight load cell which means that a strain gauge is attached to an aluminum frame. This is measured and via the bridge amplifier and AD-converter the signal is received by LABview which transforms it to results per time unit. The sample rate is 100 Hz with a National Instruments CompactDAQ system (NI 9218). For the redesign of the Meta-Grip it would be an improvement if the load cell can be inside the Meta-Grip instead of outside and visible to the user. This gives the Meta-Grip a less educational look, is more fool-proof and is more aesthetically pleasing.

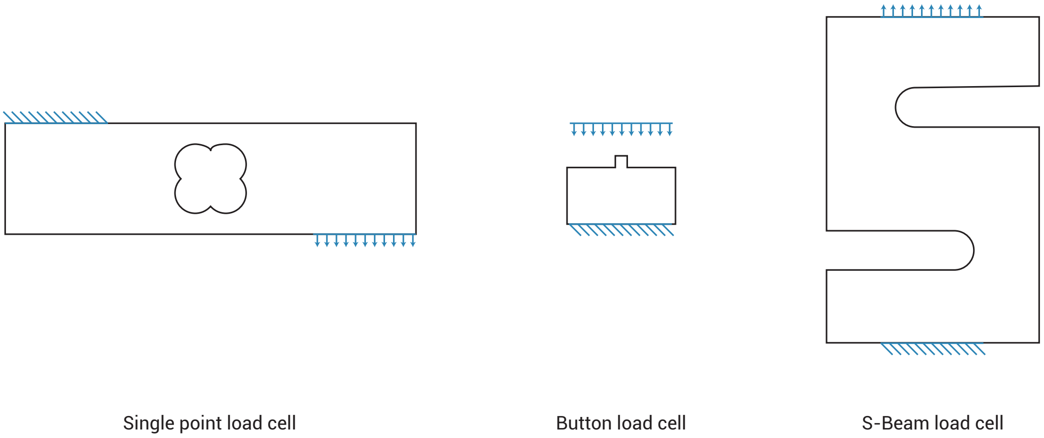


Figure R.1: Load cell types

Appendix S

Ideal use scenario

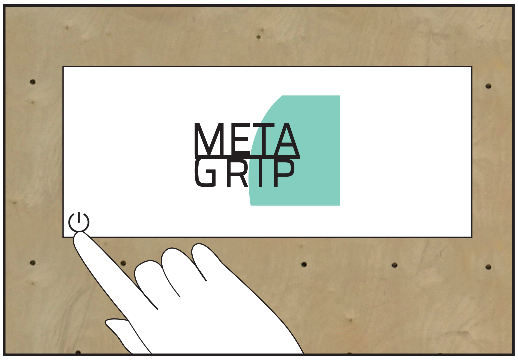
In this chapter, the improved use scenario is shown (figure S.1 on page 164, figure S.2 on page 165 and figure S.3 on page 166).

For the new and improved Meta-Grip, a more user friendly use scenario is also necessary. There are a few points of improvements central in the redesigned use scenario which will be highlighted first.

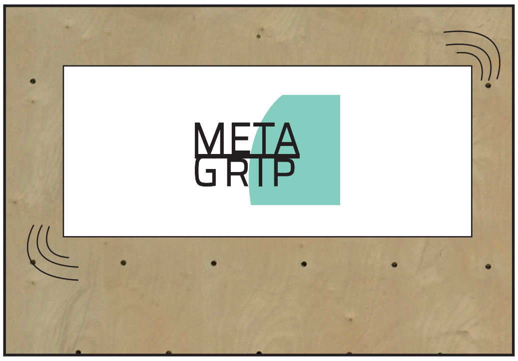
1. Understandable feedback
   Part of the unsupervised use is the ability to interpret the results of a measurement correctly by the user.
2. Database
   With every user connecting and executing measurements with the Meta-Grip the database grows.
3. Instructions
   The instructions in the app and the use cues that come with it should provide the user with enough information to do a measurement correctly.
4. Training plan
   A training plan is suggested based on the results which the user can execute through the application.
5. Feedback from the user
   The user should be able to give subjective feedback on how an exercise went to predict the effectiveness of the training.

The Meta-Grip arrives at the climbing gym.

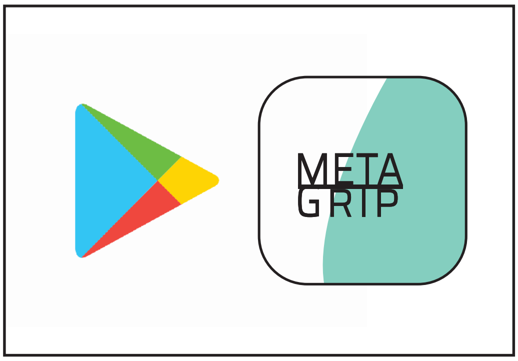
The Meta-Grip is installed with clear and simple instructions.



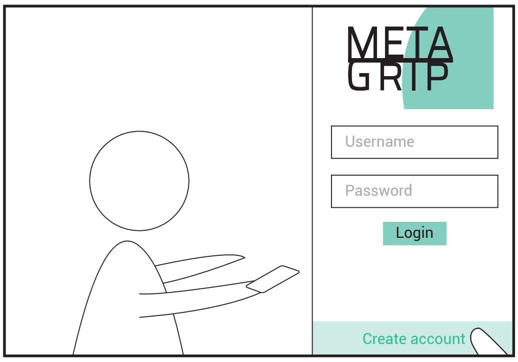
The Meta-Grip is turned on for the first time, after which it can be calibrated.



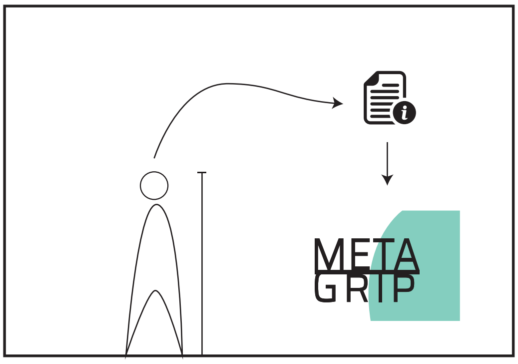
The Meta-Grip is calibrated.



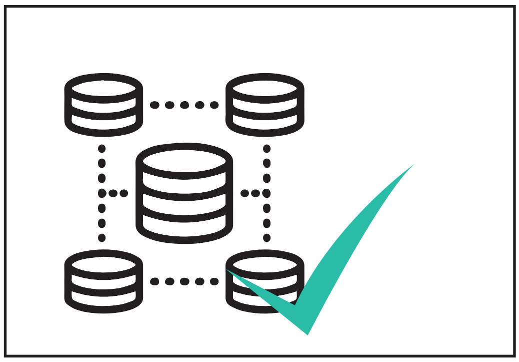
In the app store, the app for the Meta-Grip can be downloaded.



The user opens the app where they make an account.

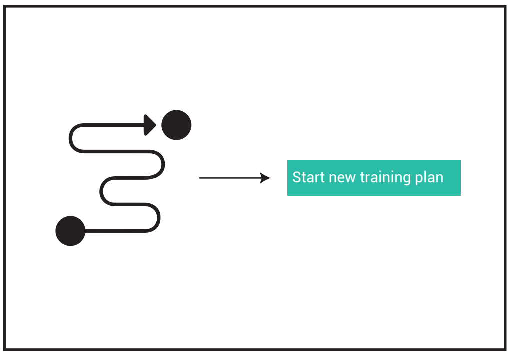


All the initial information is added in the app.

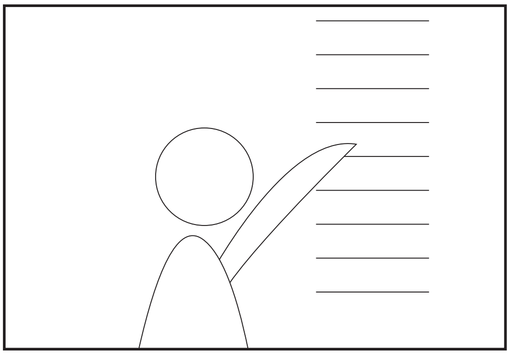


The user agrees with the terms needed to build the database.

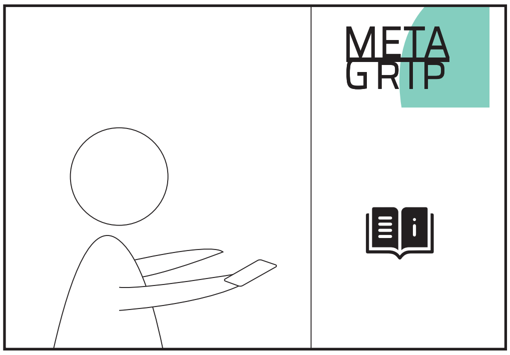
Figure S.1: Ideal use scenario part 1



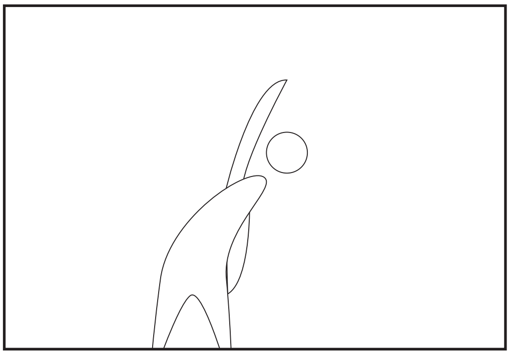
The user starts a new training plan.



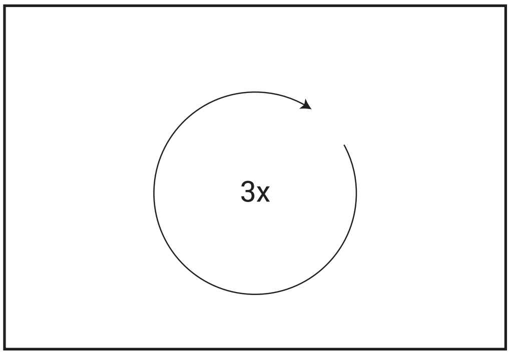
The user determines what the goal is for this training plan.



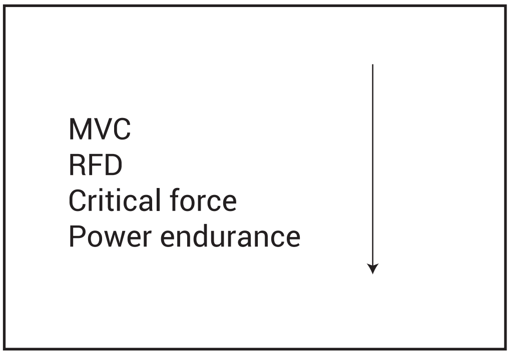
Clear instructions are given on what is going to be measured and how it should be measured.



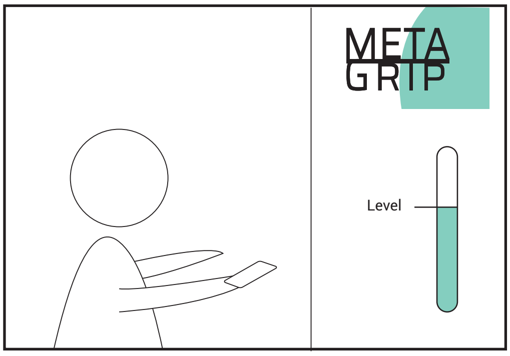
The user does his or her warm-up.



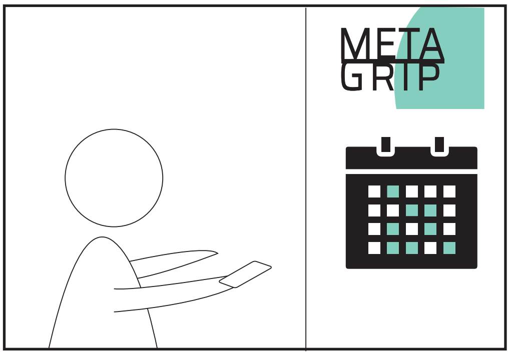
It is possible to do three test rounds before the real test is executed.



The MVC, RFD, critical force and power endurance is measured.

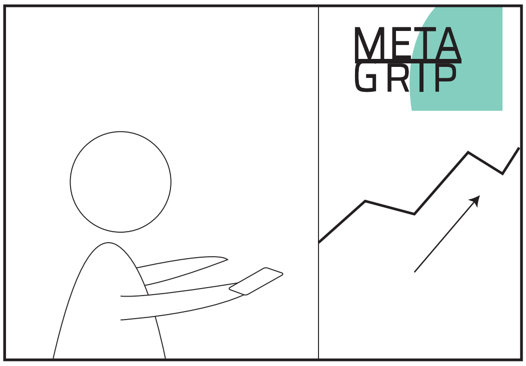


Feedback is given on the measurement.

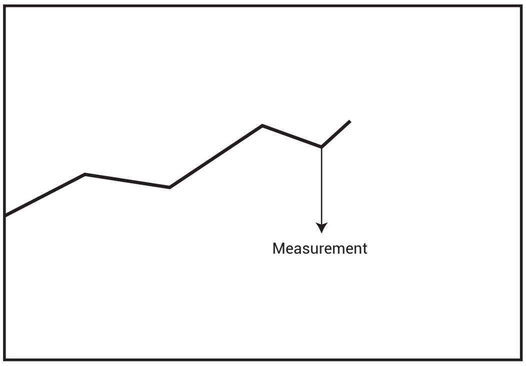


A suggestion for a training plan is given.

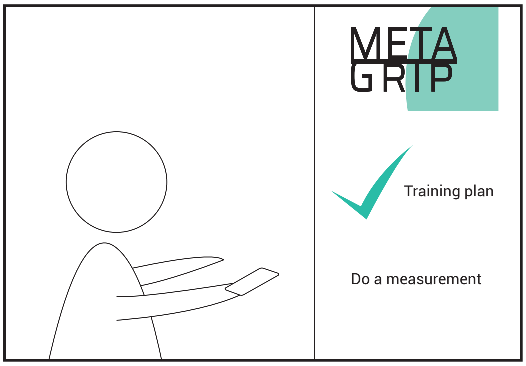
Figure S.2: Ideal use scenario part 2



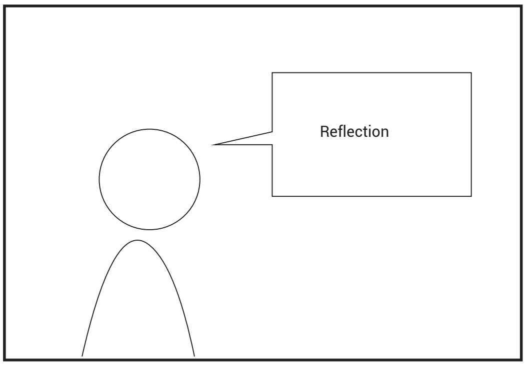
The user is able to track his or her progress through the training plan.



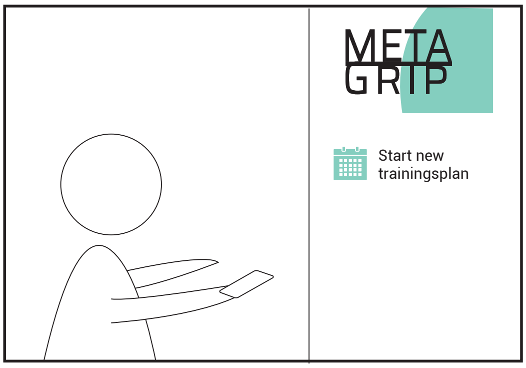
After a certain time, a progress assessment is done.



After the training plan is finished, a measurement is done.



A reflection on the measurement and trainings program is made.



A new training plan can be started if the user wants to.

Figure S.3: Ideal use scenario part 3

Appendix T

The Meta-Grip redesigned

The redesigned Meta-Grip is a device that is able to measure hand and finger strength of climbers and translate this into understandable feedback for the climber. Then the climber can choose to create a training plan based on these results and execute the practices on the Meta-Grip, closely monitoring progress. In this appendix, the design of the Meta-Grip will be discussed.

T.1 Changes to the current Meta-Grip

The current Meta-Grip differs a lot from the redesigned Meta-Grip in terms of user group, design and interaction. In the current Meta-Grip it is possible to adjust the height to accommodate every climber and their desired hangboard height. In the redesigned Meta-Grip, this is not possible. This choice was made in order to make the Meta-Grip idiot-proof and easy to use since there is no adjustment system that can malfunction or chalk and dust that can obstruct the adjustment system from working. For smaller or taller people, using the Meta-Grip can be done sitting on the knees or using a stool.

The form of the current Meta-Grip enables the user to use one hand at a time on the Meta-Grip during measurements. It is possible to measure on two different holds (sloper and crimp), but not at the same time since the angle needs adjusting. Measuring with one hand is really helpful in establishing someone's climbing grade, but training with only one hand is mostly not desired due to the high load applied. More measurements can be done on the Meta-Grip if it can be done on more holds and also with both hands, as competitive products allow (appendix D: Involved parties with the Meta-Grip on page 80). To enable more measurements, the redesigned Meta-Grip is made at a width usable for two hands as well in a correct posture. A correct posture in terms of width are that the hands are not too far out or in, but above the shoulders (figure T.1 on page 168). In Dined can be found that the minimal width of the Meta-Grip should be 501 millimeters (P95 Dutch adults (m/f) 2004) (Dined, sd).

The current Meta-Grip allows to change the angle of the grip, either to the sloper or the crimp. It can be angled horizontally and vertically on every 10 degrees. The dynamic character of the Meta-Grip is a unique feature which separates it from its competitors. However, currently, the Meta-Grip has only been used on two different angles for measurements. Furthermore, in a climbing gym there is a lot of chalk and dust which can make the turning mechanism falter (figure T.2 and figure T.3 on page 168). If a lot of measurements/trainings will be executed on the Meta-Grip it is desired that the transition between different holds is very easy. When choosing for a fixed device, there is no trouble with a faltering mechanism due to chalk and dust and switching between different holds is very easy.

When training on the Meta-Grip, different holds and sizes can be helpful to effectively train for certain goals. This is possible on the redesigned Meta-Grip as well: it features more holds and sizes than required for measurement purposes only.

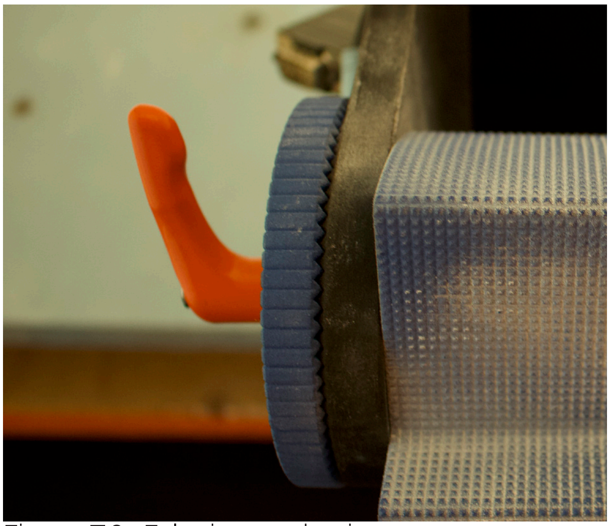


Figure T.2: Faltering mechanism

Figure T.3: Chalk and dust

Figure T.1: Shoulder position

T.2 The design of the Meta-Grip

To find the best shape of the hold, first, sketches and first prototypes were made (figure T.4, figure T.5, figure T.6 on page 170 and figure T.7 on page 171) looking for the best shape. Multiple materials will be needed for the Meta-Grip which can be used to the advantages of the design. Having two materials gives a clear suggestion on different functionalities within the product. In the Meta-Grip, the whole outer part will be wood whereas the small middle part will be PU (figure T.8). The middle part and the outer part will be divided by a line, ensuring the outer part is always 100 millimeters wide (figure T.9).

Figure T.4: Foam prototype

Figure T.5: Wooden prototype

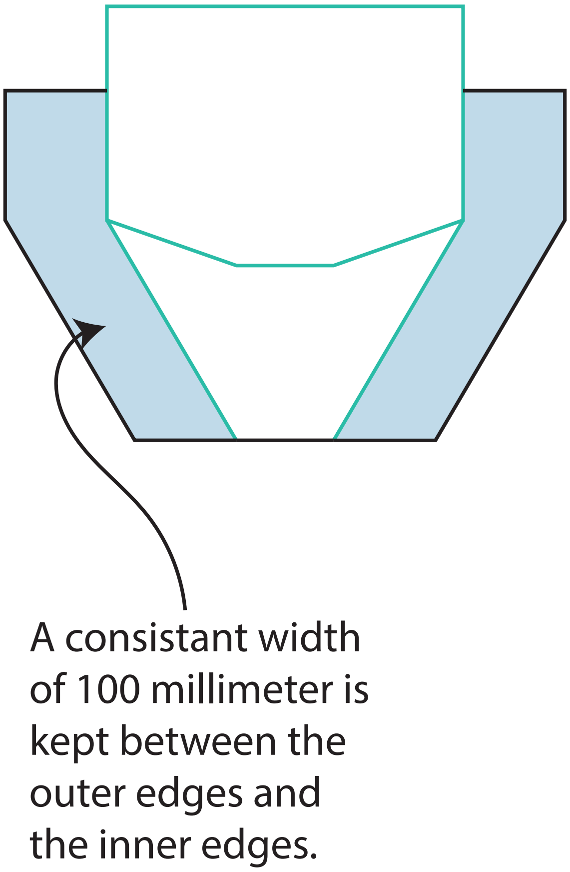


Figure T.9: Width outer part

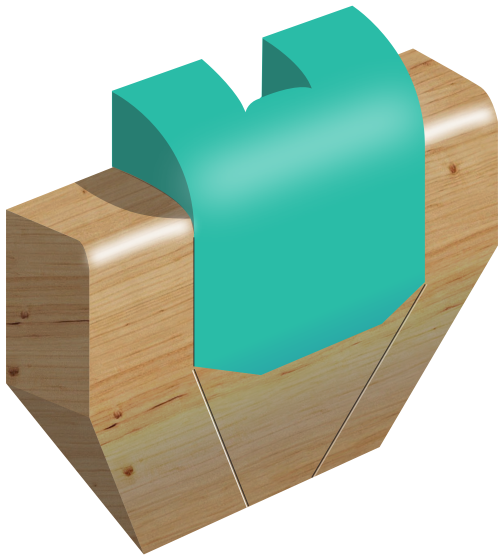


Figure T.8: Wood and PU

Figure T.6: Sketches

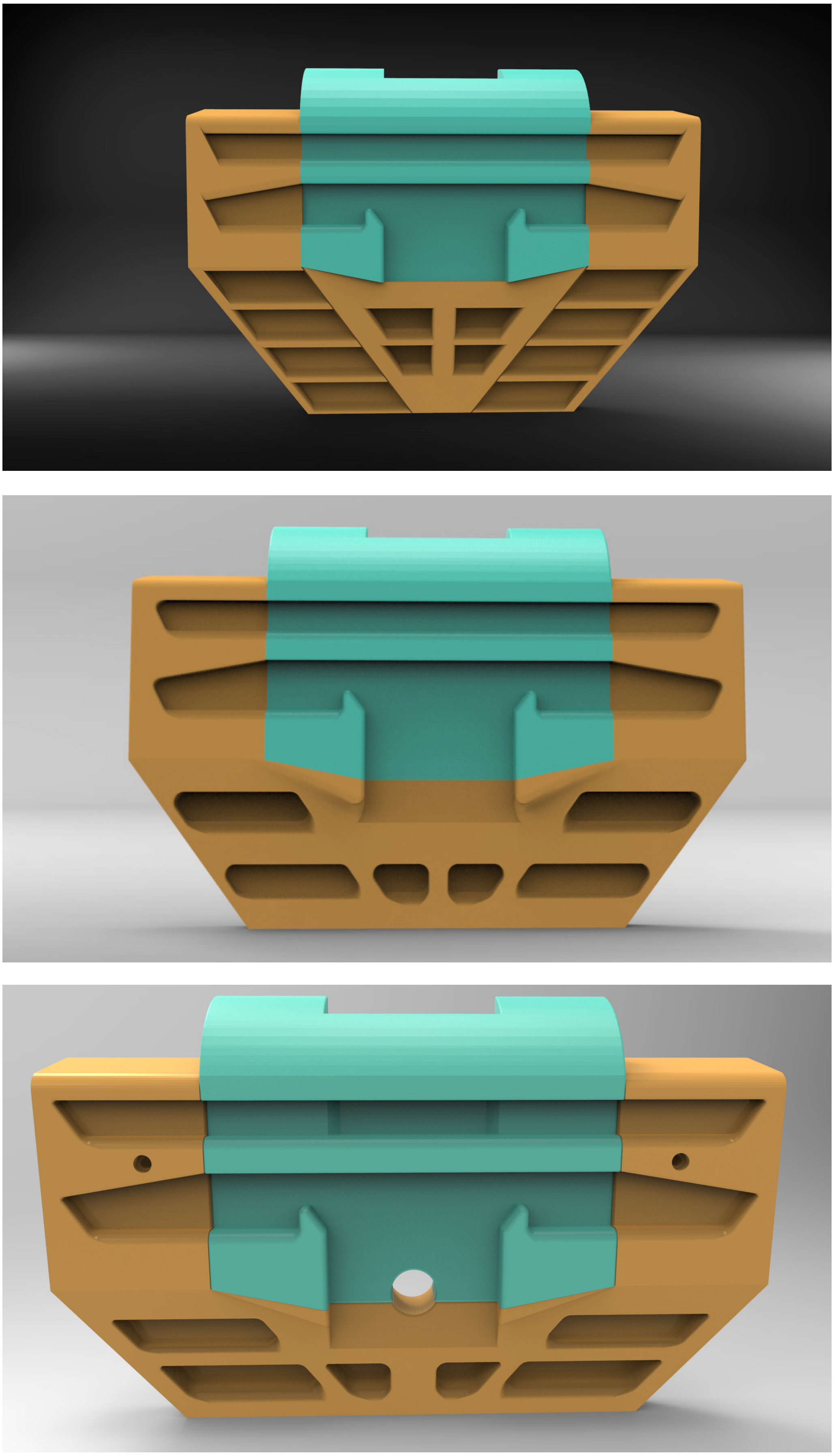


Figure T.7: Digital models

The shape of the Meta-Grip was developed by sketching the basic shape ideas at first (figure T.10, T.11 and T.12). The most aesthetically pleasing shapes were when the corners are at the same height and the beveled edges are parallel (figure T.13 on page 173). Since the measurements are done not exclusively on the PU hold, there should also be space for wooden measurement holds. This is done beneath the PU part of the Meta-Grip, clearly divided with a line from the outer part of the Meta-Grip (figure T.14 on page 173).

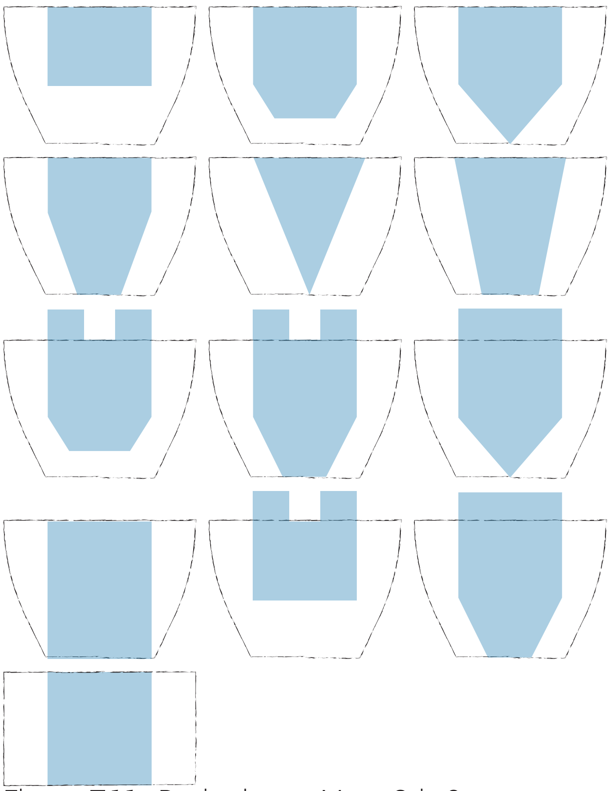


Figure T.11: Basic shapes Meta-Grip 3

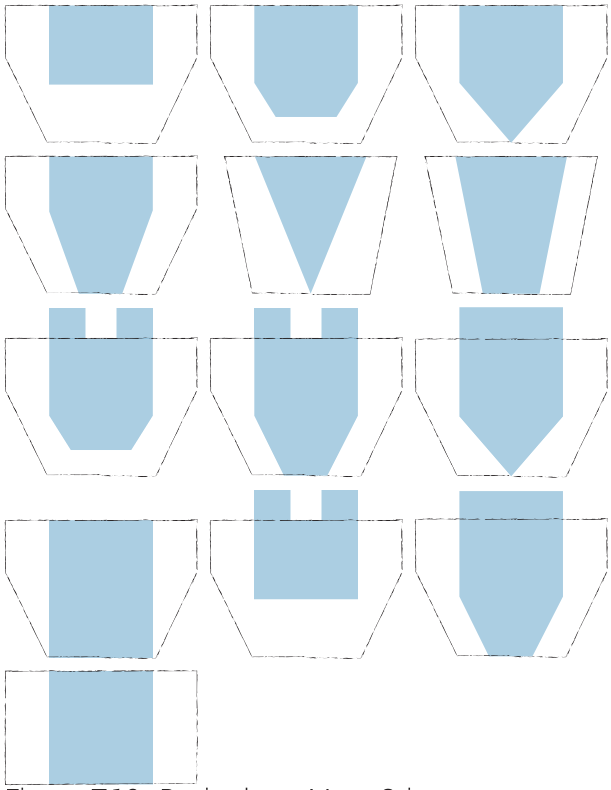


Figure T.10: Basic shape Meta-Grip

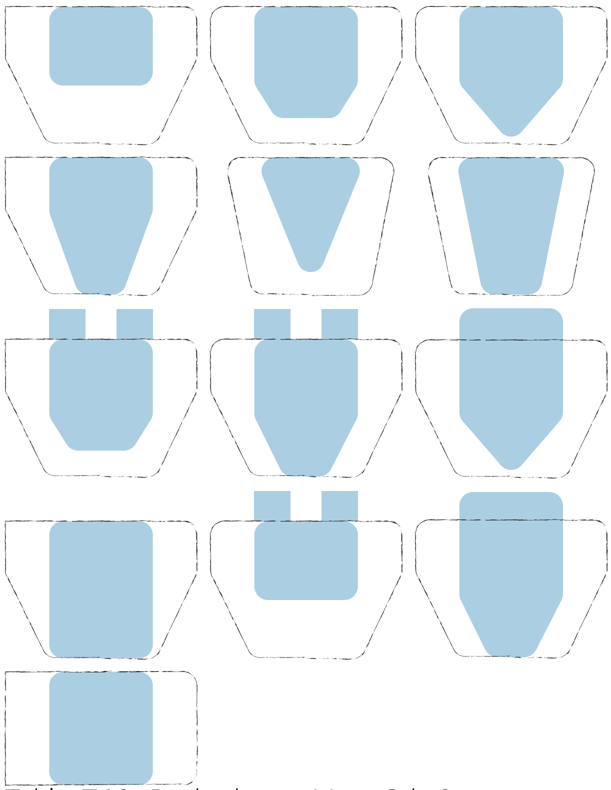


Table T.12: Basic shapes Meta-Grip 2

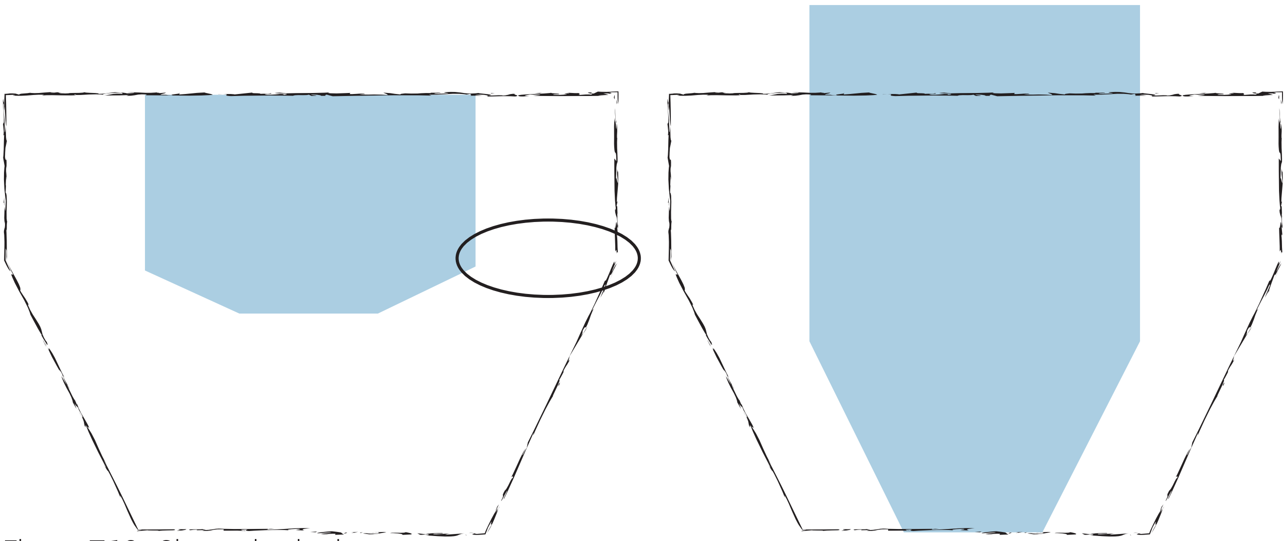


Figure T.13: Chosen basic shape

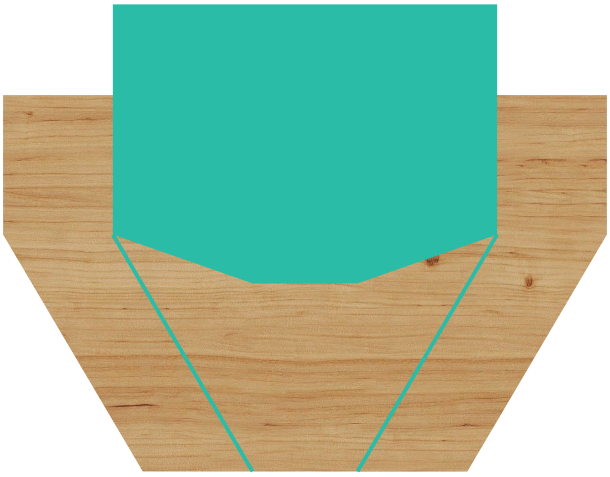


Figure T.14: Shape Meta-Grip

The crimps can have multiple variations in form as well. There is a minimal size necessary for every crimp so that every user can utilize a crimp. Furthermore, multiple end shapes can be created. However, option one, two and five have sharp edges which are not desired. Looking at the green curve in the logo of the Meta-Grip (figure T.15), the third and six option resemble this quite good (figure T.16). The third option is slightly less curved taking up less space for a crimp which is ideal. In figure T.17 is shown what the dimension area is and what the extra space is for climbers who might need it. In the oblique spaces of the hangboard, the shape of the third crimp does not fit very well due to the upward bending sides. If the inside bend is turned 180 degrees, like in crimp six, creating two opposite curves (figure T.18 on page 175), the crimps fit in perfectly in the oblique space and still resemble the logo very much.

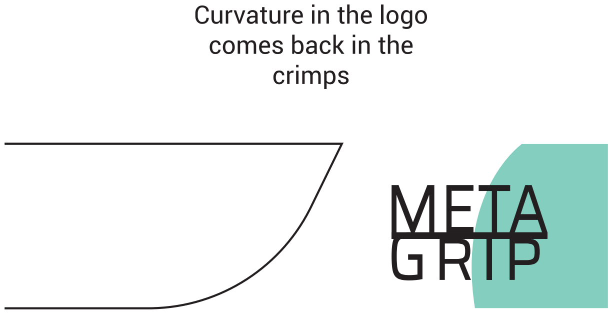


Figure T.15: Logo and crimp shape

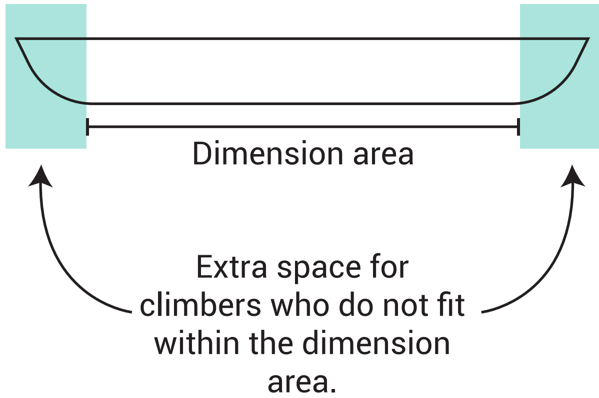


Figure T.17: Dimension area

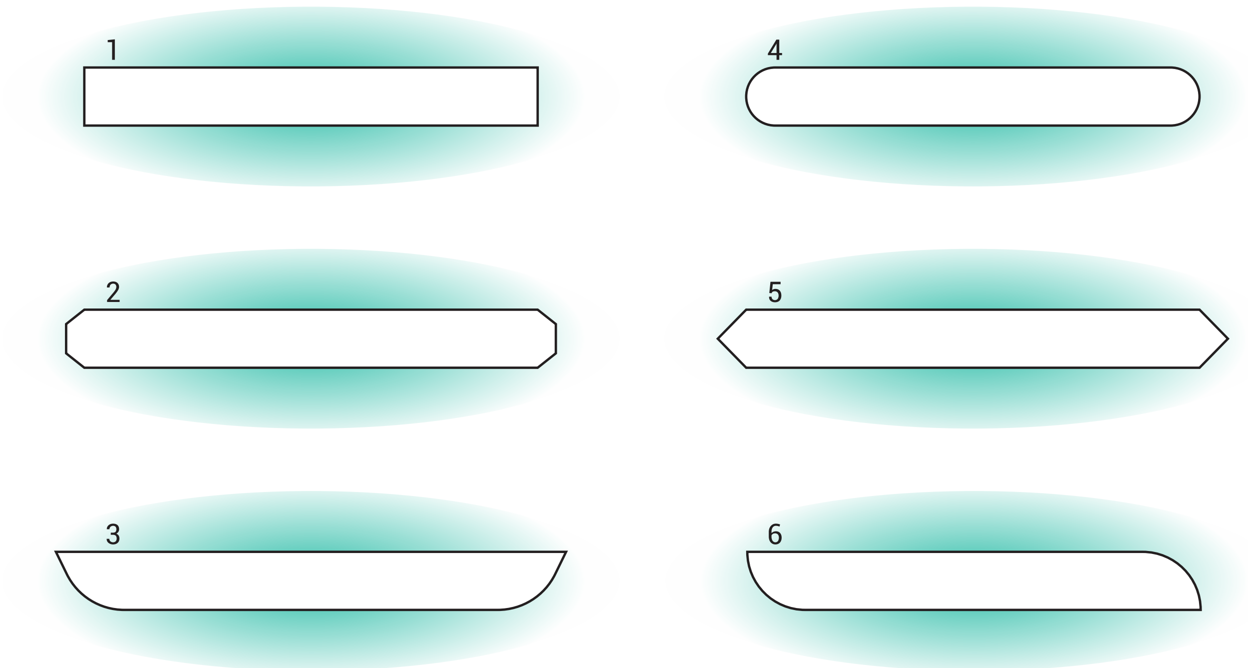


Figure T.16: Crimps shape

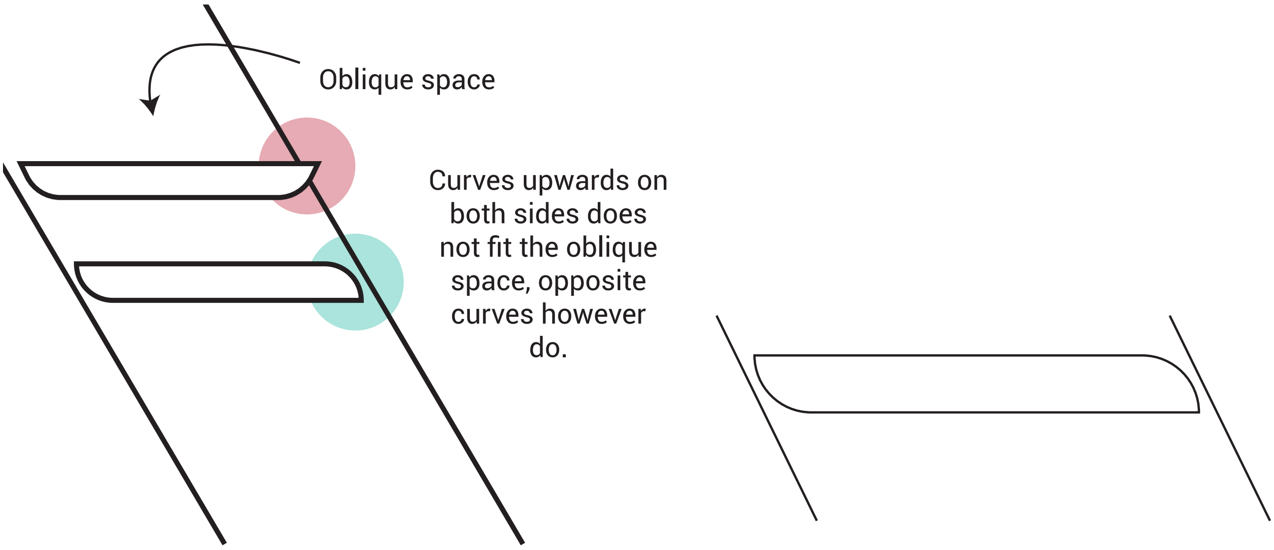


Figure T.18: Crimps in oblique space

Design principles can improve the design significantly (de Visser, 2014). There are nine design principles: balance, movement, repetition and rhythm, emphasis, simplicity, contrast, proportion, space and unity. For every design principle, it is discussed how the redesigned Meta-Grip contributes to these principles.

T.2.3 Balance
In the Meta-Grip there is a horizontal and symmetrical balance; the climbing holds are placed left and right of the central axis (figure T.19).

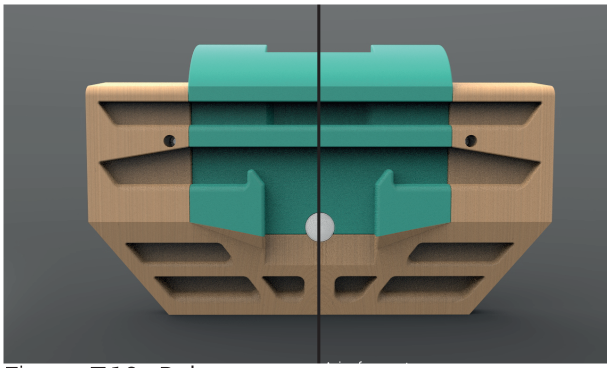


Figure T.19: Balance

T.2.4 Movement
The Meta-Grip is widest at the top of the product and narrows down halfway. This shape is also resembles in the polyurethane part of the Meta-Grip. By narrowing the width of the Meta-Grip at the bottom, the eyes of users will go from the top to the bottom, creating movement. The holds in the oblique part also create movement by suggesting a line on the insides side (figure T.20).

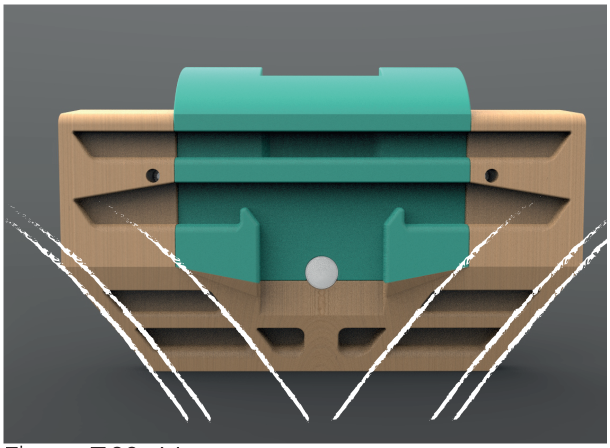


Figure T.20: Movement

T.2.5 Repetition and rhythm
The Meta-Grip consists of similar crimps, only varying in depth and width but not in looks.

T.2.6 Emphasis
The polyurethane part clearly springs out from the wooden part. This is because the polyurethane has a bright color and is in contrast with the wooden part. Furthermore, training tools are mostly made out of wood, making the Meta-Grip in general stand out more towards its competitors.

T.2.7 Simplicity

To make sure climbers can have a proper training, multiple different holds are needed. However, the assumption that more holds always make for a better training is not right. With the current holds a proper training can be executed by the target audience making it unnecessary to make the density of holds higher. With the low density of holds, the Meta-Grip looks appealing and simple, suggesting that it is easier to interact with compared to its competitors.

T.2.8 Contrast

The polyurethane part is clearly in contrast with the wooden part which makes the Meta-Grip interesting to look at. Besides contrast within itself, it also creates contrast with other tools used in a climbing gym because of the rarity of combining natural with non-natural materials.

T.2.9 Proportion

The proportion in the Meta-Grip is mostly looked at from a climbers perspective. There is a balance between it appearing to be rather small to use for training or way too large and bulky for training. Based on proper climbing positions and Dined this balance is determined.

T.2.10 Space

This design principle is similar to the proportion design principle in this case. A balance between too small and too large and bulky needs to be found in order for the Meta-Grip to be attractive.

T.2.11 Unity

When the eight design principles are applied, the ninth design principle, unity, will be fulfilled. The application is also contributing to this element since this helps with building a relationship with the product.

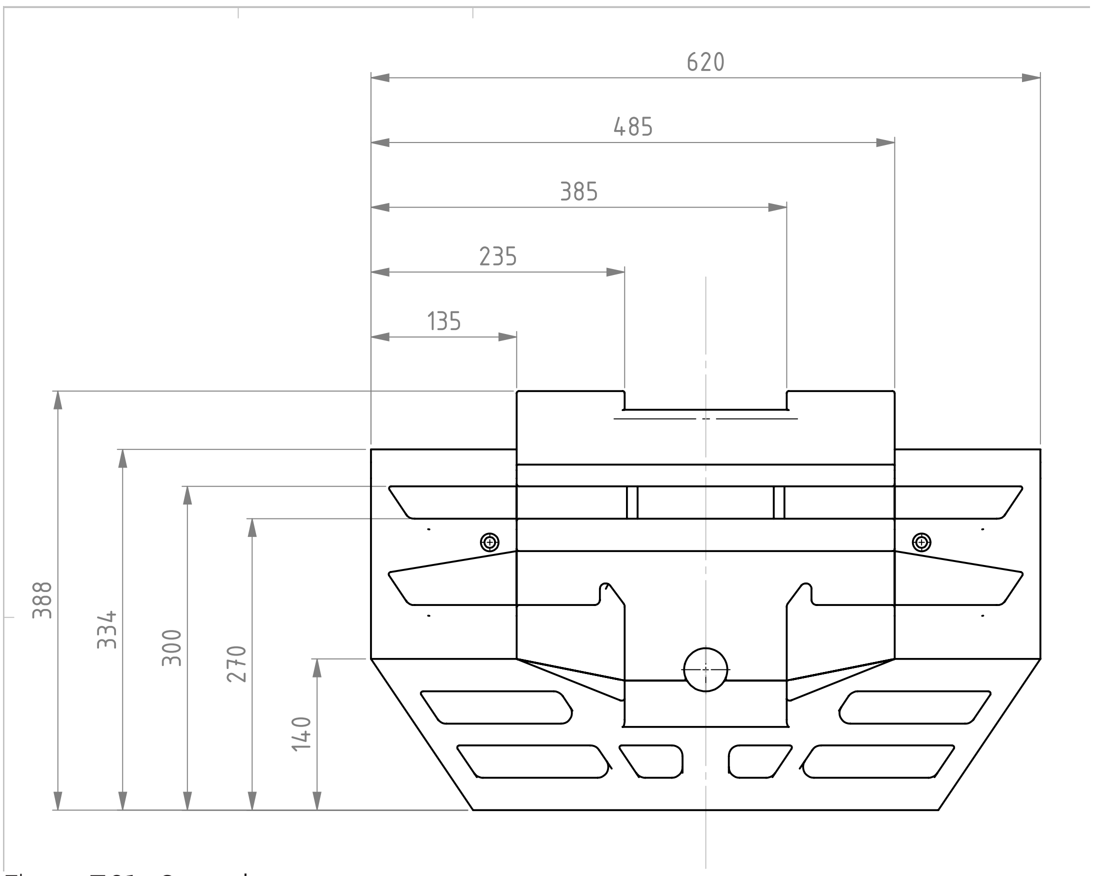


Figure T.21: General measurements

T.3 Production

The Meta-Grip will be manufactured in a small batch size (20) to start with. There are multiple parts that need to be manufactured and some parts need to be purchased like hardware. Appendix Y: Bill of materials on page 181 presents a clear overview of all the parts in the Meta-Grip. The most prominent and interesting parts production wise are discussed further in this chapter. In figure T.21 on page 176, general measurements can be seen.

T.3.1 Wooden part

The wooden part of the Meta-Grip has to be milled on both sides; for the climbing holds and for the hardware to fit in. Since this is a too technical shape to make by hand, it will be done by a CNC milling machine. Using a milling machine makes it possible to replicate the shape multiple times with a high precision. It is also the most time efficient way to cut wood in the desired shape.

T.3.2 Polyurethane part

The polyurethane part has to be cast into a mold. This is a silicon mold so the part can be easily removed from the mold. There are two possible ways to cast the polyurethane part:

1. The wooden part is used partially as a mold next to silicon to close of the shape. The polyurethane part will be glued to the wooden part and it has a tight fit.
2. There is a separate silicon mold for the polyurethane part. The polyurethane part is then fixed with screws into the wooden part. Having a separate silicon mold makes it slightly more difficult to have a very tight fit with the wooden part, but it is still possible.

The first option is chosen for the Meta-Grip because of the perfect fit in the wooden part. Curing the PU to the wood works as a type of glue and the connection is already strong. This is then made stronger by adding screws to the PU and wood part.

In the polyurethane part it is important to add ribs in the structure (example in figure T.22). Polyurethane can be slightly elastic still whereas the coating giving it texture and grip is not. For the coating to last longer, it is important to add ribs so the polyurethane part is more rigid.

T.3.3 Button

The button is a small part of the Meta-Grip which is made out of polylactic acid (PLA). This can be manufactured in two ways; 3D printing and casting. The pros of 3D printing are mostly that there is a lot of form freedom, also to develop further parts of the Meta-Grip. It furthermore is a very easy way of manufacturing small plastic parts. A 3D printer can however be an expensive expenditure. Casting can be very quick and does not show marks of manufacturing as much as 3D printing shows. However, a cast can be expensive for the batch size and does not allow quick changes in the model.

Figure T.22: Ribs in PU

T.4 Skins

This design is targeted at fanatic climbers. Different user groups require different holds to train with. In order to satisfy all users, multiple skins will be developed for the Meta-Grip. The hardware will be similar for every skin so they can be used for every skin. The skins will vary in holds and difficulty to target amateur athletes, pro athletes and injured climbers as well. Making a skin for the group fanatic climber does not exclude other user groups from using this skin as well; they can choose for that themselves.

T.5 Configuration hardware

The configuration of the hardware is completely hidden away from the climber. The attachment of the Meta-Grip to the wall can be done through the Meta-Grip (figure T.23). Here, the two load cells will be attached to the wall without the Meta-Grip skin being attached to the load cells with big enough shafts for the head of the bolt to go through the Meta-Grip. With a ring, the load cells will be spaced one millimeter from the wall to prevent friction. The other side of the load cells will be connected with an L-beam together to prevent torsion from happening (figure T.24). With M6 bolts, the load cell is attached to the Meta-Grip skin through the L-Beam (figure T.23).

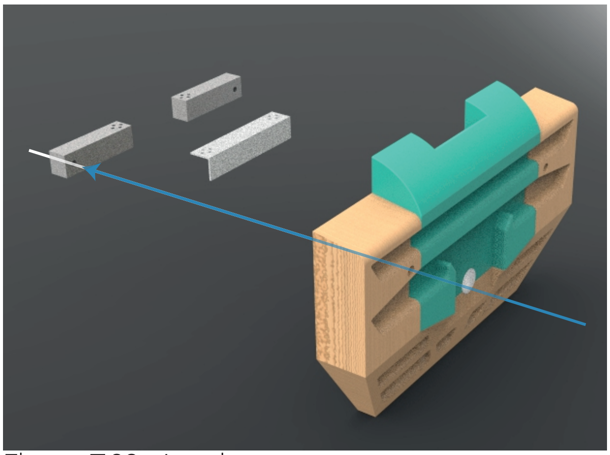


Figure T.23: Attachment

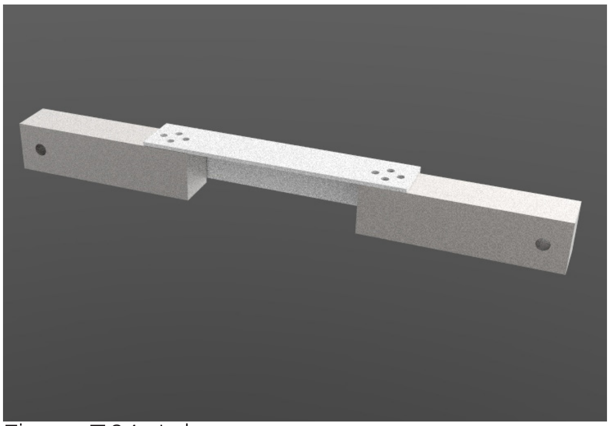


Figure T.24: L-beam

T.5 Database

There are multiple elements that will be put in the database to make a test complete. Belowthe important parameters are explained.

T.5.1 Gender

In research is found that men have a physical advantage over women (Thibault, et al., 2010). Because of this athletic difference, it is important to take note of the gender of climbers in the database.

T.5.2 Age

Age has also a significant influence on climbing performances. In general, a climber is building up to peak performance from when they started climbing as a kid. After a certain age, the performance levels will descend. Age has a significant influence in the type of training suggested by the Meta-Grip application since hangboard training is not desirable for every age group.

T.5.3 Name

Adding a name is important to identify the user and correctly address the user.

T.5.4 Timestamp

A timestamp is necessary to be able to recall measurements from the database from a certain date.

T.5.5 Body length

The body length of the climber is not necessary for the database, but can be interesting for research in combination with the climbing level.

T.5.6 Body weight

Again, this is not a necessary input for the database, but having to pull more weight up requires more muscles.

T.5.7 Dominant hand

Since the dominant hand is the most preferred hand, it is expected that this will also show in the measurements as the dominant being more physically fit.

T.5.8 Climbing experience

Climbing experience in years has also an influence on the performance of the climber and is thus relevant in the database. As explained in appendix B: Hand anatomy, physiology and biomechanics on page 76, hands of a climber take at least two years to get used to the climbing load. Besides getting used to the climbing load, more climbing experience in years also improves the technique of the climber, which is an important factor within climbing as well (appendix O: Determining a training plan on page 155). The climbing experience in years is also necessary to be able to give a proper training plan.

T.5.9 Climbing level lead/boulder

Climbing level is of great significance for the results of the measurement. Climbing level will be inserted for both boulder and lead, red point grade. The database will have the IRCRA system since this is the most complete climbing grading system. Climbing levels are also necessary to make a proper training plan for the climber.

T.5.10 Climbing sessions

The frequency of climbing sessions are important for determining the training plan. For example, if the average training load is low, it is not desired to increase this really quickly by adding multiple practices.

T.5.11 Maximum finger strength

This is one of the measurements the Meta-Grip is able to perform which need to be stored in the database.

T.5.12 Explosiveness

This is the second measurement of the Meta-Grip which needs to be stored in the database.

T.5.13 Critical force

This is the third measurement of the Meta-Grip which needs to be stored in the database.

T.5.14 Power endurance

This is the fourth and final measurement of the Meta-Grip which needs to be stored in the database.

T.5.15 Tested hand

Since a test will be performed with only one hand, it is necessary to indicate which hand is tested in the database.

T.5.16 ID Code

It is important that every result for every user, every hand and every different measurement has a unique code so the correct data can be accessed from the database when asked in the application by the user.

Appendix U

Bill of materials

In this list, the bill of materials is shown.

Part number	Amount	Part	Material	Production
1	1	Wooden skin	Alder wood	Milling
2	1	Plastic skin	PU	Casting
3	1	Instructions	Vinyl	Printing
4	1	Perspex plate	PMMA	Several
5	4	Spacer sleeve	PA	Several
6	4	M5 Bolt and nut	Stainless steel	Several
7	1	Rocker switch	Several	Several
8	1	Button	PLA	3D printing
9	1	9V battery	Several	Several
10	1	Arduino Nano	Several	Several
11	1	Bluetooth module HC-05	Several	Several
12	1	Amplifier HX711	Several	Several
13	1	10KΩ resistance	Several	Several
14	1	4.7KΩ resistance	Several	Several
15	1	Common cathode RGB LED	Several	Several
16	3	220 Ω Resistance	Several	Several
17	8	M6 bolts	Stainless steel	Several
18	2	M10 bolts	Stainless steel	Several
19	4	M10 washers	Stainless steel	Several
20	8	M6 washers	Stainless steel	Several
21	8	M6 insert nuts	Stainless steel	Several
22	1	Electronic wires	Several	Several
23	2	Load cell 200 kg	Several	Several
24	1	L-Beam	Stainless steel	Several

Appendix V

Costs

In this chapter, the costs of the Meta-Grip will be presented.

V.1 Costs chart

Part number	Part	Needed per product	Unit	Price per product	Price per 20	Source
1	Wooden skin	1	Piece	€ 11,02	€ 220,40	(Houtsoorten en prijslijst, sd)
2	Plastic skin	1	Piece	€ 20,00	€ 400,00	Frank Bogerman
3	Instructions	1	Piece	€ 5,00	€ 100,00	(Vinyl design, sd)
4	Perspex plate	1	Piece	€ 1,21	€ 24,20	(Kunststof plaat, sd)
5	Spacer sleeve	4	Piece	€ 0,43	€ 8,60	(Spacer, sd)
6	M5 bolt and nut	4	Piece	€ 0,30	€ 6,00	(inbusbouten, sd) (Zeskantmoeren, sd)
7	Rocker switch	1	Piece	€ 2,21	€ 44,20	(Rocker switch, sd)
8	Button	1	Piece	€ 1,00	€ 20,00	PMB
9	9V battery	1	Piece	€ 1,75	€ 35,00	(9V batterij, sd)
10	Arduino nano	1	Piece	€ 19,00	€ 380,00	(Arduino Nano, sd)
11	Bluetooth module HC-05	1	Piece	€ 6,00	€ 120,00	(HC-05, sd)
12	Amplifier HX711	1	Piece	€ 2,00	€ 40,00	(HX711, sd)
13	10KΩ resistance	1	Piece	€ 0,05	€ 1,00	(10K weerstand, sd)
14	4.7KΩ resistance	1	Piece	€ 0,05	€ 1,00	(4.7K weeerstand, sd)
15	Common cathode RGB Led 5 mm diffuse	1	Piece	€ 0,25	€ 5,00	(Common cathode, sd)
16	220 Ω Resistance	3	Piece	€ 0,15	€ 3,00	(220 Weerstand, sd)

17	M6 bolts	8	Piece	€ 0,98	€ 19,60	(Inbusbouten M6, sd)
18	M10 bolts	2	Piece	€ 0,70	€ 14,00	(Inbusbout M10, sd)
19	M10 washers	4	Piece	€ 0,15	€ 3,00	(Sluitringen, sd)
20	M6 washers	8	Piece	€ 0,17	€ 3,40	(Sluitringen, sd)
21	M6 insert nut	8	Piece	€ 2,88	€ 57,60	(Rampamoer, sd)
22	Electronic wires	1	m	€ 0,49	€ 9,80	(VD draad, sd)
23	Load cell 200 kg	2	Piece	€ 36,00	€ 720,00	(Load cell, sd)
24	L-beam	0,5	m	€ 5,50	€ 110,00	(Hoekprofiel aluminium, sd)
Total				**€ 117,29**	**€ 2345,80**	

V.2 Manufacturing

In the cost price, only the materials are taken into account, not the manufacturing method and the costs of the manufacturing. For manufacturing, there are three large expenditures that need to be made: a 3D printer, a mold for the PU part and a CNC milling machine. The mold for the PU part is very specific.

Frank Bogerman was consulted on giving an estimate of the PU mold. It is expected that the PU mold for the Meta-Grip will cost between the 900 and 1200 euros. A 3D printer can be bought within a large price range were the price starts at 150 euros. A CNC milling machine is quite expensive and has to be programmable to be able to easily mill the Meta-Grip.

Appendix W

Electronics in the Meta-Grip

The Meta-Grip can function because of the software developed. The software enables users to interact with the Meta-Grip without the need of supervision. It also enables for multiple users to use the same Meta-Grip. In this chapter, the functioning of the software is explained.

W.1 Proof of concept

For this project, a proof of concept was made of the software (figure W.1). In this concept, it is possible to control the load cell via a Bluetooth connection between a mobile phone and the Arduino (appendix AD: Software Arduino on page 212). To give commands to the Arduino, a serial command monitor application is used on the phone (figure W.2 (Bluetooth Terminal HC-05, sd). When a measurement is started via the serial command monitor, the feedback, raw data, will be displayed on the monitor in the application. This is not yet translated to a climbing grade or understandable data for the user. This is something that should be done within the application.

In the software of the Arduino, multiple different measurements can be executed by using three variables. In every measurement, there is a test time, a rest time and a number of repetitions. So for example, for the maximum finger force or the maximum voluntary contraction, there are three repetitions of pulling 10 seconds with 2 minutes rest in between. By using these three variables for a measurement in the software makes it easy to change and implement different measurement protocols.

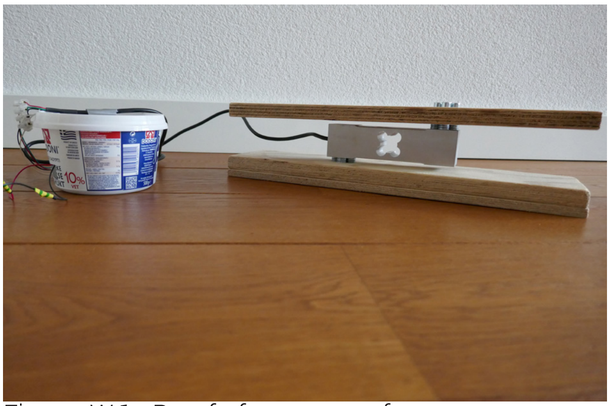


Figure W.1: Proof of concept software

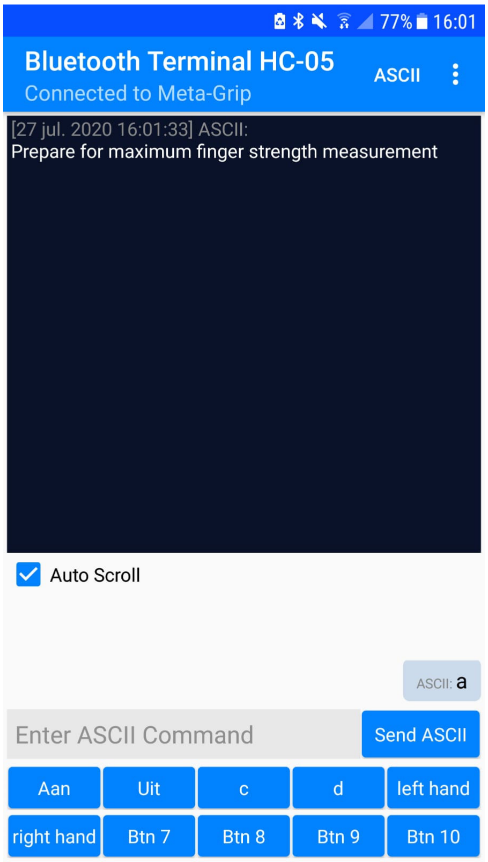


Figure W.2: Serial monitor

In the concept developed in this project, a light and buzzer are still used to give feedback to the user. When the light is on, a measurement is in progress and when it is off, no measurement is being executed. A buzzer is used for countdown before a measurement and before a rest starts. This will be replaced by the application in the final model.

The load cell used in this model can hold up to 200 kg with a safe overload of 150 % of the capacity of the load cell. This is sufficient for the final design of the Meta-Grip as well. In the test setup a relative soft wood is used. Therefore the load cannot exceed 40 kilograms (figure W.3).

The Bluetooth module has a range of ten meters (bluetooth-hc-05-module-rf-transceiver-master-en-slave, sd). This is ideal because the device will be used by multiple users with their own phone. If a user walks away from the device because he or she is finished with a measurement, but forget to disconnect, the connection will be shut down after a range of ten meters.

The components that are included are shown in the bill of materials (appendix U: Bill of materials on page 181). This is connected as shown in figure W.4 on page 186 and figure W.5 on page 187. In the current model, the sample rate is 10 Hz. This can be scaled up to 80 Hz by adapting the HX711 module. For the rate of force development, a sample rate of at least a 1000 Hz is ideal, to be able to see small and quick changes in force as well. However, the HX711 does not support this. And an alternative should be found. The Arduino is able to support a sampling rate up to 10.000 Hz (AnalogRead(), sd).

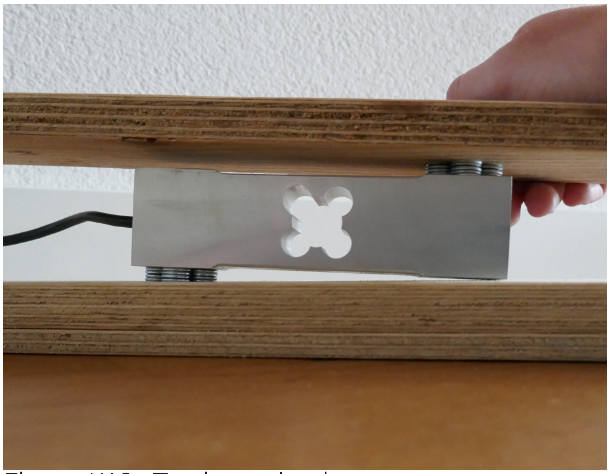


Figure W.3: Too heavy load

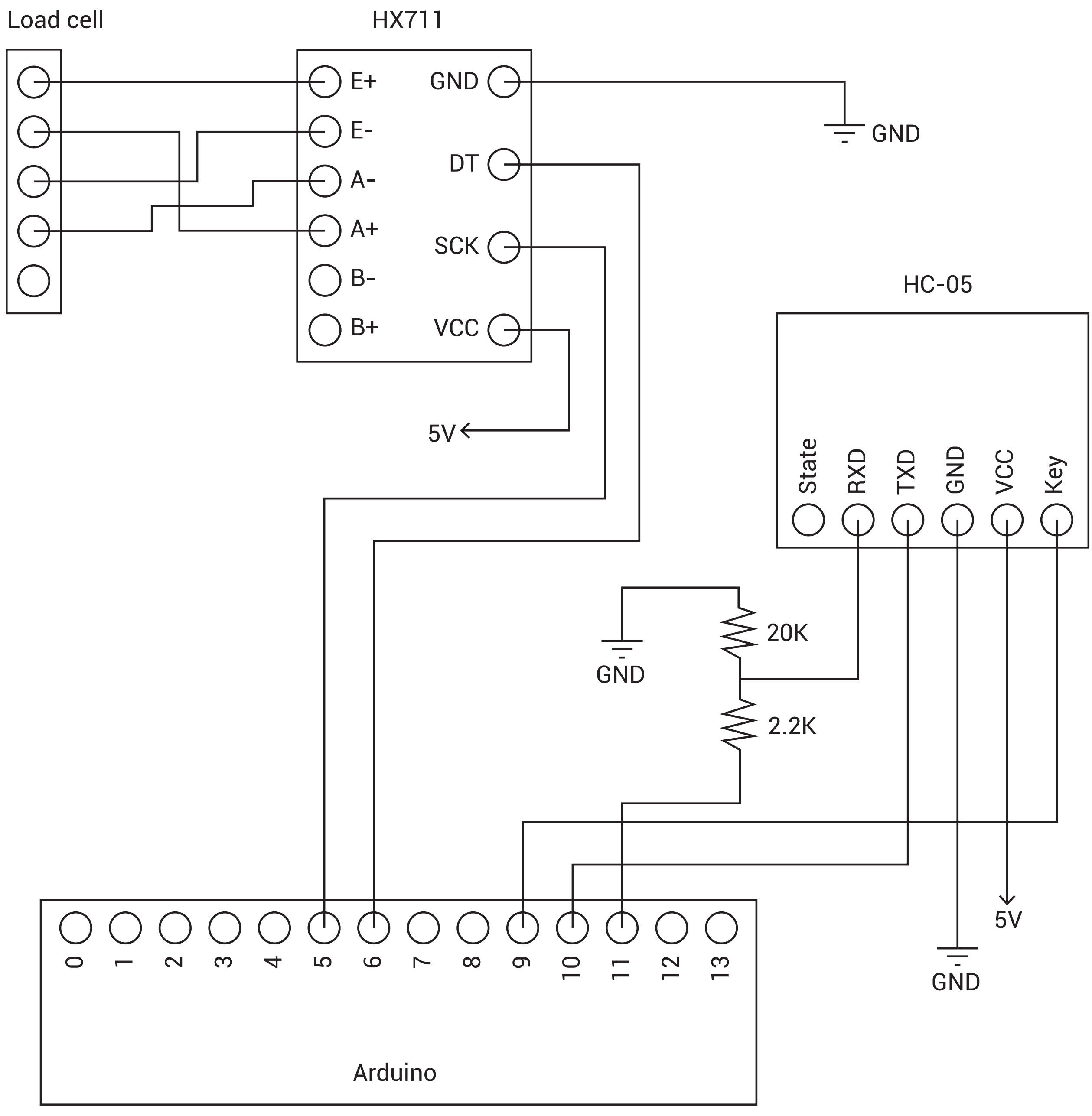


Figure W.4: tWiring load cell

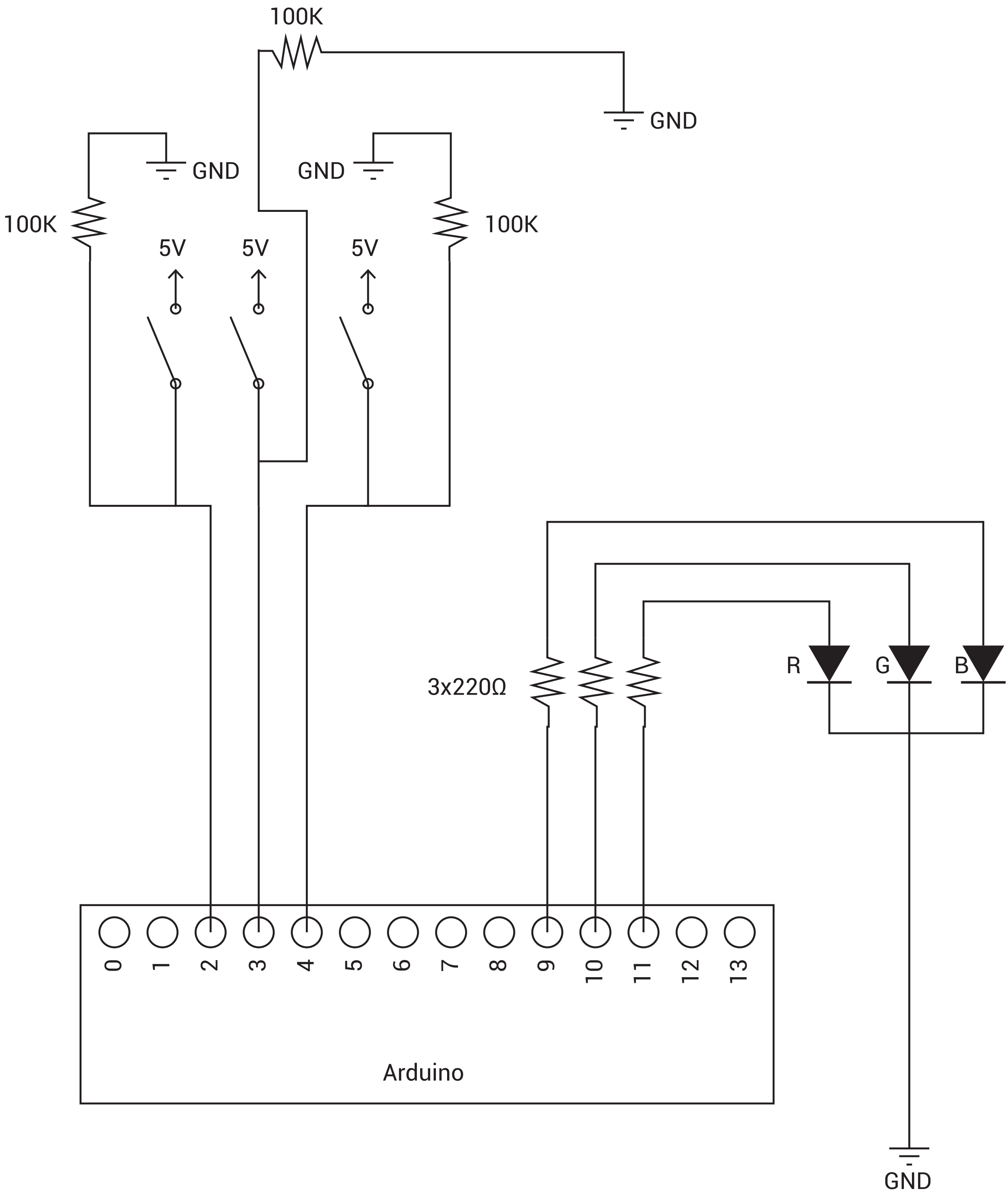


Figure W.5: Wiring cathode

W.2 Final design

For the final design, changes need to be made in the electronic hardware and software. The software needs to be idiot proof and understandable for all users.

W.2.1 To the application

Since the software in the Arduino is only able to read the weight put on the load cell, a step has yet to be taken to make the results available for the user. This analysis is done within the application of the Meta-Grip.

W.2.2 To the database

The data that is collected with a measurement needs to be transferred to a database. This can be done in multiple ways. Right now, with only a Bluetooth module, the data is transferred to the database via the application, using the internet connection of the user. Another option that can be explored more is the connection of the Meta-Grip itself to the internet. The data can then directly be transported to the database without having to go via the application.

W.2.3 Battery

The software and its components are powered by a 9 volt battery. To preserve the battery, an on and off switch is located on the side of the Meta-Grip, in the instructions. This switch is located outside of the Arduino circuit. This means that if the switch is open, there is no power to the Arduino. To change the battery, the skin of the Meta-Grip needs to be taken off completely. Another option would be to power the Meta-Grip from a wall outlet. This would make an on and off button for the power connection unnecessary and the interaction with the Meta-Grip therefore easier.

W.2.4 Interaction button

It is desired that another energy preserving option is available for when the battery is connected but the Meta-Grip is not in use. This is why the Arduino will be put in sleep mode which saves almost 50 percent power. To toggle the Arduino from or in the sleep mode, another physical button is necessary. The button on the front of the Meta-Grip is able to do this. Making the button translucent creates the opportunity to give feedback to the user as well in the form of light for the device being on, resetting Bluetooth and Bluetooth not connected. This is all programmed by using a single push button connected to the Arduino (appendix AD: Software Arduino on page 212). If the Meta-Grip is coming out of sleeping mode, the established Bluetooth connection is reset.

Appendix X

User test button feedback

On the Meta-Grip, a button is used for the main interaction that are not controlled via the phone, namely: turn device on, turn device off, connect Bluetooth and disconnect/ reset Bluetooth. Besides interactions, the user should also get feedback from the button through different light(color) variations. To find out which input and feedback type the user associates with which interaction, a user test was done.

X.1 Research question

1. Which interaction with a single button associate the users of the application with which action?
2. Which variation in light intensity and light color suggest the user with which feedback?
3. Are multiple colors needed to give correct and understandable feedback to the user?

X.2 Hypothesis

Based on the research questions and existing devices, it is expected that a fast double push on a button will be associated with resetting the Bluetooth and a long three seconds push is for turning the device on and off. To make the feedback given by light more diverse, multiple colors are needed. They add an extra layer of possibilities in terms of feedback. Red is a color mostly associated by something not going as it should be and green by things going as they should (Moller, Elliot, & Maier, 2009). Blue can be an action color for the Bluetooth since this color is associated with communication, logic and efficiency (Labrecque & Milne, 711–727). Based on this, green will mostly be a color associated with the device being on, red with something that is wrong, e.g. Bluetooth is not connected and blue for resetting the Bluetooth. When a light is blinking, it is expected that the user associates this with an action.

X.3 method

X.3.1 Participants

During this user test, twenty participants (male (n=9)/female (n=11)) from the network of the researcher were asked to participate. The average age of the participants was 26 years old (stdev = 8,4) and both climbers and non-climbers participated. Thirty-five percent of the participants defines themselves as a climber.

X.3.2 Stimuli

Google form

X.3.3 Apparatus

Laptops or mobile phones to access the questionnaire.

X.3.4 Procedure

The participant was first introduced to the topic of the questionnaire with the following introduction: “In this questionnaire, I want to ask you a couple of questions about giving feedback with a LED. The concerning device is a Bluetooth device. This device can be used by multiple users, but only by one user at a time. The device can disconnect one phone so that another phone can be connected. A button is used for disconnecting. In this questionnaire, you are asked about interacting with the button and the connected LED. First, some questions are asked for general information about you. By finishing the questionnaire, you agree with this information being used, anonymously, in my graduation project."

After this, the general information of the participants was asked:

- What is your age?
- Do you define yourself as a climber?

The first case is introduced: "Imagine a single button. This button can emit light in only one color. The interactions that are possible with the button are the following: push for three long seconds, push one single time, push twice quickly after each other. The different light feedback that is possible is the following: On, off, fast blinking, slow blinking."
After this introduction, the participant is asked to link interactions to meanings and meanings to feedback in light (one color). Per type of interaction they could pick one or more meanings. Per lightfeedback type, one or more meanings could be picked.

The second case is introduced as follows: "Imagine a single button. This button can emit light in three different colors: Red, Blue and Green. The interactions that are possible with the button are the following: push for three long seconds, push one single time, push twice quickly after each other. The different light feedback that is possible is the following: On, off, fast blinking, slow blinking in all the color variations."
The participants are asked to link meaning to feedback in red, green and blue light.

X.3.5 Measures

The research questions will be answered by analyzing the answers of the participants.

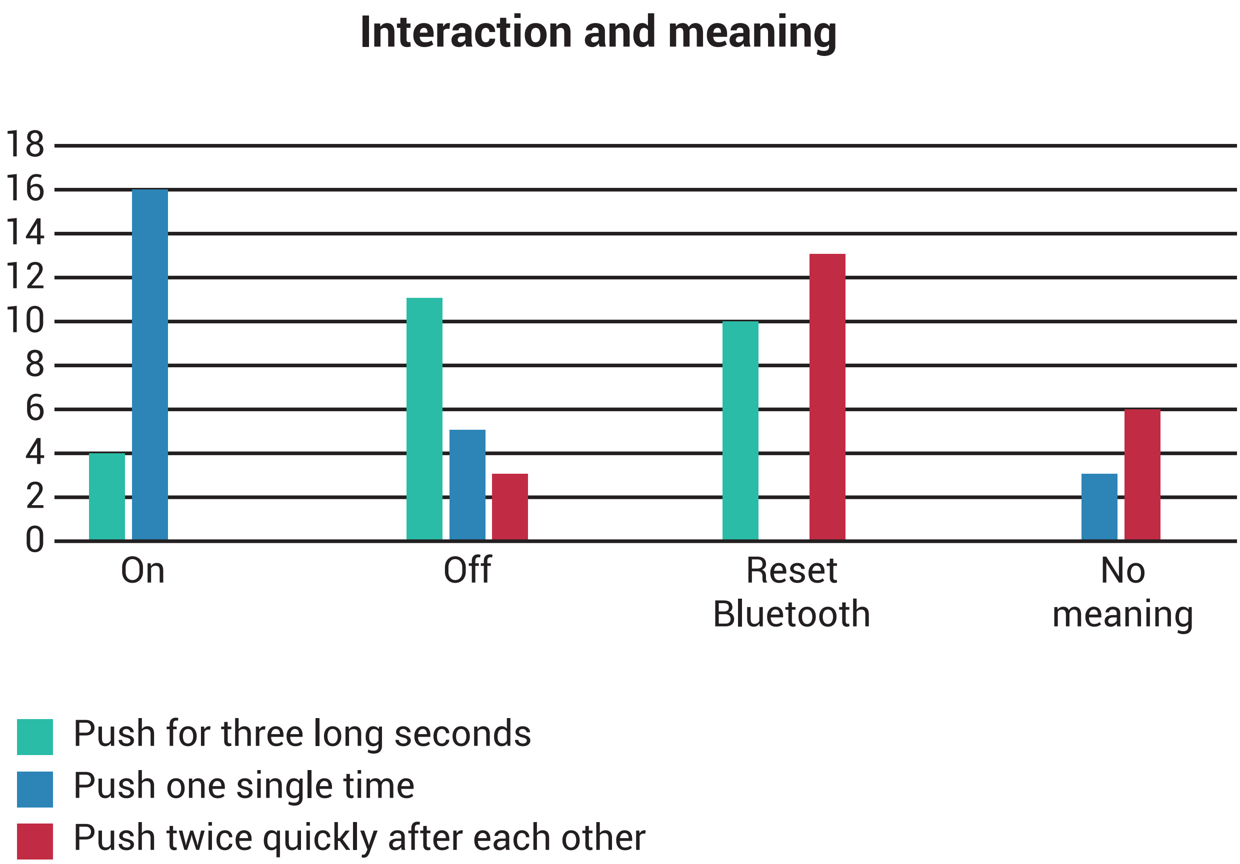


Figure X.1: Interaction and meaning results

X.4 Results

The results for interaction and meaning can be found in figure X.1 on page 190. Here it can be seen very clearly that the majority of the participants associate one single push on a button with turning the device on. For turning off the device, the majority of the participants prefers to hold the button three long seconds.To reset the Bluetooth, two pushes quickly after each other is preferred.
Looking at the results of meaning and feedback in one color (figure X.2), it can be seen that light on is mostly associated with the device being on and light off with the device being off. For resetting the Bluetooth, most participants prefer a fast blinking light. For the Bluetooth connected and Bluetooth not connected there was no clear preference among the participants for light feedback.
The results of meaning and feedback in three different colors was much less pronounced (figure X.3). Light off was again associated with the device being off. Having a green light on was associated with the device being turned on. A blue fast blinking light was associated with resetting the Bluetooth or

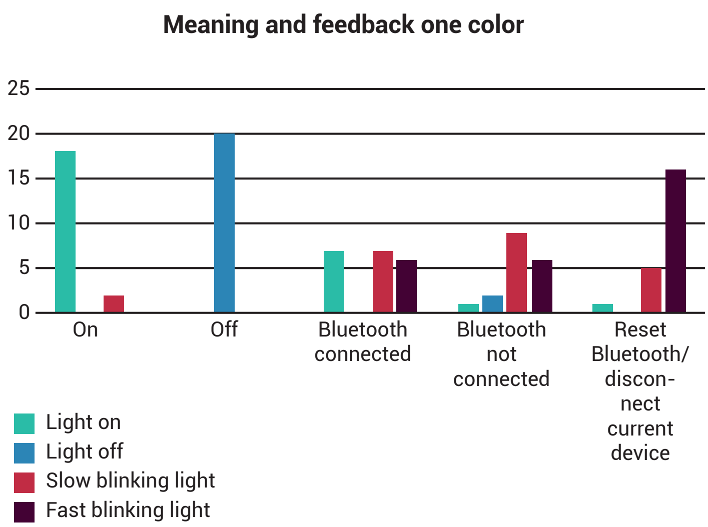


Figure X.2: Meaning and feedback one color results

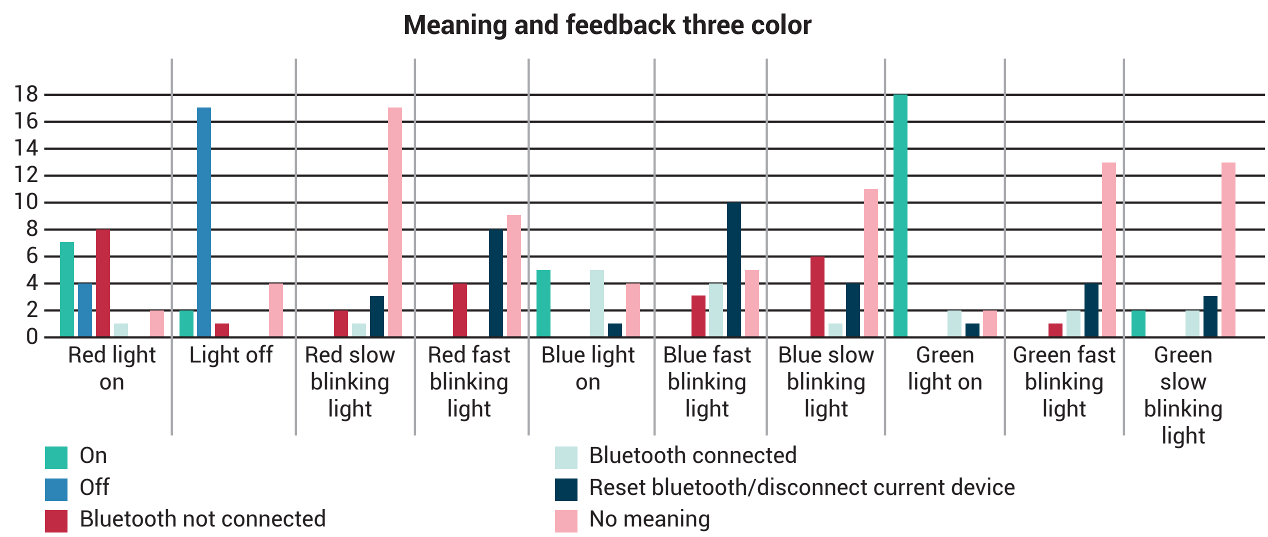


Figure X.3: Meaning and feedback three colors results disconnecting the current device. Lastly, the red light on was associated with the Bluetooth not being connected. The detailed results of all questions can be found in figure X.4 on page 193, figure X.5 on page 194 and figure X.6 on page 195.

X.5 Conclusion

1. Which interaction with a single button associate the users of the application with which action?
   One single push – turning the device on
   hold the button for three seconds – turning the device off
   two quick pushes after each other – reset Bluetooth
2. Which variation in light intensity and light color suggest the user with which feedback?
   (Green) light on – the device being on
   Light off – device being off
   (Blue) fast blinking light – resetting Bluetooth
   Red light – Bluetooth not connected
3. Are multiple colors needed to give correct and understandable feedback to the user?
   Yes, with only one color, the participants could not define when the Bluetooth was connected and when it was not connected.

The results are visualized in figure X.7.

X.6 Discussion

This user test was done fully online without any interaction between the participants and the researcher. Also, the participants had to imagine the different light feedback that was suggested in the questionnaire since there was no real prototype of this (figure X.8). To give the participants a more real experience and get better results, it can be desired to do this questionnaire with movies of the intended light feedback or in person.

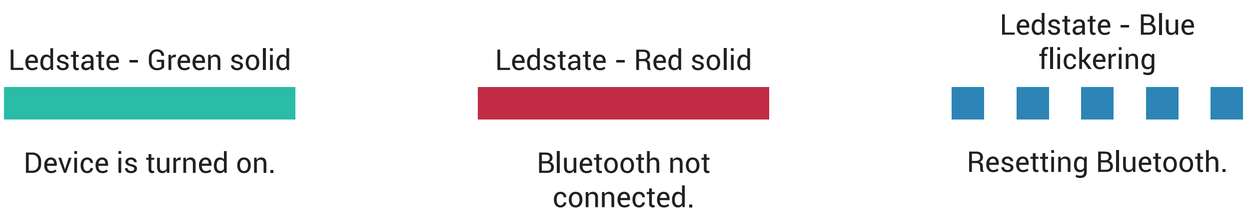


Figure X.7: Buttonstates

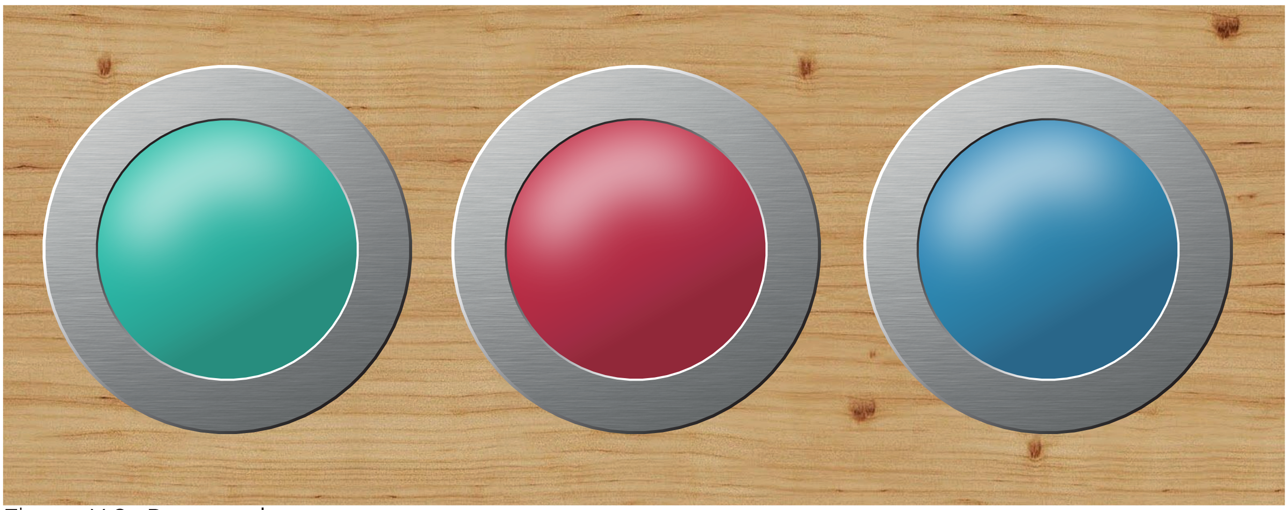


Figure X.8: Button colors

Questions	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	Participant 7
What is your age?	48	25	22	21	23	25	53
Do you define yourself as a climber?	Yes	No	Yes	Yes	Yes	No	Yes
Interaction and meaning [push for three long seconds]	Reset bluetooth	On, Off	Reset bluetooth	Off	Off, Reset bluetooth	Reset bluetooth	Reset bluetooth
Interaction and meaning [push one single time]	On, Off	No meaning	On	On	On	On	On, Off
Interaction and meaning [push twice quickly after each other]	No meaning	Reset bluetooth	No meaning	Reset bluetooth	Off, Reset bluetooth	No meaning	No meaning
Meaning and feedback in light [On]	Light on	Light on	Light on	Light on	Light on	Light on	Light on
Meaning and feedback in light [Off]	Light off	Light off	Light off	Light off	Light off	Light off	Light off
Meaning and feedback in light [Bluetooth connected]	Light on	Light on	Slow blinking light	Fast blinking light	Light on	Fast blinking light	Slow blinking light
Meaning and feedback in light [Bluetooth not connected]	Slow blinking light	Slow blinking light	Fast blinking light	Slow blinking light	Fast blinking light, Slow blinking light	Slow blinking light	Fast blinking light
Meaning and feedback in light [Reset bluetooth/disconnect current device]	Fast blinking light	Fast blinking light	Slow blinking light	Slow blinking light	Fast blinking light, Slow blinking light	Light on	Fast blinking light
Meaning and feedback in red light [Red - Light on]	Bluetooth not connected	Off	Bluetooth not connected	On	Bluetooth not connected	No meaning	No meaning
Meaning and feedback in red light [Red - Fast blinking light]	No meaning	No meaning	Reset bluetooth/disconnect current device	No meaning	No meaning	Bluetooth not connected	Reset bluetooth/disconnect current device
Meaning and feedback in red light [Red - Slow blinking light]	No meaning	Bluetooth not connected	No meaning	No meaning	Bluetooth not connected, Reset bluetooth/disconnect current device, No meaning	Reset bluetooth/disconnect current device	No meaning
Meaning and feedback in red light [Light off]	Off	No meaning	Off	Off	No meaning	On, Off	Off
Meaning and feedback in blue light [Blue - Light on]	No meaning	Bluetooth connected	Bluetooth connected	No meaning	Bluetooth connected	On	Bluetooth connected
Meaning and feedback in blue light [Blue - Fast blinking light]	No meaning	Reset bluetooth/disconnect current device	No meaning	Bluetooth connected	Bluetooth not connected, Reset bluetooth/disconnect current device	Bluetooth connected	Bluetooth not connected
Meaning and feedback in blue light [Blue - Slow blinking light]	No meaning	Reset bluetooth/disconnect current device	Bluetooth connected	Bluetooth not connected	Bluetooth not connected, Reset bluetooth/disconnect current device, No meaning	Bluetooth not connected	No meaning
Meaning and feedback in green light [Green - Light on]	On	On	On	No meaning	On, Bluetooth connected	On	On
Meaning and feedback in green light [Green - Fast blinking light]	Reset bluetooth/disconnect current device	No meaning	No meaning	Reset bluetooth/disconnect current device	No meaning	Bluetooth connected	No meaning
Meaning and feedback in green light [Green - Slow blinking light]	No meaning	No meaning	On	No meaning	No meaning	No meaning	Bluetooth connected

Figure X.4: Results 1

Participant 8	Participant 9	Participant 10	Participant 11	Participant 12	Participant 13	Participant 14	Participant 15	Participant 16
23	21	26	20	24	24	25	23	25
No	Yes	No	No	Yes	No	No	No	No
On, Off	Reset bluetooth	Off	Off, Reset bluetooth	Off	Reset bluetooth	Off	Reset bluetooth	Off
No meaning	On	On	On	On	On, Off	On	On	On
Reset bluetooth	Off	Reset bluetooth	Off, Reset bluetooth	Reset bluetooth	No meaning	Reset bluetooth	No meaning	Reset bluetooth
Light on	Light on	Slow blinking light	Light on	Light on	Light on	Light on	Light on	Light on
Light off	Light off	Light off	Light off	Light off	Light off	Light off	Light off	Light off
Slow blinking light	Slow blinking light	Light on	Fast blinking light	Slow blinking light	Light on	Fast blinking light	Light on	Fast blinking light
Fast blinking light	Fast blinking light	Fast blinking light	Light off, Fast blinking light	Light on	Light off	Slow blinking light	Light off	Slow blinking light
Fast blinking light	Fast blinking light	Fast blinking light	Fast blinking light	Fast blinking light	Fast blinking light	Fast blinking light	Fast blinking light	Fast blinking light, Slow blinking light
On	On, Bluetooth not connected	Bluetooth not connected	Off	Bluetooth not connected	On	Bluetooth not connected	On, Bluetooth connected	Off
Bluetooth not connected	No meaning	Reset bluetooth/disconnect current device	Bluetooth not connected	Reset bluetooth/disconnect current device	Reset bluetooth/disconnect current device	No meaning	Reset bluetooth/disconnect current device	No meaning
No meaning	Bluetooth connected, No meaning	No meaning	No meaning	No meaning	No meaning	No meaning	Reset bluetooth/disconnect current device	No meaning
Off	Off, No meaning	Off	On	Off	Off	Off	Off, Bluetooth not connected	Off
No meaning	On, Bluetooth connected	Bluetooth connected	Bluetooth connected	Bluetooth connected	On	No meaning	On, Bluetooth connected	Reset bluetooth/disconnect current device
Reset bluetooth/disconnect current device	No meaning	No meaning	Bluetooth not connected, Reset bluetooth/disconnect current device	Reset bluetooth/disconnect current device	Reset bluetooth/disconnect current device	Bluetooth connected	Reset bluetooth/disconnect current device	Bluetooth connected
No meaning	No meaning	No meaning	No meaning	Bluetooth not connected	No meaning	Reset bluetooth/disconnect current device	Reset bluetooth/disconnect current device	Bluetooth not connected
No meaning	On, Reset bluetooth/disconnect current device	On	On	On	On	On	On, Bluetooth connected	On
No meaning	No meaning	No meaning	No meaning	No meaning	Reset bluetooth/disconnect current device	Bluetooth connected	Reset bluetooth/disconnect current device	No meaning
Bluetooth connected	No meaning	No meaning	No meaning	Reset bluetooth/disconnect current device	No meaning	No meaning	Reset bluetooth/disconnect current device	No meaning

Figure X.5: Results 2

Participant 17	Participant 18	Participant 19	Participant 20
29	22	23	22
No	No	No	No
On, Off	Reset bluetooth	On	Off
No meaning	On, Off	Off	On
Reset bluetooth	Reset bluetooth	Reset bluetooth	Reset bluetooth
Slow blinking light	Light on	Light on	Light on
Light off	Light off	Light off	Light off
Light on	Slow blinking light	Fast blinking light	Slow blinking light
Slow blinking light	Fast blinking light	Slow blinking light	Slow blinking light
Fast blinking light	Fast blinking light	Slow blinking light	Fast blinking light
Off	On	Bluetooth not connected	On
No meaning	Bluetooth not connected, Reset bluetooth/disconnect current device	Reset bluetooth/disconnect current device	No meaning
No meaning	No meaning	No meaning	No meaning
Off	Off	Off, No meaning	Off
Bluetooth connected	On	Bluetooth connected	Bluetooth connected
Reset bluetooth/disconnect current device	Reset bluetooth/disconnect current device	No meaning	Reset bluetooth/disconnect current device
Bluetooth not connected	No meaning	No meaning	No meaning
On	On	On	On
No meaning	Bluetooth not connected	No meaning	No meaning
On	Reset bluetooth/disconnect current device	No meaning	No meaning

Figure X.6: Results 3

Appendix Y

Final evaluation

In the final evaluation, the Meta-Grip is validated through semi-structured interviews with investors and user. There are multiple models that make up the prototype for the redesigned Meta-Grip.

Y.1 Structure and content

The finale user test will be done in an interview setup (Creusen, 2016). First, the Meta-Grip is introduced by explaining what the Meta-Grip is/does. After this, permission is asked for recording the interview so after the interview, a transcription can be made. After this, the interview starts. For different participants, the questions will be different. Below the structure of the interview is shown. First, the participants are asked to introduce themselves and how they relate to the user group.

There are four topics within the semi-structured interview: the Meta-Grip as a product on the market, the embodiment of the Meta-Grip, the application of the Meta-Grip and the measurements on the Meta-Grip. These are all (part of) the product service system the Meta-Grip operates in.

- Introduction of myself, the project and the Meta-Grip (5 min)
- Ask whether the participant agrees with the interview being recorded.
- If so, start with the interview. The interview will be structured with a demonstration and explanation of the Meta-Grip combined with a storyboard on how to use the Meta-Grip.
- Let the participants introduce themselves:
    - What is your name?
    - What is your age?
    - How many years climbing experience do you have?
    - How many years have you been working as a physiotherapist?
    - How many years are you owner of a climbing gym?
    - What is your level of climbing?
    - Do you hangboard and how often?
    - Do you mostly prefer lead or boulder?
    - What percentage of patients have hand or finger injuries related to rock climbing?
    - Do you have or had any hand or finger injuries?
- Would you be interested in using/buying the Meta-Grip and why?
- What price range should the Meta-Grip be in to be attractive to buy?
- Would you use the Meta-Grip for both assessment/measurements as for training/rehabilitation?
- How often would you use the Meta-Grip?
- Would you be interested in a training plan or only be interested in specific exercises or only in results and why?
- If you would have 200 euros to improve a part of the Meta-Grip, on what will you spend it?
- What is your opinion about the holds used in the Meta-Grip?

- What is your opinion about the looks of the Meta-Grip?
- What is your opinion of the materials used in the Meta-Grip?
- Would you use the application to bundle all the trainings you do?
- What is your opinion about phones in the climbing hall?

Y.2 Models

There are multiple models used for this interview to support certain explanation and to give the interviewee a good impression of the Meta-Grip.

Y.2.1 Pretty model

The pretty model is the model which resembles the looks of the redesigned Meta-Grip the closest. This model is made by milling the shape of the Meta-Grip out of a foam board (figure Y.1). After this, a lot of sanding was done to get the shape smoothed out completely. Next, a coating of wood glue mixed with water was applied to be able to paint on the foam without the foam absorbing the paint. Then, the wood paint was applied. This paint has a woody color, trying to image alder wood (figure Y.2). When this paint had completely dried, the turquoise paint is mixed with a fine sand (grain size between zero and one millimeter) and applied to the polyurethane part of the model. When all paint had dried, the 3D printed button was put in the therefore intended place. Lastly, a LED was placed within this button to be able to show light feedback (figure Y.3) in the model.

Y.2.2 Software proof of concept

The software proof of concept is made by a test setup of the load cell (figure Y.4). This can be controlled via a serial monitor from the phone of the researchers via the Bluetooth connection. The test setup can weigh up to 40 kg maximum because of the soft wood used in the test setup.

Y.2.3 Application

There are eight example screens


Figure Y.1: Meta-Grip in foam


Figure Y.2: Model Meta-Grip


Figure Y.3: Model Meta-Grip with button

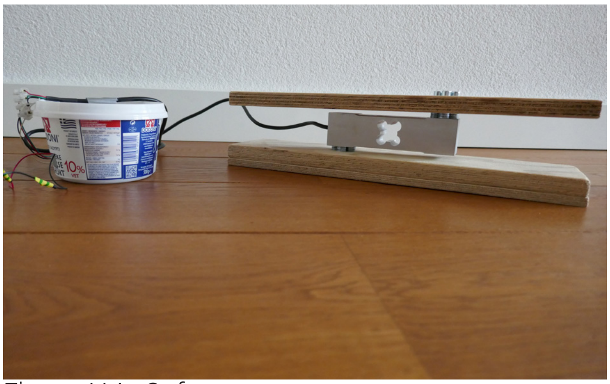


Figure Y.4: Software test setup

(appendix M: The application on page 142) of the application that are shown via the mobile phone of the researcher. These give a good indication of what the application would look like.

Y.2.4 Storyboard

The storyboard used during the interviews was made personal for the climbing gym owner (figure Y.5), physiotherapist (figure Y.6) and climber (figure Y.7 on page 199).

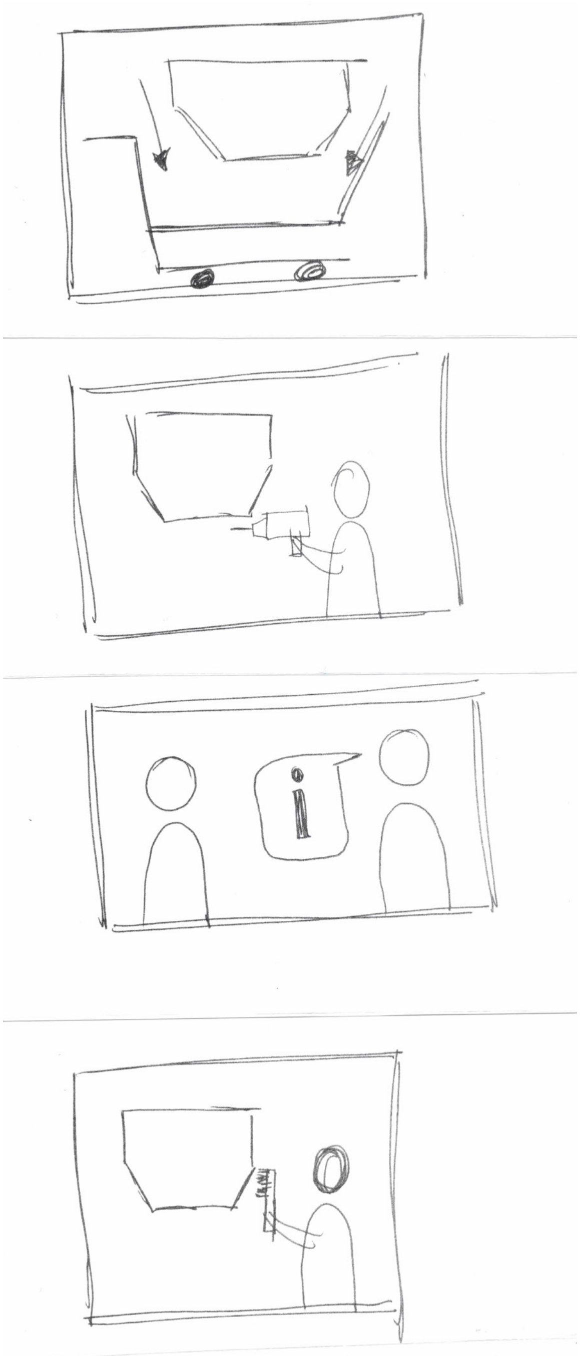


Figure Y.5: Storyboard climbing gym owner

Figure Y.6: Storyboard physiotherapist

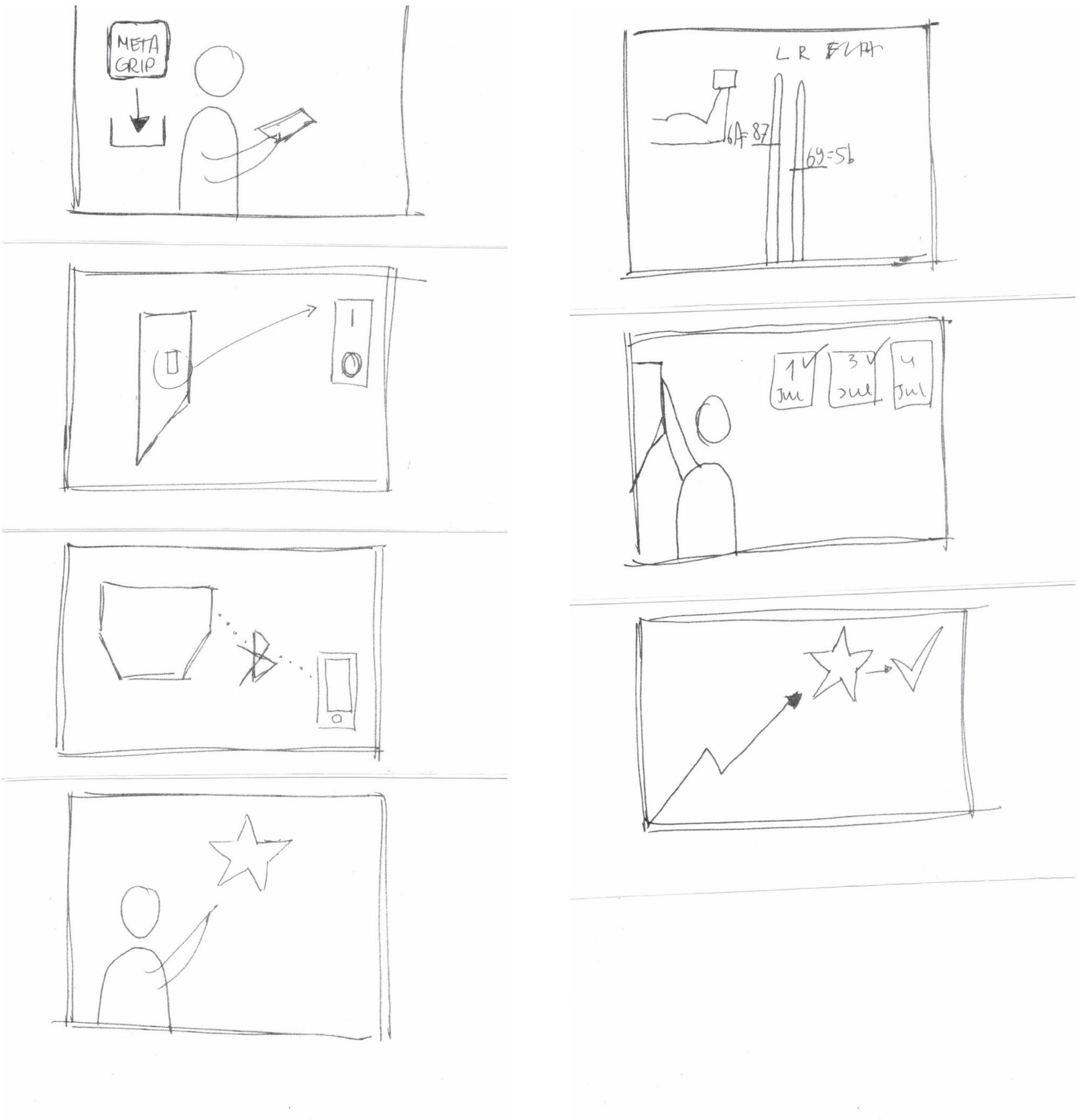


Figure Y.7: Storyboard climber

Y.3 Results

The interviews all lasted about 30 minutes and gave a lot of helpful insights and confirmation of the redesigned Meta-Grip. The interviews are discussed per user group.

Y.3.1 Climbing gym owner

Sander ter Steege, owner of the climbing gym "Delft's Bleau" for eight years already, was asked to participate in the interview. Sander has participated before in an interview for the Meta-Grip so he is aware of what the Meta-Grip should do roughly. The most important insights are listed below:

- Climbing gyms mostly make the holes using a template which means that the holes will probably not have an exact distance of 200 mm horizontal and vertical. It is important that the Meta-Grip is somewhat flexible to be able to fit on all climbing gyms walls with the inaccuracy in the M10 holes.
- The costs of the Meta-Grip are quite high but it has a lot of functionalities and is an addition to the climbing

gym. Therefore, the costs of the Meta-Grip are acceptable.

- The Meta-Grip can help show progress, even if it is smaller than the progress that can be made visible with the current tools in the climbing gym.
- Inserts can make the Meta-Grip even more versatile by being able to have multiple depths of crimps with just one milled edge.
- The Meta-Grip should have a possibility for both battery and a wall outlet connection. In climbing gyms a device like the Meta-Grip will be used quite often and a constant power connection is desired.

Y.3.2 Physiotherapists

Jelle Schouten, physiotherapists and climber who treats climbers with mostly hand and finger injuries for approximately 20 hours every week (30 people), and Erwin Smits, physiotherapists and climber with a focus on knees, hips and shoulders, are interviewed over the Meta-Grip. Jelle Schouten has tested the previous model of the Meta-Grip as well (Jans, 2019). The most important insights are listed below:

- The Meta-Grip can be interesting for treatments because the current power of an injured climber is known and an assessment can be made at which levels the climber can start climbing again for example.
- The practicalities are quite difficult still because when a hand or finger injury occurs, a climber has to train that almost daily or two days on and one day off. If the Meta-Grip is only in the climbing gym, the climber has to go to the climbing gym almost every day without being able to climb.
- The Meta-Grip should be reliable with validity and diagnostics. The validity is difficult because the position of the hand and fingers during a measurement is never exactly the same.
- The Meta-Grip is a very climbing specific measurement device which is very specific.
- The quality of the treatments can improve with the Meta-Grip by regurarly evaluating the performance of climbers.
- Climbers and physiotherapists that treat climbers are currently a small group, but Jelle experiences a growth in this and is confident this will persevere.
- Two finger pockets are less commonly used, three finger pockets are more general.
- A large database will improve the service of the Meta-Grip drastically.
- The measurements of the Meta-Grip can motivate climbers during the revalidation but this should be done properly, keeping the mindset of the climber positive.
- Using the Meta-Grip preventive could make it possible to predict whether a person is having more risk for an injury.
- Standardized protocols are good, but there should also be a possibility to make your own protocol.

Y.3.3 Climber

Tim Reuser is interviewed over the Meta-Grip. Tim Reuser has been a climber for 13 years and has a boulder redpoint level 31. He is a climber with the Dutch National Climbing team.

- The Meta-Grip is quite big in size and there are many holds on the Meta-Grip, however, the combination of the two materials is perfect for maximum measurement and skin friendliness for training.
- There are a lot of similar holds, to vary some more, the angle of the horizontal surface could be changed.
- The Meta-Grip is a good device to measure progress but sufficient time between measurements is needed, since progress will be slow
- The application can improve hangboarding and motivate a climber to go hangboarding.
- It would be interesting to be able to

- perform exercises from other people who are using the application as well.
- To first use of the Meta-Grip is maybe not that appealing, but once using the Meta-Grip it can become addicting.
- Ease of use is one of the most important things of the Meta-Grip.
- The Meta-Grip should be easily used with personal and already existing training plans.
- The possibility to train at a lower weight than bodyweight is an addition to the Meta-Grip.

Y.3.4 Trainer

Lucas Hijdra is interviewed over the Meta-Grip as a trainer. He has been a trainer for six years and is now head trainer of the selection team of the Ayers Rookies. He himself is climbing for 10 years and has a bouldering redpoint level of 25.

- For trainers it can be interesting to see the data of climbers (if climbers can share their data with trainers or physiotherapists).
- The Meta-Grip is ideal for training on fingerboards because there is a constant supervision.
- Using the application as a trainer with being able to supervise trainees and their data can be very helpful.

Y.4 Conclusion

In general, all user groups and interviewees were positive about the Meta-Grip with a few remarks. Most of the remarks will be a recommendation for the Meta-Grip. An overview is given below:

- Attachment of the Meta-Grip to the climbing wall should accommodate a little variation in distance between bolts since most climbing walls are handmade and have small deficiencies.
- Inserts can make the Meta-Grip even more versatile by being able to have multiple depths of crimps with just one milled edge.
- The Meta-Grip should have a possibility for both battery and a wall outlet connection. In climbing gyms a device like the Meta-Grip will be used quite often and a constant power connection is desired.
- The Meta-Grip should be reliable with validity and diagnostics. The validity is difficult because the position of hands and fingers during a measurement is never exactly the same.
- Two finger pockets are less commonly used, three finger pockets are more general.
- A large database will improve the Meta-Grip drastically.
- The measurements of the Meta-Grip can motivate climbers during the revalidation but this should be done properly, keeping the mindset of the climber positive.
- The Meta-Grip is quite big in size and there are many holds on the Meta-Grip, however, the combination of the two materials is perfect for maximum measurement and skin friendly.
- There are a lot of similar holds, to vary some more, the angle of the horizontal surface could be changed.
- It would be interesting to be able to perform exercises from other people who are using the application as well.
- For trainers it can be interested to see the data of climbers if climbers can share their data with trainers of physiotherapists.

Appendix Z

Requirements and wishes

In this chapter, the wishes and requirements are checked with the redesigned Meta-Grip. The wishes and requirements are based on the process tree.

Z.1 Process tree

The process tree (figure Z.1) consists of the phases originate, distribute and use (Roozenburg & Eekels, 2003). In the phase originate, the current product and competitors are evaluated after which development starts. After the necessary steps, it is ready to be distributed. It needs to be promoted among climbers and potential buyers. After it is bought, the use phase will be entirely without support or supervision from Meta-Grip, but done by climbers and buyers. Transport and installing is done by buyers after which climbers can make use of it. In the use phase the climber will be guided entirely by the app (except the brushing) to perform measurements and use the Meta-Grip for training. This part can be found as well in the process tree as in the software flow.

Z.2 Wishes and requirements

In the following pages, the wishes and requirements are shown and disucssed.

- **Originate**
  - Current product
    - Evaluate current product
    - Evaluate existing products
  - Develop product
    - Design product
    - Build prototype
    - Test prototype
  - Find suppliers
  - Make ready for production
  - Produce
  - Check quality
  - Packaging
  - Store
- **Distribute**
  - Set price
  - Advertise
  - Sell
  - Advice
  - Distribute
- **Use**
  - Transport and install
  - First use
    - Measure offset
    - Make user account
    - Insert initial information
    - Perform test measurement
  - First measurement
    - Zero measurement
  - Results
    - Interprete results
    - Change trainingsplan accordingly
  - Repeat measurement
    - Measure offset
    - Perform measurement
    - Interpret results
    - Change trainingsplan accordingly
  - Cleaning
    - Brushing

Figure Z.1: Process tree

Originate	Develop product	The product has to withstand a static load of 200 kg.	Requirement	Yes (1)
		The product has to be able to withstand a dynamically applied force from the user.	Requirement	Yes (1)
		The holds should altogether be for every user, fitting the same amount of phalanges.	Requirement	Yes
		The product has to have at least a sample rate of 80 Hz.	Requirement	Yes
		The Meta-Grip has to have a width of at least 501 mm.	Requirement	Yes
		Preferably, the sample rate of the product will be a 100 Hz.	Wish	No (2)
		The product should fit within a climbing gym aesthetically.	Wish	Yes
		The product should feel similar to materials used for climbing holds.	Wish	Yes
		The material used for the hold must have the perfect amount of friction; being able to measure force instead of the friction and not damaging the skin too much.	Wish	Yes
		The product should ideally not have any corners sharper than 90 degrees.	Wish	No (3)
	Produce	The product will ideally be made in batches due to the unfamiliarity with the product.	Wish	Yes
		The initial batch size should be 20 units.	Requirement	Yes
		The manufacturing costs should be reduced drastically relative to the current manufacturing costs.	Wish	Yes
Distribute	Set price	The manufacturing costs should not exceed 800 euros.	Requirement	Yes
		The retail price of the product should be aimed at 1200 euros.	Wish	Yes
	Advertise	The product should target climbing gyms, physiotherapists and trainers as the investor group.	Requirement	Yes
		The product should target individual climbers as the user group.	Requirement	Yes
Use	Trans-port and install	Installation has to be possible with written instructions without guidance of an expert.	Requirement	Yes (4)
		Installations have to be possible with the tools available in the climbing gym.	Requirement	Yes
		The product has to be attached using common techniques used in climbing gyms to attach holds.	Requirement	Yes
		The product has to be attached using common techniques used in climbing gyms to attach holds.	Requirement	Yes
		Installation should be quick and easy.	Requirement	Yes (5)
	First use	The user has to be able to use the Meta-Grip at all times unsupervised.	Requirement	Yes

		The looks of the product should make it clear to the user what it is used for.	Requirement	Yes
		The product has to measure hand and finger strength on at least two types of holds: a sloper and a crimp .	Requirement	Yes
		Ideally, every hold can be used to measure.	Wish	Yes
		The product should feature more holds and hold sizes than required for measurement only.	Wish	Yes
		The user has to experience no unpleasant feeling from using the holds.	Requirement	Yes
		It should be easy to transition between different holds.	Wish	Yes
		The digital interface should be easy to understand and evoke interaction.	Wish	Yes (6)
		Multiple holds have to be available at the same time for easy switching between holds within a training or measurement.	Requirement	Yes
	Results	There should be a possibility to have more in-depth feedback on max-finger strength, explosiveness, stamina and power endurance.	Wish	No (7)
		Data transfer systems should be easier to use and much cheaper than in the current Meta-Grip.	Wish	Yes
		The feedback has to include a way on how to implement the results in a training.	Requirement	Yes
		In the app, users have to be able to compare results over time and different hands.	Requirement	Yes
		Unedited results have to be available if the user wants to review them.	Wish	No (7)
		The app should be sufficient in providing instructions on how to use the product.	Requirement	Yes
		The feedback has to be translated to 'climbing terms'.	Requirement	Yes
		It should be easy to transition between different measurements.	Requirement	Yes
		It should be easy to transition between different users.	Requirement	Yes (8)
	Repeat measu-rements	The product has to perform with extensive use of chalk and dust	Requirement	Yes
		The product has to be used for at least ten years.	Requirement	Yes (9)
		The product has to be fool proof.	Requirement	Yes
		The product has to be used not only for measurements, but also for a training.	Requirement	Yes
	Cleaning	The product should be able to be cleaned using the common climbing brush used to clean holds as well.	Requirement	Yes

1. The load cell is able to withstand a load of 200 kg and expected is that the Meta-Grip is able to withstand a dynamically applied load. However, this has not been simulated in Solidworks with a model or tested with a model in a test setup. This should be done before a definite answer can be given if the Meta-Grip is able to withstand a load of 200 kg and a dynamically applied load.
2. The current amplifier, HX711, is not able to have a sample rate higher than 80 Hz. However, the Arduino is compatible up to a sample rate of 10.000 Hz which is more than enough for the Meta-Grip.
3. There are corners sharper than 90 degrees in the Meta-Grip. However, the corners where the user interacts with are not sharper than 90 degrees.
4. Installation is probably possible with good written instructions and thus without guidance of an expert, but this has not been verified yet. To be able to completely satisfy this requirement, this should be tested with users.
5. The installation can be done with only two M10 bolts which is expected to be quick and easy. However, this is not tested and to be sure installation is quick and easy, this should be tested with the user.
6. There is an example of how the digital interface will look like. When the digital interface is designed in more detail, it should be tested with the user to make sure it is easy to understand and evoke interaction.
7. Currently, the application is made as such that there is no possibility to more detailed feedback or raw data. This should be implemented in the final application to make the application for all users.
8. Transition between different users is quite simple by disconnecting the Bluetooth from user one and connecting the Bluetooth of user two. This however can cause some confusion since every user needs their own device.
9. The lifespan of the product should at least be 10 years, however, this cannot be tested and only estimated.

Appendix AA

Accuracy test of the load cell

For the load cell, it is important that the accuracy is tested. For the measurements with the Meta-Grip, it is important that every measurement has the same accuracy. The level of accuracy is less important than the consistency in the measurements.

AA.1 Research question

1. What is the accuracy of the load cell?

AA.2 Hypothesis

It is expected that the load cell measures accurate and consistent enough for this purpose.

AA.3 Method

AA.3.1 Stimuli

There are five objects which will be weighed on a scale. The weight ranges between 0,025 gram and 2,30 kg. Furthermore, the test setup of the load cell is used (figure AA.1).

AA.3.2 Apparatus

A phone is needed to see the results of a measurement.

AA.3.3 Procedure

Three measurements with the same object will be done and this raw data will be transferred to an excel sheet for further analysis. This will be repeated with every object.

AA.3.4 Measures

The research question will be answered by analyzing the result of a measurement.

AA.4 Results

Objects	Weight	Measured weight with accuracy
Object 1	0,025 kg	0,025 kg ± 0,004 kg
Object 2	0,415 kg	0,420 kg ± 0,006 kg
Object 3	1,248 kg	1,266 kg ± 0,121 kg
Object 4	2,369 kg	2,412 kg ± 0,018 kg
Object 5	2,232 kg	2,273 kg ± 0,007 kg

AA.5 Conclusion

Besides object 3, the deviation does not exceed the 0,018 kg, which is pretty consistant and accurate considering the weights applied to the Meta-Grip.

AA.6 Discussion

The test setup is not a good representation of how the initial setup with the Meta-Grip will be. To better evaluate the accuracy, a test should also be done when the initial setup with the Meta-Grip is made. Furthermore, the weight applied will likely be 50kg or higher (body weight) and in this test, weights

of less then 2.5 kg were used. A more
representative test should be carried out.

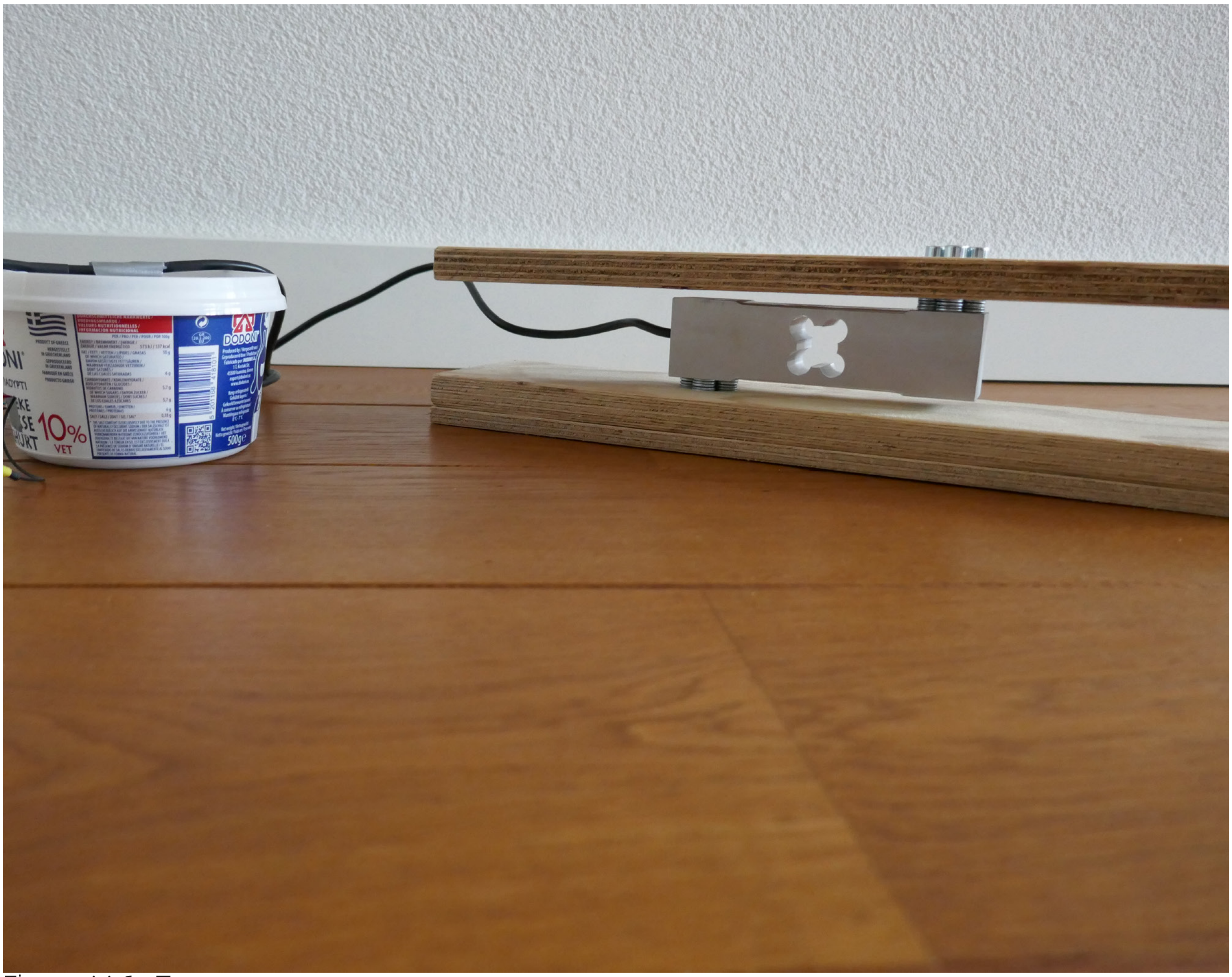


Figure AA.1: Test setup

Appendix AB

Climbing gyms

This chapter will explain how attachment of holds is done in a normal climbing gym. This is important for the attachment of the Meta-Grip.

Climbing walls are typically made quite similar across gyms nationally and internationally. The gyms normally have 18-millimeter plywood in which holes for holds are made. These holes are placed in a diamond pattern on the wood with a distance of 200 millimeter both horizontally and vertically. At the back of the plywood sheet, weft nuts are added to give the holes a screw thread. Most climbing holds are attached using M10 bolts in the holes in the plywood (figure AB.1).

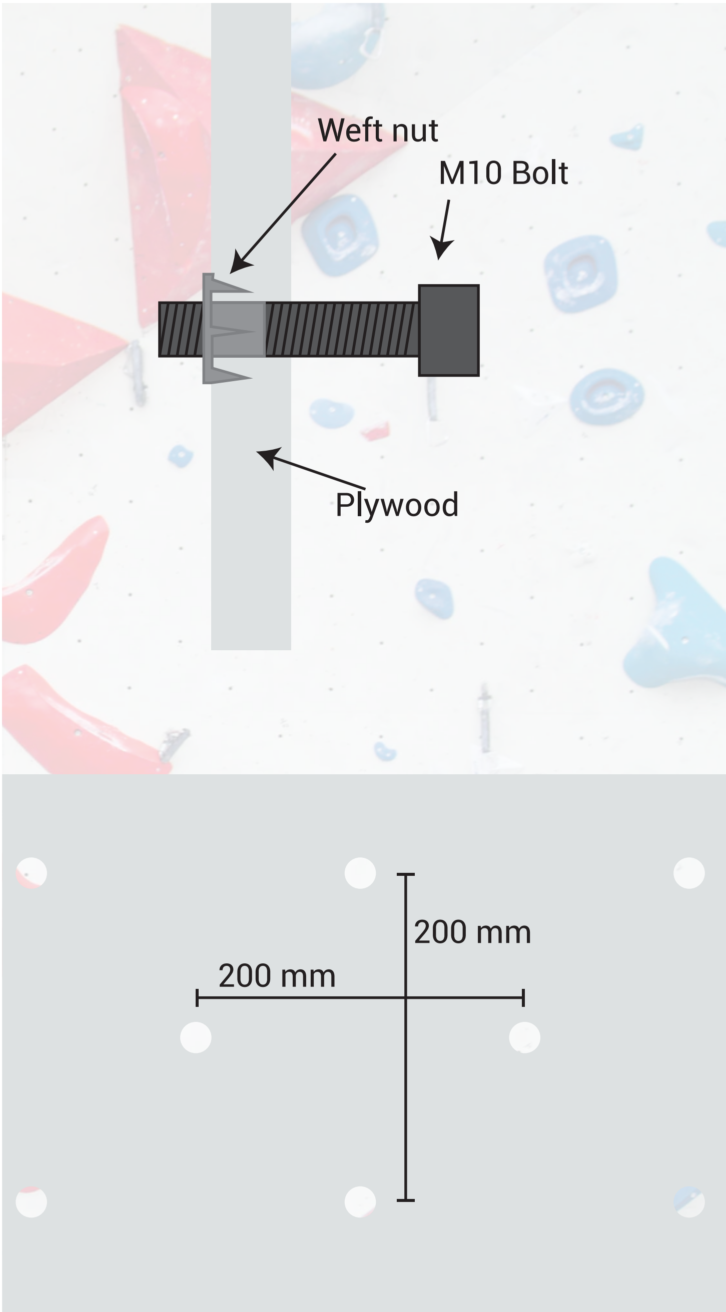


Figure AB.1: Climbing wall attachment

Methods

In this appendix, the methods and experts used in this project will be briefly discussed. Specific methods will be discussed when used in the process.

For this graduation project multiple methods will be used to conduct research, get useful results and make choices. The structure in the project comes from the model of Pahl and Beitz (Roozenburg & Eekels, 2003)(figure AC.1). This model also corresponds with my planning. The model they made, the consensus model, has four phases: problem analysis, conceptual design, embodiment design and detail design. Where problem analysis is the analysis in the planning, conceptual design is the ideation, embodiment design is conceptualization and detail design is the final user test and the evaluation.

Within each step, the basic design cycle (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2013) will be used multiple times and for different smaller parts in the product. The basic design cycle (figure AC.2 on page 210) consists of synthesizing, simulating, evaluating, deciding and iterating. These steps will be made within each phase and for multiple smaller parts in the process.

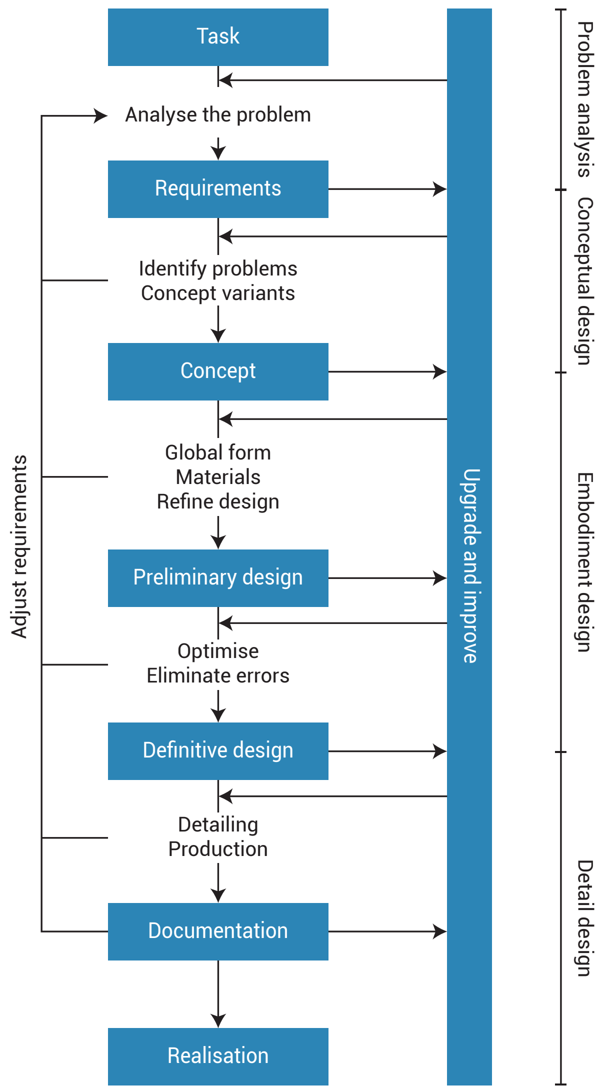


Figure AC.1: Pahl en Bietz model

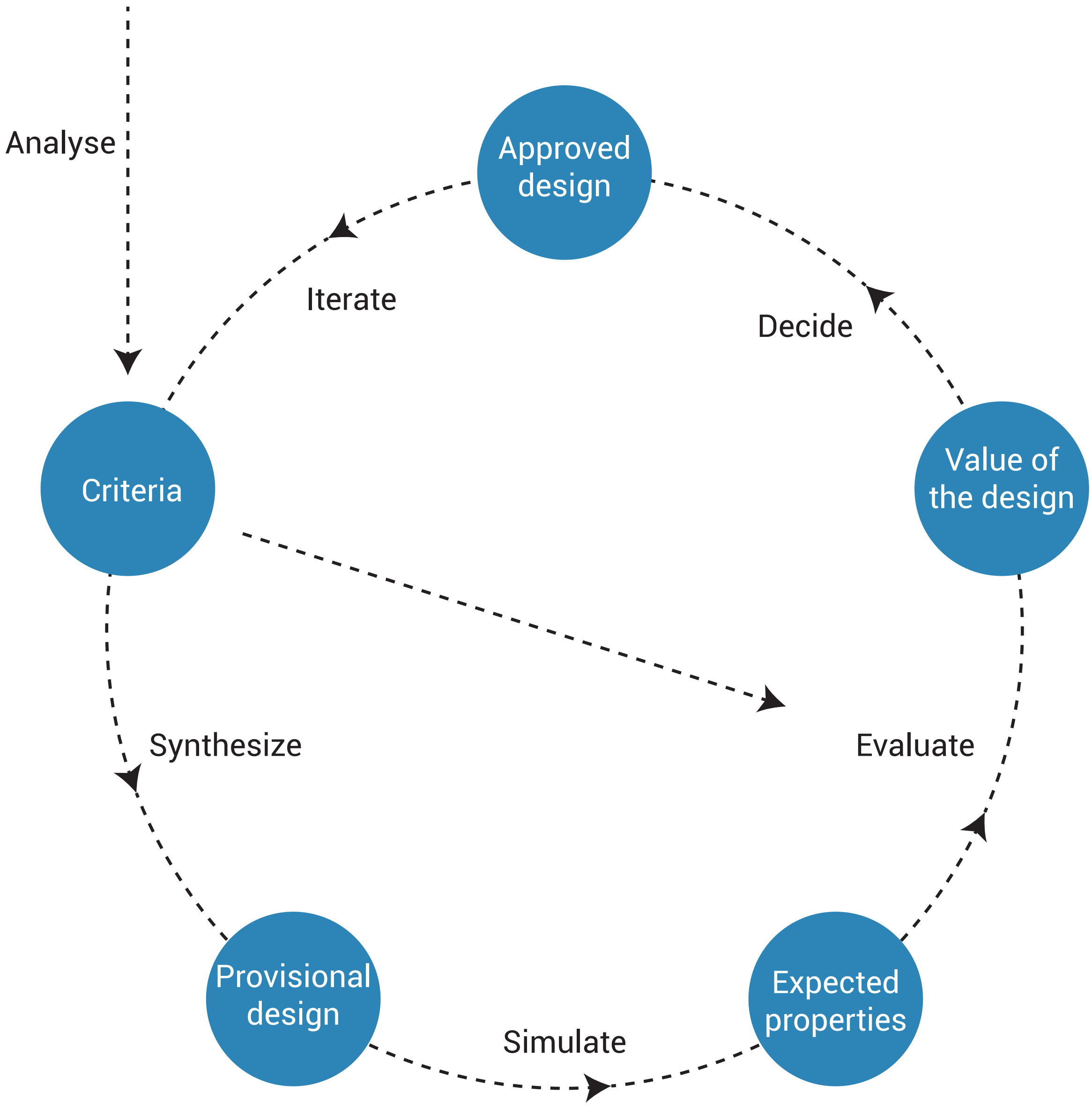


Figure AC.2: Basic design cycle

AC.1 Experts

For this project, multiple experts were consulted on certain aspects. They will be introduced in the following paragraphs.

AC.1.1 Nikki van Bergen

Nikki van Bergen has been a climber in the Dutch national team since 2007 in the youth team. She has achieved to become eight time Dutch champion lead climbing and she has twice been Dutch champion bouldering (Schijf, 2019). In 2019 Nikki decided to stop as a competition climber. Nikki studied Human Movement sciences at the Vrije Universiteit in Amsterdam where she as well did here master's degree and is now a PhD candidate. Nikki has worked a lot on monitoring climbing movements and made the first model of the Meta-Grip together with a team of researchers. Now, Nikki is working as a trainer and climbing coach as well as a route setter besides researching more into climbing and human movement.

AC.1.2 Jelle Schouten

Jelle Schouten graduated as a physiotherapist in 2015 from the Hogeschool Leiden (de Praktijk, sd). He started working as a physiotherapists and has grown an expertise for climbing related injuries as he himself is also a climber.

AC.1.3 Frank Bogerman

Frank Bogerman is the owner of Axis Round Edges, a climbing hold producer. He started with making all the holds himself and eventually branching out and making the holds in a factory. He has experimented a lot with the proper materials and proportions for climbing holds.

AC.1.4 Robert Hogenelst

Robert Hogenelst has been working with wood for a long time already. He started in the furniture factory of his father where he was responsible for the interior design in expensive yachts. Since 2012 he has his own company; Hogenelst Interieurprojecten + Consultancy where he is realizing luxurious interiors for among others the Royal Household Service (Dienst Koninklijk Huis) and the Government buildings Agency (Rijksgebouwendienst) (Over Hogenelst, sd).

Appendix AD

Software

AD.1 Load cell calibration

Code from instructables.com

```
/*
 Setup your scale and start the sketch WITHOUT a weight on the scale
 Once readings are displayed place the weight on the scale
 Press +/- or a/z to adjust the calibration_factor until the output readings
match the known weight
 Arduino pin 6 -> HX711 CLK
 Arduino pin 5 -> HX711 DOUT
 Arduino pin 5V -> HX711 VCC
 Arduino pin GND -> HX711 GND
*/

#include "HX711.h"

HX711 scale(6, 5);

float calibration_factor = -21250; // this calibration factor is adjusted
according to my load cell
float units;
float ounces;

void setup() {
  Serial.begin(9600);
  Serial.println("HX711 calibration sketch");
  Serial.println("Remove all weight from scale");
  Serial.println("After readings begin, place known weight on scale");
  Serial.println("Press + or a to increase calibration factor");
  Serial.println("Press - or z to decrease calibration factor");

  scale.set_scale();
  scale.tare();  //Reset the scale to 0

  long zero_factor = scale.read_average(); //Get a baseline reading
  Serial.print("Zero factor: "); //This can be used to remove the need to tare
the scale. Useful in permanent scale projects.
  Serial.println(zero_factor);
}

void loop() {

  scale.set_scale(calibration_factor); //Adjust to this calibration factor

  Serial.print("Reading: ");
  units = scale.get_units(), 10;
  if (units < -50)
  {
    units = 0.00;
  }
  ounces = units * 0.035274;
```

```
  Serial.print(units);
  Serial.print(" grams");
  Serial.print(" calibration_factor: ");
  Serial.print(calibration_factor);
  Serial.println();

  if(Serial.available())
  {
    char temp = Serial.read();
    if(temp == '+' || temp == 'a')
      calibration_factor += 1;
    else if(temp == '-' || temp == 'z')
      calibration_factor -= 1;
  }
}
```

AD.2 LED button software

```
const int button1 = 2;
const int button2 =  3;
const int button3 =  4;


int State1 = 0;
int State2 = 0;
int State3 = 0;

int red_light_pin = 11;
int green_light_pin = 10;
int blue_light_pin = 9;

void setup() {
  pinMode(red_light_pin, OUTPUT);
  pinMode(green_light_pin, OUTPUT);
  pinMode(blue_light_pin, OUTPUT);
  Serial.begin(9600);
  pinMode(button1, INPUT);
  pinMode(button2, INPUT);
  pinMode(button3, INPUT);
}

void loop() {

  State1 = digitalRead(button1);
  State2 = digitalRead(button2);
    State3 = digitalRead(button3);

  if (State1 == HIGH) {
    analogWrite(red_light_pin, 0);
    analogWrite(green_light_pin, 255);
    analogWrite(blue_light_pin, 0);
    Serial.println(1);
  } else {
    // turn LED off:
    analogWrite(red_light_pin, 0);
    analogWrite(green_light_pin, 0);
    analogWrite(blue_light_pin, 0);
  }
  if (State2 == HIGH) {
    analogWrite(red_light_pin, 255);
    analogWrite(green_light_pin, 0);
    analogWrite(blue_light_pin, 0);

   Serial.println(2);
  } else {
    // turn LED off:
```

```
    analogWrite(red_light_pin, 0);
    analogWrite(green_light_pin, 0);
    analogWrite(blue_light_pin, 0);
  }
  if (State3 == HIGH) {
    Serial.println(3);
    flickering(10, 500);
    flickering(5, 100);

  } else {
    // turn LED off:
    analogWrite(red_light_pin, 0);
    analogWrite(green_light_pin, 0);
    analogWrite(blue_light_pin, 0);
  }

}

void flickering (int repeats, int time) {
  for (int i = 0; i < repeats; i++) {
    analogWrite(red_light_pin, 0);
    analogWrite(green_light_pin, 0);
    analogWrite(blue_light_pin, 255);
    delay(time);
    analogWrite(red_light_pin, 0);
    analogWrite(green_light_pin, 0);
    analogWrite(blue_light_pin, 0);
    delay(time);
  }
}
```

AD.3 Load cell software

```
#include "HX711.h"
#include "pitches.h"
#include <SoftwareSerial.h>

#define DT 6
#define SLK 5
HX711 scale (DT, SLK);

SoftwareSerial MyBlue(10, 11); //RX | TX

String inputString = "";

float calibration_factor = -21250; //Calibration factor for the load cell

unsigned long sampleTimer = 0;
unsigned long sampleInterval = 100; //100 ms = 10Hz rate = sample rate of the
load cell

const int ledPin = 13;
int ledState = LOW;

int melodyInbetween [] = {
  NOTE_C4, NOTE_E5
};
int noteDurations1 [] = {
  2, 1
};
int melody [] = {
  NOTE_C4, NOTE_C4, NOTE_C4, NOTE_E5
};
int noteDurations [] = {
  2, 2, 2, 1
};
int buzzer = 8;

void setup() {
  Serial.begin(9600);
  pinMode(13, OUTPUT);
  MyBlue.begin(9600);
  scale.set_scale();
  scale.tare();
  pinMode(ledPin, OUTPUT);
  digitalWrite(ledPin, ledState);

}

void loop() {
  if (MyBlue.available()) {
```

```
    while (MyBlue.available())
    // when there is a bluetooth connection, the following code can be
executed.
    {
      char inChar = (char)MyBlue.read();
      inputString += inChar;
    }

    if (inputString == "a") { //The user choses for a maximum finger strength
measurement

      ledState = !ledState;
      digitalWrite(ledPin, ledState); ;

      MyBlue.println("Prepare for maximum finger strength measurement") ;

      scale.tare(); // Start the load cell at zero

      startingSound(); // a countdown start for the user to know when to start

      measurement (3, 10000, 120000); //All measurements are specific, in this
case, a measurement is repeated 3 times where there is 10s of executing the
measurement and 120 seconds rest inbetween

      finish();
    }
    else if (inputString == "b") { //The user choses for a explosiveness
measurement

      ledState = !ledState;
      digitalWrite(ledPin, ledState); ;

      MyBlue.println("Prepare for explosiveness measurement") ;

      scale.tare();

      startingSound();

      measurement (5, 10000, 90000);

      finish();

    }
    else if (inputString == "c") { //The user choses for a endurance
measurement

      ledState = !ledState;
      digitalWrite(ledPin, ledState); ;
```

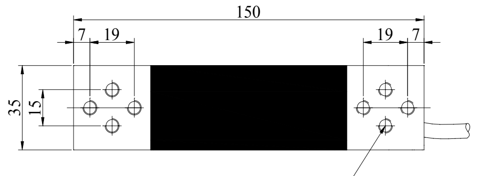
```
      MyBlue.println("Prepare for power endurance measurement") ;

      scale.tare();

      startingSound();

      measurement (24, 7000, 3000);

      finish();

    }
    else if (inputString == "d") { //The user choses for a stamina measurement

      ledState = !ledState;
      digitalWrite(ledPin, ledState); ;

      MyBlue.println("Prepare for stamina measurement") ;

      scale.tare();

      startingSound();

      measurement (1, 7000, 3000);

      finish();
    }
  }
  inputString = ""; // the input is put back at nothing when a loop for a
certain inputstring is finished. the user can choose a new measurement.
}

void startingSound() {
  for (int thisNote = 0; thisNote < 4; thisNote++) {
    int noteDuration = 1000 / noteDurations[thisNote];
    tone(buzzer, melody[thisNote], noteDuration); //here the melody is played
    int pauseBetweenNotes = noteDuration * 1.30; // the pause between tunes is
calculated
    delay(pauseBetweenNotes);
  }
}

void inbetweenSound() {
  for (int thisNote = 0; thisNote < 2; thisNote++) {
    int noteDuration = 1000 / noteDurations1[thisNote];
    tone(buzzer, melodyInbetween[thisNote], noteDuration);
    int pauseBetweenNotes = noteDuration * 1;
    delay(pauseBetweenNotes);
```

```
  }
}

void inbetweenFinish() {
  tone(buzzer, NOTE_C4, 500);
  MyBlue.println("rest");
}

void finish () {
  tone(buzzer, NOTE_C4, 1000);
  ledState = LOW;
  digitalWrite(ledPin, ledState); //Led is going back to its original state;
off
  MyBlue.println("Measurement finished");
}

void measurement (int repititions, int testTime, int restTime) { // a
measurement is dependent on three variables; reptitions, test time and rest
time.
  for (int x = 0; x < repititions; x++) {
    if (x > 0 ) {
      inbetweenSound();
    }
    for (unsigned long tstart = millis(); (millis() - tstart) < testTime;) {
      scale.set_scale(calibration_factor); //Adjust to this calibration factor
      unsigned long currMillis = millis();
      if (currMillis - sampleTimer >= sampleInterval) {
        sampleTimer = currMillis;
        MyBlue.print("Reading: ");
        MyBlue.print(scale.get_units(), 3); //3 is the decimals behind the
comma.
        MyBlue.print(" kg");
        MyBlue.println();
      }
    }
    if (x < repititions - 1) {
      inbetweenFinish();
      for (unsigned long tstart = millis(); (millis() - tstart) < restTime;) {
        unsigned long currMillis = millis();
        if (currMillis - sampleTimer >= sampleInterval) {
          sampleTimer = currMillis;
        }
      }
    }
  }
}
```

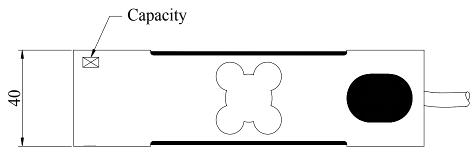
Load cell specifications

足立特殊测器(厦门)有限公司NTS INSTRUMENT(XIAMEN) CO.,LTD.
壕门电子科技(厦门)有限公司HOPE TECHNOLOGIC(XIAMEN) CO.,LTD.

NA2 (原NEA) 称重传感器 (Former NEA) LOAD CELL



俯视 (Top View)



主视 (Front View)

用途特点：计价秤、计数秤
Usage & Features：Pricing Scale，Counting Scale

技术参数Technical Parameter

额定负荷Rated Capacities	60，100，150，200，250，300，350，500（kg）
额定输出Rated Output	2.0 mV/V±5%
非线性Non-linearity	0.02 %F.S
滞后Hysteresis	0.02 %F.S
重复性Repeatability	0.02 %F.S
蠕变(20分钟)Creep(20min)	0.02 %F.S
输出温度影响Temperature Effect On Output	0.002 %F.S
零点温度影响Temperature Effect On Zero	0.003 %F.S
零点平衡Zero Balance	±0.0200 mV/V
输入阻抗Input Impedance	390±15 Ω；410±15 Ω
输出阻抗Output Impedance	350±5 Ω
绝缘阻抗Insulation Impedance	≥5000 MΩ
安全过载率Safe Overload	150 %F.S
极限过载率Ultimate Overload	200 %F.S
工作温度范围Operating Temperature Range	-20~60 ℃
推荐工作电压Recommended Excitation	5~12 VDC
最大工作电压Maximum Excitation	15 VDC
材质Construction	铝合金Aluminum Alloy；钢合金Steel Alloy
防护等级Protection Class	IP66 / IP67
电缆Cable	φ5×1.5 m
台面尺寸Platform Size	400×400 mm
接线方式Mode of Connection	红：电源+，黑：电源-，绿：信号+，白：信号- Red（EXC+）,Black（EXC-）,Green（SIG+）,White（SIG-）

地址:厦门市湖里区悦华东路恒盛大厦三楼(Address:3FL HENG SHENG BUILDING YUE HUA E. RD. HU-LI XIAMEN CHINA)
TEL:+86-592-5629881/882 FAX:+86-592-5629883 http://www.mavin.cn E-mail:mavin@mavin.cn

Appendix AF

Original project brief

DESIGN FOR our future

3975

TUDelft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Den Hengst

initials: N given name: Nienke

student number: 4440307

street & no.:

zipcode & city:

country:

phone:

email:

Your master programme (only select the options that apply to you):

IDE master(s): [x] IPD [ ] Dfl [ ] SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: [ ] Honours Programme Master

specialisation / annotation: [ ] Medisign

[ ] Tech. in Sustainable Design

[ ] Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Toon Huysmans dept. / section: AED

** mentor: Stefan van de Geer dept. / section: HCD

2nd mentor: John van der Kamp

organisation: Vrije Universiteit Amsterdam

city: Amsterdam country: The Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Toon Huysmans date 02.03.2020 signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 33 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

[X] YES all 1st year master courses passed

[ ] NO missing 1st year master courses are:

name date 17-3-2020 signature CB

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: [✓] APPROVED [ ] NOT APPROVED

Procedure: [✓] APPROVED [ ] NOT APPROVED

comments

name Monique von Morgen date 30-3-2020 signature MvM

Improving the Meta-Grip: redesigning for unsupervised use

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 02 - 03 - 2020 | 27 - 08 - 2020 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Climbing has recently grown to be a popular sport; in the Netherlands only there are currently already 32.000 climbers and it has recently been added to the Olympic Games (Sport Climbing, sd). Climbing can be done indoors on artificial holds or outdoors on natural rock. In every climbing discipline, hand and finger strength is essential for athletes. While climbing, hands and fingers are challenged in a variety of ways that differ significantly to general day-to-day activities. Indeed, in studies across climbers it is found that hand and finger injuries occurred more frequently than other injuries among climbers (Jones & Johnson, 2016). There are tools for climbers to train hand and finger strength such as hang-boards. However, without direct feedback it is difficult to be aware of the efficiency of the training.

Currently, a tool developed by the VU in Amsterdam is used to do research to broaden the knowledge about hand and finger strength among climbers. The 'Meta-Grip' has three hand positions specific for climbers: a sloper, a crimp and an empty space to which any hold that fits can be attached. Through a single load cell, the data is transformed with a bridge amplifier and an AD-converter to a computer with LabVIEW. Here, the magnitude of the force applied to the grip is shown over time. The MVC (Peak force), RFD (Time needed to obtain peak force), critical force (stamina) and power endurance (recovery ability) are calculated which are then interpreted by the researcher.

The Meta-Grip has the potential to improve training of climbers significantly. However, for that it must be able to be used regularly by climbers to train, to test their improvement (or decline) and it must be attractive to use. Currently, the Meta-Grip is fairly expensive (€ 2520,00) due to expensive manufacturing techniques and data transfer systems which makes it unattractive for users to buy ('Meta-grip': monitoring grip force to minimize hand injuries and improve climbing performance). Furthermore, the digital interface is difficult to understand (Jans, 2019). During a 10-week test with physiotherapist, it was found that the shape of the Meta-Grip is not ideal in terms of material, size and difficulty of the holds (Jans, 2019).

People in three sectors would benefit from a hand and finger strength measuring device; physiotherapists, climbing gyms and individual climbers. Depending on the cost, in-depth feedback and ease of use, the Meta-Grip will be used by one or more of these user groups. The Meta-Grip will ultimately be used unsupervised in climbing gyms by climbers.

The Meta-Grip will not be the only hand and finger strength measuring device on the market. There are devices like the Jamar (Jamar Hand Dynamometer, sd) and the E-cone (van Alebeek, Hoeksma, & van Merend, 2012) that can measure hand pressure distribution or grip strength, however these do not measure climbing specific strengths. A big competitor is the Lattice Training Digital Research Rung (Lattice training, sd) since it is specifically made for climbing. However, like the Meta-Grip, the results are difficult to interpret by anyone besides researchers.

The Meta-Grip will be improved with already found points of improvement in previous research and new points of improvements from user tests. The embodiment of the instrument can be improved in terms of manufacturing, form and materials. The feedback system can be made such that end-users can easily use the data on their own and without the need of a laptop connected with a wire. Important with interpreting the data is the ability to obtain direct feedback and to be able to compare both hands. Overall, there should be an effective cost reduction which can be achieved by the use of, for example, different manufacturing methods and sensors.

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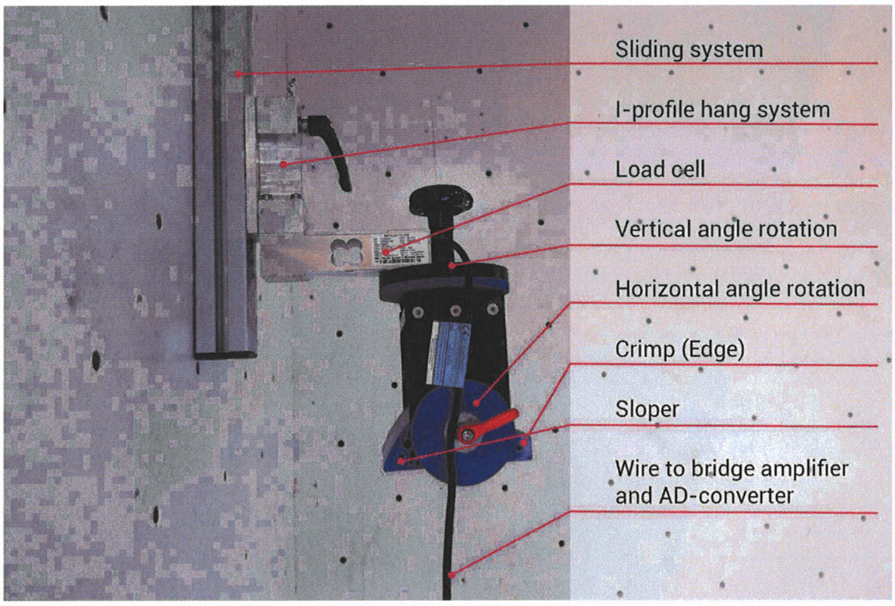


image / figure 1: The current Meta-Grip

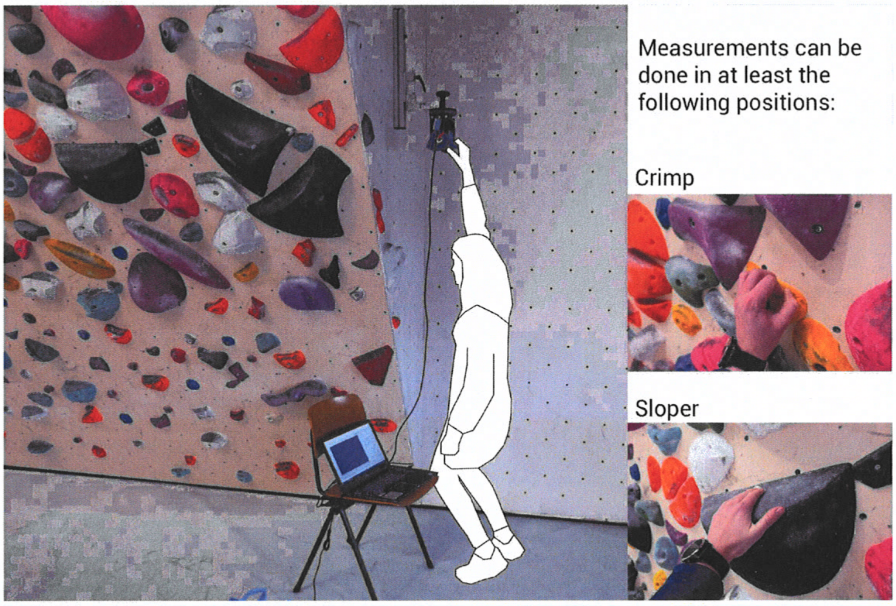


image / figure 2: The current test setup of the Meta-Grip

Initials & Name N Den Hengst Student number 4440307

Title of Project Improving the Meta-Grip: redesigning for unsupervised use

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The current Meta-Grip is a tool for researchers to observe and test climbers on finger and hand strength. This means that unsupervised use is currently not possible and interpreting the data is only done by trained researchers. The next iteration step for this product is to make a product which has a drastic cost reduction and can be used unsupervised – both steps reflect high priority improvements of the current Meta-Grip.

The ideal situation for the Meta-Grip will be a product-service system where both parts work seamless together. The user interacts with the embodiment and the feedback system. In order to make both working together, software needs to register user activities and transform this to feedback for the user. In the future, feedback to the user should be based on a database, but this is outside the scope of this project. The focus will be on the embodiment and the feedback system of the Meta-Grip, focusing on the user interaction with the system. For the embodiment and the feedback system to work together sensors and software are needed. Sensors and software will be dealt with in this project to the extent that it is functional and ideally able to connect all parts of the product-service system together; optimizing this, is outside the scope.

To improve the current Meta-Grip, changes need to be made in costs, feedback system and the embodiment:

- Cost reduction can be achieved by reducing the costs of the sensor, bridge amplifier and the AD-converter. These three can be replaced or eliminated by price friendlier options.
- To ensure unsupervised use, the feedback system needs to be improved and the use of a laptop needs to be replaced by either a fixed screen or a portable screen (mobile phone).
- The embodiment has been tested and there are some improvements that can be made regarding form, material and aesthetics. The current embodiment is made with 3D printing which enables large form variability, but limits the production capacity. Different manufacturing methods as well as the form and material need to be evaluated.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The Meta-Grip should be a tool to measure finger and hand strength that climbers are able to use unsupervised. The Meta-Grip will be redesigned regarding the embodiment, the feedback system and the software to make sure this is possible and a cost reduction should be realized.

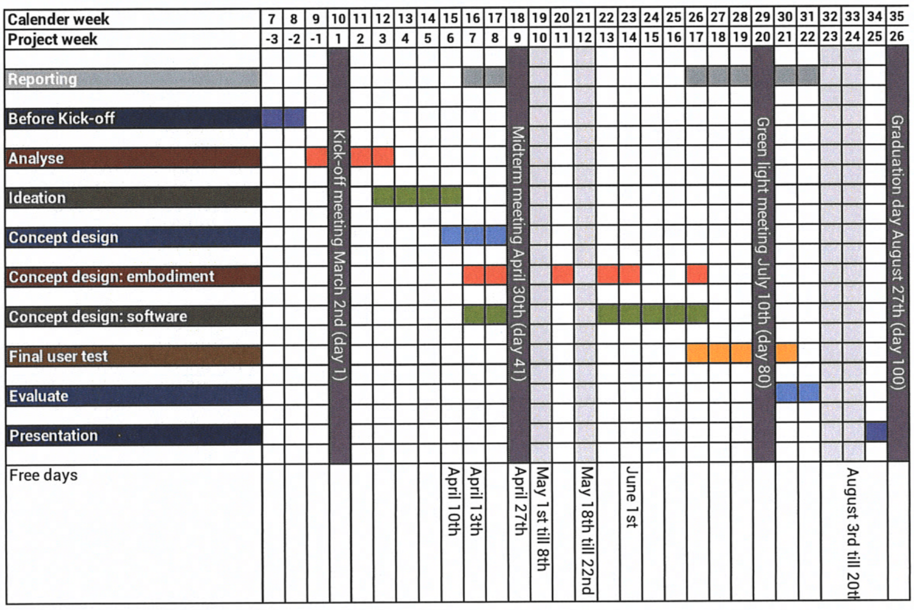
After this 100 days assignment, I want to deliver a system that can be used unsupervised, the users are able to intuitively understand the software, and it is in an affordable price range. To achieve this, the sensors need to be replaced by cheaper ones and the system of interpreting data needs to be revised to something that is understandable for the user. Earlier executed tests show that the current product can be improved regarding embodiment, aesthetics and materials, which I will try to implement. I will also execute user tests of my own to get a better image of the user and to validate findings of this project.

To narrow down the scope of this project, already executed tests will be used as a base-line. Because of new sensors, an accuracy test is necessary for the force measurement system. The feedback accuracy will however be tested outside of my project. The results of this project will be a model, preferably a prototype. This model includes as many features as possible (sensors, feedback, improved embodiment, new software). However, multiple models might be needed to implement all features. The project has to be executed with a limited amount of money (€ 1500) which exclude expensive manufacturing ways which will then be simulated with models.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 2 - 3 - 2020 27 - 8 - 2020 end date



In this planning you can see that my graduation project will be stretched over the holidays. To ensure my graduation project does not exceed the 100 days, I have planned some holidays after my midterm meeting and after green light (when I have handed in my graduation). I will use the basic design cycle for the different steps in my planning. I start with an analysis of the current situation and of users which will result in a list of wishes and requirements and an ideal scenario. With this, the ideation phase starts, the outside towards inside approach will be used. I prefer to first think about big solutions for all aspects in the product after which I can narrow it down to the specific components and how to achieve this best solution. At the end of the ideation phase I would like to present a MVP (minimal viable product) to ensure that everything is realizable. Just before the midterm meeting I will start with the concept phase, again with the outside towards inside approach. I will put main focus on two parts; embodiment and the feedback system; to make these work together I will pay minor attention to the sensors and software. After testing and finding the best solutions for these parts I combine both parts of the concept design and start working on a test model to execute the final user test. After that, the user test will be evaluated and recommendations will be made. Throughout the whole process, reporting will be done after every phase to minimize the work building up. The last week before my graduation day will be spend on making my presentation.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Besides an industrial designer, I am also a climber and alpinist. I work as a training coach in climbing and have been climbing myself for already 18 years. I found out a couple of years ago that climbing is my passion and that designing for sport and specifically climbing is something I really enjoy. This project is therefore perfect to combine my passion with my expertise: designing. A perfect learning ambition for me is getting more inside knowledge about climbing from a designer perspective. Important to be aware of is the comprehensibility of the project; even non-climbers should understand what it is about.

The course that I enjoyed the most was Advanced Embodiment Design. I particularly liked that there are so many improvements possible on already existing products in the embodiment, the software, the sensors, the feedback. For my graduation project I wanted to do something like AED knowing that it would be a big project to tackle in 100 days. This is why a detailed planning is important as well as accepting that not every aspect of this product can be tackled in one graduation project.

Since this project starts with an already existing MVP that will be improved throughout the project, user testing to validate the changes to the design are an important element. This will result in a lot of user testing to validate the changes made to the design. Performing user tests correctly is not an easy task, but if so, the results can be really helpful to the project. With the access to a lot of climbers and even the Dutch Climbing Team, the user group has a very big range of athleticism which could deliver interesting results. User testing has always been something that I enjoy doing because of the high validation it can give. Being able to conduct an efficient and effective user test where the results are relevant is something I am still in the process of learning.

Being able to use the Meta-Grip unsupervised requires a feedback system that the user can understand without any prior knowledge. Feedback systems can be very interesting since there are a lot of ways of giving feedback to the user through different senses. It is also important that the user can interpret the data and transform it to something they can use in their training. Giving the correct feedback to the user, which requires a lot of testing, is something I would like to improve in.

Lastly, I like designing and thinking about the aesthetics of a product. It interests me how people perceive certain textures and forms and how for example a well-chosen texture can make or break your product. With the knowledge I gathered about aesthetics and personal experience of the product during AED I would like to implement and improve this knowledge in the redesign of the Meta-Grip through research and user tests.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Appendix AG

Reflection

I started out this project in the beginning of March and halfway through March, Covid-19 made everyone work from home. This made the beginning of the project go more slowly than planned because working from home was not ideal. However, I got used to working from home and I am proud to say that Covid-19 did not hinder my graduation. It did however change some approaches and methods I would normally apply to a design process. It was my personal ambition to be able to make a detailed planning and finish my graduation project in a 100 days. The planning made in the beginning changed after my midterm to more evenly divide the workload; I used my intended 2-week holiday to take every friday off.

In the project brief (appendix AF: Original project brief on page 221) I had the ambition of doing a lot of user tests. Since it was not possible to come together in rooms in the beginning of Covid-19, I had to either do user tests online or do it with my family since they are all climbers. The user tests were not as extensive or frequent as intended, but still the necessary information from climbers was obtained. The most difficult part of doing online user tests is not having the ability to discuss the user test or ask further questions than written in the online user test. Online user testing asks for much more preperation since no changes can be made once the online survey is shared with the participants.

In this project, I wanted to improve a lot of different aspects of the Meta-Grip. I was warned that this might be too much to do in a 100 days which was correct in my case. I had to adjust the level of detail I wanted to achieve for every aspect. Since my ambition was to design and think about aesthetics, I prioritized the design of the physical device.

This project alligned perfectly with my personal interests; climbing. In the beginning of the project I had to figure out which information was obvious to me and not for people not involved with climbing. After I figured this out, I had to explain it as well, which took me some time to master in the beginning. It is difficult to explain things that have been part of your life since you were three years old. I learned a lot in this, but improvements can still be made in the length of explanations.

Writing this report has been more difficult than doing the project itself. I can write quite lengthy and at the same time forget to include information. The process I went through is very detailed and writing this down in a short and clear way was difficult. Nevertheless, I am proud of what I achieved and glad that it is finished.

Lastly, the guidance during the project was somewhat different as what I was used to in different IDE courses. The only real guidelines are in the rubric and the guidance of the supervisors was not consistent every time. I find it difficult to assess my own work and assess if it is sufficient for graduation. Hardly any fellow students were able to help with *this because of Covid-19 and the individual character of a master thesis project. The guidance received from fellow students and climbers was very helpfull in combination with guidance from the supervisor team. However, for me, more guidance would have been more reassuring. Important to remember for me is that even if I do not encounter a real problem and everything is going alright, I can still ask for guidance and advice.*