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School of Engineering
&
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Development of an individualized rowing seat for para-rowers

PAPER WITHIN *Product development - MASTech*

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Abstract

Background: Rowing is a demanding sport where extreme positions and high physical loads are obtained. This leads to injury risks, especially in the lower back. Another issue relates to comfortability. When rowing, the buttocks are the pivot point, and lots of pressure is placed on the sitting bones and surrounding tissues. For para-rowers, these issues can be even more prominent and important to consider.

Purpose and aim: The purpose of this project was to develop a solution that enhances the enjoyment and comfortability for para-rowers. To do that, this project aimed to develop an individualized add-on product for rowing seats, with an included method to translate individual measurements into the design.

Method: The Double Diamond Model was used to guide the project, where both qualitative and quantitative methods were included to reach the aim and purpose. To discover and define the problem, data was collected with literature review, benchmarking, and semi-structured interviews. With that data as a base, concepts were developed and selected, and the selected concept was tested with regards to pressure distribution.

Results: The final concept was based on one individual and includes a seating area that has the exact shape of that individual. It does also include an increased back support and sideways support. To get measurements to design the individualized seat, a method consisting of scanning a vacuum pillow was used.

Conclusion: The findings indicate that a perfectly fitted seat will spread out pressure more evenly around the buttocks, which enhances comfortability. There is, though, still much to consider and evaluate before this product can reach the market.

Keywords:

Para-rowing
Rowing
Comfort
Stability
Lower back pain
Ischial tuberosities

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Table of Contents

1. Introduction 1
   1.1. Background 1
   1.2. Problem description 3
   1.3. Aims and objectives 3
   1.4. Delimitations 4
   1.5. Outline 4
2. Theoretical framework 6
   2.1. Rowing 6
      2.1.1. The rowing ergometer 6
   2.2. Para-rowing 7
   2.3. Anthropometry 8
   2.4. Design framework 9
3. Literature review 11
   3.1. Rowing biomechanics 11
   3.2. Para-rowing biomechanics 14
   3.3. Anthropometry in design 16
      3.3.1. Custom-made seat 18
4. Method 21
   4.1. Discover 21
      4.1.1. In-depth literature review 21
      4.1.2. Semi structured interviews 21
      4.1.3. Benchmarking 21
      4.1.4. Pressure measurement 21
   4.2. Define 22
      4.2.1. Data analysis 22
      4.2.2. Market segment 22
      4.2.3. Product specification 22
   4.3. Develop 23
      4.3.1. Brainstorming 23
      4.3.2. Concept scoring 23
   4.4. Deliver 24
      4.4.1. Individualized seat development 24
      4.4.2. Concept testing 24
5. Implementation and Findings 25
   5.1. Discover 25

5.1.1. In-depth literature review 25
5.1.2. Semi structured interviews 25
5.1.3. Benchmarking 27
5.1.4. Pressure measuring 31
5.1.5. Ethical considerations 32
5.2. Define 33
5.2.1. Data analysis 33
5.2.2. Market segment 36
5.2.3. Product specification 36
5.3. Develop 37
5.3.1. Brainstorming 37
5.3.2. Concept scoring 41
5.4. Deliver 42
5.4.1. Shape capture 42
5.4.2. Seat production 43
5.4.3. Seat completion 45
5.4.4. Concept testing 46
6. Results 49
7. Discussion 50
7.1. The final concept 50
7.2. Research questions 54
7.3. Limitations 55
7.4. Future work 56
8. Conclusion 57
References 58
Appendices 63

1. Introduction

This chapter describes the background to the project, why it is a project worth doing, and what problems rowers face with today's equipment. Furthermore, the purpose and aims of the project are explained, as well as the research questions that were considered.

1.1. Background

It is widely known that being physically active is beneficial for overall health and well-being. Regular exercise contributes to the improvement of the cardiovascular system, but it also affects mental aspects in a positive way, often reducing the level of anxiety and depression (Tortora & Derrickson, 2019). For people with disabilities (PWD), this is no different, and one can argue that it is even more important for PWD to exercise regularly. Wheelchair users, for example, have a higher risk of developing cardiovascular diseases and type 2 diabetes (Anderson et al., 2023), and physical activity is one way to reduce that risk. Physical activity and sports participation amongst PWD is also associated with social integration and community participation (Anderson et al., 2023; Engdahl-Høgåsen & Bentzen, 2023). Being able to participate in organized sports enhances the feeling of inclusion and belonging (Engdahl-Høgåsen & Bentzen, 2023), and it can also promote empowerment (Martin Ginis et al., 2021). Compared to the general population, people with spinal cord injuries engage far less in physical activities (Wong et al., 2022). One reason for that is that there is insufficient access to, and lack of, adaptive equipment (Wong et al., 2022), which makes it difficult to participate in physical activities in a safe and controlled way. To address the barriers, and thereby promote the inclusion of PWD in physical activities in general, it is of great importance to consider the development of assistive technology and adaptive equipment.

Rowing is a sport and a type of physical activity that can be adapted to PWD. Adaptive rowing, or para-rowing as it is called in competitive mode, has been a part of the Paralympics since 2008, which means that it has been widely practiced for many years. Rowing is a demanding activity where extreme body positions and high physical loads are obtained throughout the rowing stroke cycle (Trompeter et al., 2021). It combines both endurance and strength with the use of the full body, including the lower limbs, the trunk, and upper limbs, which makes it an attractive training method (Volianitis, 2020). Because of the high physical loads, the injury risk is quite high, especially in the lower back as the spine is exposed to high forces (Trompeter et al., 2021). It has been found that the rotation and positioning of the pelvis is of great importance to keep the lumbar spine in a neutral position (Nugent et al., 2021; Trompeter et al., 2021).

Keeping the spine in a neutral position can be difficult when being exposed to fatigue, high physical loads, and repetitive mechanical strain (Alijanpour et al., 2023; Trompeter et al., 2021), but not doing so will most likely lead to lower back pain (LBP) (Trompeter et al., 2021). LBP is a condition that ultimately, to some degree, affects almost every rower (Trompeter et al., 2021).

There are different kinds of rowing, and the set-ups can differ a bit. In traditional rowing boats, the seat is fixed, and the rower relies on upper body movement to create power (Agius et al., 2023), but nowadays, the rowing boats used for competition are almost in all cases employed with a sliding seat (Thornton et al., 2017), meaning that the seat can be moved back and forth in the boat. The employment of the sliding seat allows the rower to engage the lower body in the rowing stroke, and thereby a more powerful stroke can be created. This means that in able-bodied rowing, almost the full body is in work, with approximately 70% of the body´s muscles involved in the rowing stroke (Chien et al., 2021). In para-rowing, this can differ depending on the type of disability of the rower. Having parts of the body that do not function properly means that less muscles, joints, and body parts are involved in the rowing stroke, which leads to a more isolated force generation (Puce et al., 2023). This can increase the injury risk even more.

When rowing, the person is sitting on the buttocks the entire time. By carrying most of the weight, while also being the pivot point in the rowing stroke, the buttocks are exposed to high pressure. For some rowers, this will lead to pain and discomfort. Thornton et al. (2017) mean that abrasions, which are portions of the outer skin layer that has been scraped away (Tortora & Derrickson, 2019), are common in rowing, and although not being significant, it is important to monitor it closely. This can occur in the buttocks due to seats not fitting the user properly (Thornton et al., 2017). Pressure injuries of this kind are more common for wheelchair users than for the general population (Vecin & Gater, 2022), so it can be even more important to monitor this for PWD. There is also indication that pain and discomfort in the buttocks could originate from LBP, creating a dull and achy feeling (Hosea & Hannafin, 2012).

To address these issues, Göran Andersson, the owner of the company Code of Practice AB, had the idea to change or add something to the rowing seat. Code of Practice AB is an independent company specialized in orthopedic and medical technology that works together with manufacturers and departments for specially adapted products, with the goal of securing the quality of the products. Göran, who is a veteran able-bodied rower, often feels that the rowing seat is not comfortable, and that there is a growing pain in the buttocks and the lower back.

Hypothetically, this could be even more prominent for para-rowers, as their movement is limited and more isolated than able-bodied rowers.

1.2. Problem description

There is a proven and widely spread issue of discomfort in the form of LBP amongst rowers, and the equipment that rowers use today is ultimately not designed in a way that prevents this pain from occurring. It is stated that this problem might originate from a suboptimal technique, which in connection with extreme body positions and fatigue contributes to the growing pain (Nugent et al., 2021; Thornton et al., 2017). Focus is often set on the technical aspects, but very rarely on the seat itself and how that could influence the seating position throughout the rowing stroke cycle.

There are complaints about discomfort in the buttocks from rowing, and the general seats that are used cannot properly fit everyone. Everybody is different, and when looking at PWD, it is not only anatomical measurements that are different, but also body function determined by the type of disability. To ensure that the rowing seats can fit everyone, there is an indication that they need to be individualized. A seat that is tailored to the specific rower might reduce the discomfort levels from sitting on the seat, but maybe it could also support a good seating position, reducing the risk of feeling discomfort and pain in the lower back.

1.3. Aims and objectives

The purpose of addressing the problems connected to rowing is primarily to develop a solution that enables PWD to engage in a good physical activity with better enjoyment and lesser risk of feeling discomfort. A secondary purpose is to make this solution applicable to able-bodied rowers as well. The aim of this thesis is to develop an individualized add-on product for rowing seats. It includes developing a method where certain anatomical measurements of an individual could be translated into the design of the add-on product.

To guide the research and to address the aim and purpose, the main research questions that will be attempted to be answered is formulated:

> **RQ1:** *How can an individualized add-on product for rowing seats be designed to reduce discomfort for para-rowers?*
>
> **RQ2:** *How can individual anatomical measurements be translated into, and change, the design of the product to enhance the comfortability of the individual?*

To be able to answer these research questions, the following objectives need to be assessed:

- Analyze the challenges that rowers face and what rowing mechanics support a functional and healthy rowing stroke.
- Investigate the human anatomy and its relation to rowing and the rowing seat to determine how certain individual anatomical measurements could adjust the product.
- Get in touch with rowers to get knowledge of their perceptions of the existing rowing seats, as well as their needs and wishes.
- Analyze and compare existing solutions on the market.

Assessing these objectives provides a base to achieve the goal of this project, which is to develop a prototype of this product. The idea from Göran consists of developing a product where the underside has the shape of the sitting area of a common rowing seat, while the upper side is designed according to individual measurements of a user.

1.4. Delimitations

This project only considers the seat and its configurations, and no other parts of the rowing boat. To narrow it down even more, the seat that the eventual developed product will compile with is a Concept2 seat, which is the standard seat for indoor rowing. Limiting the product to fit the Concept2 seat should not limit the design and configurations of the product, but it creates a base for prototyping, testing, and evaluation.

The eventual product will be based on the measurements of one individual. It is similar to a case study, but the thought is that the method used to take measurements of this individual will be transferable to all people. This individual will, due to ethical issues, be an able-bodied rower, and not a para-rower. Although the target population (para-rowers) is not represented, the results will still show if there have been improvements, and it is therefore deemed that this will not affect the overall validity of the project. In the case that there are doubts if the design of the product has been too tailored to the able-bodied rower, this will be discussed and evaluated.

1.5. Outline

The structure of the report represents the journey of how this project proceeded. It starts with *Introduction*, where the background to the project is explained. Thereafter comes *Theoretical*

framework, where necessary information that was deemed to be important for the reader to understand is concluded. It also provided a base for *Literature review*. In the literature review, existing articles that cover relevant information are reviewed and used to further increase the knowledge of the area of interest. In *Method*, the methods that were utilized to assess the problems and to answer the research questions are explained, and in *Implementation and Findings* the findings from all the methods are presented and analyzed. In *Results*, the result of the product development process is presented. Lastly, the *Discussion* and *Conclusion* includes observations and critical thinking of the results provided, as well as the future work that is needed for this product to be fully developed.

2. Theoretical framework

In this chapter, the basic knowledge relevant to this project is covered. For the reader to understand further argumentation in the thesis, the theoretical framework provides a base of information that is needed.

2.1. Rowing

When rowing, the body is exposed to challenging positions due to the movement that is performed (Trompeter et al., 2021). The movement is called the rowing stroke cycle, which is a repetitive movement consisting of the four phases catch, drive, finish, and recover. The rowing stroke cycle is visualized in figure 1. It starts at the catch position, where the rower sits with flexed knees and hips, and with an inclined trunk (Thornton et al., 2017; Trompeter et al., 2021). Once this position is obtained, the rower is prepared to start the drive phase, which includes applying push force to the foot plate and pull force to the handles of the oars (Cutler et al., 2017). The rower extends the knees and the trunk and reaches the finish position where the arms are flexed and positioned close to the body, and the trunk is angled up (Cutler et al., 2017; Thornton et al., 2017; Trompeter et al., 2021). The rowing stroke is concluded by the recovery phase, where the rower is performing the opposite movements to the drive phase to set up for the next stroke. This includes straightening the arms, inclining the trunk, and bending the knees into full flexion (Thornton et al., 2017).

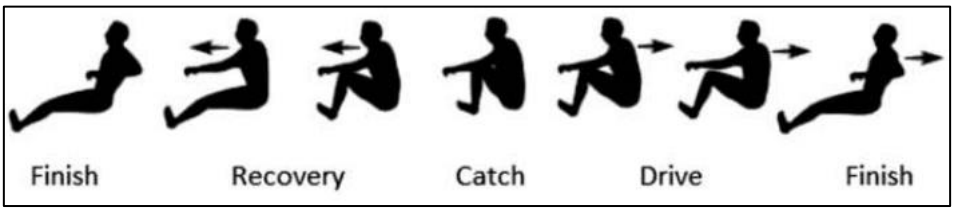

Figure 1: *The rowing stroke cycle (Trompeter et al., 2021)*

2.1.1. The rowing ergometer

The complex, full body movement in rowing puts lots of demands on the musculoskeletal system, and there are often high training volumes included (Nugent et al., 2021). The training is sometimes done in the rowing boat on open water, but often, training is conducted on a rowing ergometer (see figure 2), which is a rowing machine placed on land (Engstrom et al., 2023). This ensures that the training is performed in a safe and controlled environment, without any risk of bad conditions, but it can also be a valuable tool for testing and for measuring performance parameters (Blervaque et al., 2022; Treff et al., 2022; Trompeter et al., 2021).

Figure 2: *Concept2 rowing ergometer.*

Rowing on an ergometer at dry land will provide almost the same movements as rowing in a boat (Cutler et al., 2017), but there are some differences. The oars are replaced by a single handle that is connected to a flywheel that provides air resistance through the drive phase of the rowing stroke (Cutler et al., 2017; Treff et al., 2022). The flywheel and air resistance are supposed to imitate how the water affects the rowing stroke when rowing in a boat. Overall, the movement of body parts involved are the same, but due to the change from oars to a single handle, the upper body movement will be slightly different in ergometer rowing.

2.2. Para-rowing

Compared to regular rowing, para-rowing is a sport that utilizes adapted equipment for PWD to be able to perform the sport, but other than that, it is similar. Disabilities among PWD can vary, and therefore, there are lots of considerations that are made to enhance the ability of para-rowers to perform the sport. A para-rower could, for example, have limited functions in muscles and joint, deficiencies in limbs, visual impairments, or intellectual impairments, which mean that lots of different adaptations needs to be done depending on what type of disability the para-rower lives with (Puce et al., 2023). Depending on the type of disability, one rower might have a better body function than another rower, so to ensure that para-rowers compete on the same grounds and have the same prerequisites when competing, there are three different classes (Thornton et al., 2017).

PR1, previously called AS (arms and shoulders), is the class assigned for rowers with minimal to no function of the trunk and the lower limbs (Cutler et al., 2017; Puce et al., 2023), which means that these rowers only use their arms and shoulders to produce power in the rowing stroke. As PR1 athletes have a lack of strength and function of a large part of their body, they need to be supported by a backrest, and they need to be strapped to that backrest in the thoracic region to maintain stable throughout the stroke (Cutler et al., 2017; Thornton et al., 2017).

Another difference with the set-up compared to able-bodied rowing is that the seat must be kept fixed as these athletes cannot use their lower body. These conditions create a different rowing stroke compared to able-bodied rowing, where the power is solely produced by the upper extremities and the upper thorax (Thornton et al., 2017).

PR2, previously called TA (trunk and arms), is the class assigned for rowers with minimal to no function in the lower limbs, but with full function of the trunk and the upper body (Cutler et al., 2017; Puce et al., 2023). This means that these rowers can use the trunk and the core muscles in addition to the upper extremities, which compared to PR1 will produce a higher force output (Cutler et al., 2017). Rowers in the PR2 class are also forced to use a fixed seat, and they are usually strapped to the seat around the thighs, just above the knee, to increase stability and balance, but also to prevent the rower from flexing and extending the knee (Cutler et al., 2017; Puce et al., 2023). Comparing the rowing stroke of a PR2 rower compared to an able-bodied rower, the catch position and the drive phase is not the same. Without the use of the lower limbs, PR2 rowers utilize a combination of the upper extremities and an upper body swing to generate force through the drive phase (Thompson et al., 2017).

PR3, previously called LTA (legs, trunk, and arms), is the class assigned for rowers with visual or intellectual disabilities (Cutler et al., 2017), but it can also include people with a verifiable functional disability who has residual function in the lower limbs (Puce et al., 2023; Thornton et al., 2017). These rowers can use their full body, including the legs, which means that a sliding seat is used in this class. Therefore, this is the class which is the most similar to able-bodied rowing.

2.3. Anthropometry

Anthropometry is the study and science of human body measurements, such as height, width, circumferences, and other types of data connected to the human body which could be of relevance for a specific topic (Albin & Molenbroek, 2023; Tosi, 2020). Anthropometry can help designers in designing products that suits the user by incorporating the anthropometric data into the design of the product (Bragança et al., 2020), but achieving a physical fit between a product and the user can be difficult (Albin & Molenbroek, 2023). One reason for that is that anthropometric dimensions change during certain activities. For example, hip breadth increases when sitting compared to standing, but certain measurements could also change in the course of time (Albin & Molenbroek, 2023). It is, though, important to consider the relation between physical dimensions of individuals to the product that will be used, as a poor match between

them affects the usability of the product (Albin & Molenbroek, 2023). Having a poor anthropometric fit can in the long run result in problematic postures, and besides a decrease in performance, it could also affect the overall health and well-being. (Albin & Molenbroek, 2023).

When using anthropometric data in design, it is important to specify the target group (Tosi, 2020). Albin and Molenbroek (2023) argue that there are several approaches where anthropometric data have been tried. One approach explained is the "one size fits all" method, where anthropometric data is used with the aim of satisfying everyone. This can relate to the Concept2 seats on rowing ergometers, which is designed in a way that could fit in with the diversity of the users. This approach often results in a limited satisfaction level (Albin & Molenbroek, 2023). Another approach explained is the utilization of different sizes to accommodate the variation of human anatomy. It can be in the presence of having choices of the size of the product, or it can be that the design can be adjusted to match individuals (Albin & Molenbroek, 2023). The third approach explained is the one that will be utilized in this project, which is to tailor the design for a specific user. Modern production processes, such as 3D-printing, have made this a viable option, and with the current abilities, this approach is not as expensive as it has been before (Albin & Molenbroek, 2023).

2.4. Design framework

A model that can guide designers in the work of developing a product or a service, and the model that this project will utilize, is the Double Diamond Model. Wang et al. (2023) describe it as a standardized methodological process where the problem, and the solution to that problem, is found in an effective way. The Double Diamond Model, visualized in figure 3, consists of two diamonds where each diamond symbolizes one diverging stage and one converging stage. The first diamond starts with the discover phase, where open-mindedness and divergent thinking is required to discover, explore, and understand the problems (Wang et al., 2023). The second part of the first diamond is the define phase, where the problem is refined and the design process is clarified through convergent thinking (Wang et al., 2023). Next step is to explore potential solutions to the refined problem, which again requires open-mindedness and divergent thinking (Wang et al., 2023). Lastly, the second diamond is closed with the deliver phase, where convergent thinking is needed to test, evaluate, and improve the chosen solutions (Wang et al., 2023). It is important to notice that this is not a linear model. There are always new things to learn, and an innovation is in a way never finished, meaning that it is an iterative process where

feedback and new problems takes you back to the start again (Design Council, n.d.; Wang et al., 2023).

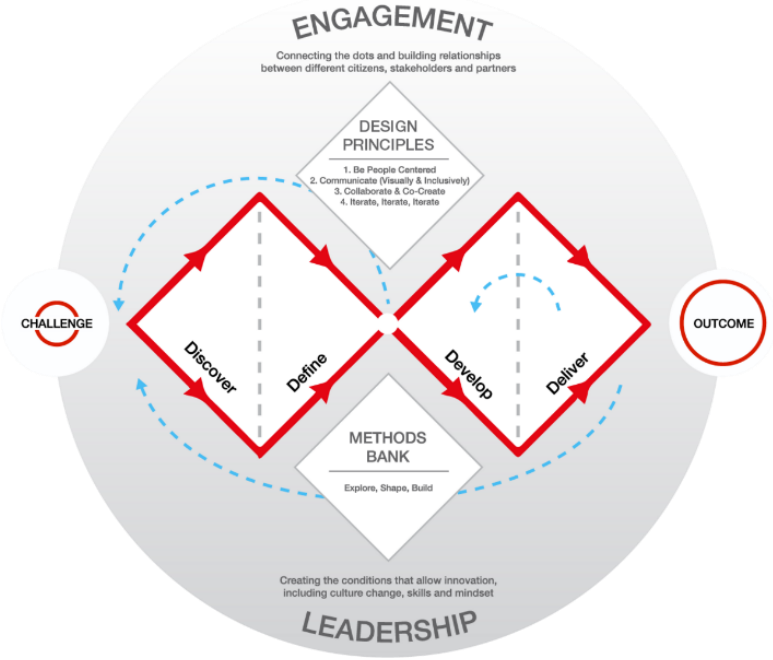

Figure 3: *The Double Diamond Model. (Design Council, n.d.)*

3. Literature review

This chapter is a continuation of the theoretical framework where the information provided is further analyzed with the intention of finding detailed knowledge of what the problems are. Additionally, this process is part of the discover phase, where problems are discovered, but also where information that could be important to consider in subsequent idea generation is identified.

Search procedure:

Searching for and finding relevant articles connected to the theoretical framework included the use of three different databases. Web Of Science was the main database, complemented by PubMed and Google Scholar. To ensure the quality and validity of the articles, Primo was used to check that every article was peer reviewed.

The search terms, combined with Boolean operators, that were used to extract information are summarized in table 1.

Table 1: *Search terms applied in the literature review.*

Topic	Search terms
Rowing biomechanics	- Rowing biomechanics - Rowing AND biomechanics OR mechanics - Rowing stroke cycle - Rowing injuries - Rowing seat
Para-rowing biomechanics	- Para rowing OR Para-rowing - Para rowing biomechanics OR Para-rowing biomechanics - Para rowing injuries OR Para-rowing injuries
Anthropometry in design	- Anthropometry AND rowing - Anthropometry AND seat design - Custom AND wheelchair seat - Custom wheelchair AND spinal cord

3.1. Rowing biomechanics

With the aim to understand and define kinematics and muscle activity in rowing, and to compare the differences of these parameters of rowers with and without LBP, Nugent et al. (2021) made a systematic review of the literature available. From the review, which included 22 studies, it was found that rowers with no discomfort in the form of LBP show a neutral, or even a slight

anterior, rotation of the pelvis in the catch position and a flat lumbar spine position at the finish position. These rowers also have a greater range of motion (ROM) in the hips. In contrast, rowers who experience LBP have a lesser ROM in the hips, resulting in a posterior rotation of the pelvis at the catch position (Nugent et al., 2021). This argumentation is in line with the findings of Thornton et al. (2017), who explain that rowers must perform an anterior rotation of the pelvis in the catch position to reduce the flexion and ROM of the lumbar spine. To visually get a sense of how anterior and posterior rotation of the pelvis looks like, see figure 4.

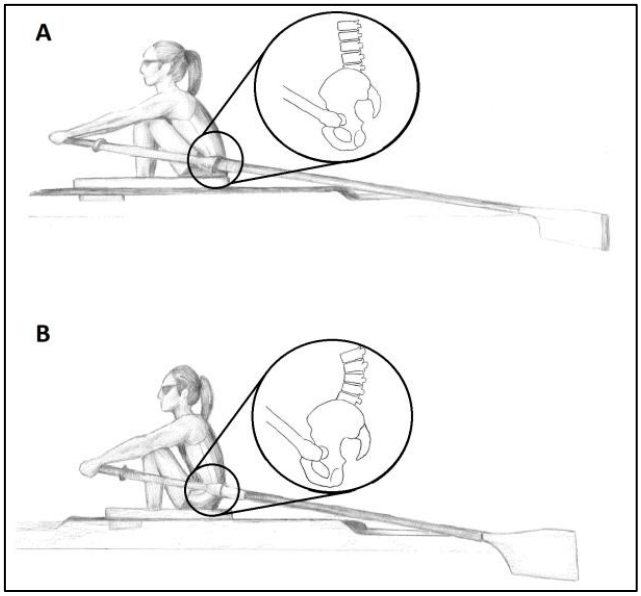

Figure 4: *The catch position of an able-bodied rower with A) an anterior rotation of the pelvis, and B) a posterior rotation of the pelvis. (Nugent et al., 2021)*

When comparing the muscle activity of healthy rowers to rowers with a history of LBP, Nugent et al. (2021) found that rowers without LBP activate their trunk extensors in a more consequent manner, especially the erector spinae. Thornton et al. (2017) explain that the erector spinae is the dominant muscle in the rowing stroke, and that it needs to be considered in rehabilitation and training, but also argue that there are inconclusive arguments that can relate muscle activity to injuries and LBP. Yamashita et al. (2023), though, found that there are higher amplitudes of muscle activity in the erector spinae among rowers with LBP. This suggests that rowers with LBP use their trunk more than healthy rowers when generating force in the drive phase, where healthy rowers instead complement the stroke with the use of lower limbs and upper limbs to a greater extent (Yamashita et al., 2023). This suggests that rowers that cannot use their lower limbs need to use other muscles to a greater extent, causing a greater injury risk.

There are evidence suggesting that healthy rowers have distinct kinematics that rowers with LBP do not have, but it is also difficult to know whether the kinematics of rowers with LBP

causes the pain and discomfort to grow, or if it is the pain and discomfort that causes the dysfunctional kinematics. Nugent et al. (2021) explain that it is impossible to evaluate this, but also mean that aiming for the kinematics explained for healthy rowers might reduce the risk of LBP. One limitation of this review, which Nugent et al. (2021) state by themselves, is that all but one of the articles reviewed did testing on the rowing ergometer and not in rowing boats. As stated before, a rowing ergometer is a good substitute to a rowing boat, and it is easier to do testing on them, but combining results from an ergometer and a boat would have given a deeper argumentation with more context, especially since Nugent et al. (2020) state that overuse of ergometers can be a risk factor to developing LBP.

To evaluate the differences of rowing in an ergometer compared to a boat, and to test the hypothesis that the kinematics differ in the different settings, Trompeter et al. (2021) compared the kinematics of healthy rowers when performing a one-hour training in both an ergometer and an indoor rowing tank. An indoor rowing tank is an indoor facility that is supposed to simulate the environment and situation of rowing in a boat in open water (Trompeter et al., 2021). Eight healthy, competitive rowers were recruited and asked to perform a routine training protocol consisting of altered interval phases where angular changes of the spine and the pelvis were recorded. The most significant result from the research was that the ROM of the lumbar spine was greater when rowing on an ergometer, with the difference being that the rowers extended the lumbar spine more at the finish position on the ergometer. Trompeter et al. (2021) explain that the appropriate kinematics at the finish position is to have more rotation of the pelvis and less extension of the lumbar spine, which means that rowing on an ergometer is unfavorable in comparison to rowing in a boat.

The differences in kinematics when rowing on an ergometer compared to rowing in a boat is explained by Trompeter et al. (2021) to be caused by the slight differences in the equipment. The relation between the position of the feet and the seat is different, and the handle is different both with regards to design and position, which might cause dissimilarities in force generation and load distribution. This means that the seating configurations influence the kinematics when rowing.

Although there were differences in spinopelvic kinematics, the differences were not as apparent as first hypothesized. This is argued by Trompeter et al. (2021) to be influenced by the fact that all rowers participating in the study competed at a high level and that they have developed a good and functional technique. But this could also be a strength. Having participants that

previously have developed a functional technique and a body built for this type of testing enhances the credibility of the study, as the data is more believable.

3.2. Para-rowing biomechanics

To evaluate the different set-ups for PR1, PR2, and PR3, and to analyze and compare the postures and kinematics obtained, Cutler et al. (2017) made a study where each configuration was tested by 17 able-bodied rowers on a Concept2 ergometer. Because the equipment for PR3 is similar to able-bodied rowing, a comparison could be made between para-rowing and able-bodied rowing. The results showed that when using the PR2 configuration, there is a significant increase of lumbar motion in comparison to the configurations used for PR3. This is an expected result, because when not being able to use the legs in the rowing stroke, the rower is much more dependent on the upper body to generate force (Agius et al., 2023). They are compensating for the inability of using the legs with swinging the upper body by performing large amplitudes of forward and backwards tilt (Agius et al., 2023; Puce et al., 2023). The initial drive phase is a crucial, but also risky, part of para-rowing (Puce et al., 2023), because the forward flexion of the trunk increases the injury risk of the lumbar spine (Cutler et al., 2017). This is in line with the previously described kinematics of able-bodied rowing, which says that greater ROM of the lumbar spine causes LBP (Nugent et al., 2021; Thornton et al., 2017; Trompeter et al., 2021). As it, according to the study by Cutler et al. (2017), is an increase of trunk flexion in a PR2 configuration compared to PR3, it is deemed that there is a greater risk of LBP for PR2 athletes.

Other results presented by Cutler et al. (2017) was that shoulder abduction angle increased with decreased mobility of body parts and joints. The PR2 configuration caused a greater shoulder abduction angle than PR3, but the PR1 configuration caused an even greater shoulder abduction angle. Again, when not being able to use the lower body in the rowing stroke cycle, para-rowers need to compensate with other movements. PR1 athletes also have limited function of the trunk, which puts more demands on the upper limbs and the shoulders. This puts stress on the upper thoracic region and the ribs, increasing the injury risk of para-rowers even more compared to able-bodied rowers. Para-rowers will in most cases have limited functions in some body parts, and the more isolated force generation creates a condition where injuries are more likely to occur (Puce et al., 2023).

The results presented by Cutler et al. (2017) are interesting, but there are some drawbacks with the study that make the results somewhat questionable. Firstly, the fact that only able-bodied rowers were part of the study might influence the results in a way that does not correlate to

reality. The rowers were not used to the different configurations, meaning that they might not have performed the wanted movements correctly. Also, able-bodied rowers have the body function to get to certain angles and to use their strength in a way that para-rowers cannot (Cutler et al., 2017; Puce et al., 2023), which could have affected the results. But as the main objective of the study was to compare the configurations and to determine the impact of the configurations, the general trends are deemed to be useful. Also, the results can be supported by other literature, which increases the trustworthiness of the results.

There are not many studies focusing on the seat specifically, but Severin et al. (2021) tried to evaluate and compare the performance and biomechanics of a PR1 rower when testing three different angles of the seat. The seat configurations used are visible in figure 5. Noticeably, the seat is complemented with a backrest as that is a requirement for PR1, so it can be difficult to generalize the results to other para-rowers and able-bodied rowers. It is, though, interesting to evaluate if the seat influences the rowing stroke.

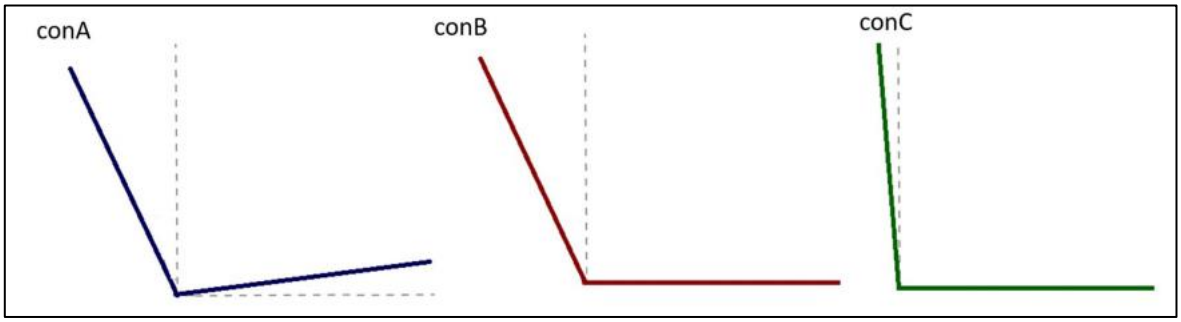

Figure 5: *The three different seat configurations tested. ConA: 25° backrest tilt and 7.5° seating area tilt. ConB: 25° backrest tilt. ConC: 5° backrest tilt. (Severin et al., 2021)*

The test was performed by an elite paralympic rower and included three 4-minute sessions for each seat configuration, where one of the sessions was an all-out, maximum effort. Measurements included numbers related to both performance ability, such as force output, and biomechanics, such as trunk ROM. The results showed significant changes, especially in performance ability. Comparing conA to conC on a maximum effort, the participant had a 10 cm longer stroke length, a difference in power output by 38 W, resulting in a 78 m longer distance. It can therefore be concluded that an angled backrest influences the performance ability in a positive way. Comparing conA to conB, where the only difference is the angle of the seating area, the results did not differ that much, but the participant rowed 16 m longer in conA. So, having an upright angle on the seating area does influence the rowing stroke as well. Severin et al. (2021) discusses that the difference of performance between the seats derives from the trunk movement. Even though the trunk function of the participant was minimal, the

angled backrest influenced an increased trunk motion, and therefore more power was produced. The reason for the marginal increased performance with an angled seating area (conA) is speculated to derive from better stability, where the participant does not slide forward during the stroke.

The numbers regarding biomechanics from Severin et al. (2021) showed that the trunk was much more extended with an angled backrest, which is not surprising considering that the participant sits with a more extended trunk when leaning towards the backrest. The health aspects of this are hard to evaluate. Nugent et al. (2021) explain that rowers with LBP have a greater trunk extension, suggesting that extending the trunk to a certain level is bad for the lower back. That is when the trunk is swinging forward and backwards, but for this example, with the PR1 athlete, the trunk is almost constantly extended. There can, though, be increased injury risks when having an upward-angled seat (conA). Severin et al. (2021) argue that it provides stability, and it might do that, but it does also provide a deeper seating position that makes the pelvis tilt posteriorly (Vanlandewijck et al., 2011). Thereby, the ROM of the trunk is decreased (Vanlandewijck et al., 2011) and the lower back is at further risk of getting injured (Nugent et al., 2021; Trompeter et al., 2021).

The fact that the numbers provided by Severin et al. (2021) comes from a case study, with one participant, makes it difficult to generalize the results. The results and conclusions from this study cannot be fully trusted, as there is no way to know if the results are an outlier to the norm. It is, though, still interesting to evaluate because the results were so different from each other. Most importantly, it shows that different seating configurations provide different results, both when it comes to performance and health.

3.3. Anthropometry in design

The use of anthropometry in designing products can be crucial for overall health and well-being (Albin & Molenbroek, 2023). It is therefore important to choose and use a methodology that could provide the numbers that are necessary to tailor the design of the product. Through a literature review, consisting of 116 reviewed articles, Dianat et al. (2018) discussed and compared different methods and techniques to get anthropometric data. Generally, there are three types of anthropometric measurement methods (Dianat et al., 2018). Firstly, a one-dimensional measurement, which is a direct manual method, can be used. Dianat et al. (2018) explain that this can be managed with a ruler, a measuring tape, or a caliper. It is an inexpensive and easily handled method that was found to be applied often for the design of products for

general use. Secondly, a two-dimensional measurement can be used. Dianat et al. (2018) explain it as a photogrammetric system where the surface of the body can be obtained, including images from different angles. Thirdly, a three-dimensional approach can be used with the use of 3D scanning (Dianat et al., 2018).

The one-dimensional methods come with a risk of human error and variation, and it is also a time-consuming approach as there often are multiple angles and measurements that need to be collected (Dianat et al., 2018). It is therefore limited in its application (Dianat et al., 2018). Having image-based systems, to get a 2D or 3D scan, can overcome some of the limitations of manual measurement (Dianat et al., 2018). It is generally faster, and it can capture more complex angles and shapes to get a better representation of the body (Dianat, et al., 2018). But there is a reason manual measurement is still a popular option. It is often easier and more accessible with manual measurement equipment, and scanning methods come with their own errors, such as modeling errors or equipment errors (Dianat et al., 2018). Bragança et al. (2020) state that the use of 3D scanning for wheelchair users are not as popular as for able-bodied people and discuss that it might originate from the difficulty of scanning and receiving data when not being in the standard standing position. It is, though, a great advantage of using 3D scanners to collect body measurements as the subject will not have to get into uncomfortable positions for a long period of time (Bragança et al., 2020).

Vasile et al. (2021) utilized measurements in all dimensions to find how rowing postures, specifically the posture received in the catch and finish position, effect body measurements and skin-sportswear interface pressure, and how that could be implicated into garment fit. When using anthropometry for the design of a product, it is important to identify the necessary anthropometric data (Tosi et al., 2020). In this case, Vasile et al. (2021) identified five necessary measurements for designing a rowing suit: upper arm girth, thigh girth, knee girth, back length, and across back width. When comparing these measurements in a catch position, finish position, and a standing, static, position, it was found that all the selected measurements changed for every position. Changes of posture are relevant to the development of garments (Vasile et al., 2021), so it should also be relevant in the development of add-on products to the rowing seat. The necessary measurements are not the same though. In garments, both upper and lower body postures and measurements are relevant, but for the rowing seat, there is a smaller area of the body that is in contact with the product.

When sitting on a rowing seat, most of the weight is carried by the ischial tuberosities, commonly called the sitting bones (see figure 6) (Makhsous et al., 2009). A high pressure on

the ischial tuberosities is linked to discomfort in the buttocks (Makhsous et al., 2012) and because of the compression force of the muscles between the ischial tuberosities and the skin, there is a great risk of pain in this area from prolonged sitting (Waongenngarm et al., 2020). In addition, a high pressure on the ischial tuberosities is also linked to a high load of the spine (Akkarakittichoke & Janwantanakul, 2017; Makhsous et al., 2009), indicating that pressure to the ischial tuberosities is connected to LBP. Makhsous et al. (2009) is therefore claiming that a decrease of the pressure to the ischial tuberosities could prevent LBP. Contradictory, Waongenngarm et al. (2020) describe that decreasing the pressure to the ischial tuberosities could be a negative thing. Having a pressure relief of the ischial tuberosities means that the surrounding tissues and muscles are more relied on to carry the weight, which could lead to discomfort (Waongenngarm et al., 2020). It is, though, clear that ischial tuberosities are important to consider when designing products to be sat on.

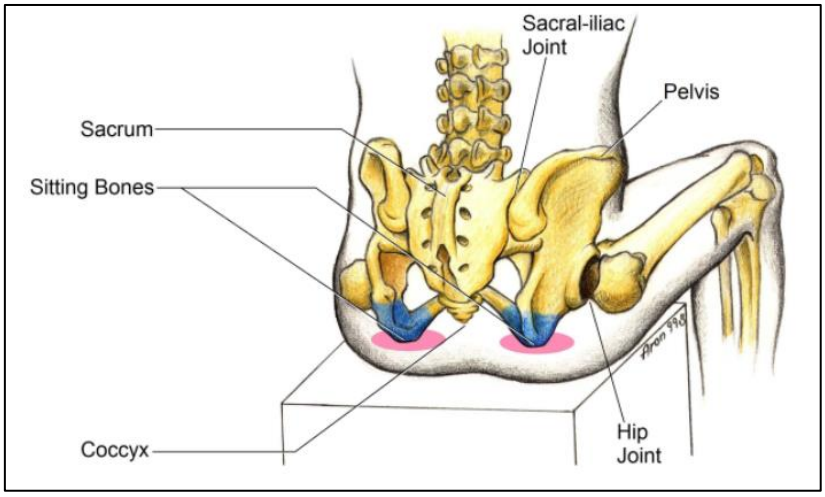

Figure 6: *Illustration of significant bones and joints in the pelvic area.*

3.3.1. Custom-made seat

One product which is sat on a lot by people with a mobility impairment is a wheelchair, and the knowledge of how wheelchair design influences postural control or pressure distribution is interesting for this project. As wheelchair users often sit in the same position on the seat, it is crucial that the user feels comfortable. Having an off-the-shelf, general, seat can create a poor fit between the buttocks and the seating area, which could cause discomfort, postural asymmetry, and pressure injuries (Hosking, 2023). Using a seat that is tailored to the specific user, where the shape of the seat matches the shape of the individual, could distribute the pressure more evenly on the contact surface (Nace et al., 2019). Nace et al. (2019) state that this can reduce the pressure of the ischial tuberosities and the coccyx, but also that it can provide postural support to the user. All of this creates a more comfortable situation.

The importance of having an individualized seat is further proven by Sonenblum et al. (2020), who investigated the tissue thickness around the buttocks and under the ischial tuberosities, and how that differs between able-bodied people and wheelchair users. It was found that wheelchair users have less tissue thickness, resulting in a sharper contour of the buttocks, and it was also found there was less gluteal maximus coverage at the ischium. Damiao (2022) argues that these characteristics further increase the risk of pressure injuries.

Nace et al. (2019) describe several methods of how to develop individualized seats for wheelchairs. A common denominator for every method is a general approach including a 3-step process with capturing the shape, producing the seat, and completing the seat (see figure 7).

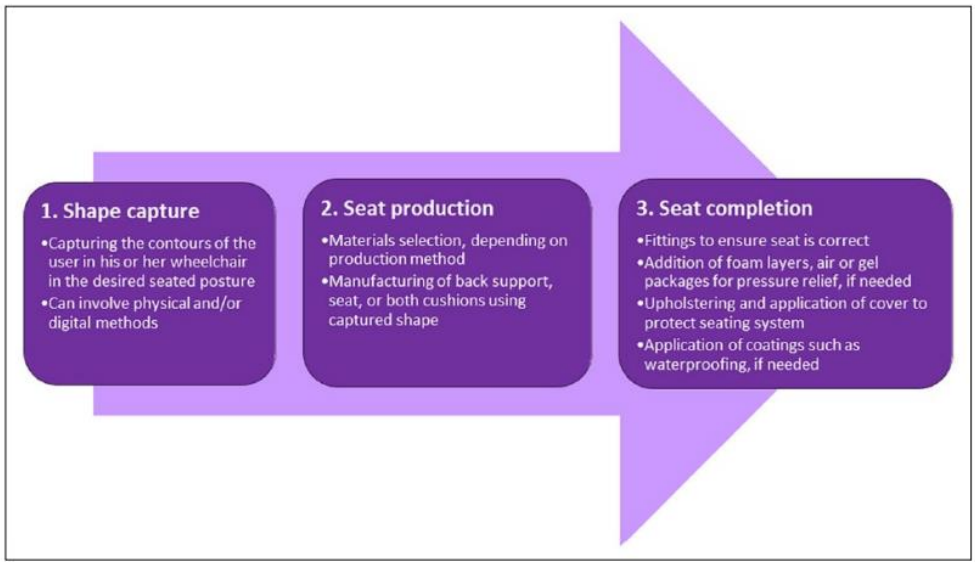

Figure 7: *General approach for developing an individualized seat. (Nace et al., 2019)*

Foam-in-place seating is a method where shape capture and seat production is combined. The user is placed on a molding bag which has a liquid of foam material inside it. The user sits on the molding bag until the foam has expanded and set into a solid seat cushion. When this has happened, the cushion is removed, and the seating surface should have the shape of the user´s buttocks. Nace et al. (2019) explain that a major downside with this method is that the user is placed in a dangerous position in two ways. Firstly, the temperature of the cushion can reach almost 50°C, and secondly, the user is placed close to the chemical reaction happening in the plastic bag.

Plaster molding is a similar method, but where shape capture and seat production is divided into two tasks. Nace et al. (2019) describe that this method addresses some weaknesses of Foam-in-place seating, including having a safer approach where the user is not placed close to a high-temperature, chemical reaction. In Plaster molding, the shape capture includes using a

vacuum bag. The user is placed on the vacuum bag, and when the air is extracted, a rigid cushion is formed in the shape of the user. To produce the seat, a plaster cast is first placed on the surface of the rigid bag. When the cast has dried, the inner surface is coated with silicone which creates a condition where the foam material can be poured and later expand without sticking to the plaster. The same material that is used for Foam-in-place seating is poured and later expanded into the shape of the cast, and when it has set, the cast is removed.

Other methods described by Nace et al. (2019) includes the use of scanning and additive manufacturing, for example 3D-printing, to make an individualized seat. The process used is similar to the 3-step process, with first capturing the shape of a subject, then producing the seat, and finally completing the final shape (Nace et al., 2019). A difference is that shape capture is divided into two parts, with first capturing the shape physically with the use of, for example, a vacuum bag, and then capturing that shape digitally with a 3D scanner. Producing the seat includes working with the data to form the cushion according to the scan, and lastly, the shape is 3D-printed. A strength with this is that design changes could be made quicker and more precise, and there is also little to no material waste (Nace et al., 2019). Nace et al. (2019) also argue that all the shortcomings from the other methods could be addressed with additive manufacturing, indicating that it is the superior method.

4. Method

This chapter describes the methods that were used in the project. Through the Double Diamond Model, the methods are grouped into the four categories discover, define, develop, and deliver.

4.1. Discover

4.1.1. In-depth literature review

As the problem is wide and includes several aspects, it was decided that an in-depth literature review was important to cover all the aspects and to get a base knowledge of the relevant areas. A literature review is defined as a systematic and reproducible method where existing work from researchers and practitioners is identified and evaluated (Fink, 2019, as cited in Booth et al., 2022). It is important to be systematic in the review as this will reduce the risk of introducing bias, and it will also create a more efficient and organized work (Booth et al., 2022).

4.1.2. Semi structured interviews

To get insights from potential users and from people that have lived experience of areas related to the problem, semi-structured interviews were chosen to be used in the study. A semi-structured interview is an interview process which allows both focus and flexibility (Forero et al., 2018), with the benefit that it gives the interviewer the opportunity to explore ideas and topics that comes up during the interview (Adeoye-Olatunde & Olenik, 2021). Through open-ended questions and discussions, a better understanding of unique problems and perspectives, rather than general knowledge, could be gathered (Adeoye-Olatunde & Olenik, 2021).

4.1.3. Benchmarking

To discover and analyze existing solutions on the market, but also to discover opportunities, benchmarking was conducted where related products were compared. Ulrich et al. (2020) mean that getting an understanding of competitive products is critical to the success of the new product, as it can give knowledge, but also ideas, of how the new product could be designed.

4.1.4. Pressure measurement

It was deemed that a visual representation of the problem would benefit the process of fully discovering the issues with existing seats, and therefore, pressure measuring of a user´s buttocks during rowing was conducted. The instrumentation used for this was the CONFORMat seating and positioning system, where pressure distribution and peak pressure, amongst other variables, can be analyzed in real time.

4.2. Define

4.2.1. Data analysis

The discover phase provides lots of data that needs to be analyzed and defined to identify clear customer needs. To do that, the five-step process explained by Ulrich et al. (2020) was followed. The first step involves gathering raw data from potential users and customers, which is a part of discovering the problem. This could for example be done by interviewing users (Ulrich et al., 2020). When the raw data has been gathered, the statements from the users should be interpreted and translated into needs statements to define the data. In this step, it is important that the needs are expressed as what the product has to do, and not what it might do (Ulrich et al., 2020). The third step includes organizing these needs into a hierarchy, where a set of primary needs are followed by a set of secondary needs. This is done to summarize the data and to have a better overview of what the needs are (Ulrich et al., 2020). In the fourth step, the organized needs are graded regarding the relative importance. In the development of products, there are always some trade-offs, and the relative importance is useful when determining what these trade-offs will be (Ulrich et al., 2020). Lastly, the final step of this process is to reflect on the results.

4.2.2. Market segment

Specifying the target group for the specific application is important, especially when aiming to use anthropometrical data (Tosi, 2020). One method to do that is market segmentation. Market segmentation is a tool to decide the target market and to understand unique customer needs, by dividing the users into different segments (Dolnicar et al., 2018). The four segments often used are geographical, demographical, physiographical, and behavioral. Respectively, they describe the location of residence, demographic factors such as age and gender, physiographical factors such as interests and aspirations, and behavioral approaches (Dolnicar et al., 2018).

4.2.3. Product specification

Sometimes called product requirements, engineering characteristics, or technical specifications, a product specification is a detailed description of the product (Ulrich et al., 2020). Identifying customer needs is a good starting point to get a sense and an overview of the problem and potential solutions, but they are often expressed in a subjective manner with an inadequate specific guidance about the engineering aspects of the product (Ulrich et al., 2020). To reduce the level of subjective interpretation, specifications based on the identified customer needs are established where measurable parameters explain what the product must do (Ulrich et al., 2020).

Ulrich et al. (2020) explain that a specification consists of a metric and a value. Sometimes, when translating customer needs to a metric, it can be difficult to make it a quantifiable metric with a value. In these cases, Ulrich et al. (2020) mean that the need statement can be repeated as a metric, and that the value connected to the metric is descriptive with the unit entered as "subj." for subjective. This way, important needs will not be forgotten in the specification.

Ulrich et al. (2020) describe that setting final specifications of a product includes assessing constraints with testing of several concepts. Due to time and limitations, this project only made use of a target specification, which is a specification that is set before concept generation that represents aspirations of what the product must do. They are preliminary specifications that describe a product that is believed to succeed on the market (Ulrich et al., 2020).

4.3. Develop

4.3.1. Brainstorming

Explained by Ulrich et al. (2020) to be the "most open-ended and creative of any task in product development", brainstorming was utilized to generate ideas and explore possible solutions. Brainstorming is an internal search where previous knowledge and knowledge gathered throughout the project is used to generate ideas (Ulrich et al., 2020). It can be carried out both individually and in groups, and a combination of them can be beneficial to generating concepts. Working alone means that you can focus on your own ideas, and you can excel in your own dimension of creativity, but it is crucial that group sessions are carried out to build consensus and to discuss different ideas (Ulrich et al., 2020).

4.3.2. Concept scoring

To evaluate the concepts generated, concept scoring was chosen. Concept scoring is a method where a weighted matrix is composed, where each concept is evaluated with regards to selected criteria (Ulrich et al., 2020). If the process beforehand has included a hierarchical list of needs, the primary needs can be used as selection criteria. Every criterion is then allocated a weight with how important it is, where the sum of the weights is 100 percentage points. This process is the reason why concept scoring was chosen, as it was deemed that the relative importance of needs is important to determine trade-offs in the design.

4.4. Deliver

4.4.1. Individualized seat development

To develop a prototype of the selected concept, the general approach to develop individualized seats, explained by Nace et al. (2019), was followed. In order, it includes capturing the shape of the individual, producing the seat that fits the individual, and completing the seat with necessary additions.

4.4.2. Concept testing

Wang et al. (2023) mean that the deliver phase consists of testing, evaluating, and improving chosen solutions. To do this, concept testing was used. Ulrich et al. (2020) describe that concept testing is a wide expression that can be used for several purposes, including choosing between similarly valued concepts, or gathering information and feedback from customers on how the concept can be improved. For this project, concept testing meant the process of firstly testing the performance of the product with pressure measurements, and secondly getting feedback from potential customers.

5. Implementation and Findings

This chapter explains how the methods were implemented in this project, and what the findings were from each method. Through the Double Diamond Model, the findings from each method are presented in chronological order, which ends with the deliver phase where the chosen concept is showed both in the form of 3D-models digitally and as a prototype. Additionally, the chosen concept is tested and evaluated.

5.1. Discover

5.1.1. In-depth literature review

The complete literature review can be found in Chapter 3: *Literature review*, which covered the main areas of rowing, para-rowing, and anthropometrics. It was confirmed that rowing comes with injury risks, and that the injury risk in para-rowing is even more prominent, further indicating that this project is worth proceeding with.

5.1.2. Semi structured interviews

The semi-structured interviews were conducted with three participants. The first two interviews were conducted with potential customers of the product, and that included one able-bodied rower and one PR1 para-rower. Talking to rowers with different experiences and different views was deemed to be crucial for the project. Even though the main target group is para-rowers, there is a secondary purpose that the solution could be applicable to all rowers, and having discussions with people where the conditions to perform the sport are different broadens the information and it gives more perspective to the problem, as well as the subsequent solution. The inclusion criteria were that they were adults (18+), and that they were active competitive rowers of today.

The third interview was conducted with a seating expert. Initially, this was not thought to be included in the study, but through working with the project, it was deemed that more knowledge about seating would benefit the project. This participant works daily with PWD and has a good knowledge of seating problems, so this interview gave even more width to the problem, but also more clarity to what needs to be assessed. All the questions from each interview are available in Appendix A.

Findings from the interview with the able-bodied rower:

- There are add-on products on the market that can be useful, but they are often too soft. It is a fine line between too soft and too hard. Too soft makes the buttocks go numb, and too hard is uncomfortable.
- The participant has tried many different rowing seat designs and paddings and feels that the comfort and performance correlates. When uncomfortable in the seat, you twist, turn and try to change the position, which affects the rowing stroke.
- The main parts of the rowing boat are a seat, handles, and a footplate. Among these, the seat is most important as it carries most of the weight.
- The participant has had lots of problems with LBP, which often arises with an increased amount of exercise. It was mentioned that it might also arise from an uncomfortable seat. Having a comfortable seat correlates with having a comfortable and stable posture. Thereby, you do not have to move around and change the posture to reduce discomfort levels.
- It is important to be able to rotate freely.
- In the finish position, you do not want the seat to get in the way, but it should not be too unsupportive either.
- The ischial tuberosity and the coccyx (tailbone) are parts of the body that need to be considered. Some contact with the ischial tuberosities is preferable.

Findings from the interview with the para-rower:

- There are, to the knowledge of the participant, no add-on products for para-rowing set-ups.
- From explaining the general idea of this project, the participant thought that the product could be helpful to everyone who rows, independent of body function.
- The seat used by para-rowers differs a lot, because something that works for one individual might not work for another. It is very dependent on body function and type of disability, even within the same class.
- The type of seat used is also dependent on resources. Many use the standard seats, but others can have custom made seats.
- The participant uses padding to increase comfortability and stability, but feel that having an individualized add-on product, that fits the body correctly, would be beneficial.
- Problems with the ribs are a re-occurring injury, but there are also major problems with pressure sores for many para-rowers.

- Due to body function, it is difficult to feel discomfort in the buttocks for many para-rowers. Therefore, you need to remind yourself to switch positions and relieve pressure. This can be difficult.
- LBP can arise due to less connection between the muscles.
- The main problem with the general seat is that you need to position yourself correctly. Optimally, the seat should position you correctly.
- The pelvis plays a crucial role in rowing.

Findings from the interview with the seating expert:

- It is important that people with paraplegia are stable in their seat. If stable, they are more confident, and power will not be wasted on changing position.
- Having a seat that is individualized and fits the individual perfectly will have great phycological effects. It will be more fun, motivation will rise, and performance will be better.
- If the pressure on the buttocks is distributed on a larger area, the pressure will be reduced. This could be done by having a seat that follows the shape of the buttocks.
- Important parts of the body in seating are the ischial tuberosities and the coccyx.
- A complete pressure relief of the ischial tuberosities is not good, because other parts will then be exposed to higher pressure.
- Having holes in the seat at the place of the ischial tuberosities is not recommended, as this puts pressure on the surrounding tissues. This could potentially reduce the blood flow.
- Scanning would be beneficial to get a good view of the body.
- Other methods that could be used include a vacuum pillow and pressure measurements.
- It is important that the measurements are taken in the same position that is obtained when using the seat.

5.1.3. Benchmarking

There are many types of add-on products available, especially for able-bodied rowers, and they can look quite different to each other, which is highlighted in figure 9. What these three designs, and other add-on products, all have in common is that they try to make it more comfortable for the rower, either by having a softer material, or by having a design that tries to distribute the pressure better over the buttocks.

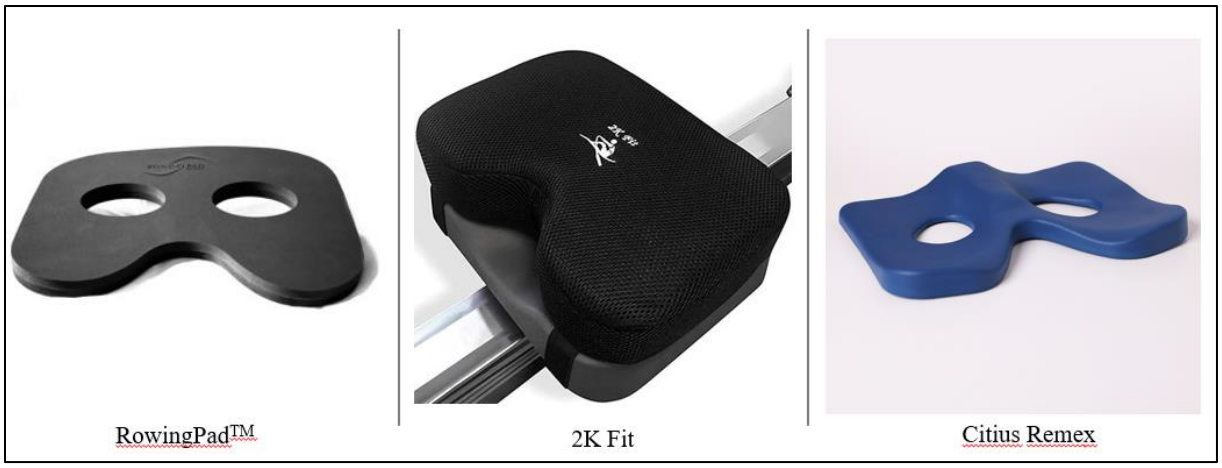

Figure 9: *Three examples of add-on products that fit onto the Concept2 seat.*

The add-on product to the right in figure 9, from Citius Remex, has emerged as the most popular option for professional athletes. By the look of it, it looks uncomfortable, but there is a reason many professionals use it. It reduces the pressure of the ischial tuberosities as the rower is lifted with the inclusion of the bar in the middle, which also supports good blood flow through the surrounding tissues. Compared to a Concept2 seat, it distributes the pressure better.

RowingPad™ and 2K Fit have multiple designs of add-on products depending on what the customer needs. In table 2, several of these designs, as well as the seat design from Citius Remex, are described and evaluated with regards to advantages and disadvantages. The statements are based on both the company´s descriptions of the pads and on previous knowledge gathered from the literature review and interviews.

Table 2: *Benchmarking of competitive products.*

Seat design	Description	Advantages	Disadvantages
RowingPad™	A dual-density pad with one soft side and one firm side. Cutouts where the ischial tuberosities are placed. Dimensions: 308.0x225.1x19.8 (mm)	Option to switch sides to change firmness of the pad.	Basic. Cutouts which might reduce blood flow. Not machine washable.

RowingPad™ 	Single-layered, soft-density foam pad with no additional heights. No cutouts. Dimensions: 309.5x219.1x9.98 (mm)	Good grip on the seat. Does not add any height to the seat.	Basic. No real function. Just a soft, general, pad. Not machine washable.
RowingPad™ 	Two-layered, soft-density foam pad that provides the option to use a seat both with cutouts and not. Dimensions: 308.0x219.1x16.5 (mm)	Option to have cutouts or not. Good grip on the seat.	Might be too soft with two layers of soft foam. Not machine washable.
2K Fit 	A firm, high-density memory foam pad with a non-slip surface. No cutouts. Dimensions: 317.5x243.8x50.8 (mm)	The cover is washable in the machine. Memory foam which conforms to your body. Good grip on the seat.	Flat high-density pad that might feel too firm, especially at first. Due to size and firmness, it might be difficult to transport easily.
2K Fit 	Soft and big pad made of memory foam. The cover is a cloth mesh cover. Includes straps to lock the pad onto the seat. No cutouts. Dimensions: 317.5x243.8x76.2 (mm)	Memory foam which conforms to your body. Breathable mesh cover. Machine washable.	Adds much height. Very soft, meaning that you could sink into the pad. Due to its size, it might be difficult to transport easily.
2K Fit 	A thin cushion with gel material inside. Outside, there is a high-friction material (neoprene). No cutouts. Dimensions: 317.5x243.8x12.7 (mm)	Good grip on the seat. Flexible. Can be rolled and folded, meaning it is transported easily.	The gel adds weight to the seat. Not machine washable.

Citius Remex 	Firm foam pad with a bar in the middle to raise the rower. Elliptical cutouts. Dimensions: Unknown	Compared to others, it is more shaped to the buttocks. The bar in the middle lifts you up, providing pressure relief. Supports a neutral pelvic position.	Uncomfortable at the start. Need a while to get used to it. Not machine washable. Holes might be unnecessary.

These add-on products are all made to be used by able-bodied rowers on a Concept2 seat. Because para-rowers have varying body functions, some para-rowers that do not need extra stability on the seat might be able to use these with good results. There are, though, no add-on products that are specifically designed for para-rowers that use substitute seats. These substitute seats, of which examples can be seen in figure 10 and figure 11, are generic and designed to fit all potential users.

Figure 10: *Para-rowing seat from WinTech Racing.*

Figure 11: *Para-rowing seat from Swift Racing.*

The seat from WinTech Racing is an adaptive seat which is adjustable. It provides support to the rower in the form of a seat belt and chest strap, and it is available with and without padding. The sitting area is just a flat surface with an option to have some padding to make it softer. This is a disadvantage as it will be difficult for the rower to feel stable in the seat. The seat from Swift Racing has lots of similarities. Figure 11 does not show it, but there is a chest strap and leg strap included, and the seat is adjustable with regards to height and backseat angle. The flat seating area has four different widths available, ranging from 230 mm to 380 mm with a 50 mm span. This seat is often customized by the rower with their own padding to make it more comfortable, which is a disadvantage of the product. It is then reliant on the customer to find ways to make it more usable. The seating area can, though, be replaced by two types of bucket

seats that are available (see figure 12). These can provide some sideways support and thereby create more stability, but they still have a basic shape where padding is needed to make them more usable.

Figure 12: *Optional seat designs from Swift Racing.*

5.1.4. Pressure measuring

The pressure measurement tests were performed together with the able-bodied rower. The participant was asked to sit statically in the catch position, the finish position, and the start of the recovery phase. Additionally, dynamic tests were performed at a variety of speeds and stroke rates to discover differences when more power is applied to the stroke. Lastly, one test was performed on a fixed-seat setting that represents how a para-rower with no function in the lower limbs would move on the rowing machine. That way, differences between rowing and para-rowing could be analyzed. To see the general setup used in the tests, see figure 13.

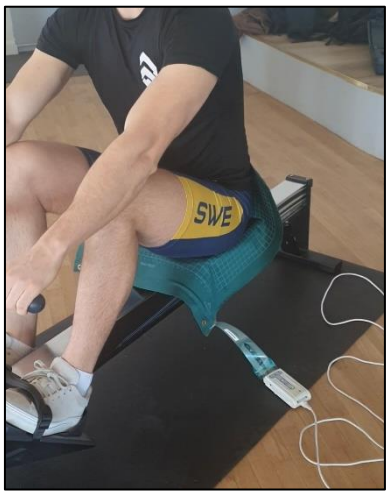

Figure 13: *Captured photo from one of the dynamic tests.*

When analyzing the data from the tests, it was found that something was not right. It seemed that a saturation point was reached, which made the data not showing the complete results. Why that happened is discussable, but a guess is that the shape of the seat, together with the motion, was a combination that the equipment did not support, and the calibration file was therefore not working. Because saturation was reached, no numbers could be evaluated, but an overview of

how the pressure is distributed could still be seen. This is captured in figure 14-16, where figure 14 shows data from the catch position, figure 15 shows data from the start of the recovery phase, and figure 16, which comes from the test that replicated fixed-seat para-rowing, shows data from the finish position. What can be seen is that there is a pressure concentration (the red area) presumably where the ischial tuberosities are placed. This is especially highlighted in figure 15, where the red area is quite small, meaning that there is a small area that is exposed to high pressure. This indicates that pressure caused by sitting on the Concept2 seat is badly distributed.

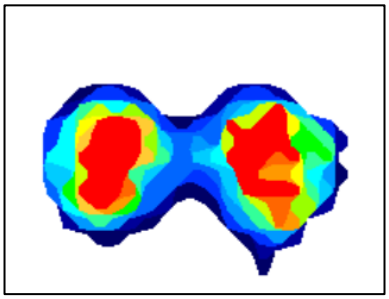

Figure 14: *Pressure obtained in the catch position.*

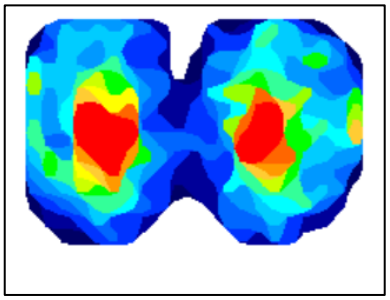

Figure 15: *Pressure obtained in the early recover phase.*

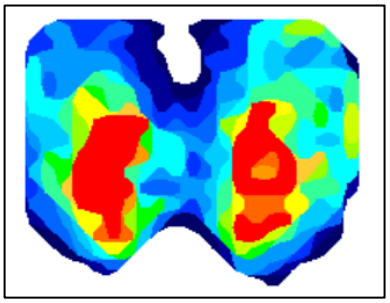

Figure 16: *Pressure obtained in the finish position.*

When analyzing the test on the fixed-seat set-up, it was noticed that a larger part of the buttocks has contact with the rowing seat throughout the rowing stroke cycle. This could mean that pressure is distributed more evenly, but the peak pressure is still prominent in the area around the ischial tuberosities.

5.1.5. Ethical considerations

Before conducting interviews and completing pressure measuring tests, the ethical issues related to the project needed to be handled. When including participants in the process of gathering information for the project, it is required that a self-assessment form of ethical issues is assessed together with the supervisors. This document, which is provided by the School of Health and Welfare at Jönköping University, can be found in Appendix B. If any answer implied that there was an ethical issue, a reflection, together with supervisors and the examiner, about how these ethical issues would be handled to ensure the safety of the participant was needed.

When going through the self-assessment form, it was clear that a few questions needed further explanation and assessment. Firstly, one of the participants for the interview could be viewed as part of a minority/vulnerable group, which makes it an ethical issue. It was determined that having an interview with a para-rower was fine if the discussion was about rowing, and not about topics that could be sensitive to the participant, for example medical history. Secondly, doing a physical intervention on a participant could potentially be risky. Due to the risk of doing

this with a para-rower, both ethically and health related, it was decided to only do tests with an able-bodied rower. As the test was performed on a rowing machine, on which the able-bodied rower is very comfortable, it was deemed that there was no substantial risk in doing the physical intervention. Thirdly, there was some uncertainty whether the para-rower´s identity could remain confidential. The para-rowing community is not that big, which made it difficult to know, at the start of the project, if the participant could be identified afterwards. It was determined that the findings from the interview only would relate to rowing and the rowing seat, which is hard to trace back to an individual. Regarding personal facts, the only fact intended to be presented beforehand was that the participant is a PR1 para-rower. This was necessary to present for the context, but it was deemed to be insufficient to identify the participant afterwards. To read a full written answer to the ethical issues, see Appendix C.

As part of ensuring the ethics in the project, a written consent form was handed out to the participants, which explained the purpose of project, the purpose of the intervention, and the rights that the participants have before, during, and after the intervention. These consent forms can in its entirety be found in Appendix D, but the most important aspect of it was that the participation was completely voluntary, that the participants had the right to withdraw from being part of the study, even after the intervention, and that personal identity and unrelated information would not be presented or shared in any way.

5.2. Define

5.2.1. Data analysis

The findings from the interviews were the first step in identifying customer needs. This raw data was then interpreted and analyzed, and in table 3, the statements of the participants have been defined and translated into correlated needs statements.

Table 3: *Identified needs from the interviews.*

Customer statement	Needs statement
The position of the pelvis is important in rowing.	The product can place the individual´s pelvis in a functional position.
The coccyx is easily injured in rowing.	The product´s design can prevent pressure on the coccyx.
Add-on products are often too soft, but the seat itself is too hard.	The product is comfortable.
Reducing pressure is good, but I still want to have some contact between the ischial tuberosities and the seat.	The product can reduce the pressure of the ischial tuberosities. The product is designed in a way where the ischial tuberosities still carry some weight.

I want to be able to rotate freely in the rowing stroke.	The design of the product does not interfere with the rowing stroke.
I do not want the seat to get in the way of the stroke, but it should not be too unsupportive either.	The product supports a healthy rowing stroke and posture.
The seat is very important as it carries much of the weight.	The product can withstand the full body weight of the user.
Comfortability and performance are connected, and I want to be able to perform.	The product can enhance the performance level.
The problem with a general, flat, seat for para-rowers is that you need to position yourself.	The product can automatically position the user correctly.
Pressure sores are common in para-rowing	The product can distribute the pressure over a larger area.
There are no add-on products specifically designed for para-rowers.	The product is beneficial to para-rowers.
A seat that works for one individual might not work for others. Therefore, para-rowing seats differs a lot.	The product can be combined with lots of different seats.
The quality of a para-rowing seat is dependent on resources.	The product is affordable.
I must remind myself to switch positions to relieve pressure.	The product can reduce the pressure of exposed areas.
It would be great if your product could fit everyone.	The product can be adjusted to the individual´s needs.
Expert statements	
Stability is crucial for people with paraplegia.	The product can provide stability.
The pressure will be reduced if it is distributed on a larger area.	The product can distribute the pressure on the buttocks on a larger area. The product follows the shape of the individual´s buttocks.
Having holes in the seat puts extended pressure on surrounding tissues.	The product does not include any cutouts.
Measurements should be taken in the same position as the seat will be used in.	The method to get individual measurements is taken in a rowing position.
Using scanning is the best method to get a full view of the individual	The method includes the use of scanning.

These needs are just based on the interviews taken, but there are other needs that originate from the discover phase, as well as the project description and deliverables that were handed out by the project owner beforehand. Continuing with the five-step process explained by Ulrich et al. (2020), the next step was to conclude and organize all these needs in a hierarchy with primary and secondary needs. This is concluded in table 4, where the bolded text represents primary needs, and the normal text represents secondary needs. The needs have also been graded with

regards to the relative importance, where the importance is indicated by the number of *´s from 1-5, with * indicating that it is not important, and ***** indicating that it is very important. This was established single-handedly, but it was based on the experience of talking with the interviewees and the project owner.

Table 4: *Identified needs graded and organized into a hierarchy.*

No.	Need	Importance
1	**The product is comfortable**	*****
1.1	The product follows the shape of the individual´s buttocks	****
1.2	The product prevents pressure on the coccyx	****
1.3	The product can reduce the pressure of the ischial tuberosities	****
1.4	The product can decrease the risk of getting LBP	***
2	**The product can provide a stable posture**	****
2.1	The product automatically positions the rower in a functional position	****
2.2	The product provides back support	***
2.3	The product provides sideways support	***
3	**The product supports a healthy rowing stroke and position**	***
3.1	The product enhances the ability to place the pelvis in a neutral position at the catch position	***
3.2	The design of the product does not interfere with the rowing stroke	****
3.3	The design does not include cutouts	**
4	**The product is reliable**	**
4.1	The product can withstand the full body weight of the rower	**
4.2	The product has a good grip on the rowing seat	****
4.3	The cover of the seat is machine washable	*
5	**The product is beneficial for para-rowers**	****
5.1	The product enhances performance level	**
5.2	The product can fit onto all sorts of rowing seats	***
5.3	The product can be adjusted to the individual´s specific needs	*****
5.4	The product is affordable	**
6	**The method to get individual measurements is easy to handle**	**
6.1	The measurement devices are accessible	**
6.2	The method includes the use of scanning	**
6.3	The measurements are taken in a position which replicates the rowing posture	****

5.2.2. Market segment

The market segment composed in table 5 was based mainly on the information provided by the project owner, but also on findings from the literature and interactions with potential users.

Table 5: *Market segment.*

Segment	Description
Geographical	- High income country. - Independent of geographical location.
Demographical	- Gender: Unlimited. - Age: 15-70. - Income: Medium to high.
Physiographical	- Interests: Rows a lot. Rowing is a hobby or even a profession. - Aspiring to become a better and healthier rower. - Active people.
Behavioral	- Curious and open to try out new products. - Willing to spend time and money for this.

The market segment indicates that the product should be detailed, where a lot of effort is put into making a product which fits the individual. There are products that could be used for general use, mainly for able-bodied rowers, so this product should offer something else for people that really need or want a product that fits them perfectly.

5.2.3. Product specification

Based on the identified needs, a product specification was composed (see table 6). For the product specification, only parameters that relate to the design of the seat were considered. As this project was limited to designing a product specifically for a Concept2 seat, this product specification was composed with regards to that.

Table 6: *Product specification.*

Metric no.	Need no´s.	Metric	Unit	Target value	Source
1	1.1	Shape of product	Subj.	Exact shape of user.	Interviews
2	1.2	Peak pressure of coccyx	Mmhg	0	Interviews
3	1.3	Peak pressure of ischial tuberosities	Mmhg	<Concept2	Literature review
4	1.4 2.1 3.1 5.1	Functional positioning	Subj.	Automatic seating.	Interviews
5	2.2 3.2	Back support	Yes/No	Yes	Literature review
6	2.3	Sideways support	Yes/No	Yes	Interviews
7	3.2 3.3	Height of product (in relation to Concept2 seat)	Mm	<75	Benchmarking
8	3.3 5.2	Seating area size	Mm^2	>300x240 <340x280	Concept2 measurements
9	3.4	Cutouts in product	Yes/no	No	Interviews
10	4.2 5.2	Shape of underside of the product	Subj.	Exact shape of Concept2 seating area.	Project goal
11	4.2	Non-slip surface	Yes/no	Yes	Benchmarking
12	4.3	Machine washable cover	Yes/no	Yes	Benchmarking

5.3. Develop

5.3.1. Brainstorming

As brainstorming is a method which could be carried out both individually and in groups, ideas were generated both in isolation and with other people. First, quick sketches and descriptions of ideas were generated individually, and the result from that is available in figure 17. In this session, both research questions were thought of. To the left in figure 17, ideas on how individual measurements could be translated into design of the product (RQ2) were generated, and to the right, ideas and sketches on design considerations (RQ1) were generated. These ideas were basic and quite rough, but the focus was mostly on coming up with ideas that potentially could be viable options.

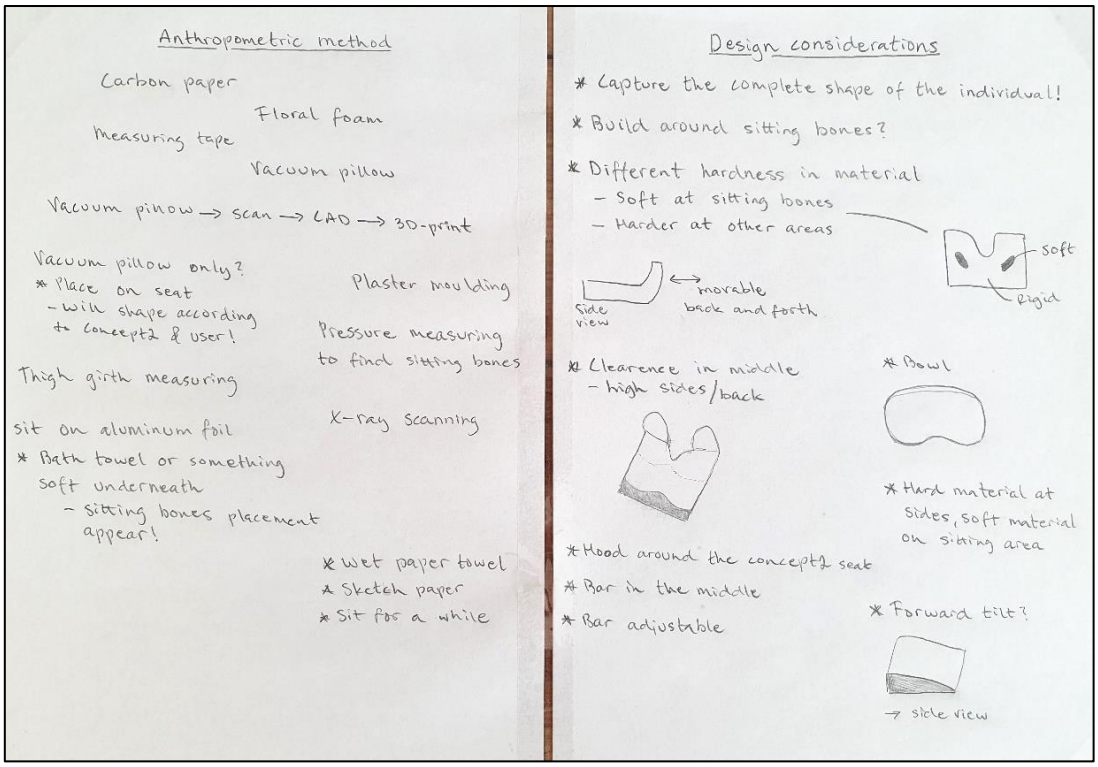

Figure 17: *First brainstorming session with rough sketches and descriptions.*

Quickly after this individual session, a group session was carried out together with Göran (project owner) and the able-bodied rower. In this session, the ideas that had been generated were discussed and consensus was built. Additionally, discussions were carried out with the objective of combining the ideas related to RQ1 with the ideas related to RQ2. For example, if an idea was that the seat should be exactly shaped as the buttocks of the user, a measuring tape cannot be the main instrument as small details are hard to measure with it.

Based on these discussions, as well as internal innovation and general impressions from interviews, four concepts were developed, where both design considerations and methodology to get individual measurements are included. It was difficult to make detailed sketches of the concepts as it, firstly, was a requirement that the underside of the product should fit a standard rowing seat, in this case a Concept2 seat, which limits the design options of the product a bit. Secondly, as there were indications that the product should be shaped in accordance with the individual, it was difficult to make a detailed design where details from the individual was part of the concept. Therefore, the concepts presented below are conceptualized to the level where the concepts are descriptive, including a simple sketch to create a better understanding of the idea.

Concept A

Concept A, visible in figure 18, is a product which is supposed to be formed exactly like the individual. The methodology to do this involves placing the individual in a vacuum pillow, where the shape that comes out of it is scanned with a 3D-scanner. The result from the scan, which has captured the shape of the individual, provides a base for modelling the product, and with the use of Computer-Aided Design (CAD), the product is later 3D-printed.

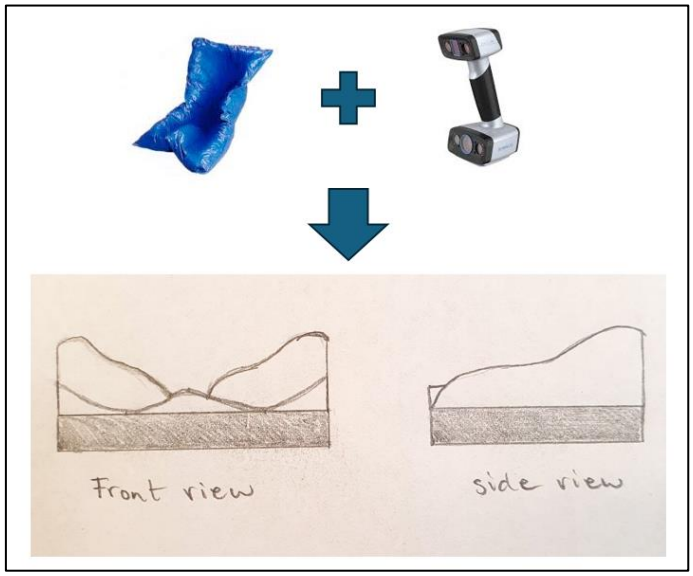

Figure 18: *Concept A*

The product itself consists of a bottom which has a “hat-design”, which means that the bottom of the product surrounds the Concept2 seat. This part is illustrated in figure 18 as the rectangle that is filled. The sides are high, and the back is even higher, but the back is consistently lowered towards the middle where there are no heights to provide clearance for the coccyx. The material is the same throughout the whole product, and it is quite firm.

Concept B

Concept B, visible in figure 19, is again a product which is supposed to replicate the individual´s buttocks completely. For this concept, the methodology consists of having a vacuum pillow the size of the Concept2 seat. The vacuum pillow is placed on the seat and when the individual sits on the seat while air is extracted, what is left of the pillow is a permanent product that has an underside that fits the Concept2 seat perfectly, and an upper side which fits the individual perfectly. Thus, the process of capturing shape and producing the seat is done at the same time.

Figure 19: *Concept B*

Regarding the design of the product, it is difficult to predict the overall look of it. There will probably be some sideways support and some back support, but depending on the thickness of the pillow, this can vary. One thing that will not be part of this design is clearance for the coccyx as it can be difficult to pre-design the pillow. The material is a bit softer than the material for concept A, so the pressure to the coccyx will not be as prominent as if it was a firm material.

Concept C

Concept C, visible in figure 20, is similar to Concept A in design, but it utilizes a method which is more accessible. Instead of capturing the detailed shape of the individual, the methodology used for this concept captures the most necessary measurements. To get the distance between the ischial tuberosities, a combination of accessible, everyday, things is used. The method consists of placing a slightly wet paper towel on a hard and flat surface, and upon that, a sketch paper is placed. When the individual sits for a few seconds on the paper, an illustration of the ischial tuberosities should be visible on the paper towel. To complement this, measuring tape is used to get other measurements of the body. This includes thigh girth and hip width. With these measurements, a custom-made seat can be designed by using CAD and 3D-printing.

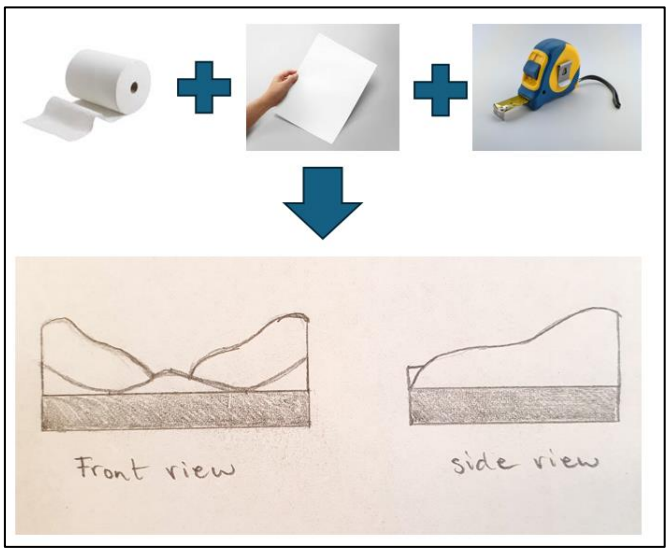

Figure 20: *Concept C*

The design of the product looks very similar to concept A with regards to the “hat-design”, as well as the modelling of the back support and sideways support. The main difference between the two is that this concept does not provide a complete replica of the individual´s shape of the buttocks.

Concept D

Concept D, visible in figure 21, is a simplified version of Concept C. The methodology includes only measuring the ischial tuberosity placement and distance. When having the distance between the ischial tuberosities, the seat can be designed so that there is soft material in that area, and a more rigid material in the surrounding parts.

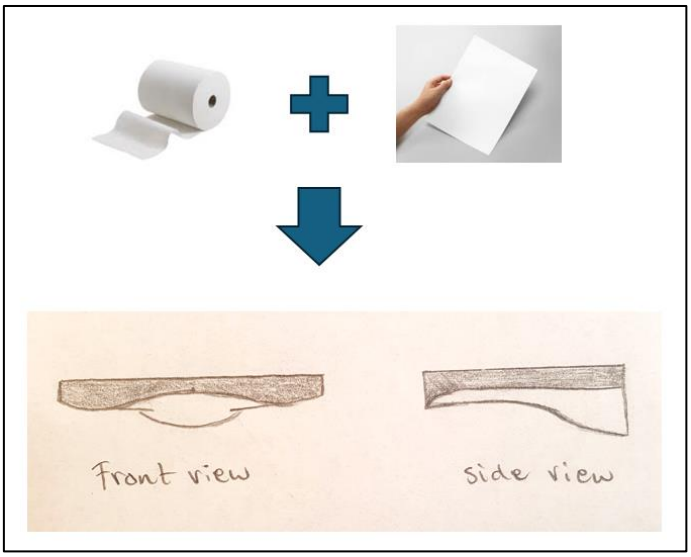

Figure 21: *Concept D*

The design of the product is simple and similar to many of the benchmarking products, where it is flat and does not have a lot of support. It is custom made because the ischial tuberosities are considered, but nothing more is capturing the shape of the individual. It does not include the “hat-design”, but the underside has a non-slip surface to provide grip.

5.3.2. Concept scoring

The concept scoring matrix, shown in table 7, consisted of six criteria. Those criteria are the six primary needs that were defined in the data analysis. The weight that was put on each criteria replicates the relative importance that was concluded for each need, which means that the most important needs also provide a higher score in the matrix. To rate the concepts, Göran and the able-bodied rower helped to give their thoughts and evaluations. Through discussion, each

concept with the associated need was rated from 1-5, and the total score revealed the winning concept. It was determined that Concept A was the best concept to continue working with.

Table 7: *Concept scoring matrix.*

		Concept							
		A		B		C		D	
Selection criteria	**Weight**	**Rating**	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**	**Rating**	**Weighted score**
Comfortability	25%	5	1.25	4	1	4	1	2	0.5
Stability	20%	5	1	2	0.4	4	0.8	3	0.6
Healthy rowing stroke and position	15%	4	0.6	3	0.45	3	0.45	2	0.3
Reliability	10%	5	0.5	2	0.2	5	0.5	2	0.2
Beneficial to para-rowers	20%	4	0.8	4	0.8	4	0.8	2	0.4
Easy method	10%	1	0.1	4	0.4	2	0.2	5	0.5
	Total score	4.25		3.25		3.75		2.5	
	Rank	1		3		2		4	
	Continue?	Yes		No		No		No	

An interesting part of the concept scoring matrix is that Concept A was deemed to be the best in every criterion, except the one about methodology where the score was the lowest. It is a complicated method, where complex instrumentation is used to capture the shape of the individual. But, due to its performance in the other criteria, it was the overall best concept.

5.4. Deliver

5.4.1. Shape capture

To follow the methodology that was part of the winning concept, the first thing that was done in the process of producing a prototype was to capture the shape. This was done in several steps. Firstly, a Concept2 seat was scanned with a 3D-scanner provided by the School of Engineering at Jönköping University. This was done so that the underside of the add-on product could fit perfectly with a Concept2 seat. Secondly, the shape of the individual´s buttocks was captured with the use of a vacuum pillow. This is illustrated in figure 22, where the able-bodied rower sits on the vacuum pillow similarly to how the finish position would look like in the rowing stroke. Other positions were also used to capture the shape. It was important that the individual was in a rowing position, as it was found in the early stages of the product development process that the measurements should be taken in the position that the seat is supposed to be used in.

Figure 22: *Physical capture of the shape of an individual´s buttocks.*

The individual sat on the vacuum pillow while air was extracted, until it was deemed that the pillow was firm enough to be scanned. To maintain the shape that was created, the individual sat completely still while being lifted straight up, without causing the pillow to change its shape. The pillow was then 3D-scanned. The outcomes from the shape capture process were two scan files, one that replicated the Concept2 seat, and one that replicated the individual´s buttocks.

5.4.2. Seat production

The production of the seat consisted of several processes. Firstly, the scan files were imported to SolidWorks, where they worked as a base for modelling the design of the concept. The concept consists of two parts (see figure 23), including a bottom part that with the “hat-design” surrounds and enfolds the Concept2 seat, and a top part which is designed according to the scan from the individual. While modeling this, contact was initiated with Blatchford Ortopedi, which is a company that produces orthopedic aids. Discussions were held regarding how to use the scan files most efficiently, and how to model the seat the best. While the discussions did not lead to anything specific, it contributed into realising that it could be done.

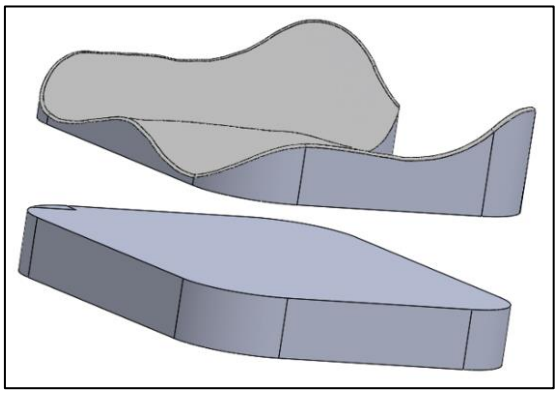

Figure 23: *Exploded view of the concept.*

The complete concept is visible in figure 24 and 25. In figure 24, the final concept can be seen from many angles, providing an overview of how it looks, and in figure 25, the function of the concept is shown.

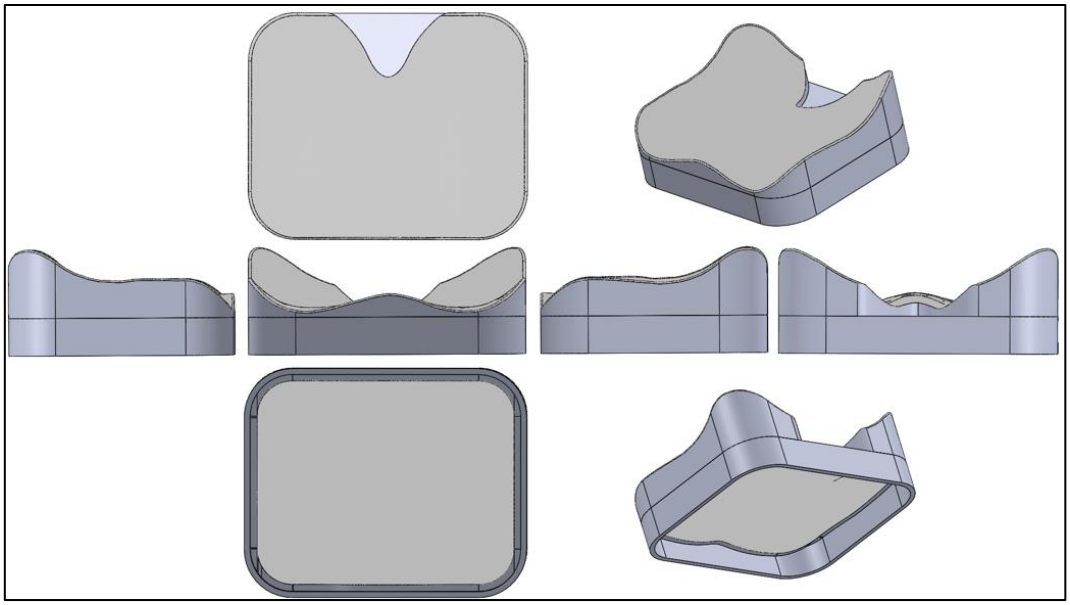

Figure 24: *An overview of the final concept.*

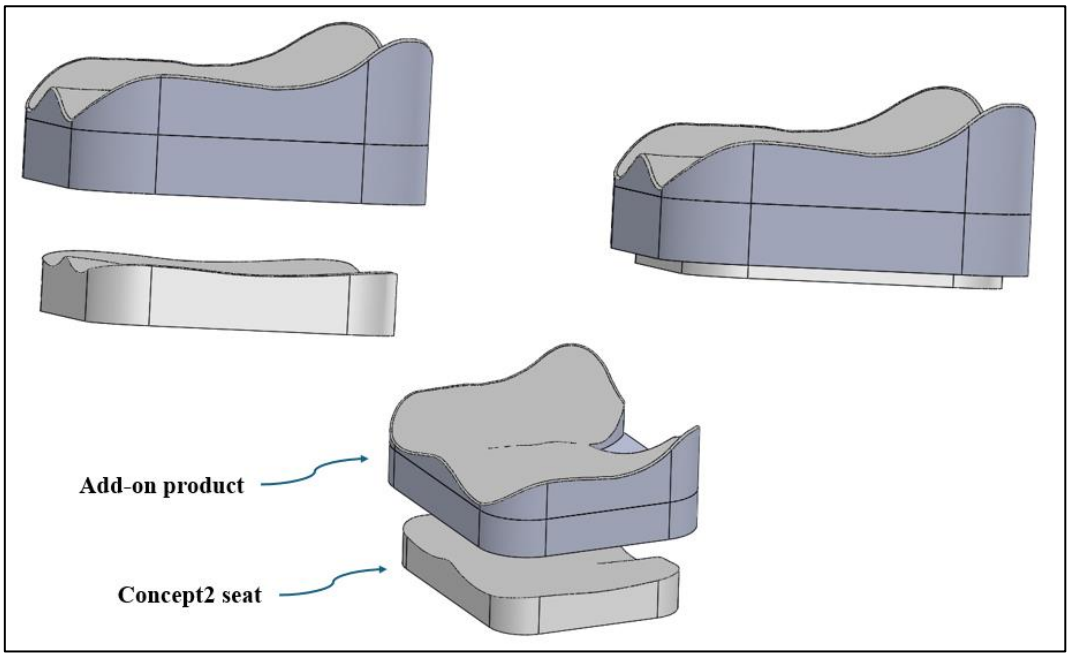

Figure 25: *Illustration of the function of the concept.*

After modelling the concept, it was 3D-printed. This was done in collaboration with Anatomic Studios, as they could provide quick and well performing prints in good material. The files of the two parts of the concept were shared separately instead of as one unit, with the reason that

the printer would perform better when the parts had a strong, flat face to be supported from. In addition to this, the bottom and the top were split in halves to fit the printer. Therefore, four separate parts were produced (see figure 26).

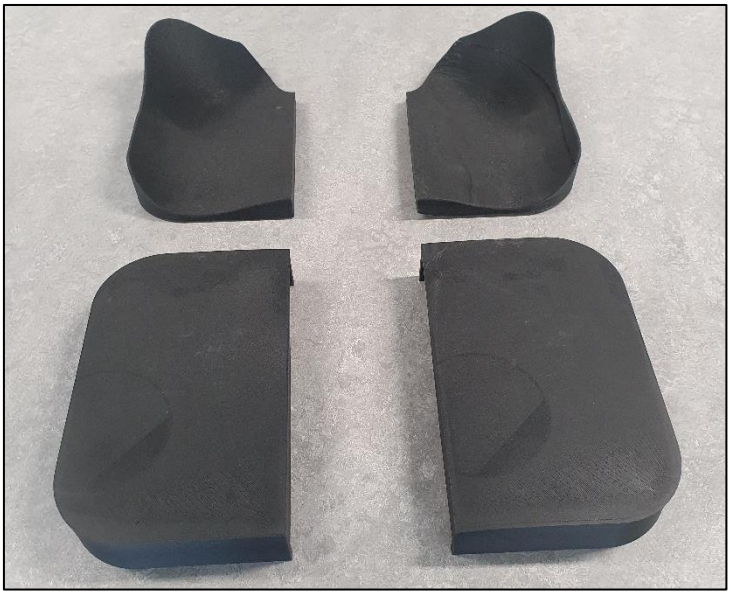

Figure 26: *3D-printed parts of the concept.*

The parts were printed with the filament Fiberlogy Mattflex 40D, which is a material that performs similar to thermoplastic elastomers, and according to the contact at Anatomic Studios, it is a good and flexible material for early prototyping. In comparison with the material that could be provided by the School of Engineering at Jönköping university, which is a PLA filament, this material was deemed to fit the application better as it is softer and more flexible.

5.4.3. Seat completion

To complete the prototype making, the four 3D-printed parts were fastened together into one piece. Initially, the parts were supposed to be glued together, but due to certain problems with the result from the 3D-printing, this was revised. Three of the four parts did not come out completely as they should have due to warping, which means that lack of adhesion between the material and the working bed caused bending and a slight material shrinkage. The temperature of the working bed was too low, and the size of the parts made it difficult for the 3D-printer to perform well. Because of this, but also because of lack of knowledge of the material used, where it was difficult to project how the glue available in the school would react to it, it was decided that double-sided tape would be used. Double-sided tape is not something that would work when constructing a final product, but for the process of making a prototype, it was deemed that it was enough. The result from this is visible in figure 27.

Figure 27: *Prototype.*

5.4.4. Concept testing

Pressure measurements

To test if the concept was an improvement to the Concept2 seat, pressure measurements were again carried out with the able-bodied rower. The tests were made in two rounds. First, the Concept2 seat was tested again because the first tests, part of the discover phase, did not provide good results with regards to the peak pressure. Tests were again performed both statically in different positions and dynamically, as well as in a fixed-seat set-up representing para-rowing. The same tests were then carried out with the add-on product.

When analyzing the results, two parameters were particularly of interest. Those were peak pressure and contact area. The idea of analyzing these parameters was to analyze and later conclude if the add-on product can provide comfortability to the user. Comfortability is often a subjective variable, but reducing the peak pressure and distributing the pressure over a larger area should hypothetically increase the levels of comfortability.

In figure 28, the peak pressure over time is plotted and compared between the Concept2 seat (green) and the add-on product (red) when rowing in a fixed-seat setting. Unfortunately, the saturation point was reached once again, causing the peak pressure to be hard to evaluate, but there are still some differences with it that is interesting. With the add-on product, peak pressure was lower in the drive phase of every stroke taken, indicating that it performs slightly better than the Concept2 seat. But, as saturation was reached, the validity of this is quite low.

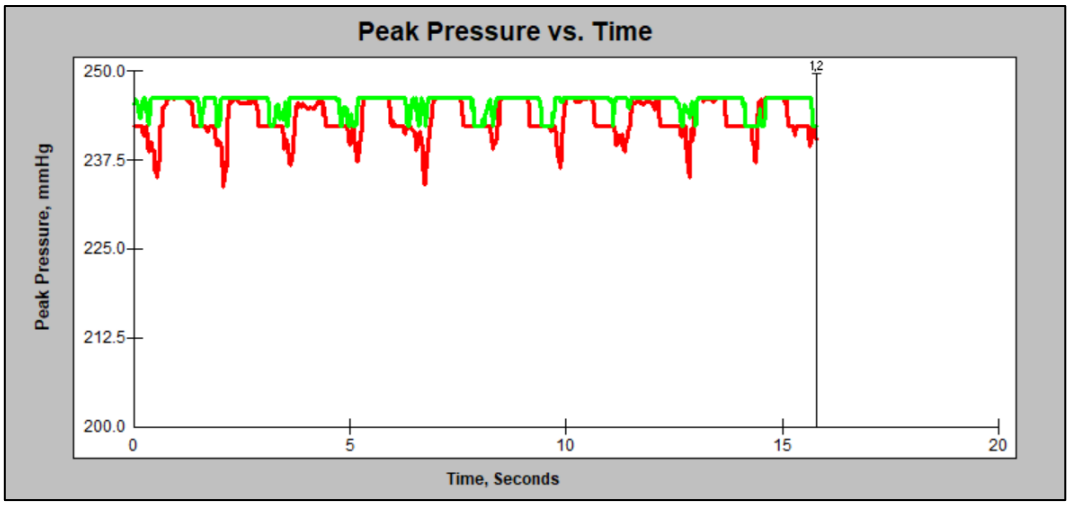

Figure 28: *Comparison of peak pressure.*

In figure 29, the contact area over time is plotted and compared. The red line represents the add-on product, and the plot shows that there is a significantly bigger contact area when rowing on it compared to when rowing on the Concept2 seat. When the pressure is distributed over a larger area, it should theoretically be reduced. This is a strong indication that the add-on product is beneficial to rowers in general.

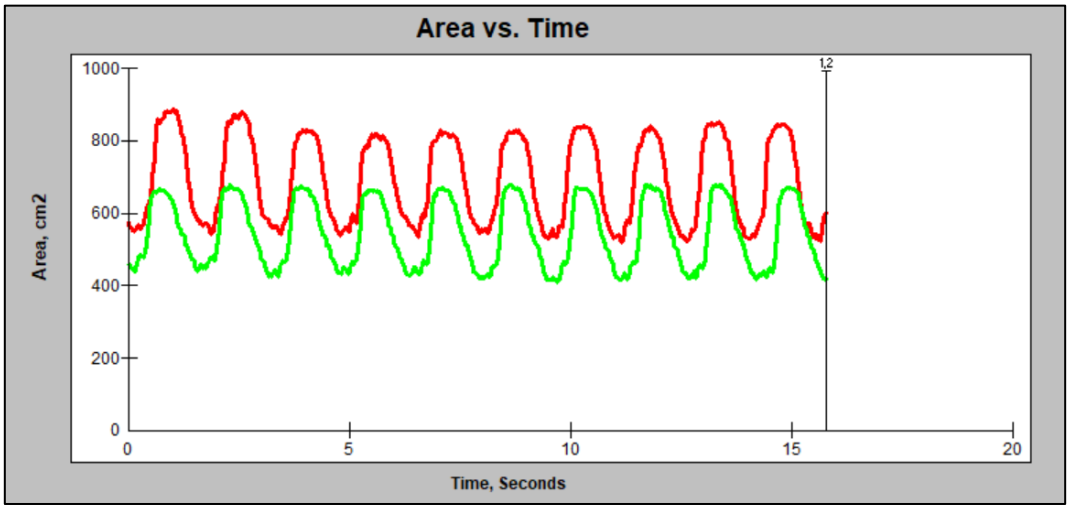

Figure 29: *Comparison of contact area.*

User feedback

Feedback from both the able-bodied rower and the para-rower was given to get an understanding of the good and the bad, but also about areas that could be further developed. As the para-rower could not test the product, the feedback given was hypothetical and based on what was seen in pictures. That is not ideal, but it was still deemed to be important. The following feedback was given from the para-rower:

- It looks very cool. It seems like it should provide more stability to the user, which is good.
- It is important that the rower can be positioned correctly, especially para-rowers, so having a seat which is tailored perfectly to the individual might be needed for PR1 and PR2 athletes. For able-bodied rowers and PR3 athletes, it might be enough with customization of the area around the ischial tuberosities.
- To provide even more stability and support, the sides could be a little higher.

As the product was tested by the able-bodied rower, more detailed feedback could be given, including the feeling of rowing with it. The feedback was as following:

- It feels very good. It is easier to find the right position and it is more stable. Therefore, it is more comfortable to sit on it.
- As the position is stable, every stroke feels the same, which gives a more effective stroke.
- In the recovery phase, when the pelvis is rotated, it is easy to find the correct position.
- Another thing making it comfortable is that the pressure to the sitting bones feels better. There is still some pressure on them, but it is more controlled.
- One downside is that the sideways support made it uncomfortable in the finish position. When the legs are straightened, the edge of the sides go into the tissues. So, lesser side support would be better.
- This material feels good. It is quite firm, but because the product is perfectly fitted, it is no problem.

6. Results

This chapter is a continuation of the deliver phase. It explains the results from the process, with a render and an explanation of the final concept.

The result of the project is presented in figures 30 and 31, with figure 30 being a render of the final concept and figure 31 showing the prototype placed upon the Concept2 seat. It is a two-part product, where the underside fits the Concept2 seat perfectly, and the upper side fits the individual´s anatomy perfectly. The method of translating individual measurements to the design of the seat, thus making the seat individualized, includes a process of scanning a vacuum pillow that has been shaped to the individual, and working with that scan to, in the end, 3D-print a product. The material for the product has not been chosen, but the general idea is that the material should be quite firm to provide stability.

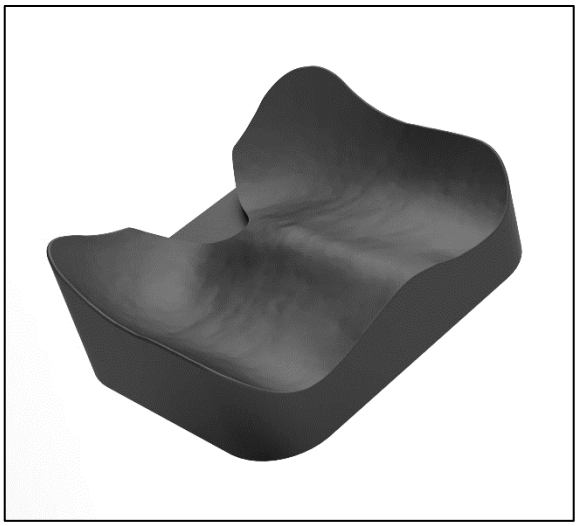

Figure 30: *Render of the final concept.*

Figure 31: *Prototype placed on the Concept2 ergometer.*

The add-on product has a sitting area of 335x270 mm. The height of the product varies depending on placement, but the maximum height, at the back, is 115 mm. Just looking at the upper part of the product, the height at the back is 70 mm, but the height at the front is only 5 mm in relation to the Concept2 seat. At the sides, the height in relation to the seating area is 45 mm at the lowest points. These measurements contribute to increasing the stability when rowing.

7. Discussion

In this chapter, the results and the overall process are discussed and analyzed with regards to the project aim, purpose, and research questions. Additionally, the project´s limitations and future work needed are deliberated.

7.1. The final concept

Through the concept testing, the final concept is deemed to be an improvement to the Concept2 seat. It helps to distribute the pressure over a larger area, which both in theory and practice reduces the peak pressure. It is, though, more difficult to evaluate the concept in comparison to other add-on products on the market. As no testing was made on either of the benchmark products, this discussion can solely be based on hypothetical thoughts and theoretical knowledge.

To assess if the purpose of this project has been addressed, that is, if the solution enables PWD to engage in rowing with better enjoyment and less risk of feeling discomfort, the list of primary needs provides a basis for discussion.

1. The product is comfortable

From testing the product, the able-bodied rower expressed that it was more comfortable than the Concept2 seat. That is just one subjective thought from one person, who also is not part of the target group, making that thought not trustful enough to base a conclusion upon. But the product has some parts and functions that hypothetically and theoretically should enhance comfort. It is designed so that it has the shape of the user´s buttocks, which spreads out the pressure more evenly on a larger area than what both the Concept2 seat and benchmark products do. Reducing the pressure on the ischial tuberosities reduces the discomfort in the buttocks (Makhsous et al., 2012), but it might also create a condition where LBP is reduced. As it is argued that substantial pressure to the ischial tuberosities can be linked to a high load of the spine (Akkarakittichoke & Janwantanakul, 2017), it should be good for back health as well. That should create better enjoyment when rowing.

It was important that there was not a pressure relief of the ischial tuberosities, but just a reduction of it. Reliving the pressure of a body part that is supposed to carry weight means that other tissues around are more relied on, causing more pressure on those tissues, which causes discomfort in the buttocks (Waongenngarm et al., 2020). That is why the design choice of not having any cutouts in the product, which lots of benchmark products has, was applied. This

phenomenon was discussed during concept testing, and the able-bodied rower expressed that the pressure to the ischial tuberosities was still there, but that it was a more pleasant pressure than before. That was great to hear, because that is at least an indication that this design choice was successful.

2. The product can provide a stable posture

The stability when rowing with the add-on product was also something that the able-bodied rower expressed was an improvement. The back support and side support provide a feeling of being stuck in a good way, where the rower does not move around in the seat. It slightly grasps the rower, creating a condition where a functional position is retrieved automatically, meaning that the rower will not have to waste energy to find a good position. This was something that the para-rower expressed was one of the most important needs, as today´s products for PR1 and PR2 athletes does not assess this at all.

Having automatic functional positioning can also benefit lower back health for all rowers. From interviews, it was discussed that having a badly fitted seat makes a rower move and trying to find a good position, which can cause a bad posture throughout the rowing stroke cycle. Bad posture can in the long run cause LBP (Nugent et al., 2021), but with the solution that this project presented, it should not be as prominent.

3. The product supports a healthy rowing stroke and position

This need is slightly connected to the previous one, as a stable posture should be positive for the rowing stroke. A healthy rowing stroke includes having a neutral or slightly anteriorly rotated pelvis in the catch position (Nugent et al., 2021), and an ability to rotate the pelvis through the drive phase into the finish position with little flexion of the lumbar spine (Trompeter et al., 2021). This is difficult to assess with the equipment and time available for this project, but the subjective opinion from the able-bodied rower was that the position felt great, where it was easy to rotate the pelvis from the finish position into the recovery phase. It is an indication that the product supports a healthy rowing stroke, but a weak indication. It relies on one person´s thoughts, as well as on a test which included only ten rowing strokes. Trompeter et al. (2021) argue that altered technique due to fatigue is one of the causes to LBP, so it might be the case that the same thing would happen when rowing with the add-on product. It is hard to evaluate without a detailed and thorough testing method, like a motion analysis, and without exposing the participant to fatigue. The stable posture does at least create a condition where it could be easier to keep the same position through a long period of time.

4. The product is reliable

The reliability of the product is mainly based on the how trustful it is. Regarding this, the add-on product is deemed to be good. It might require more testing to assess if it can keep the shape for a significant amount of time, but that also requires that a material is chosen and evaluated.

One part of the add-on product that enhances the reliability is the “hat-design”. Compared to other add-on products, which often are placed upon the rowing seat, the product developed will without a doubt be placed in the same position throughout the entire rowing cycle. It cannot move because it grasps the standard seat, but also because the underside of the product has the exact shape that fits, in this case, the Concept2 seat. This contributes to the purpose of having a lesser risk of discomfort.

5. The product is beneficial for para-rowers

A big question about this product is if it is compatible to para-rowers, and the opinion is that it is. Because of certain constraints, it was only possible to test the seat with an able-bodied rower, which made it natural to also design the seat according to that individual. But the target group was always in mind when developing the product, and there are features that make this product applicable to para-rowers. Wheelchair users have a greater risk of getting pressure injuries, and a poorly fitted seat could contribute negatively to this, but also to discomfort and postural imbalance (Hosking, 2023). The idea that the rowing seat is individualized to the point where the seat has the exact shape of the user´s buttocks contribute to a perfectly fitted seat where the pressure is distributed better, which then should lower the risk of feeling discomfort and getting pressure injuries. Wheelchair users do often have less tissue thickness and a sharper contour of the buttocks (Sonenblum et al., 2020), which further indicates that detailed individualization is necessary to provide a comfortable experience.

Another feature making the add-on product compatible to para-rowers is the support that is provides. Stability is an important factor, and this product assesses that. But there needs to be further testing and evaluation to really know if there is enough support. For the able-bodied rower, it was almost more than enough, but for other rowers, and specifically para-rowers, this can differ from person to person. The body function for para-rowers can differ a lot, and every rower can have different opinions of what is needed for them. That is another reason why this concept and product is beneficial to para-rowers. It is easily customizable and can be designed to the individual´s needs.

The add-on product is especially beneficial to the para-rowing community as it provides something that is not available right now. Hypothetically, it fulfills the purpose of having better enjoyment and a lesser risk of feeling discomfort when rowing. Sports participation is important, especially for PWD to enhance the feeling of inclusion and belonging (Engdahl-Høgåsen & Bentzen, 2023). Being able to enjoy sports can therefore be crucial, and it can even promote social sustainability. Number three of the Sustainable Development Goals developed by the United Nations reads: "Ensure healthy lives and promote well-being for all at all ages". The target group for this product is narrow, but if a few people can benefit from it and feel better both physically and mentally, it is a great outcome.

6. The method to get individual measurements is easy to handle

The method to get relevant anatomical measurements that was utilized for this concept felt necessary to provide all the features that would benefit para-rowers the most. That includes, specifically, the shape of the upper side of the product that fits the individual perfectly. But there are drawbacks with this method. It is not easy to handle. The idea from the start included finding a method where the individuals themselves could make easy measurements that could be translated into the design. Examples of that are Concept C and Concept D from concept generation. But when reading through literature, talking to potential customers, and doing the concept selection, it became clear that para-rowers would benefit the most from having perfectly fitted seats. For this product to reach the market it is, though, necessary to find a method that is easier and more accessible. For now, it is probably too expensive to implement as a business idea.

Even though this method is not easy, it performed well. Comparing the results of the concept to the target specifications, almost all of them were achieved. In table 8, this is visible. A green mark indicates that the target value has been achieved, and a red mark indicates the opposite. A yellow mark means that the concept needs further development and evaluation. All target values were achieved except for the last two because the material needs to be defined for them to be evaluated. Therefore, it is deemed that the process was successful, just in terms of performance of the product.

Table 8: *Validation of product specification.*

Metric no.	Need nos.	Metric	Unit	Target value	Source
1	1.1	Shape of product	Subj.	Exact shape of user.	Interviews
2	1.2	Peak pressure of coccyx	Mmhg	0	Interviews
3	1.3	Peak pressure of ischial tuberosities	Mmhg	<Concept2	Literature review
4	1.4 2.1 3.1 5.1	Functional positioning	Subj.	Yes	Interviews
5	2.2 3.2	Back support	Mm	Yes	Literature review
6	2.3	Sideways support	Mm	Yes	Interviews
7	3.2 3.3	Height of product (in relation to Concept2 seat)	Mm	<75	Market research
8	3.3 5.2	Seating area size	Mm^2	>300x240 <340x280	Concept2 measurements
9	3.4	Cutouts in product	Yes/no	No	Interviews
10	4.2 5.2	Shape of underside of product	Subj.	Exact shape of Concept2 seating area.	Project goal
11	4.2	Non-slip surface	Yes/no	Yes	Market research
12	4.3	Machine washable cover	Yes/no	Yes	Market research

7.2. Research questions

RQ1: *How can an individualized add-on product for rowing seats be designed to reduce discomfort for para-rowers?*

This is a question that still needs a lot more evaluation to answer. There is an indication that the seating area should fit the user perfectly to reduce discomfort the most, but there are other design choices that need to be assessed more. What has been confirmed is that back support and sideways support both can create better stability, and that it also provides a larger contact area that presumably distributes the pressure better. But how much support can there be without inhibiting the rowing stroke? And how much is needed to reduce the discomfort to a level that the rower feels comfortable with? These are questions that are still to be considered before the research question can be fully elaborated and answered.

By individualizing the product, this question can probably be answered differently depending on the user. This was visible when getting user feedback. When talking to the para-rower, it was stated that more sideways support would be better, but when talking to the able-bodied rower, it was stated that the sideways support could be lowered. Different users have different needs, and therefore, an established answer might not be possible.

RQ2: *How can individual anatomical measurements be translated into, and change, the design of the product to enhance the comfortability of the individual?*

The challenges to answering this question lie in the needs of the user. Throughout the project, there were mixed ideas of how complicated the method to translate individual anatomical measurements into the design should be, and there are two sides to it. Just focusing on the best possible design for the individuals, it became clear that the most complicated method, with scanning, would benefit the users the most regarding comfortability. There is, though, one drawback with this method regarding the design options it provides. Measurements of body parts change in different postures (Vasile et al., 2021), and the rowing stroke itself is dynamic. Having a measuring method where the rower sits statically in one position might therefore not provide a perfectly fitted seat in all positions that is obtained by the rower in the rowing stroke. This is particularly questionable for able-bodied rowers and PR3 rowers, as they can utilize their legs and therefore get into more unique positions with the lower body. But even for PR1 and PR2 athletes, this can be a problem as they are not completely static in their movements either, even if the legs are not part of the stroke.

The other side to it is about accessibility and costs. The complicity of this method brings up the costs, which can make it inaccessible to many. Having an easier method, where one-dimensional tools are utilized would make it a lot more accessible, but it would also make it less functional. But again, what is enough to make it more comfortable for the user? Maybe it is enough to just have simple measurements of the placement of the ischial tuberosities. This is something that should be tried out, because having a simpler method would make it easier to commercialize this idea and to reach out to more people.

7.3. Limitations

A limitation of this project is that there were not enough participants to, with certainty, get valuable insights and to draw valid conclusions. Through the development process, three people with three different backgrounds provided thoughts and insights about the problem described. It helped a lot, and it contributed to increased understanding of the problem area in general, but to ensure that there was substance in the information given, it would have been better if more people were contacted. That would also have provided more knowledge to base choices and conclusions upon.

The concept in its entirety has the limitation that it was developed for an able-bodied rower, even though the target group for this project was para-rowers. It was a necessity, but it made it

difficult to solely design it for rowers with a disability. Even though the concept is deemed to benefit para-rowers, it would have been more substance in that statement if the product was designed according to a para-rower´s anatomical measurements, and then also tested by that para-rower. For example, the able-bodied rower thought that the stability was enhanced with the add-on product, but it is hard to use that statement when evaluating how stable it is for rowers who do not have the same postural control or the same movement possibilities.

The research itself did also have lots of connection to able-bodied rowing. There were several reasons for that. It was mainly included to give more width to the problem and to create a justification for the project. But another reason for it, which can be a limitation of the project, is that the project idea from the beginning was to develop a product for all rowers, but particularly for able-bodied rowers. Even if the purpose and the target group was changed before the project started, it made it difficult to solely focus on para-rowers and the issues that they face. Therefore, it might have limited the work slightly.

A final limitation is that only one iteration of the product development process was included in the project. When testing the concept and getting user feedback, it is important to reflect on that information to refine the concept (Ulrich et al., 2020). A reflection was made, but there was no time available to go back in the process to refine the concept.

7.4. Future work

To finalize the selected concept, there needs to be more focus on the material. Right now, the concept includes a description of the material as “quite firm”, but there needs to be analyses of the performance, the cost, and the environmental impacts. While discussing with Blatchford Ortopedi when modeling the concept, discussions were also held regarding how to produce the seat and what materials should be included. Through short discussions, Thermoplastic Polyurethane (TPU) and PA12 (Nylon) came up as potential choices, but an analysis regarding advantages and disadvantages with several materials should be done.

When refining the concept, a concept testing method that could be used to evaluate the performance is motion analysis. Being stable in the seat can contribute to a more consistent rowing stroke, but it does not mean that the rowing stroke is healthy. LBP is a prominent issue amongst rowers, and it arises from altered technique and bad rotation of the pelvis (Nugent et al., 2021). To assess if the add-on product can have positive effects on this, a motion analysis is required.

8. Conclusion

This project focused on the design features of an add-on product for rowing seats to make it more comfortable and enjoyable for para-rowers to row. By following the Double Diamond Model, the project goal, consisting of developing a prototype of an add-on product that is designed according to an individual´s anatomical measurements, was achieved. The findings and the results indicate that comfortability in rowing is enhanced with having a seat that fits the user perfectly. This creates a condition where the contact area is larger, which contributes to a more evenly spread-out pressure on the buttocks. Reducing the pressure of the ischial tuberosities will enhance comfortability, and it can also help to prevent LBP from arising.

The final concept provides support to the rower both to the back and on the sides, which increases stability when rowing. In combination with a perfectly fitted contact area, this contributes to a functional positioning which can help to provide healthy rowing mechanics. This enhances comfortability and stability, which will make it more enjoyable to row.

This project has provided a good base for future work, but there is a lot that needs to be done for it to reach the market. More testing and evaluation are required, as well as material selection. Additionally, the methodology to translate individual anatomical measurements complicates the concept, whereas the aim for it is to be simple and feasible. Therefore, this needs further consideration.

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Appendices

Appendix A – Interview guide able-bodied rower

What is your experience when it comes to rowing and rowing seats? For example, have you tested many rowing seats? What have you changed?

What is the difference between different rowing seats?

What is your perception of the rowing seat that you are using today? Why do you use that one?

What is your perception of add-on products for rowing seats?

Have you ever felt pain in your lower back? If so, how did it happen? How severe was the pain?

Describe your relation to comfort/discomfort in rowing. For example: In which situations do you feel discomfort? Where on the body do you feel the discomfort/pain?

How does discomfort in the buttocks arise?

What body parts or measurements do you feel are important to consider when designing an individualized add-on product for the rowing seat?

What do you think is important to include in the design to increase the level of comfort?

Appendix A – Interview guide para-rower

As someone who has experience of both rowing and para-rowing, what would you say is the biggest and most significant difference?

What are the differences between rowing and para-rowing when it comes to rowing seats?

What is your experience when it comes to rowing and rowing seats? For example, have you tested many rowing seats? What have you changed?

What is your perception of the rowing seat that you are using today? Why do you use that one?

What is your perception of add-on products for rowing seats?

I have noticed that the seat for para-rowers differs a lot, even within the different classes. Is there something general that is applied to everyone? If so, what is that?

Describe your relation to comfort/discomfort in rowing. For example: In which situations do you feel discomfort? Where on the body do you feel the discomfort/pain? Risk of abrasions? What about the lower back?

What body parts or measurements do you feel are important to consider when designing an individualized add-on product for the rowing seat?

What do you think is important to include in the design to increase the level of comfort?

Appendix A – Interview guide seating expert

What is important to think about when designing a seat?

Which parts of the area around the buttocks are important to take into account?

The ischial tuberosities have been identified as an important part. How is the pressure on the ischial tuberosities reduced in the best possible way?

How is PWD affected by a standard seat, which may not fit them anatomically, versus an individualized seat that fits them well?

How could the seat be designed to position the pelvis in a neutral, or slight anterior, position?

What methods can be utilized to get necessary casts or measurements of a person whose seat later will be individualized?

Do these methods differ depending on the patient's type of functional impairment? If so, what might be important to consider? Is there something that works for everyone?

How do measurements vary depending on the position of the patient? For example, sitting versus standing? What is important to think about regarding this?

It might be important that the method utilized is simple. What simple methods can work?

Appendix B – Self-assessment form

Form for Self-Assessment of Ethical Issues in Degree Projects[1] at the School of Health and Welfare

Date:	2024-02-28
Title of the degree project	Development of an individualized add-on product for rowing seats to enhance the comfortability of para-rowers.
Student(s)[2]:	Ludvig Dahlquist
Student's/Students' e-mail address:	dalu22gv@student.ju.se
Degree programme:	MASTech – Product development specialized in assistive technology
Education cycle:	2024
Supervisor:	Louise Bæk-Larsen Marisol Rico Cortez
Supervisor's e-mail address:	louise.baek-larsen@ju.se marisol.ricocortez@ju.se

Degree projects at the School of Health and Welfare, Jönköping University, must comply with the ethical principles expressed in the Act concerning the Ethical Review of Research Involving Humans (Etikprövningslagen, "EtRAct"). This form is a tool for reviewing ethical issues related to the degree project.

The student and the supervisor carefully go through the form together, identify potential ethical problems, and agree on how these should be addressed. If there is still doubt, the course examiners needs to be consulted.

Research that falls within the EtRAct must be reviewed by the Swedish Ethical Review Authority[3].

The distinction and boundary between research and degree projects are described in Part A.

Part B deals with what falls under the EtRAct and ethical principles that are important to consider **before** conducting a study/degree project.

The Self-Assessment of Ethical Issues in Degree Projects should always be approved by the course examiner before the degree project is started.

[1] The form also applies to quality improvement projects in health care and social welfare.
[2]Alternatively, the implementer of quality improvement projects in health care and social welfare.
[3] https://etikprovning.se/

Part A: Is this a research study?

The purpose of the questions in Part A is to determine if the study is to be regarded as research. A degree project is not usually considered as research and thus cannot be reviewed by the Swedish Ethical Review Authority. Under certain circumstances, however, a degree project may be research, namely if:

1. the intention is to publish it in a scientific journal
2. it addresses a scientific question and has a design that can answer that question
3. it is led by researchers within the discipline, either as part of a larger project or with a researcher as the supervisor.

Is the study research in these three respects?

☐ YES (The study needs to be reviewed by the Swedish Ethical Review Authority.)

☒ NO (Proceed to Parts B and C.)

Part B: Does the degree project contain what is regarded as ethically sensitive according to the Ethical Review of Research Involving Humans?

The questions in Part B aim to examine;

1. if the degree project has such ethical problems that if it were research - it would require to be reviewd by the Ethics Review Authority. In these cases, the degree project must not be completed.
2. how ethical principles are handled in the degree project.

If any of the questions are answered with "not sure" or "yes" (questions 1-13) and with "not sure" or "no" (questions 14-23), an in-depth ethical reflection involving students and supervisors should be carried out on how these ethical risks and problems must be managed or how the study can be modified to counteract identified risks. In these cases, the course examiner should also be involved in the self-assessment and the ethical reflection to make a final decision on the implementation of the degree project. **The ethical self-assessment must always be approved by the examiner before the degree project begins.**

		Yes	Not sure	No
1	Does the study intend to process what the General Data Protection Regulation (GDPR) considers to be sensitive personal data, i.e., data that at any stage can be linked to a person and that reveals racial or ethnic origin, political opinions, religious or philosophical beliefs, trade union membership, or information about an individual's health or sex life?	☐	☐	☒
2	Does the study intend to collect and process personal data relating to violations of the law that involve criminal offences, convictions in criminal proceedings, penal law sanctions, or administrative deprivation of liberty?	☐	☐	☒
		Yes	**Not sure**	**No**

3	Does the study intend to include people who can be identified as vulnerable groups and / or people who are dependent on the person who recruits or carries out the data collection	☒	☐	☐
4	Does the study intend to include children (persons under the age of 18)	☐	☐	☒
5	Does the study involve a physical intervention on the participants, eg some type of physical examination or sampling (also something that is part of normal routines, but is also part of the study)	☒	☐	☐
6	Is the purpose of the study to affect the participants physically or psychologically eg, ?	☐	☐	☒
7	Are there an apparent risk to harm the participants physically or psychilogically?	☐	☐	☒
8	Will the study use biological material that can be traced to an identifiable individual or deceased person (e.g., blood samples or tissue specimens)?	☐	☐	☒
9	Can voluntariness be questioned (e.g., vulnerable groups, such as children, people with cognitive impairment or mental disabilities, or individuals in a dependent relationship to the principal investigator, such as a patient or student)?	☐	☐	☒
10	Will the study involve individuals with limited autonomy (for instance individuals with cognitive difficulties, minors), whose understanding of the meaning of the consent is limited?	☐	☐	☒
	Selection of participants and social vulnerability			
11	Do the participants belong to a particularly vulnerable or disadvantaged group in society (a minority group)?	☒	☐	☐
12	Will the study involve the establishment of a personal register where data can be linked to a physical person?	☐	☐	☒
	Informed consent			
13	Does the information letter contain persuasive formulations (implying that the person must or should participate, without showing full respect for the choice, for example mildly persuasive formulations, such as “thanks in advance”)?	☐	☐	☒
14	Is the study described in such a manner so that the participants understand its purpose and structure, and what participation in the project entails (e.g., number of visits, duration of the project, and written in easy-to-understand Swedish without technical terms or professional jargon)?	☒	☐	☐
15	Is it clearly stated in the written information to the participant that the participation in the study is entirely voluntary?	☒	☐	☐
16	Will informed consent be obtained as a part of the study (in other words, will the participants receive full information about the study and/or the opportunity to opt out from participation?	☒	☐	☐
17	Is it clearly stated that the participants may choose not to participate, without prejudice to the participants’ being offered care or treatment or, if relating to students, it affecting their grades?	☒	☐	☐

		Yes	**Not sure**	**No**
18	Is it clearly stated that the participants may discontinue the participation at any time and without the need to state any reason, without prejudice to	☒	☐	☐

	the participants' being offered care or treatment or, if relating to students, it affecting their grades?			
	Confidentiality and the security of the participants			
19	Are there procedures in place to ensure confidentiality in the collection of data?	☒	☐	☐
20	Are the results/findings described in such a manner so that the participants' identity remains confidential, meaning that they cannot be identified afterwards (including a minimal potential for reverse identification)?	☐	☒	☐
21	Are there procedures to ensure confidentiality?	☒	☐	☐
22	Are there clear routines for ensuring that the collected data material is handled according to GDPR?	☒	☐	☐
	Degree project results and/or findings			
23	Are there reasons to offer participants the opportunity to obtain a copy of or otherwise gain access to the degree project results/findings?	☒	☐	☐

Appendix C – Written answer to ethical issues

From the Form for Self-Assessment of Ethical Issues, there are some questions that need a further explanation and an in-depth reflection regarding the ethical risks. These are answered down below.

3. Does the study intend to include people who can be identified as vulnerable groups and / or people who are dependent on the person who recruits or carries out the data collection? (YES)
11. Do the participants belong to a particularly vulnerable or disadvantaged group in society (a minority group)? (YES)

The interview process in the project will include a para-rower who is paraplegic, which means that the study includes an individual from a minority/vulnerable group. As the target group of the study is para-rowers, it is important to include a para-rower in the process to gain knowledge and to further explore the problem and the potential solutions. The interview process will stick to information regarding rowing, and it will not include discussions about previous medical history or topics that might be sensitive to the interviewee.

5. Does the study involve a physical intervention on the participants, eg some type of physical examination or sampling (also something that is part of normal routines, but is also part of the study) (YES)

The study will involve pressure measuring of a Concept2 seat. This testing will include both able-bodied rowing set-up (sliding seat) and para-rowing set-up (fixed seat) to compare differences in pressure distribution. For these tests, I aim to collaborate only with an able-bodied rower, and not a para-rower. The physical intervention will only include rowing, which the able-bodied rower is very comfortable with. Therefore, I do not see any substantial risk.

20. Are the results/findings described in such a manner so that the participants' identity remains confidential, meaning that they cannot be identified afterwards (including a minimal potential for reverse identification)? (NOT SURE)

The reason why the answer "not sure" was given to this question is that para-rowers are quite a small group of individuals. The study will only include relevant information to answer the research questions, and no personal facts that could be linked to an individual will be presented. But, as the target group is quite small, there might be a risk that someone can trace some answers to a certain individual. This risk is not that likely to happen though, because results/findings covering the rowing seat and the rowing stroke should be hard to trace back to an individual. The only fact that I will present about the participant is that he/she is an elite para-rower with a background from able-bodied rowing, which is not enough to identify someone.

Appendix D – Written consent form interview

This is an informed consent form for participation in an interview. The information from the interview will be used as a resource for the development of an add-on product for rowing seats.

Title of research

Development of an individualized add-on product for rowing seats to enhance comfortability of para-rowers.

Research background and study aim

This research is a part of a master thesis conducted in the program *Master in product development – specialization in assistive technology (MASTech)*. It is a program focusing on innovative development of assistive devices for people with disabilities.

The thesis involves developing an add-on product for rowing seats that could enhance comfort when rowing. This idea originates from Göran Andersson, a veteran rower, that often feels discomfort when rowing, primarily in the buttocks. Research has found that discomfort is quite common, and that almost every rower feels pain in the lower back. Regular rowing is a full body workout with the use of the lower limbs, the trunk, and the upper limbs, but in para-rowing, this can differ depending on the type of disability of the rower. A more isolated force generation leads to greater risk of injuries.

Everybody is different, and regular rowing seats (Concept 2 for example) do not fit everyone. Para-rowers are not only different in anatomical measurements, but also in body function. There are reasons to believe that individualization is necessary for everyone to enjoy the sport of rowing to the fullest, so the idea is to find a method where certain measurements could be translated into the design of an add-on product to the rowing seat. As the program specializes in assistive technology, the purpose of this thesis is to develop a solution to the issue of discomfort for para-rowers. A secondary purpose is, though, to make the solution applicable to all rowers.

Statement of activity

There will be a semi-structured interview, with a preliminary duration of 30 minutes, where we discuss rowing/para-rowing in general, but specifically the configuration of the seat.

Purpose of activity

The information gained from the interview will play a part in getting knowledge, but also in identifying user needs and wishes to guide the development of the product.

Risks to the participant

There are no potential risks in being part of this interview.

Benefits to the participant

The participant will not benefit from participating in the study directly, but the answers given could contribute to the development of the product. The product can potentially in the future be used by the participant.

Confidentiality and data handling

In order to maintain participant anonymity, no information of personal identity will be given in the thesis. Any information gathered that is not relevant to the study will not be presented or in any way shared.

Voluntary participation

Participating in this interview is a voluntary decision. The participant can withdraw from being part of the study whenever they want, even after the interview has been conducted. During the interview, the participant has the right to not answer certain questions if they do not want to.

If the participant wants to withdraw from the study afterwards, please contact the student and the supervisors. The information gathered will then be erased from the study.

Consent statement

I have read and understood the information provided in the consent form, and I agree to participate in this study.

Appendix D – Written consent form testing

This is an informed consent form for participation in an intervention containing pressure measuring of a Concept2 rowing seat. The information from the intervention will be used as a resource for the development of an add-on product for rowing seats. Potentially, pressure measuring of a prototype will also be a part of the intervention.

Title of research

Development of an individualized add-on product for rowing seats to enhance comfortability of para-rowers.

Research background and study aim

This research is a part of a master thesis conducted in the program *Master in product development – specialization in assistive technology (MASTech)*. It is a program focusing on innovative development of assistive devices for people with disabilities.

The thesis involves developing an add on product for rowing seats that could enhance comfort when rowing. This idea originates from Göran Andersson, a veteran rower, that often feels discomfort when rowing, primarily in the buttocks. Research has found that discomfort is quite common, and that almost every rower feels pain in the lower back. Regular rowing is a full body workout with the use of the lower limbs, the trunk, and the upper limbs, but in para-rowing, this can differ depending on the type of disability of the rower. A more isolated force generation leads to greater risk of injuries.

Everybody is different, and regular rowing seats (Concept 2 for example) do not fit everyone. Para-rowers are not only different in anatomical measurements, but also in body function. There are reasons to believe that individualization is necessary for everyone to enjoy the sport of rowing to the fullest, so the idea is to find a method where certain measurements could be translated into the design of an add-on product to the rowing seat. As the program specializes in assistive technology, the purpose of this thesis is to develop a solution to the issue of discomfort for para-rowers. A secondary purpose is, though, to make the solution applicable to all rowers.

Statement of activity

The participant will perform several cycles of the rowing stroke on a concept2 seat. The intervention will be divided into two sessions. The first session includes rowing with normal

settings of the rowing seat (sliding seat), like an able-bodied rower would usually do, and the second intervention includes rowing with a fixed seat. The legs can thereby not be used in the rowing stroke, which is the case for lots of para-rowers.

The seat will be modified with equipment for pressure measuring.

In the case that a prototype has been developed, the participant will perform the same tests but with the developed product.

Purpose of activity

To identify points of pressure in the buttocks, and to see how the pressure is distributed throughout the rowing stroke cycle. This information might provide important aspects in identifying the problem.

Also, doing the same measurements with a prototype will create a base for comparison between the Concept2 seat and the developed seat. This way, the prototype can be evaluated.

Risks to the participant

There are no apparent risks with participating in this intervention. If you read this, you are probably very comfortable at the rowing ergometer, so there should not be any risks involved.

Benefits to the participant

The participant will not benefit from participating in the study directly, but the results provided could contribute to the development of the product. The product could potentially in the future be used by the participant.

Confidentiality and data handling

In order to maintain participant anonymity, no information of personal identity will be given in the thesis. Any information gathered that is not relevant to the study will not be presented or in any way shared.

Voluntary participation

Participating in this intervention is a completely voluntary decision. The participant can withdraw from being part of the study whenever they want, even during and after the intervention.

If the participant wants to withdraw from the study afterwards, please contact the student and the supervisors. The information will then be erased from the study.

Consent statement

I have read and understood the information provided in the consent form, and I agree to participate in this study.