Essential design parameters for a Olympic trapeze harness

An exploration towards a new design

Essential design parameters for a Olympic trapeze harness

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"Experience inspires, data proves, thoughts create"

This was the first thought after having studied all the gathered data while staring at a trapeze harness. How did I get to this point in the project?

A quote that is summarises my path towards graduation. Throughout the project I have been inspired by the experiences of others and listened with great care to find out why the experience is the way it is and what factors lay at its basis. A great deal of the time I have spend to find an logic answer or explaination to why this is true. In most cases too much time, as I was absorbed in finding an answer. I found myself abruptly dashing from one question to the next hoping to find prove in between. An inquisitive and chaotic way of working that eventually led to an unforeseen outcome.

(The 'experience inspires - part was added by Quiel. So not my work, but a prefect fit :))

Prologue

I proudly present you my master's thesis. For many a shock, relieve or confirmation that they were able to witness this very moment. When I first walked through the doors of the faculty in 2011 I set the goal to finish a master, as I found myself privileged to study at an university. However, not mentioning how long I was going to take to fulfill this goal. Anyway, we are here now and it has been a battle.

I want to thank....

Arjen for his critical, but great supervision and guidance. Most of the times I dropped by Arjen's office unannounced, because I want to share something I just found out or had done. You have always found the time to listen and talk about the project, sharing the enthusiasm with a critical view. Especially those critical remarks were the ones that motivated me the most.

Quiel for her awesome coaching and guidance. We both have the tendency to jump from idea to idea, resulted in great brainstorming sessions to find answer or rationalise an experiment outcome. Usually meetings took longer than planned, because other subjects with little, or mostly none, connection to the project were being discussed.

Douwe for his fabulous coaching and criticism, resulting in numerous discussions and occasional laughs. You supported the hands-on-approach of quick and small experiments. Keep those healthy lunches going!

My parents who always supported me with whatever I was doing. Of course, like any parent will have experienced, our opinions were not always in line, but I consider that to be something beautiful. You have given me the opportunity to study and always supported me in my quest, I will be forever grateful. Let's keep those discussion going though!

Close and distant friends for the ever motivational and supportive question: "When are you finally done studying?" Always loved to answer this question with the greatest enthusiasm. Throughout the years you might have wondered why I was doing what I was doing, but I was just doing my thing. In many cases studying might not have always stood at the top of my agenda, because I found myself preoccupied and absorbed by study-unrelated activities. However, never you have led me down and supported me all the way. Thanks to all!

All members, coaches and staff of the Dutch Sailing Team who have participated in user studies or have shed their light on matters with relation to the trapeze harness.

Koen, Hans and Dorien for their memorable jokes and good moods.

Executive summary

Executive summary

Within the Dutch Sailing Organisation research concerning the trapeze harness has been limited. Before starting the research no concrete information concerning the interaction between a trapeze harness and the human body or important design requirements regarding the influence of new boat designs were documented. The purpose of this research was to develop a better understanding of the previously mentioned points and put forth a new harness design based on the insights that were gathered. This thesis has been divided into two parts; part one presenting the results and part two presenting the origin and foundation for the results.

Part one;

In thesis the trade off between freedom of movement and support was identified to be the main decision criteria for a trapeze harness. The degree of freedom of movement or support is dependent on multiple factors. In order to provide an overview of the influence of these factors on the trade off, a tool was developed allowing to program the design requirements of a trapeze harness. The programming board consisted of seven input parameters split into two layers determining the degree of freedom of movement or support a trapeze harness is supposed to provide according to the given input. The primary layer determines the basis for the harness with on water conditions, physical conditioning and position in the boat as determinants. The secondary layer consists of design elements that affect the trade off, but are less influential. In these layer material thickness, harness type, spreader bar width and back curvature were the input parameters. Based on the input of the parameters on the programming board a design direction according to specific design requirements was produced suiting the degree of freedom or support.

Besides the programming tool, a redesign proposal was presented with the main objective to improve the freedom of movement of the trapeze harness. This was achieved by altering the strap orientation and separating the functions of the trapeze harness, resulting in a trapeze harness with an upper and lower half and a detached lumbar support strap. For validation of the design a prototype that embodied the design elements was fabricated and tested. Based on the results of this study, the trapeze harness was redesigned. Producing a trapeze harness with a lumbar support strap that was stiffer and increased in height. As a result the initial open space on the back was reduced and more support was created, but still maintaining the mobile properties.

Part two;

The basis for the results could be found in five main parts, consisting of a desk research and four user studies.

In the first chapter the primary steps towards understanding the trapeze harness were taken. Identifying what design requirements are important for a trapeze harness and why. The trapeze harness was simplified to its most simple form; one strap around the hips and two over the shoulders. Simplifying the harness made the interaction between sailor and body easier to understand, resulting in the formulation of a model to quantify the forces on the hips and shoulders while hiking at 90 degrees angle relative to the mast.

In user study one interviews with twelve sailors were conducted to obtain a better understanding of choice criteria for trapeze harness and how the harness was experienced. The results indicated that on water conditions and physical condition were main determinants for the degree of freedom or support a trapeze harness had to provide. Additionally, sailors indicated that trapeze harness should enhance the feeling for the boat.

User study two consisted of fitting test of four trapeze harnesses with nine participants who had little to no sailing experience. During the study, participants rated comfort of a trapeze by expressing it in the degree of support a harness gave. Support was identified by material stiffness and cushioning.

The third user study focused on identifying

finding that the body deforms to fit the harness

lower back pressure is found important but is missing equal distribution on the back leads to a more comfortable and supportive harness

Glossary

Bow: The front part of a boat.

Drift: The magnitude of sideway speed caused by wind or current.

Jib: A sail on the front part of the boat between the mast and forestay.

Gennaker: An asymmetrical spinnaker that is attached to the top of the mast and bow or bowsprit.

Gunwale: The outer edge of the deck.

Hooking in: Attaching the trapeze wire to the hook on the trapeze harness

Gybing: Basic manoeuvre that is the opposite of tacking. By turning the stern of the boat through the wind so that the wind changes from one side of the boat to the other side. Less common manoeuvre than tacking and mostly performed during reaching or downwind runs.

Leg: A section between two buoys or waypoints.
Leeward: The side where the wind is blowing to seen from a boat.

Mainsail: The sail attached to the back of a mast, in most cases supported by a beam on the bottom.

PFD: Personal Floatation Device or buoyancy aid, an often obliged piece of sailing gear keeping a person afloat during an overboard situation.

Planing: The state were a certain boat speed is reached were the hull gets lifted from the water by hydrodynamic lift.

Sheet: A rope that is pulled or released to determine the position of the sail.

Sheeting: Pulling and releasing of the sheet. Mostly done in wavy water or when the wind is blowing hard.

Spinnaker: A large flown at the front side of the boat in downwind legs, more or less handled like a kit.
Starboard: The right side of the boat.

Reaching: Sailing when the wind is coming from the side.

Tacking: Basic manoeuvre that is the opposite of jibing. By turning the bow of the boat through the wind so that the wind changes from one side of the boat to the other side. During the upwind run this is a very important manoeuvre.

Wire: Referring to the trapeze wire. A steel wire that is attached to the mast allowing the sailor to hang his / her weight on and thereby generating a righting moment.

Research planning

A design process is rarely lineair, instead it hits rock bottom or requires to back to a previous point in order to move on. The schematic overview of the process in Figure *01* is an idealistic situation and does not take the workings human brain into account or any other influence from the outside. This said, the overview provided a basis to work from and now helps the reader to understand how it was possible to get towards an end result. The main outline of the project was divided into three distinctive phases, where one experiences, proves and creates.

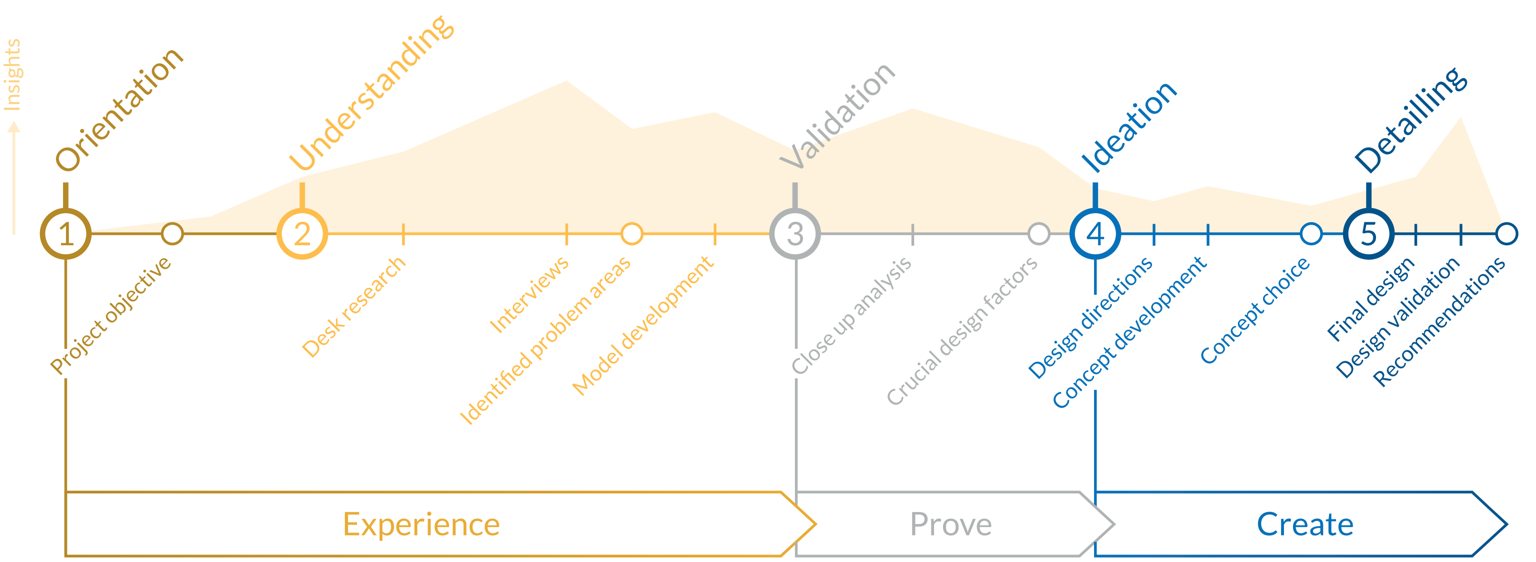
In the experience phase the main goal was to create an understanding for the problem, obtained by becoming the user and grasping the context. In this case by diving into the field of trapeze sailing, interviewing sailors, wearing trapeze harnesses and to some degree critical thinking. Ending with a set of insights that served as a basis for further analysis.

These gathered insights were valuable, but proving and knowing what is the source of these findings was even more valuable. The prove for the insights was found by zooming in on the situation and showed how tweaking a certain design parameter would change the outcome.

The knowledge that was acquired could subsequently be used to create new designs. Resulting in redesigns that were focussed on enhancing an specific part of the experience of the harness or solving a problem.

The final result of the project is an overview of important design parameters for a harness and what the effect of this parameter is. A part of these design parameters have been incorporated into a prototype to experience the outcomes.

Figure 01 ; Schematic overview of the process



Thesis outline

This thesis is divided into two main parts, starting off with presenting the final results and insights of the research. Second part presents the foundation for these results and describes the path how these insights were obtained (see Figure *02*).

Throughout the thesis references and links direct the reader to learn more about how and where these findings found their origin in user studies, desk research, literature studies, interviews or experiments. For every chapter its research question and small summary of the insights is given upfront.

For the best reading experience and not miss out on the extra's, it is advised to install or use a QR-scanner application on your mobile phone.

Insight — In story remarks that provide an important fact or hidden piece of information relevant to the research.

Quote — Quote by a sailor or other expert in the field of sailing.

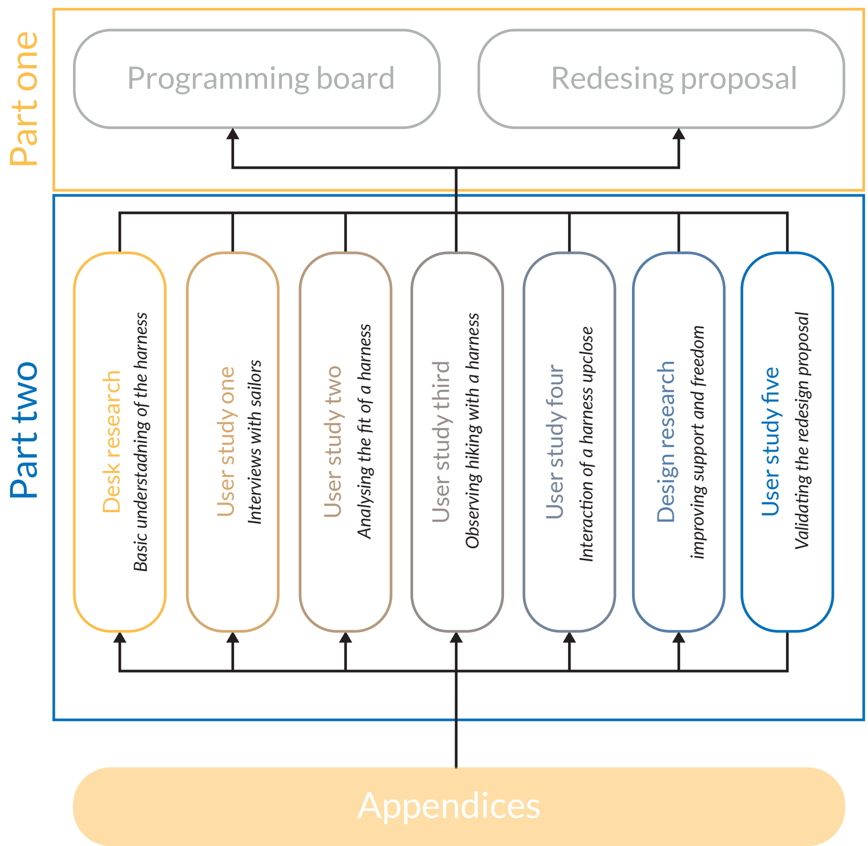
Sidestory — An event or story that contributed to the process that has no direct connection to the research outcome.

Literature — Reference to an article or other literature fragment that is relevant for the subject.

Appendix — Reference to the appendix for more detailed information about the subject being discussed.

QR-code — Throughout the thesis QR-codes have been put in place to link to appendices or additional information.

Figure 02 ; Thesis outline schematically illustrated



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Orientation

This chapter describes the starting point of the project, starting off with a definition of the problem at hand and the intended objective. The trapeze harness, direct object of this thesis, has a specific use in the world of sailing. To introduce the harness a brief summary of its use and relevance is given.

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Figure 03 ; Two 49er dinghies with their crew trapeze hiking

1.1 Outline

1.0.1 Problem definition

Sailing is sport that has seen a considerable changes in the past 30 years. Building materials have evolved into lighter and stronger replacements, but also boat designs have changed remarkably. Boats have become faster and more agile, making sailing more spectacular to watch. Changes that are also reflected in the Olympic sailing program, where classes have been adopted that should appeal to a broader audience and increase popularity due to their spectacular characteristics. With the current Olympic format there are ten medal events, or ten different fleets, adding up to a total of fifteen sailor positions (International Olympic Committee, 2017). Of which eight positions involve trapezing as the type of way generating righting moment. An increase that clearly supports the current trend. Trapeze hiking is one of the preferred hiking methods that used on the faster dinghies as it is a effective hiking method that can generate more righting momentum. Allowing boat designers to increase the sail to weight ratio. The trapeze harness wraps tightly around the body, trying to distribute the pressure over the body evenly and still allowing the sailor to mover freely. The growing popularity of boats that involve trapeze hiking has asked for a demand to know more about the trapeze harness. Currently, information about the harness in terms of class specific demands and its parameters is limited. In addition, there is the fact that most trapeze harnesses are unisex and therefore the best of both worlds.

1.0.2 Objective

The aim of this project is to provide a deeper understanding in the functioning of a trapeze harness in terms of influencing parameters determining pressure and support on the body and experience of trapeze harness by the sailor while hiking. Using the insights of sailors active in different Olympic classes to find where harness requirements overlap or diverge. The goal is provide an overview of all important parameters in a trapeze harness design and eventually redesign the trapeze harness based on these findings.

1.0.3 Client

The Sailing Innovation Centre Scheveningen (SIC), formerly known as the InnoSportLab, is the initiator of the project towards the redesign of the trapeze harness. The SIC is an initiative between NOC*NSF, Watersportverbond (Dutch Watersports association), TU Delft, VU Amsterdam and the municipality of The Hague to stimulate innovation in the sailing sport (Figure 04). The SIC's mission statement is: More medals, more people experiencing the sailing sport, and more business. A ambition that is pursued by supporting the Dutch Sailing Team and working closely together with companies. Improving preparation of sailors in terms of prediction of the wind and current, physical fitness and apparel design. With as target the Olympic Games of 2020 in Tokyo.The SIC is housed in the same building as the National Training Centre (NTC) of the Dutch sailing team, allowing close contact with sailors and coaches and the possibility to perform tests.

Figure 04 : The SIC in the middle with the supporting institutions that work together to realise new innovations in the world of sailing.

1.2 Context

Sailing could be defined as proppelling an object forward using the wind. Although this is true, the description is far too vague and too comprehensive. In order to get a sense of the context, narrow it down and define some of its elementary factors, a brief analysis was conducted.

1.2.1 What is sailing?

Sailing involves using the energy of wind as a means to move forward. In most cases the wind is caught by a piece of material (sail) that is extended from by a pole (mast) that reaches to a certain height. Since the mast is attached to a floating object (boat), the force is transfered to boat. What happens from here largely depends on the angle between the sailing and wind. If a boat is sailing downwind (see Figure 05), with the wind from behind and thus an angle of 180 degrees between boat and wind, the boat is pushed forward by the wind. However as the angle between the sail and wind decreases, the physics becomes more comparable to one of a wing. Wind passes over the sail and gets deviated by its shape, resulting in force that is exerted on the sail (Figure 06). The resultant force can be split into a forward y-component and sideway x-component. This sideways component tries to push a boat sideways, which is known as drift. To counter the sideways motion boats have either a keel or centreboard that is placed underneath the hull. The forward component is significantly smaller than the sideway component, nevertheless it is bigger than the friction force and thus makes a boat go forward. Since the point where the wind engages is at a certain distance from the pivot point of the boat, it generates a moment and tilt the boat. Stronger winds mean more tilt (or heel). Heeling reduces speed and increases drift, both disadvantageous and thus must be countered in order to maintain or increase boat speed. To compensate a sailor can trim the sail by easing of the sail or by moving their weight away from the pivot point of the boat, creating a counter moment.

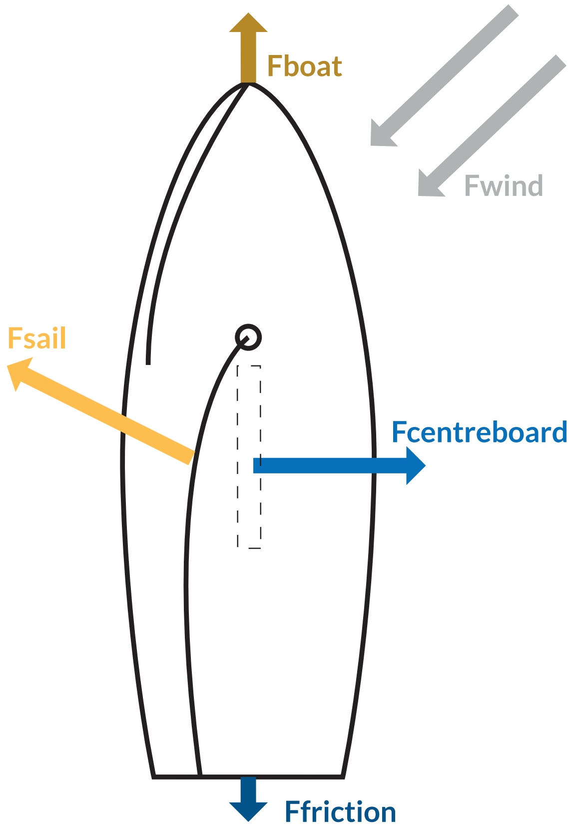

Figure 06 ; A simplified illustration of boat sailing upwind with the forces acting on it

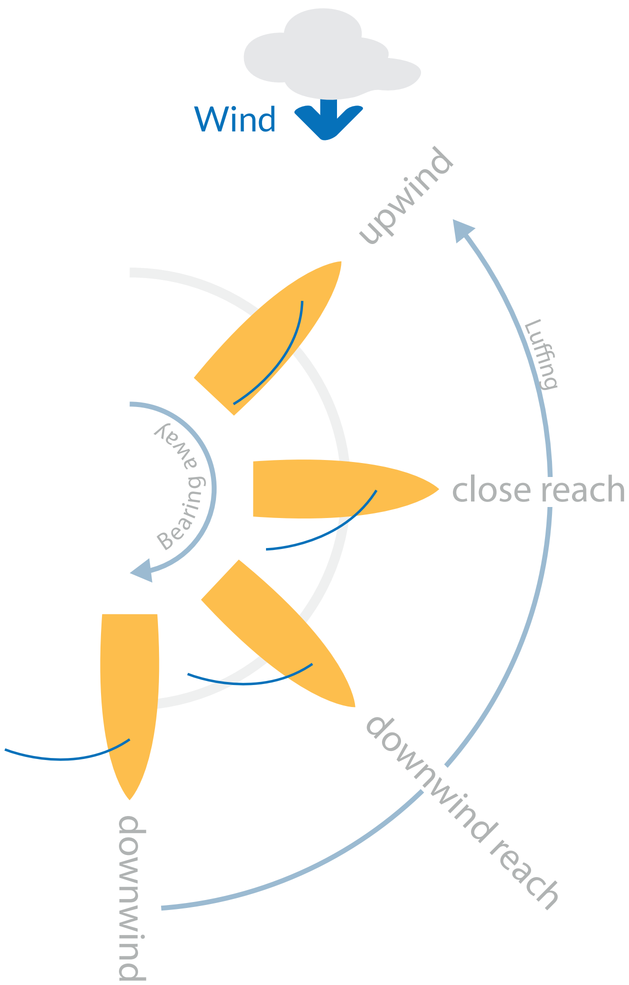

Figure 05 ; Point of sail,showing the relation between wind and sail in different headings

Body weight and stature are main influencers of the counter moment generated by a sailor.

Appendix B01 provi-des a full description of the model used to determine the force on the wire.

1.2.2 What is trapeze hiking?

In trapeze sailing a counter moment is generated by bringing the body as far away from the pivot of the boat is possible, increasing the length of the arm. In Figure 07 in overview of this hiking technique is provided. The sailor in the figure wears a specifically designed piece of clothing, a trapeze harness, that sits tightly around the body fully supporting the sailor. Near hip height, the harness has a hook that can be attached to a special wire on the boat. This wire is better known as the trapeze wire and fixed to the mast at about three-quarters of its length. Once attached the wire is attached to the trapeze wire (hooked in) the sailor can move outward by placing the feet at the side of the boat (gunwale). By adjusting the length of the wire or stretching the legs, the sailor is able to determine their outward position and thus the magnitude of the counter moment. A swift analysis of the situation as displayed in Figure 07 learns that this counter moment is mainly dependent on the weight and stature of the sailor.

1.2.3 Basic physics

In races the mix of boat speed and tactics are the recipe for success. Keeping the boat speed high requires experience and stamina to keep the boat flat on the water. As previously pointed out, body weight and stature are the main influencers of the counter moment. To get a complete overview of the system and find out at what outward position the generated moment is at its maximum, the system was analysed up close. In order to determine the magnitude of the force that the sailor generates a model was defined. The details of the model are provided in appendix [xx]. For a sailor weighing 80 kilograms and measuring 1850 millimeters tall, the maximum force on the wire was about 1000 Newtons. This force was calculated while hiking at an angle of 90 degrees in relation to the mast. Besides quantifying the force the sailor generated, the model gave insight in the influence of certain parameters on the force the sailor generated. Body weight and stature proved to be among them, but also boat width and the position of the hook are important parameters that deteremine the force.

Figure 07 ; An image of 470 crew member hiking using a trapeze harness, with a layer of the forces acting on the boat drawn over.

1.2.4 What is a trapeze harness?

A typical trapeze harness is characterized by a part that wraps around the hips and buttocks to support the middle of the body. This is also the part where the hook is attached to the harness. To support the shoulders and back, the harness has a set of straps that wrap around the shoulder back to the middle part of the harness. Throughout the harness multiple parts have extra cushioning to distribute the pressure. Figure 08 provides an example of a typical trapeze harness. The exact layout of a trapeze harness will be examined later in this report.

1.2.5 What is Olympic sailing?

Every sailor has his or her own reason and motives to go sailing. Nonetheless, sailing is a sport and a competitive element is then automatically part of it. Experiencing the competitiveness is possible in multiple racing formats such as fleet racing, match racing and team racing. Of the three, fleet racing is the most common and usually practiced in one-design classes. Figure 10 provides an example of a fleetrace start. For an athlete competing athe the highest level is what counts. Sailors consider that these are the Olympic games. Bojsen-Møller et al. (01) described Olympic sailing as: A complex sport that comprises numerous performance parameters such as the ability to understand and foresee weather conditions, optimal equipment such as yacht and sails and technical and tactical understandin. A quote that essentially describes what sailing is, no matter the level.

01 Bojsen-Møller, J., Larsson, B. and Aagaard, P. (2015). Physical requirements in Olympic sailing.

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Figure 08 ; A typical trapeze harness produced by Zhik.

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Figure 09 ; A 470 crew-member fully stretching with her arm above her head

Side story: Stretching of the arm

In many cases sailors try to increase the counter moment by fully stretching with their arm above their heads and standing on their toes. An example of the posture is provided inFigure 09. A posture that demands extra energy and while racing fatigues the sailor. To see whether this posture actually is worth the extra effort, the model as described in appendix [xx] was slightly altered. Using the same parameters the centre of mass (COM) of the sailor moved further outward and thus the arm of the force increased. In comparison to the sailor adopting a neutral hiking posture the force on the wire (and counter moment) increases by 3 $^{5}/_{6}$%. At first sight this increase might seem small, however to put this into perspective in top sport every percentage is an improvement and not won only a daily basis.

In appendix B01 the model to determine the extra force is defined.

1.2.6 Scope

Sailing is a broad subject with numerous types of boat designs, that all are slightly different. In this world of sailing the focus for this project will be on the Olympic class dinghies that use trapeze hiking, and thus a trapeze harness, as a method to maintain the boat in an upright position. The classes relevant are the 470, 49er and Nacra 17. The 49er class is split dependant on gender, males sail the normal 49er whereas females sail the 49er FX. The 49er FX has less sail area. Within the Dutch Sailing Team there are currently only teams in the 470, 49er and 49er FX working towards the main goal: The Olympic Games of Tokyo in 2020. Therefore the main focus will be on sailors using a trapeze harness in the 470 and 49er. For the 470 this will be the sailor in the crew position and for the 49er and 49er FX this will involve both the helmsman and crew.

1.3 Sub questions

This chapter has provided a first glance at the context relevant for this thesis and provided a clear objective. In addition to the main objective, three sub questions relevant to the context were formulated. Each of them helped to develop a better understanding of the trapeze harness and in turn led to more questions.

1. What influence does the type of boat have on the requirments of a trapeze harness?
2. What design elements are considered to be crucial from a sailor's perspective sailing at a high level?
3. Why is a trapeze harness designed the way it is?
4. What is the magnitude of the forces that the body has to deal with?

Figure 10 ; A photo taken shortly after a fleetrace start of a 49er race.

System boundaries


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kelag
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Part one

The trapeze harness is a complicated product that embodies more than meets the eye. Claiming that there is one ideal trapeze harness is only possible in a world where there are no variables. The most influential variable in this case is the sailor. A harness that is perfect for one sailor, might be totally off for another. The research of this thesis has focussed on developing an understanding of the interaction between sailor and trapeze harness and to identify important design requirements. The result and conclusion have been embodied into two results. The first being a decision tool that demonstrates how specific parameters influence the design of a harness. (For further reference the term 'Cube' will be used throughout the report) The second a potential redesign of a trapeze harness that was based on the output of the cube and obtained knowledge, focussing to improve a certain feature. In the coming chapter these parts will both be presented and their underlying arguments be explained.

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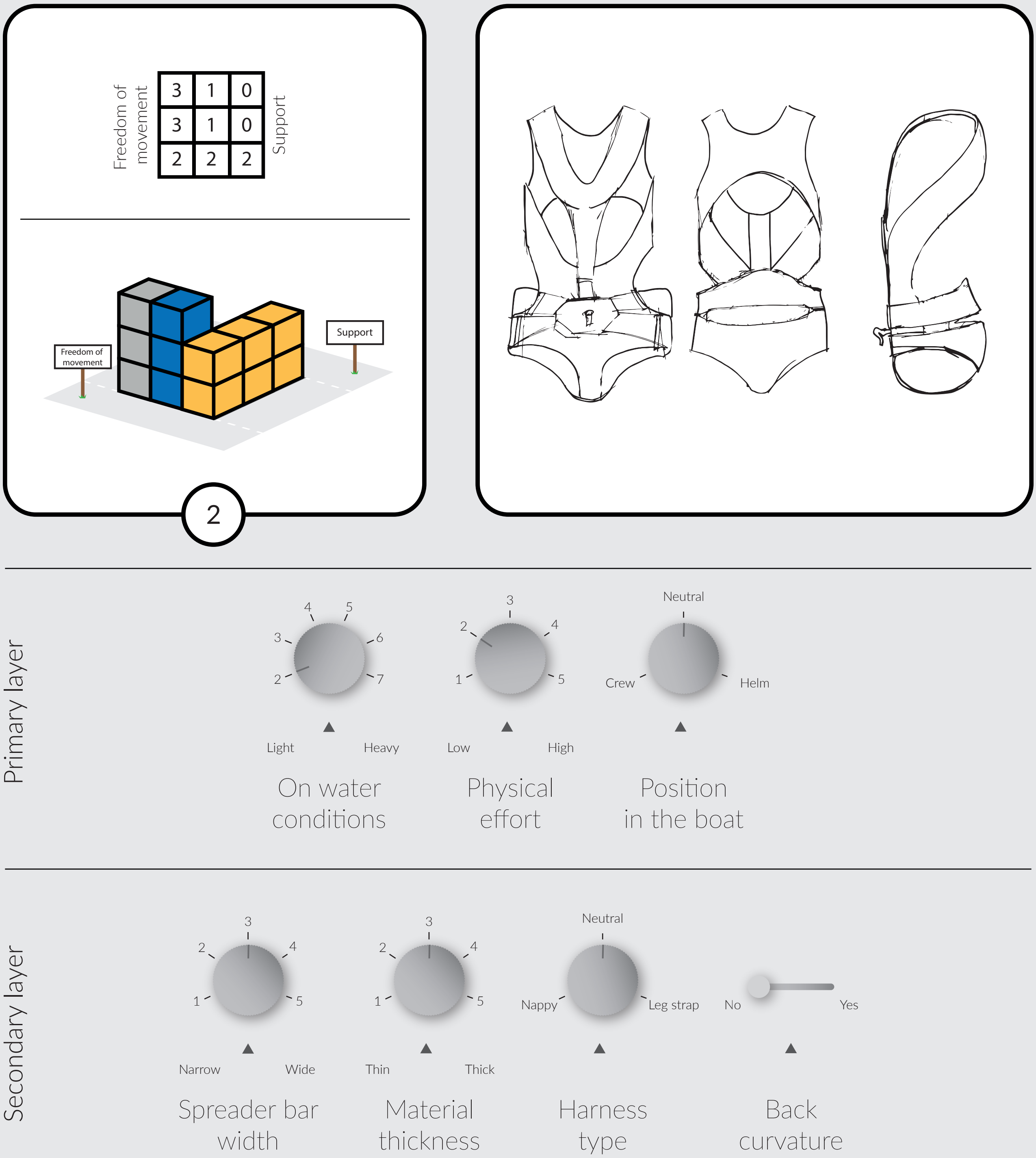
Figure 11 ; A 49er proving its spectacular character by flying over a wave.

2.1 The Programming board

The Programming board is a conceptual tool that is able to program the design of the harness based on multiple input parameters (see Figure 12). These parameters have been split into a primary and secondary layer. The primary layer determines the initial conditions of the harness or its basis. Parameters in the secondary layer are less influential on the final output and are primarily based on personal preferences.The origin for a parameter was found by conducting multiple studies and experiments, which will be discussed in detail. The purpose of the tool was to demonstrate how the most important parameters influence the design of the harness and create a method to make these parameters more insightful.

Figure 12 ; The programming board with randomised input parameters.



2.1.1 Trading off

Throughout the research a returning subject kept peaking around the corner, being the constant trade off between two distinct qualities of a trapeze harness; the degree of freedom of movement and support. Each of these qualities sitting at the far end of an imaginary scale. Studying the interaction between sailor and the harness up close showed that trade off between the two sides was influenced by three setting related parameters (primary layer) and four design related parameters (secondary layer). Combining these parameters and regarding them as design requirements would develop a harness design specifically programmed to match the input and could be placed somewhere on the scale. To visualise and enable to incorporate a multi-variable system the output has been embodied in the form of the cube made up from smaller cubes. Based on the input of all parameters, both primary and secondary, the layout or the distribution of the smaller cubes is programmed. The programming determines the distribution of the cubes and thereby its tendency to lean more towards freedom of movement or support side of the cube, which have been placed on opposite sides of the cube. Ultimately, the output generates a set of specific design requirements that fit the input parameters. The exact functioning and outputs of the cube will be discussed further in {XX}.

2.1.2 Primary layer

Choosing for a particular harness is primarily based upon the setting, which can be split into three main factors; on water conditions, physical condition and position in the boat. Determining the degree support or freedom of movement that is required to be provided by a harness.

On water conditions

One of the primary elements of sailing, the wind, has a significant influence of the type of harness and thus on the desired mobility or support. For example, if the on water conditions can be considered light (ranging from 0 - 6 knots or 1 - 2 Beaufort) a sailor favors being able to move freely above having a very supportive harness that limits their mobility. Primarily, caused by the fact that a sailor spends less time hiking in light wind conditions and has to be able to take on awkward postures that require a high degree mobility. However, if the conditions get heavier the ratio between time spend hiking and moving is shifting and quickly leaning more towards hiking. Reducing the advantages of having a mobile harness and increasing the need for a harness that can provide more support. To put it short; if the wind picks up sailing becomes more static, with support becoming increasingly important and vice versa.

Physical condition

Assessing their own capabilities and limitations in terms of physical strength is an important factor in determining the design requirements of a harness. The physical capabilities of a sailor are split into physical strength and/or injury history. On multiple occasions the connection between a harness and injuries was suspected, unfortunately, the relation between the two could not be identified. Nevertheless, the harness could be a method to prevent the development of future injuries. Sailors having a history of back injuries are more interested in having a harness that is able to provide support than freedom of movement. A similar principle applies to sailors who consider themselves to be less physically strong and prefer a harness that provides more support.

Position in the boat

Sailing in a dual handed dinghy involves working as a team and therefore each conducting a set of tasks. Depending on the boat these tasks can alter, however when observing sailing in both the 470 and 49er it became clear that the set of tasks for a crewmember required to be more mobile than the helmsman. Crew tasks involved bending over to hoist the gennaker and trimming the boat, that are easier to perform if moving freely. The helmsman generally is far more static in its movements and benefits more from having a harness that provides more support to maintain the static postures.

2.1.3 Secondary layer

The parameters is the secondary layer are personal preferences that determine the final design requirements for the harness. These personal preferences have been split into four distinct parameters that were found to be most influential on the trade of between freedom of movement and support.

Harness type

The type of harness is a parameter that refers to the bottom part of the harness, the way the harness wraps around the legs and groin. A sailor is able to choose between two designs; the leg strap and the nappy style. The latter is most often chosen by the sailors as it offers the most freedom of movement. A nappy style harness

> *Figure 13 ; Top view of the programming board and three possible states of each row.*

uses a single strap between the legs, whereas a leg strap harness has a strap around each leg and leaves the groin part free. The drawback of the leg straps is the reduction in freedom of movement, for instance when squatting, but can offer more support and comfort.

Spreader bar width

Trapeze wire and hook are an interlocking system and allow the sailor to easily move in and out. The hook is attached to the harness by a spreader bar. Depending on the personal preferences of the sailor the width of the spreader bar can alter. A wider spreader bar reduces the compression on the hips, but at the same time increases support as the sailor is able to maintain the posture for a longer time. Having the opposite, a narrow spreader bar, provides more freedom of movement for the sailor and more pressure on the hips. The last factor is especially preferred during light conditions.

Back curvature

Supporting the back is one of the primary functions of a trapeze harness. One of the methods to provide support in the back is by having a back piece that is matching the curvature of the sailor's back. Having a matching curvature creates an equal distribution of the pressure along the back and thereby reduces the effort for a sailor to maintain a good posture. Increasing this feature of a harness does not necessarily decrease freedom of movement.

Material thickness

The cushioning and material stiffness are important parameters in a harness design as these determine how the pressure from the harness onto the sailor's body is distributed. Thicker material reduces the mobility of a harness, simply due to the fact that the harness' flexibility is reduced. Support on the other hand is increased, as pressure is distributed over a larger surface with material that is able to adjust to the shape of the body. Thinner material ensures that the harness remains flexible and allows the sailor to move quickly without any limitation.

2.1.4 Working with the board

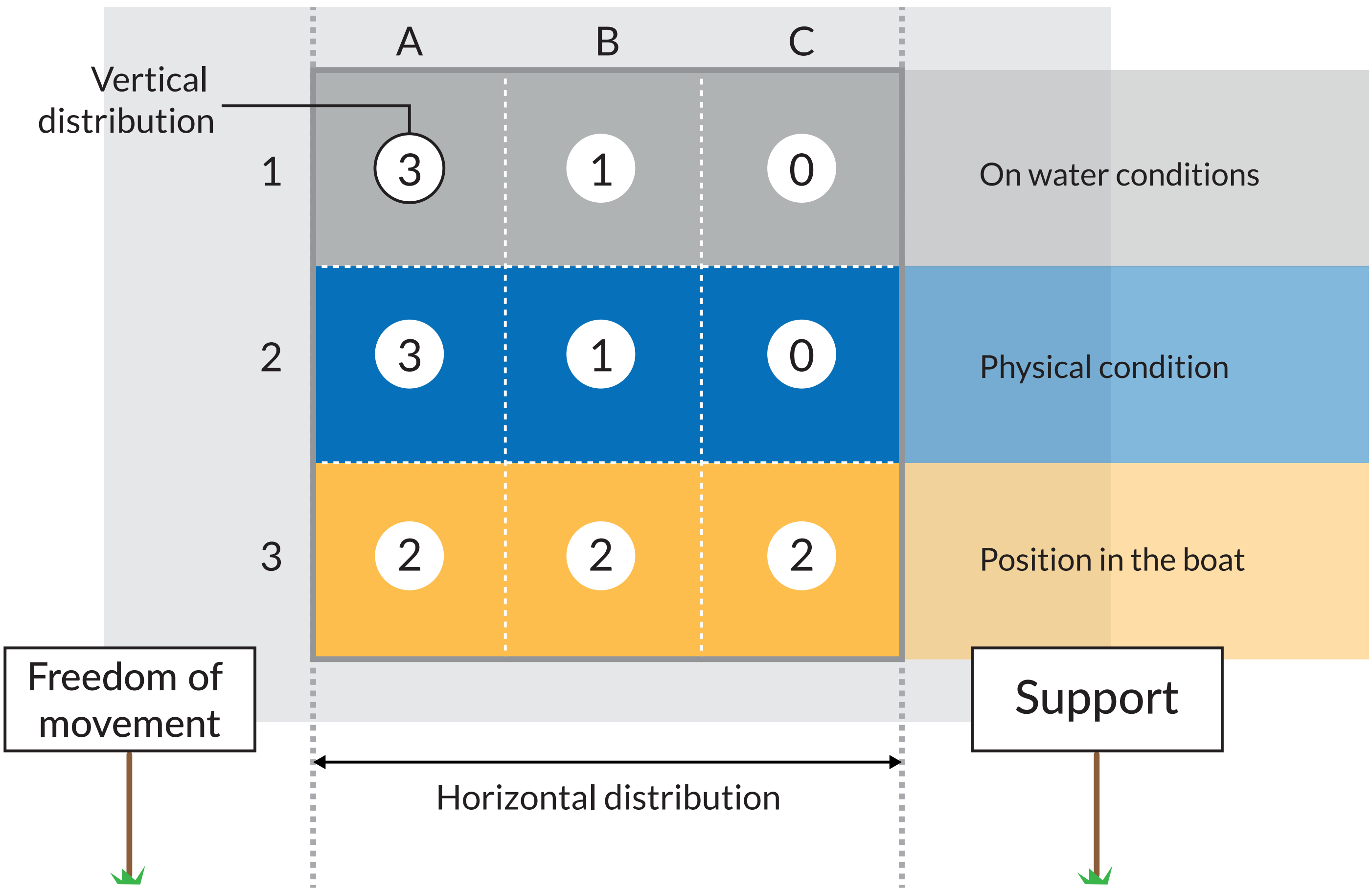
The cube provides an insightful overview of the influence of the parameters on the harness design requirements. In order to fully understand the functioning of the cube it has deconstructed and showing how the parameters influence the shape and distribution of the cubes inside the main cube.

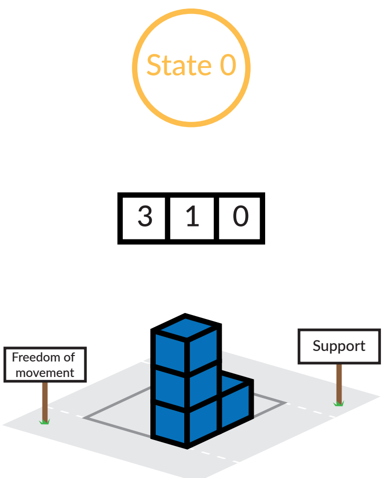
Basic setup

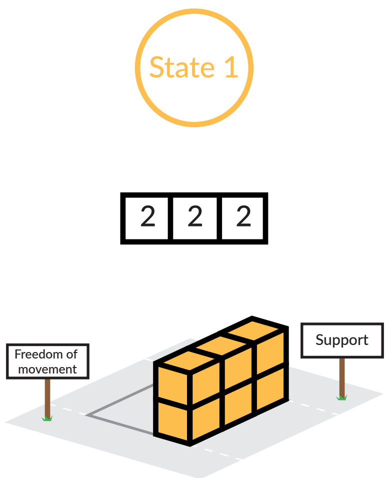
The cube provides a three dimensional output, however for this setup the output is visualised in the distribution of the cubes in the horizontal and vertical axis of the cube. In Figure 13 a top view of the layout of the cube is illustrated, showing that the base of the cube is divided into three rows from left to right. Freedom of movement placed at the left side and support on the opposite right side. Depending on the distribution of the cubes in the horizontal and vertical direction a code is created that matches a set of design criteria. For example, when taking another glance at Figure 13 the number of cubes is higher on the freedom of movement side, resulting in a set of design criteria that generates a mobile harness. In order to limit the amount of the design criteria and create distinctively different harness designs, the setup of the cube is limited to a 3 - 3 - 3 with each row having a maximum of three cube configurations (states). Resulting in a total of 27 different arrangements. States range from 0 to 2 and have a set layout, as is illustrated in Figure 13. Assigning an initial state to the row is based on the input of the primary layer parameters.

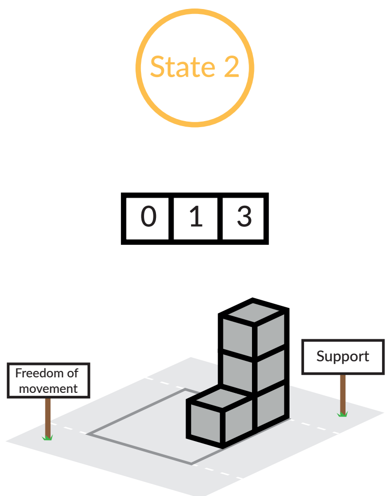
Primary layer

For each state an underlying domain for the input parameters was determined. In Figure 14 the distribution of states over the input has been visualed. In case of the on water conditions, the domain was expressed in Beaufort and with an logarithmic trendline. Indicating that if the on water conditions in terms of wind increase the output in this row would quickly lean more towards the support side of the cube, this can be demonstrated by sketching a situation. For example, in lights conditions the time spend hooked in versus hooked out could be fifty : fifty, however, when conditions slightly increase this ratio could shift to seventy : thirty. Thus more time spend is hiking and the importance of a harness' mobility decreases.
The parameter for the physical condition was found to be linear with a scale ranging from one to five. A sailor with no injury history or high physical endurance is less interested in a harness that provides a high degree of support and vice versa. As mentioned before based on the position in the boat different tasks performed, where a different degree of support or mobility are needed. For the crew this freedom of movement is more important to perform tasks in the boat, whereas the helmsman is generally more static and is more interested in support.


A
B
C
Vertical distribution
1
2
3
3 1 0
3 1 0
2 2 2
On water conditions
Physical condition
Position in the boat
Freedom of movement
Support
Horizontal distribution


State 0
3 1 0
Freedom of movement
Support


State 1
2 2 2
Freedom of movement
Support


State 2
0 1 3
Freedom of movement
Support

Secondary layer

Once the primary layer has determined the initial states, the secondary layer is used to incorporate the personal preferences into the design requirements. The secondary parameters are infused into the states by adding or subtracting a value from the state number of every row. Similar to the primary layer, the secondary has an underlying domain for the input parameter, an overciew is provided in Figure 14. For example, if the initial state is 1 and the secondary parameter has an output of -0,5, the new state becomes 0,5. State values are always rounded off in favor of the initial state, so in order to change state the output of at least one other parameter is needed. Besides this, the secondary layer can not influence the cube's initial states to turn 180 degrees. To illustrate this an example; if the current state output has very thin unpadded material and the input for the material thickness in the secondary layer is very high (5), than the design requirements will not automatically change the output to the most supportive harness. Instead, it will change the output relative to the initially chosen state and thus choose an output that has thicker material than the initial state. Both the spreader bar width and material thickness have been assigned the same scale ranging from one

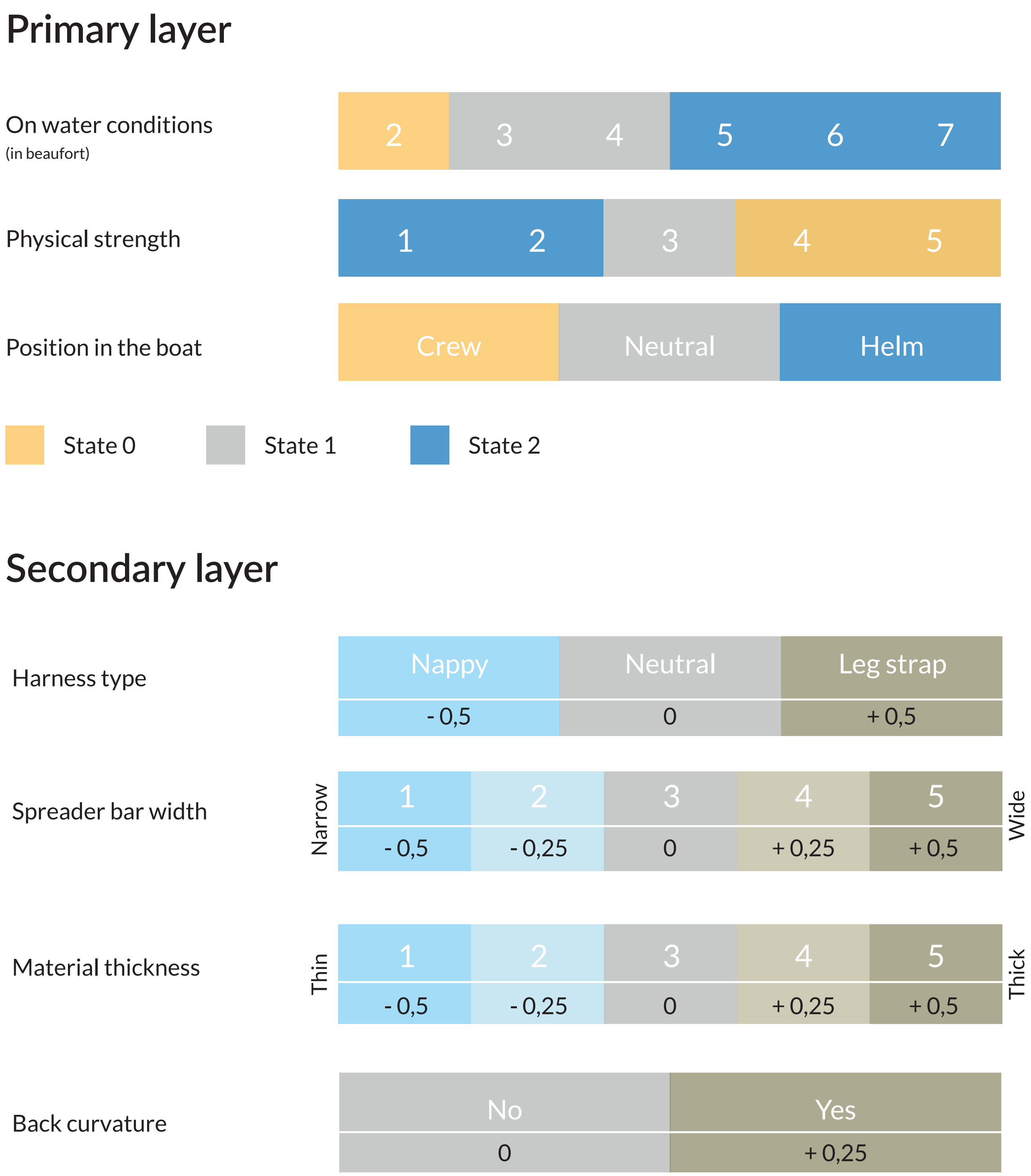


Figure 14 ; Underlying domains determining the states for the primary layer and values for the secondary layer to five. Based on the input, a matching value is added or subtracted from the state numbers. As mentioned before a narrow spreader bar and thin padding have a positive influence on the degree of freedom of movement of harness. For the type of harness there are three options; nappy, no preference and leg strap harness. With the nappy leaning the output towards freedom of movement and the leg strap towards support. The last parameter is back curvature that is treated as an on or off switch, positively the support of harness.

The output

In theory the cubes is able to create 27 different configurations. With the absence of a third dimension, the distribution of the cubes is only assessed in the horizontal and vertical directions. This reduces the configurations from 27 to 10 possibilities, analysing the output in two dimensions multiple configurations generate the same distribution. In appendix [xx] these configurations have been grouped and labelled. The labels range from 1 to 10, with labels 1 and 10 focussing on freedom of movement and support respectively. For every output an indicative harness design is sketched, that resembles a set design requirements fitting the input of the primary and secondary parameters. As result of the two dimensional setup of the cube, the outputs in group 5 could not be assigned to a side of the scale and have therefore been merged with group 6. The designs were composed using a morphological chart consisting of eight different components, merged together to create different harness designs with ranging from freedom to support. Design elements were based on information gathered by means of experiments, prototypes and tinkering with different orientations straps and supportive elements.

2.1.5 An example output

To demonstrate the use of the programming board, three possible situations were formulated and programmed on the board. In Figure 15 an overview of the three situations with their respective input parameters is provided. Situation 1 describes circumstances where the conditions are very light and the sailor prefers having a harness that provides most freedom. In situation 2 the conditions have become slightly heavier and the sailor prefers to have a wider spreader bar. Situation three is for a helmsman during heavy on water conditions, preferring a wide spreader bar setup. The sketches situations were programmed on the board, resulting in the outputs provided in figure [xx]. Situations 1 results in a harness with a high degree of freedom of movement which was accomplished by reducing the amount of fabric. Only providing support in the lower back by means of a support strap, that has been separated from the rest of the harness. The output of situation 2 is a harness that merges the qualities of both worlds, providing support and freedom of movement when needed. This feature is achieved by having a harness that tensions the shoulder and hip strap once the sailor starts to hike, in other cases the harness reduces the tensions and allows the sailor to move more freely. The last output of situation 3 is harness that focuses on support. The harness has a traditional shoulder strap setup, but with an incorporated individually adjustable lumbar support strap with a 3D shaped integrated insert.

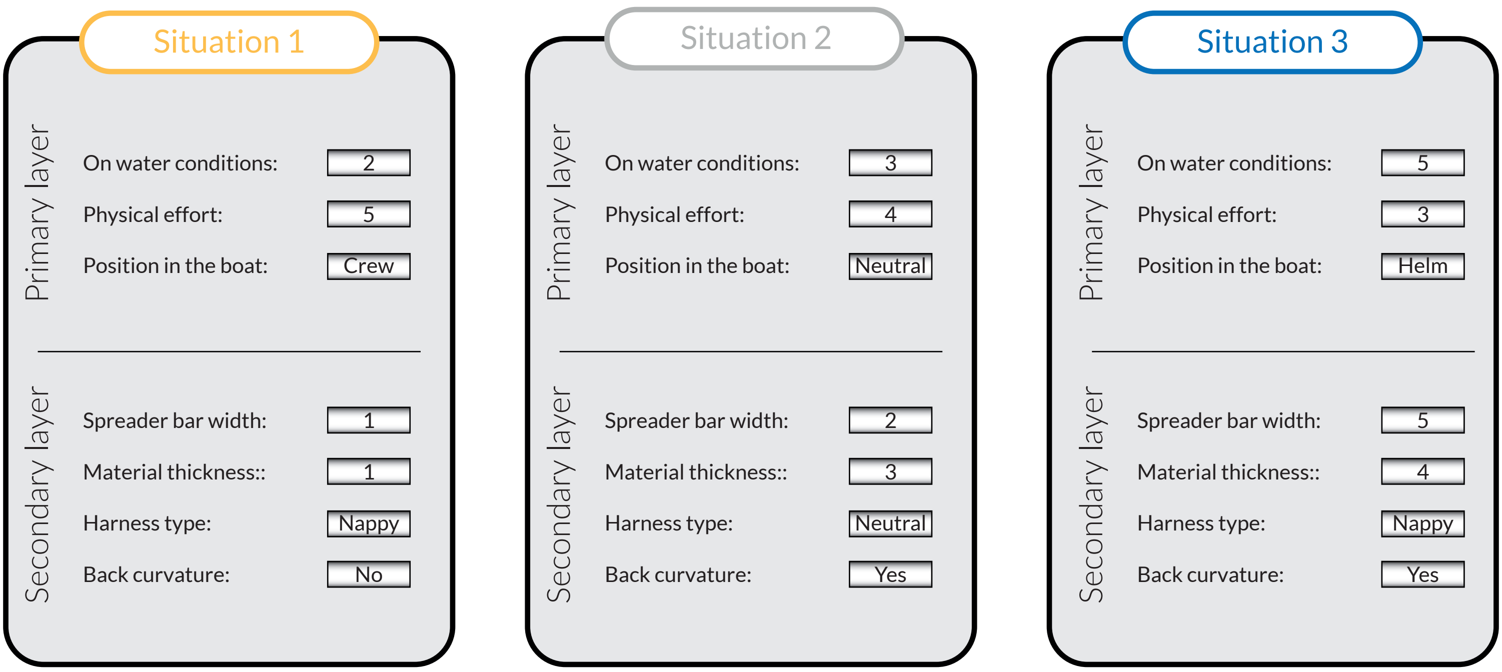


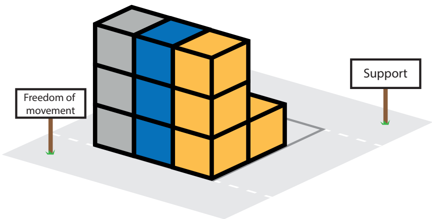
Figure 15 ; An overview of three situations with their input parameters.

Situation 1

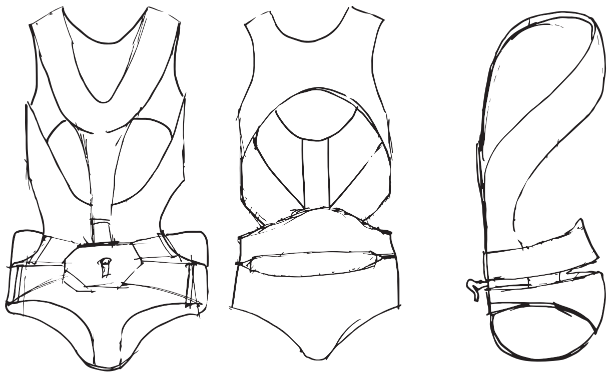
Freedom of movement

3	1	0
3	1	0
3	1	0

Support



1

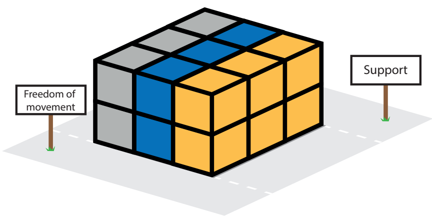


Situation 2

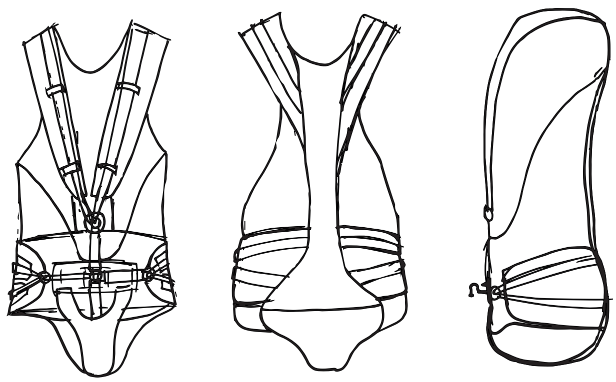
Freedom of movement

2	2	2
2	2	2
2	2	2

Support



5

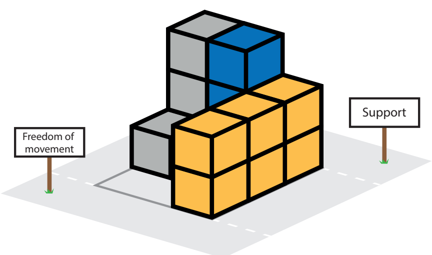


Situation 3

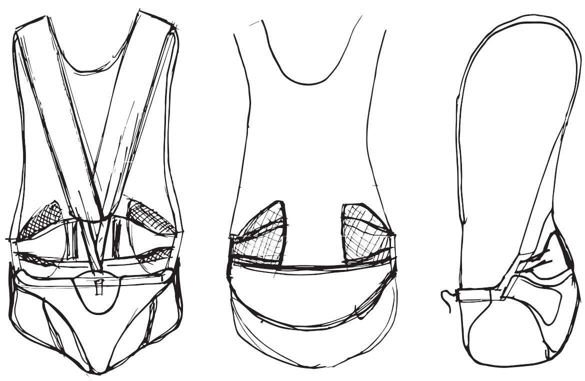
Freedom of movement

0	1	3
0	1	3
2	2	2

Support



9



2.2 Redesign proposal

Programming the design of different harnesses was the first step towards new harness designs that specifically focus on providing the sailor with either more freedom of movement or support. In the previous chapter the programming board provided an output for three different situations. These three directions have been detailed further to show what exactly sets them apart and how their supportive or mobile character is created. Eventually one of the design directions was chosen and produced into a physical prototype for testing. Concluding with a final design on the outcomes of the prototype test and opinion of the sailors.

2.2.1 Choice criteria

In the interest of further development and to study to what extent the design is feasible, one of the designs was chosen based on multiple criteria. These criteria could not be based on the trade off between freedom of movement and support, as these were the qualities of the designs. Instead, the designs were assessed based on criteria of equal importance listed underneath.

Distinctive design
The design should be inventive and not just be another harness which is similar to current designs. Alternatively, initiate the exploration towards revolution in harness designs.

Enhancing performance of the sailor
Sailing at the highest level means performance is important and that even the smallest gain is worth it. The design should bring out the best of the sailor, providing the feeling that with harness the sailor is invincible. Keeping limitations low and empowerment high.

Feasibility
The design might differentiate from current harness designs, but at the same time should prospect to be a feasible design. For example, the design should be able to carry a sailor's body or not have to many new features that could be better be handled individually.

2.2.2 Design directions is detail

In 2.5.1 the programming board provided three different outputs based on three situations, each output characterised by the degree of freedom of movement or support. In this section the detailed versions of the programming board's outputs will be presented.

<

Figure 16 : An overview of three possible outputs by the board using the input parameters given in Figure 15.

>

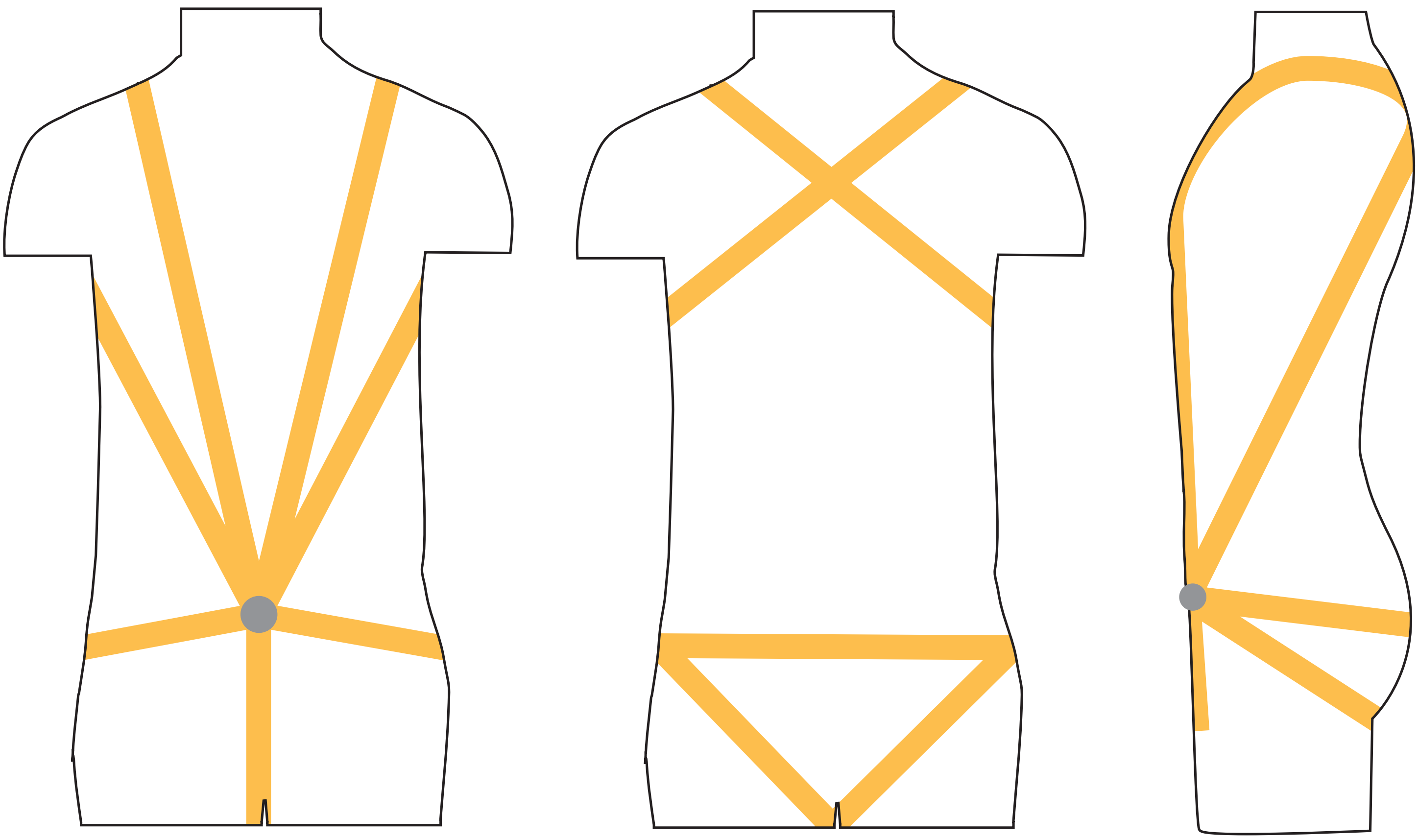
Figure 17 ; Design one seen from multiple angles with a detailed view of the Velcro adjustment.

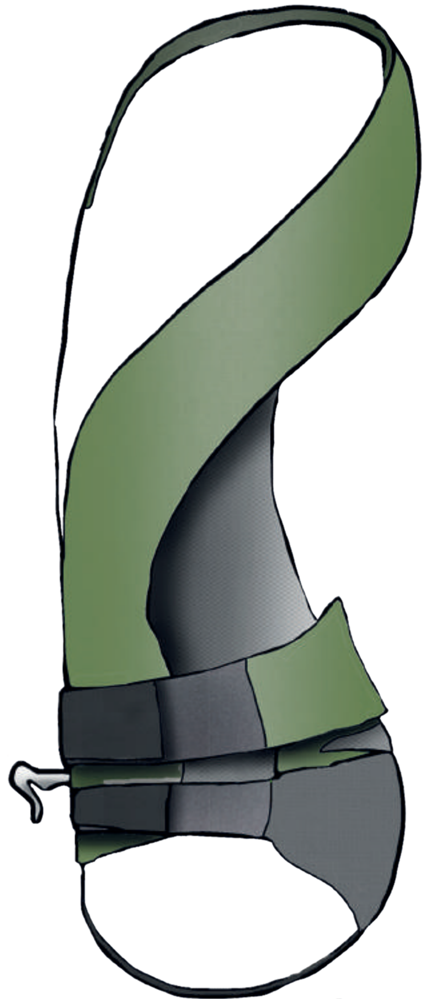
Design one - Ultimate freedom harness

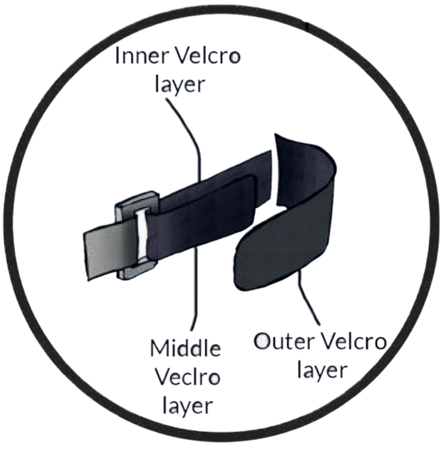
The main focus for the first design direction (see Figure 17) was freedom of movement. The parameters were adjusted to create a harness that could be used in the light conditions. Since the crew position requires a high level of agility and freedom of movement, this design could be a suiting option. The main characteristic and feature of this harness is the fact that it has an open back part. In the understanding phase a quote was put forward by one of the participants while wearing a harness. Claiming that the body was moving inside the harness and the harness did not move along and hindered bending over. Figure 18 provides an overview of the strap layout for this design. Showing how the shoulder strap is oriented in such a way it only wraps around the shoulder, crossing one another on the back and reaching directly back to the hook. A setup that distincts the design from any other harness, offering a high degree of freedom as the sailor can easily bend over and is not hindered by the limited length of the fabric.
In this design the first steps towards the separation of two distinct harness functions was taken, separating the function of carrying and supporting. This was achieved by letting the hip and shoulder straps solely focus on carrying the weight of the sailor and adding another strap to focus on supporting the lower back without being dependent on the rest of the harness. The harness is adjusted using three layer Velcro straps. The first two layers to tension the straps and the third to lock it in place. Resulting in a clean harness and allowing the hip and lower back straps to be pre-tensioned, reducing deformation of the harness while hiking. The straps are directly attached to the hook on a small plate, which serves as the centre of the harness.

V

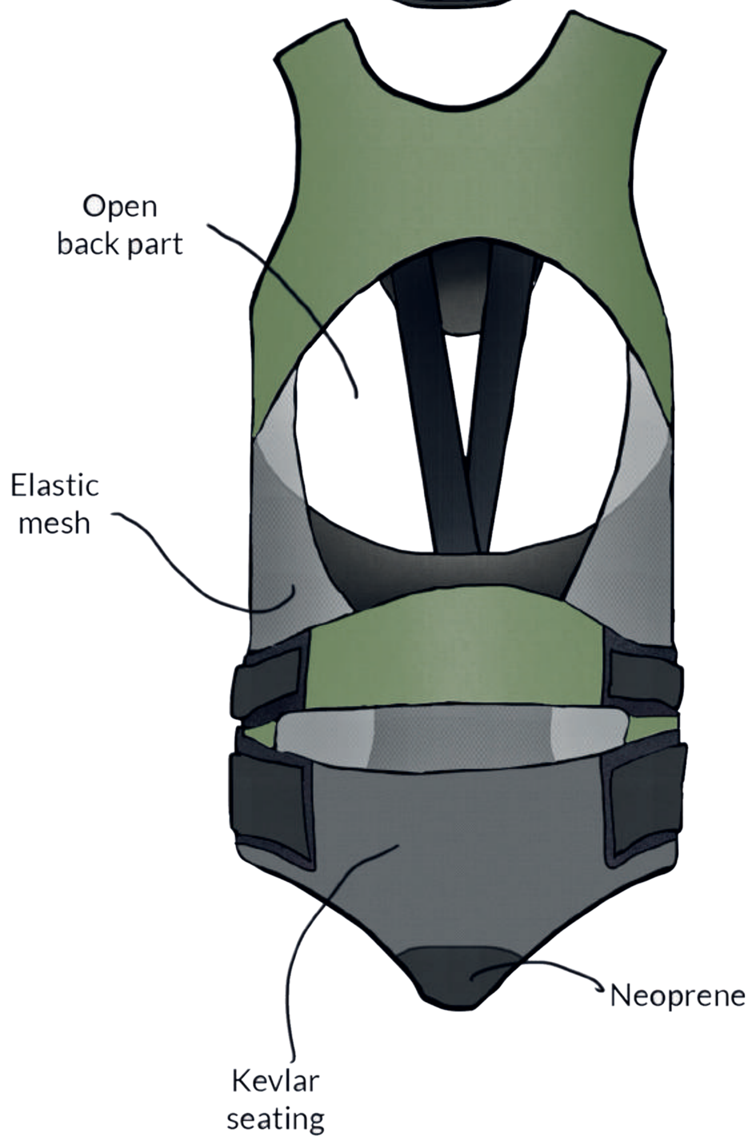
Figure 18 ; The strap setup of the harness' design illustrated by the yellow/ orange line.







3- layer Velcro

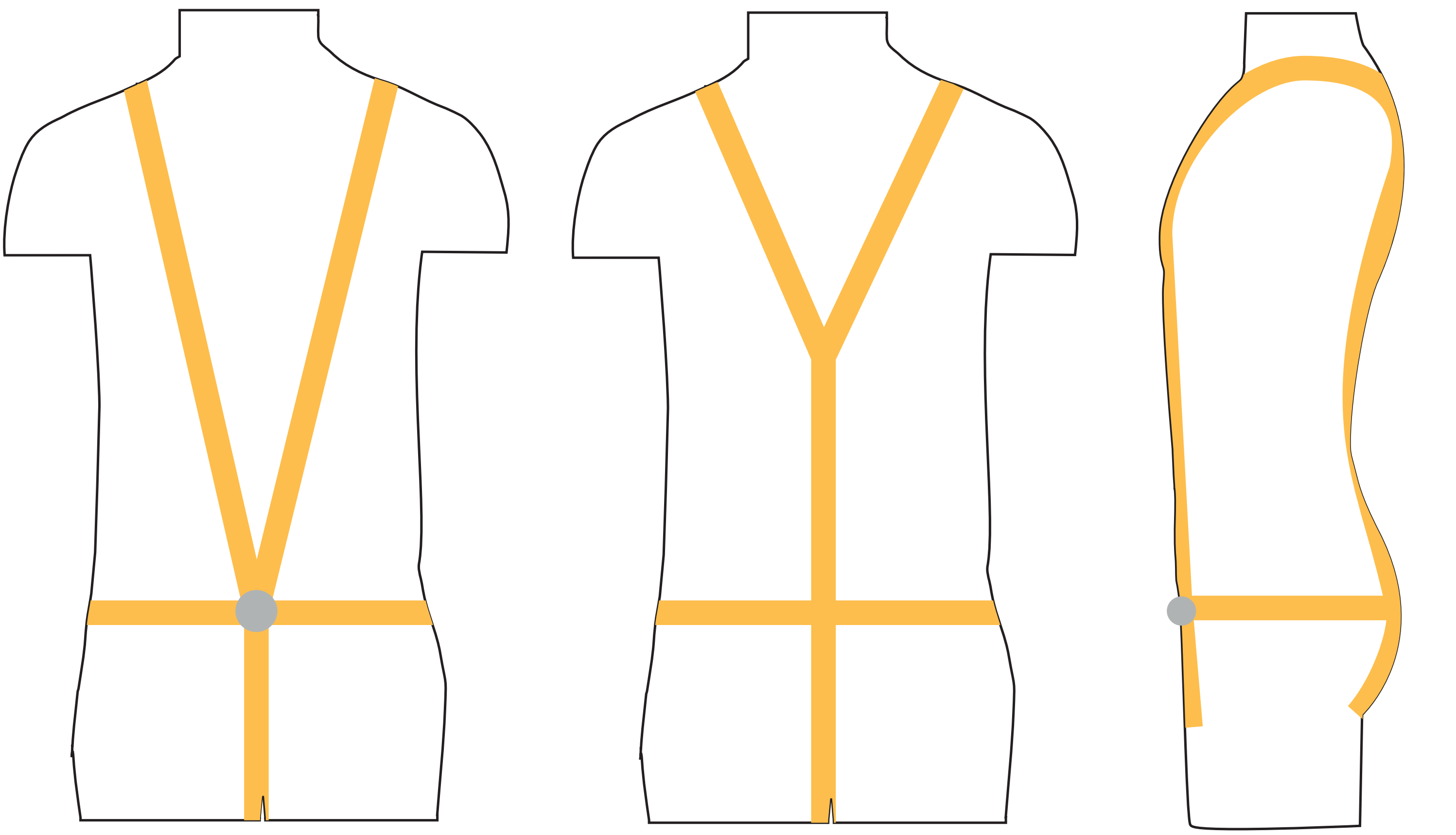


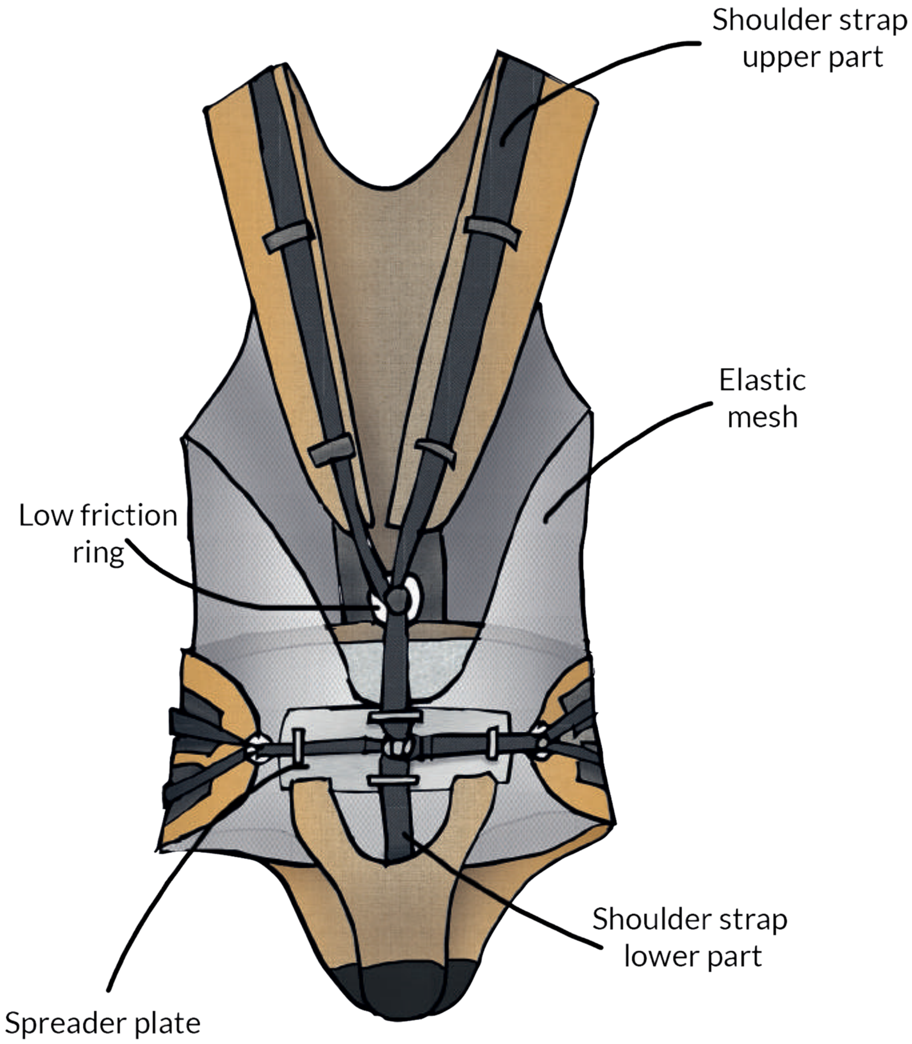
Design two - Tensioning harness

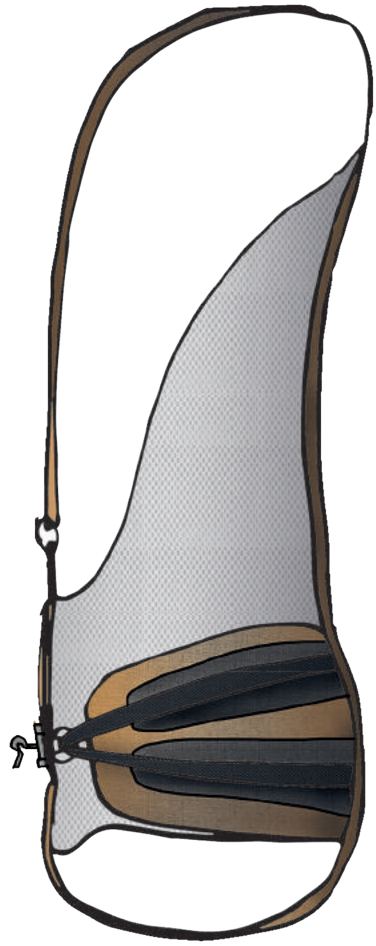
The key characteristic of the second design direction is its adaptability, allowing it to performing in multiple wind conditions and trying to find the optimal balance between freedom of movement and support (see Figure 19). The harness' main setup is neutral and almost identical to current harness designs, with the only difference being the merging of the shoulder straps on the back, as is illustrated in Figure 20. One of the main insights from the experiments was that is not the harness that alters its shape to fit body, but that it is the body altering to fit the harness. Based on this thought a potential harness design was created that does the opposite, it alters to fit the body. The design allows the sailor to move more freely when unhooked and more provides more support while hiking. This is achieved by altering the tension of the straps in the harness while hiking. The main straps, around the hips and shoulders, are connected to moveable hook. Once the sailor is hooked in and slowly moves outward to hike, the hook slides out of the spreader bar and pulls the straps, putting the harness to its supportive state. When the sailor unhooks, the hook pulls back and the tension on the straps is relieved, returning the harness to its mobile state. Switching between states requires a special type of spreader bar, enabling the hook to move in and out. Especially in the supportive state the forces on the spreader bar are high, requiring a strong and stiff design which could in turn limit freedom of movement and increase the weight of the harness. In addition, the shoulder strap also controls the state of the insert in the lower back. This insert consists of a set of narrow strips that are pulled together once tension is applied and create a hard plate supporting the lower back.

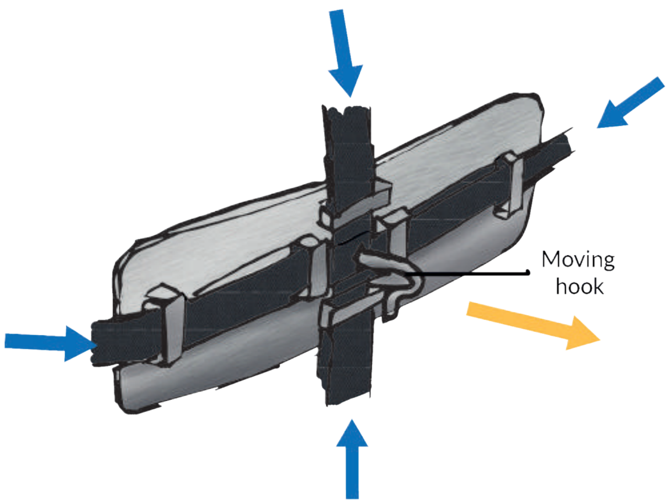
> *Figure 19 ; Design two seen from multiple angles with a detailed view of the spreader bar.*

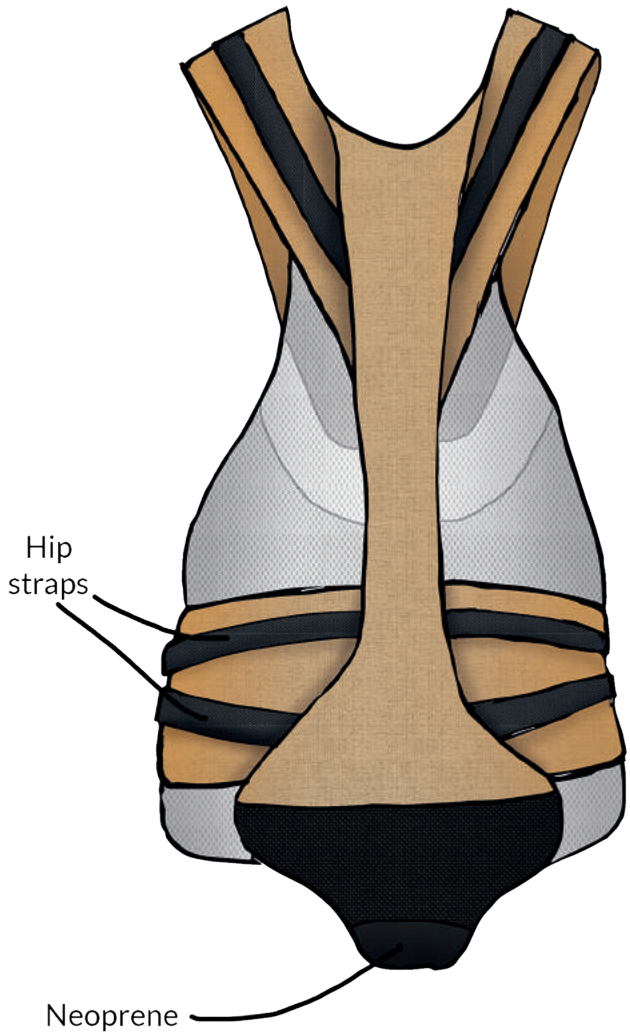
Figure 20 ; The strap setup of the harness' design illustrated by the yellow/ orange line.




Shoulder strap upper part
Elastic mesh
Low friction ring
Shoulder strap lower part
Spreader plate




Moving hook


Hip straps
Neoprene

>

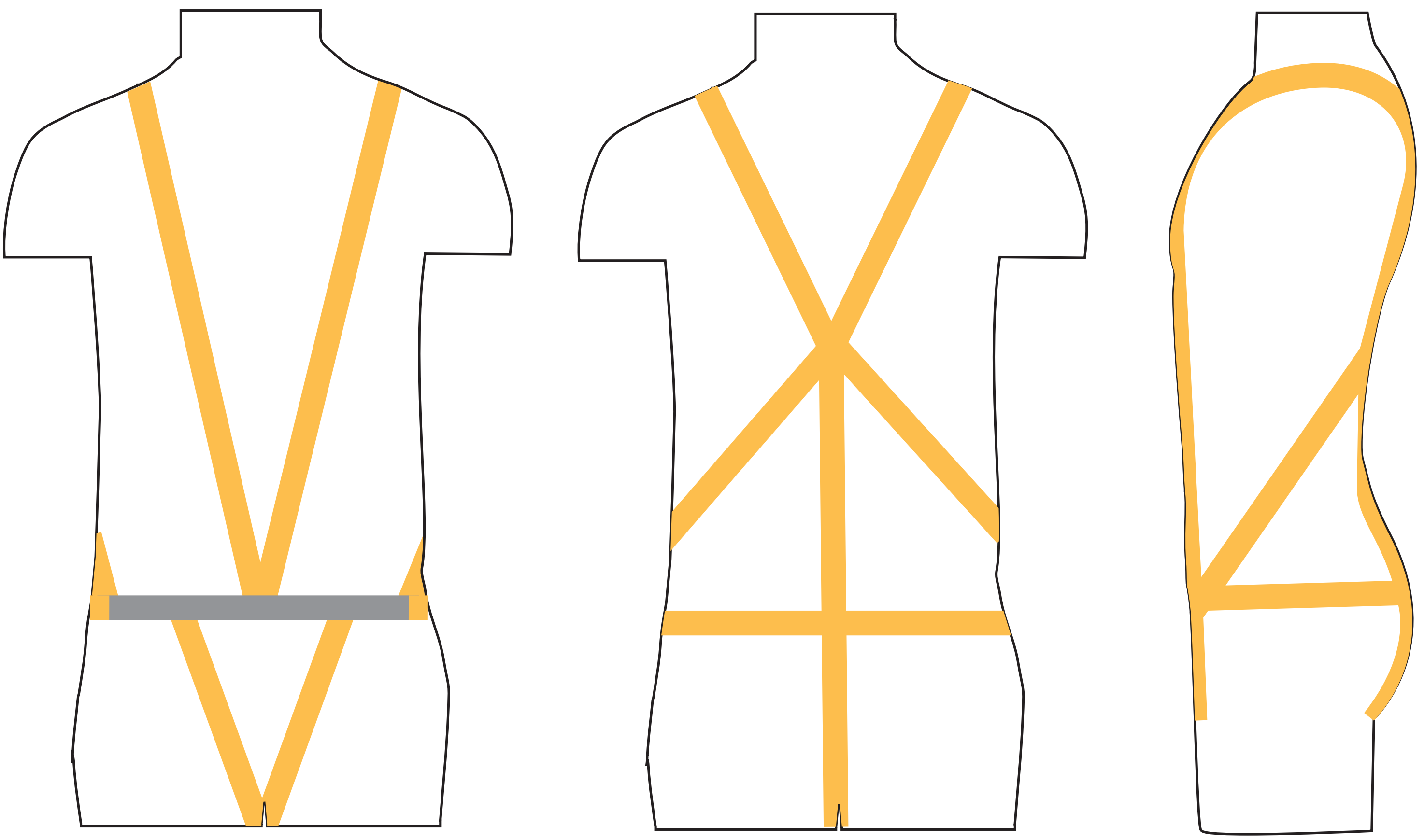
Figure 21 ; Design three seen from multiple angles with a detailed view of the spreader bar.

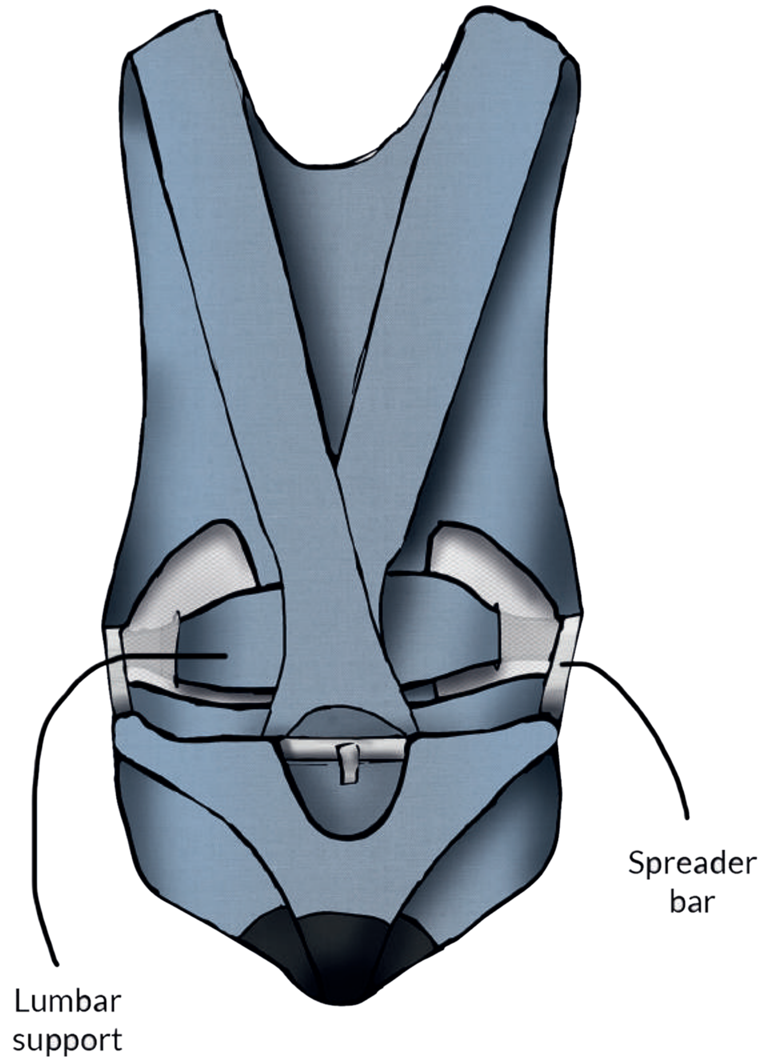
V

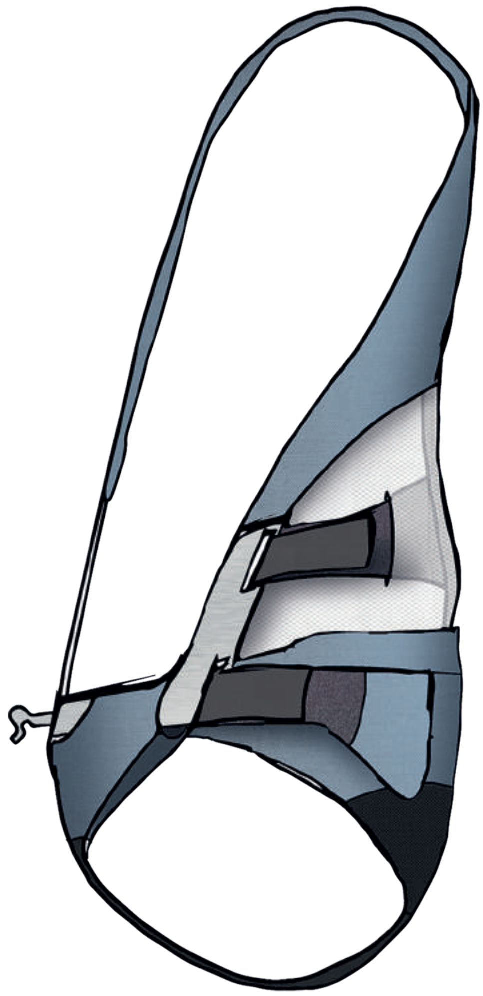
Figure 22 ; The strap setup of the harness' design illustrated by the yellow/ orange line.

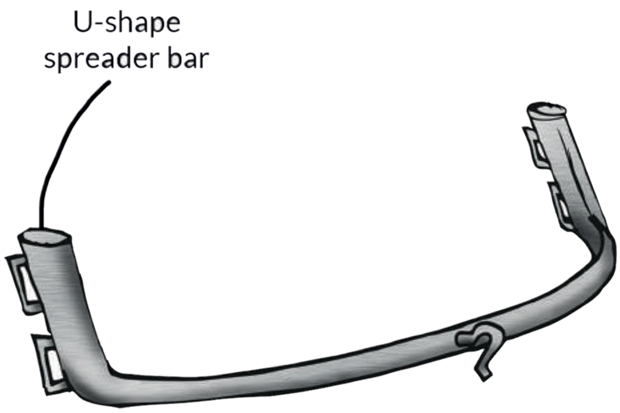
Design one - Ultimate support harness

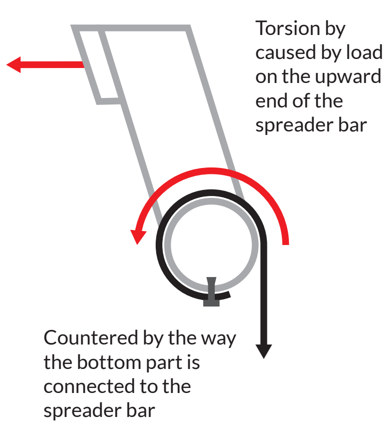
The third direction is focussed on supporting the sailor in heavier conditions and provides a high degree of support throughout the entire harness (see Figure 21). The design mainly targets the back to ensure an equal distribution of the load. The strap layout could be considered to be quite similar to current harness designs, however with a slight adjustment on the back (see Figure 22). All straps on the back come together at one point on the back and from there find their way to the spreader bar. Creating a support point on the back as the basis for optimal support. One of the specific features of the harness is its spreader bar. Compared to a traditional spreader bar setup this bar has ends that bend upward, parallel to the body. A setup that allows to provide an anchor point for lumbar support that reaches higher. The bottom part of the harness wraps around the spreader and is attached in such a way that it counters the torsion that is caused by the force acting on the parts of the spreader bar pointing upward. Partially echoing the design of direction one, the support in the lower back is separated from the rest of the harness. The lower back strap has a 3D shaped plate integrated into the strap, that matches the curvature of the sailors lower back providing extra support. Similar to the hip part, the lower back strap is adjusted using Velcro straps. Thereby making sure the harness has a clean layout and no loose parts fly around.

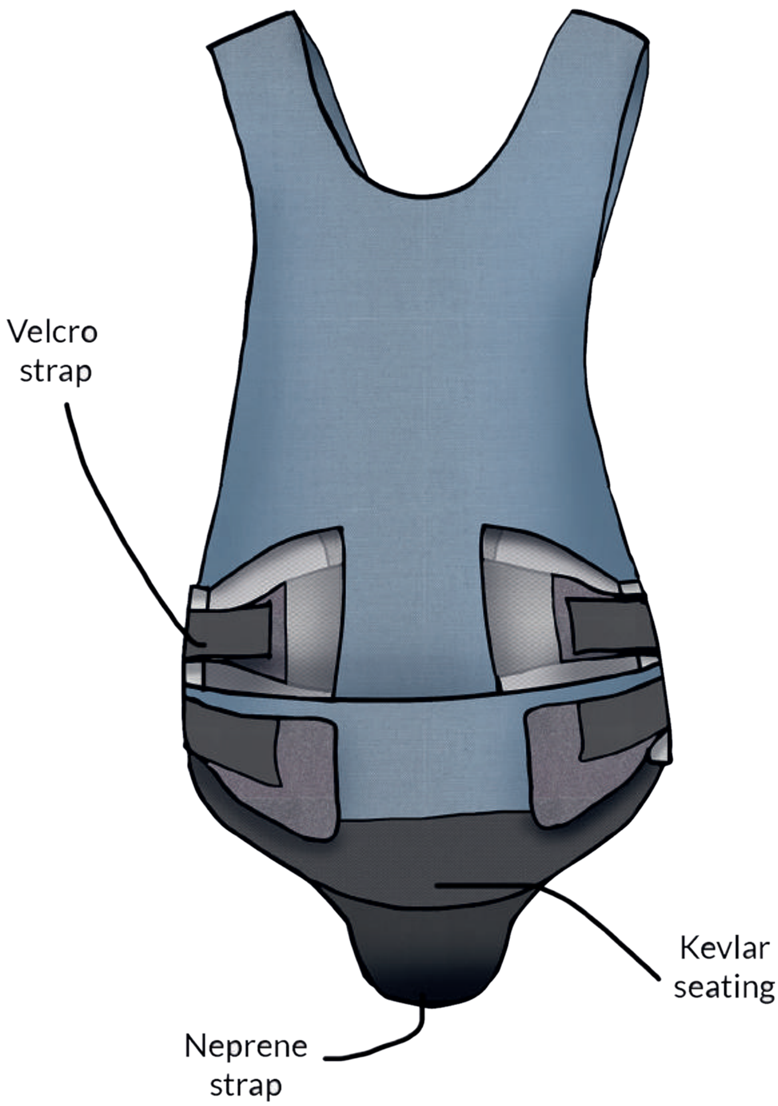



Spreader bar
Lumbar support




U-shape spreader bar


Torsion by caused by load on the upward end of the spreader bar
Countered by the way the bottom part is connected to the spreader bar


Velcro strap
Kevlar seating
Neprene strap

Design one - Ultimate support harness

Using a scale ranging from one to five for the listed choice criteria, the designs were awarded points. Subsequently, these points were added up with design one coming out on top, as is illustrated Figure 23 . Both design one and two score high on the distinctive criteria, as both designs stand out from current harness designs. However, the feasibility of design two is questionable, since it has multiple moving parts that make it hard to test the design at once. Instead, the new design elements would have to be tested individually. Design three scores high on feasibility, but at the same time can not match the distinctive design of number one. The fact that design one came out on top, allowed to further investigate the shoulder strap setup, the feature that made the design stand out from the rest.

2.2.3 Design evaluation

The next step of the path towards a new harness design was to validate the current design and identify design flaws by analysing the interaction of the design with its end user, the sailor.

Towards a prototype

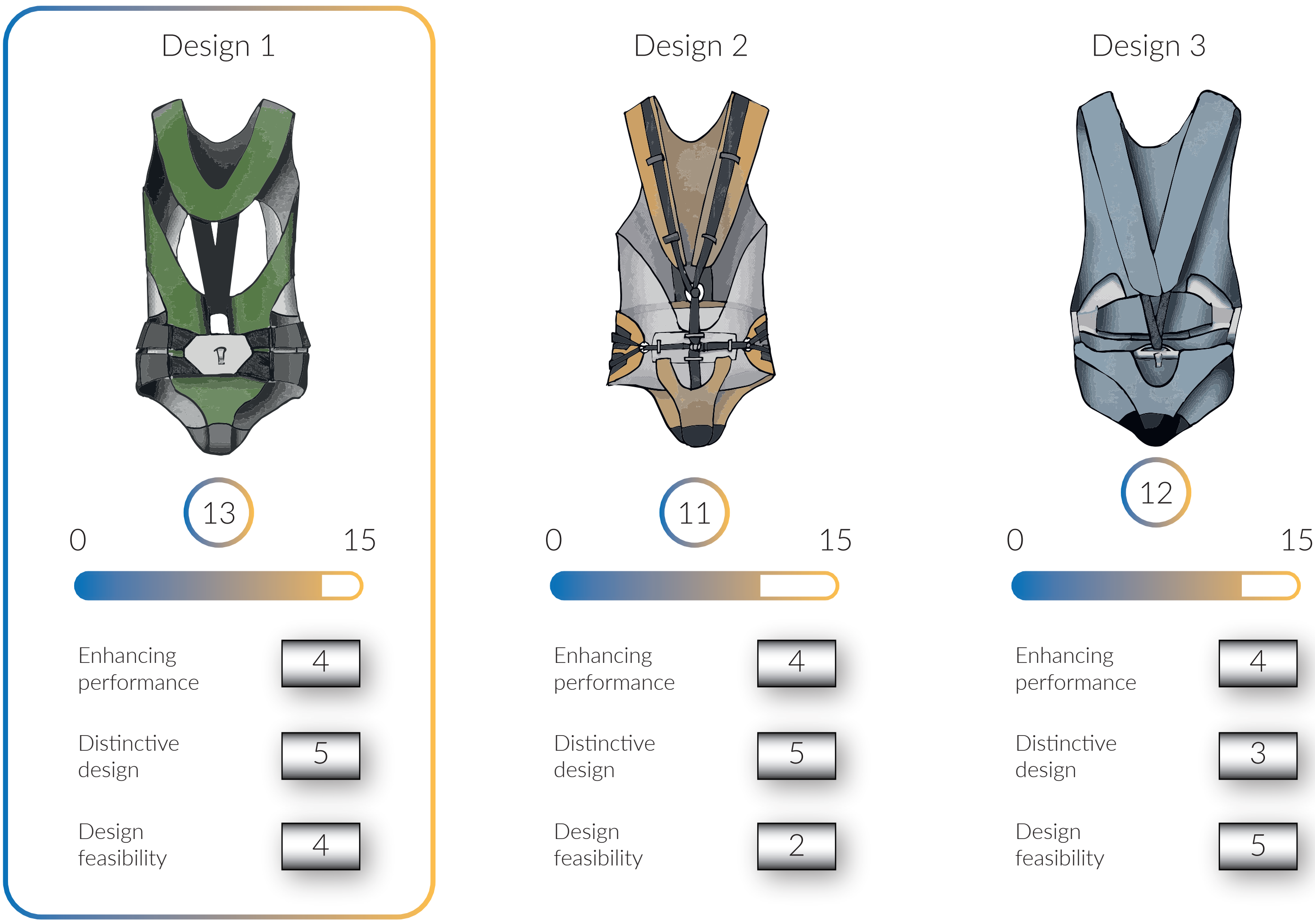
In order to investigate the interaction, a prototype of the design was fabricated that simulated the main characteristics of the design.

The harness' unique features are the division between the upper and lower back part and the shoulder strap orientation, both fundamental to create the open back. To implant these features into a prototype and restrain the influence of fit, an existing harness served as the basis. Besides the open back construction, the prototype was fitted with an adjustable strap in the lumbar region and the double Velcro adjustment on the hips. Resulting in the prototype as visualised in Figure 24. With the integration of these features into the harness prototype, it was possible to gather feedback concerning both freedom of movement and the degree of support from upper back part and lower back support strap.

Required adjustments

To test the functioning of the harness design and investigate whether the freedom of movement was indeed improved, the harness was put to the test by four sailors. The exact setup and results from this experiment are discussed in detail in [xx]. Conclusions of the test indicated that opening on the back needed to be smaller, partially by enlarging the upper back part and for the other part by redesigning the lumbar support strap. Sailors pointed out that the lumbar strap initially provided a feeling of support, but once hiking quickly became painful. Arguments ranged from a too small surface area to incorrect

Figure 23 ; Illustration of the total awarded points for every harness, showing Design one as the winner.

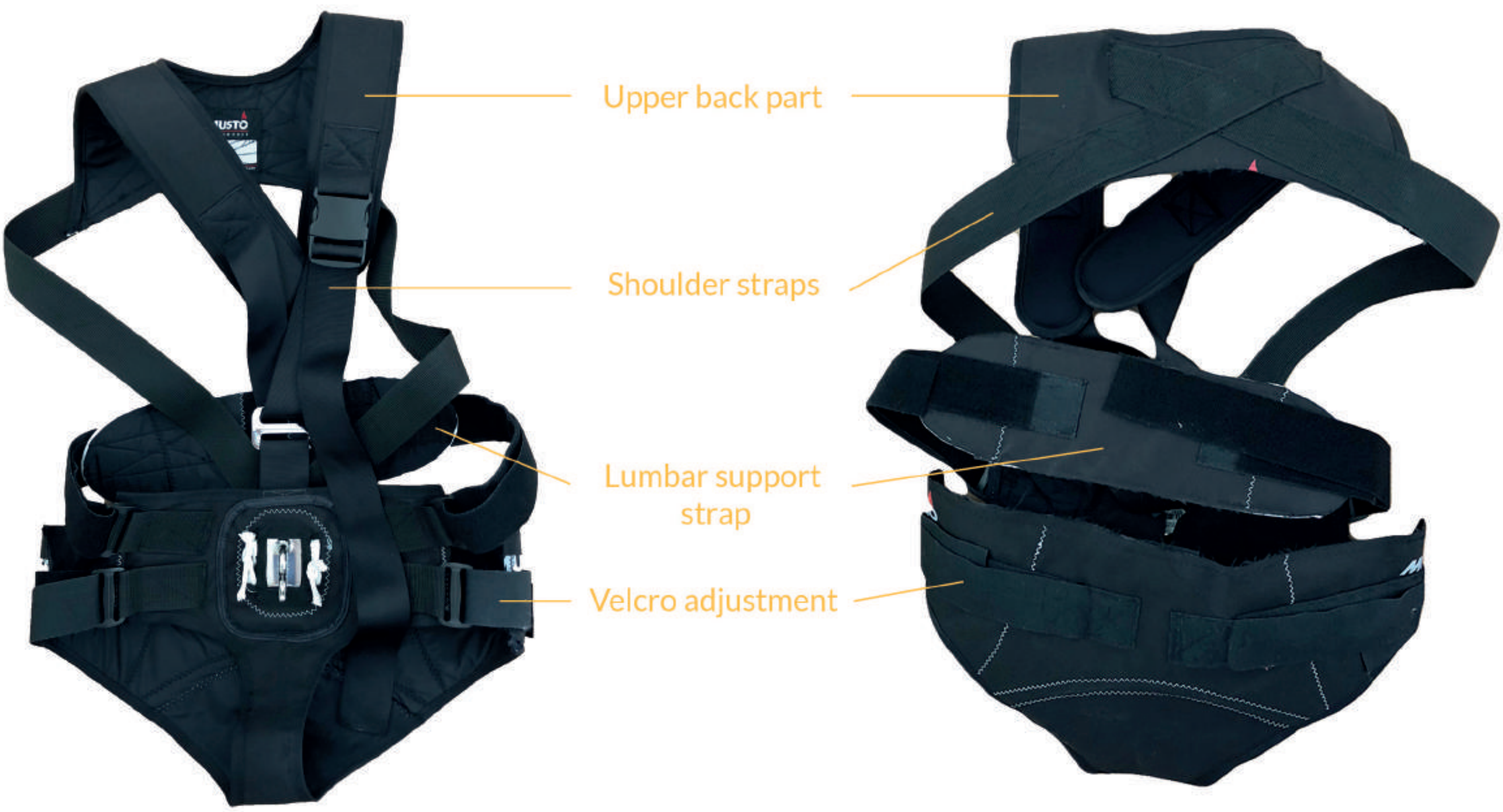


placement of the strap. First reactions with regard to the shoulder strap orientation was in all four cases with amazement. Nevertheless, sailors indicated that it lacked padding and that the straps might be to narrow. On the other hand, the Velcro adjustment on the hips was praised, as it merged the qualities of traditional straps with the cleanliness of currently used Velcro adjustments. In conclusion, the harness did offer more freedom of support as was intended, but still needs intermediate steps to create a harness that is usable over a longer period of time and to convince sailors of its advantages.

2.2.4 Proposed final design

When directly comparing the redesign harness to a traditional harness, the differences are quickly spotted. The main lines of the harness are the same, however the cuts made in the back sets it apart from the rest. Seeing the harness for the first time might result in frowned brows, but is a confirmation of its distinct design. The split back is one of the main features of the harness, providing the sailor with more freedom of movement. After testing, the gap between the top part and lumbar support was reduced to increase support in this area. Additionally, two stiff strips have been inserted in the lumbar support strap, which has also been increased in height and width to cover a larger part of the back. Similarly, the upper back part was stretched out further downward to cover a larger area and thereby distributing the pressure. To determine the optimal height and maximum distance between the upper back and lumbar support part, further testing is required. It is important to keep in mind that the lumbar support strap should not stick out to far as the PFD should still be able to be put over the harness. The split back could only be achieved by a different shoulder strap orientation. In the redesign this is achieved by having both attachment points of the strap attach at the front side of the harness, or more specifically the hook. A setup that creates the distinct look of the harness. Additionally, the attachment points of the straps both run through a buckle and are not permanently connected to the buckle. This setup allows the straps to move freely, which in turn allows the sailor to move the shoulders more easily.
Still, the lumbar support strap remains semi attached to the bottom part of the harness. The semi attachment is realised by elastic fabric that is placed between the hip part and lumbar support strap, helping to maintain the harness parts at their intended places. Also contributing to the aesthetics of the harness and giving the impression that the harness is one still largely one piece, thereby reducing the shocking reaction and limiting the subconscious negative experience

Figure 24 ; Image of the prototype used for testing.



that the prototype harness evoked.

Another feature of the harness is the method to adjust the tension on the hips and in the lumbar support strap. Using Velcro to adjust is not new in harness design, however in current harness designs multiple Velcro layers overlap and do not have an anchor point to pull two parts together. In the redesign the Velcro also consists of multiple layers; one to create tension and one strap to lock. The locking strap also ensures a clean harness, preventing the straps from flying around. With the straps the sailor can precisely adjust the tensions and thus the deformation of the harness.

Reserved for vis

sual final design


AUSTRALIAN
SAILING TEAM
NAUTICA
HAMILTON ISLAND

Part two

Part one of this thesis presented the two results. These results were based on insights that were obtained using multiple methods, ranging from interviews to observations. Part two is divided into seven chapters each describing what was studied and the method that was used find an answer. Subsequently, presenting the results and what insights were obtained.

<

Figure 25 ; A 49er crew sailing a downwind reach, while standing all the way back on the wing.

Overview of all insig

ghts and their origin

3.2 Desk research

Basic understanding of the trapeze harness

What methods

how

What came out

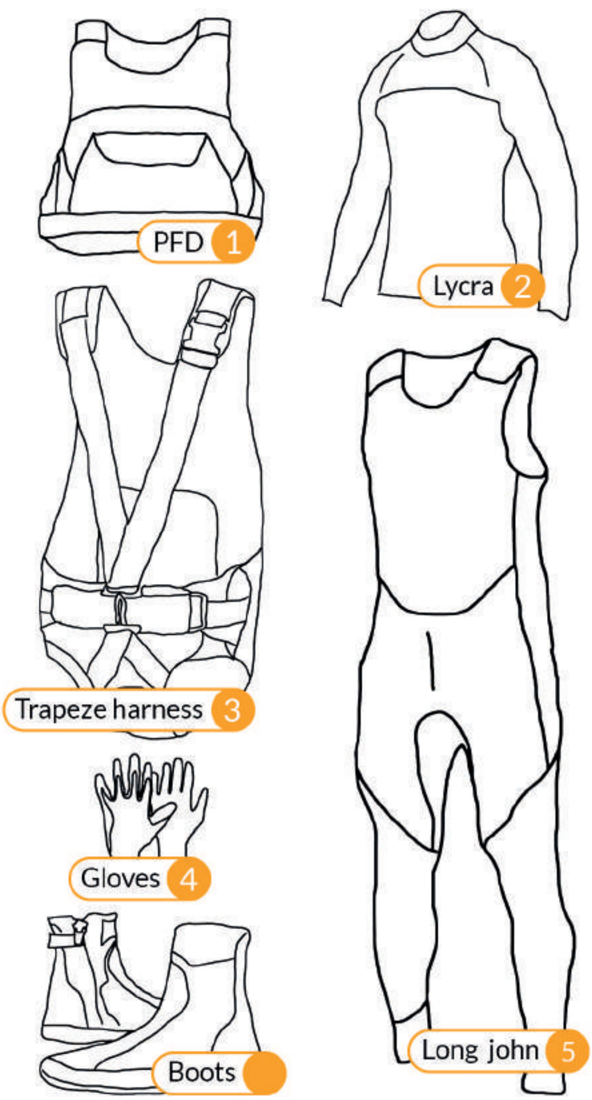
3.2.1 A trapeze harness

For a trapeze sailor, the trapeze harness and personal floatation device (PFD) are both essential pieces of clothing that always have to worn during races. Besides these pieces of clothing the sailor wears additional clothing to protect against impact or UV and insulate their bodies, with clothing pieces ranging from gloves to wetsuits. Depending on the on water conditions, such as wind strength, temperature and wave height, the clothing combinations alters. Figure 26 shows an image two sailors wearing a typical clothing combination. Additionally presenting an important fact, being that the trapeze harness is worn underneath the PFD, potentially blocking movements. Sailors wear an additional lycra over their PFD and harness to prevent straps or other loose parts from getting strangled somewhere on the boat.

3.2.2 Rules and regulation

When deciding to compete in a race, a competitor automatically agrees to adhere to the rules that were drawn up to create a fair race. World Sailing, the overarching sailing organisation, has drawn up these racing rules that are reviewed every three years. These rules, better known as The Racing Rules of Sailing (short: RRS), include right of way rules and how to conduct a race, but it also includes rules for clothing [02]. The RRS specifically mention clothing in the rules to try to reduce the advantage that might be gained by wearing clothing that increases the weight of a person. Rule 43.1 (a) describes that: "Competitors shall not wear or carry clothing or equipment for the purpose of increasing weight." Which is quantified in rule 43.1 (b) that states that a competitor's clothing and equipment shall not weigh more than 8 kilograms, this is excluding a hiking or trapeze harness and clothing worn below the knee. World Sailing has left some room for class organisations to increase this weight up to 10 kilograms. On top of that, 43.1 (b) specifies that a hiking or trapeze harness shall have a positive buoyancy and shall not weigh more than 2 kilograms. Again with the addition that class organisations may increase the weight up to 4 kilograms, in case of the 470 this weight has been increased to 3 kilograms. These rules prohibit the addition of weight gaining methods such as water pockets that fill while sailing. To keep a standard weight throughout the thesis 2 kilograms will be considered to be the maximum weight of a trapeze harness.

02 World Sailing Class Organisation. (2016). "International 49er Class Rules 2016."



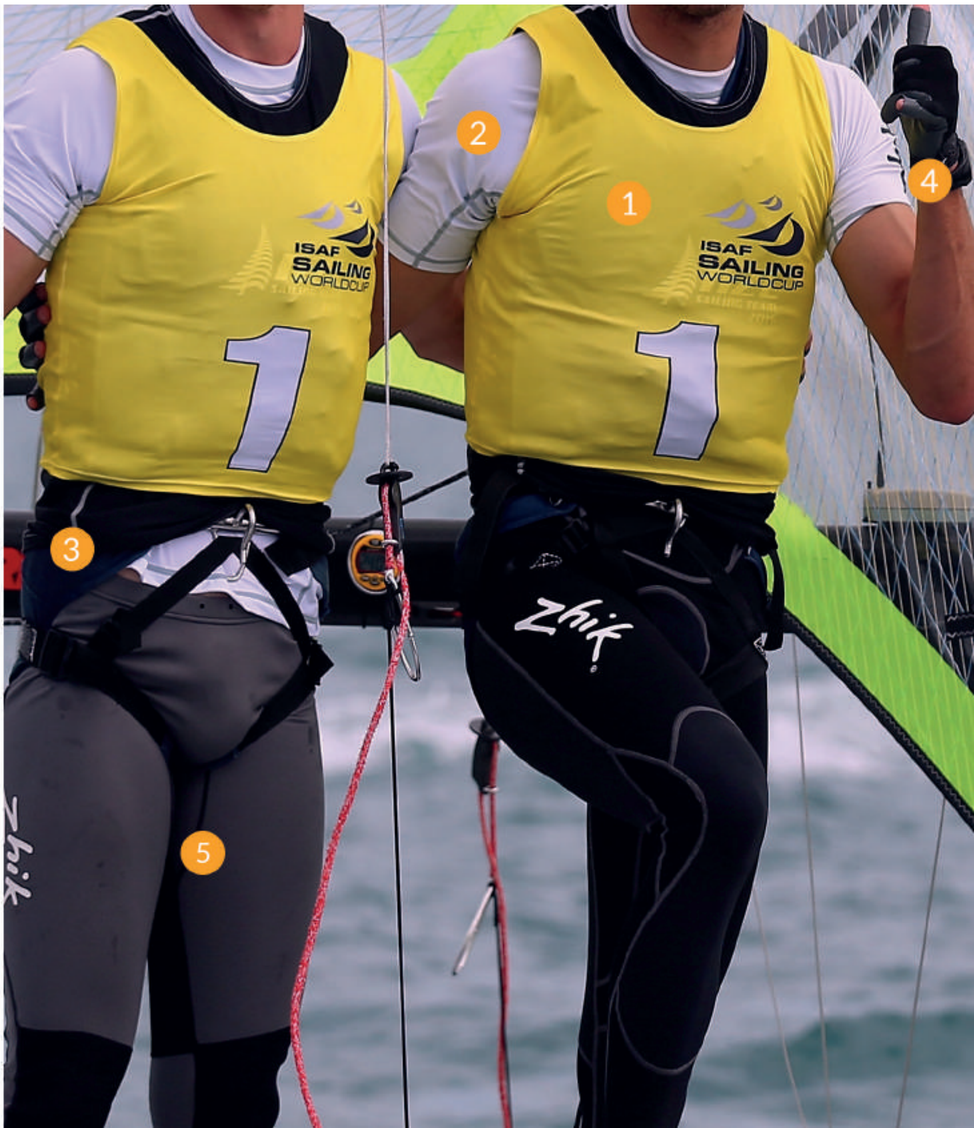


Figure 26 ; A 49er crew sailing wearing a typical combination of sailing gear.

> Figure 27 ; *A custom made harness by Bigfoot.*

> Figure 28 ; *An example of a nappy style harness by Magic Marine.*

3.2.3 Harness designs

The harness is a piece of technical sailing gear that was designed to connect the sailor to the trapeze wire and suspending the sailor when standing on the gunwale. At this point the sailor's full body weight is pressing on the fabric of the harness that in turn is all directed to one point, the hook. There is a variety of harness design, however all sharing the same fundamental design elements. In general trapeze harnesses can be categorised in to distinct groups based on their design: The nappy and the leg strap style harness.

The nappy

The nappy style harness finds its origins in the world of custom harnesses, a design that shares similarities with a diaper and initially was designed to be as light as possible. Due to the simplicity it can be easily produced to fit a specific sailor based on anthropometric measurements. In Figure 27 an example of a custom made harness is provided. Specifically showing the simplicity of the nappy as it only has one adjustment option, the shoulder strap, since the circumference of the harness around the hips is made to fit. Nowadays, larger clothing manufacturers have picked up the nappy design and used it to develop new harnesses that are lightweight (see Figure 28). In terms of design, the nappy is characterised by its simplicity and having a single strap that wraps around the genital area, leaving the legs free to move. The simplicity is highlighted by the type of hook that is used. Instead of having a wider spreader bar setup, that requires more adjusting, a typical nappy has a hook that is incorporated into the harness. The nappy style harness design is not specifically designed for comfort, but for freedom of movement. This quality is slowly fading as manufacturers are trying to find the best of both worlds by designing harnesses that have

Side story: The development of the trapeze harness

The exact history of the trapeze harness is debateable. Despite that, it must have started with something similar to what can be seen in the image far left. In the 1930's, with pieces of canvas underneath the armpits suspended from a rope attached to the mast. Unfortunately, the idea of the harness was not introduced until much later by the first sailors of the Flying Dutchman and

the nappy style setup with the support of leg strap harness.

The leg strap

As the name of this category reveals the harness is characterised by the straps that wrap around the legs. Besides the leg straps, the harness is in most cases fitted with a spreader bar. In Figure 29 an example of a modern day leg strap harness is provided. In order to fit every user, the harness has multiple adjustment options to allow the user to fit the harness to their body. This is realised by equipping the harness with a set of straps focussing on wrapping the harness around the hips and waist. In contrast to the nappy, the leg strap harness usually has more padding to reduce strain on the body in specific areas, as it focussed on providing comfort to the sailor. In addition, modern leg strap harnesses have stiffer material integrated into the fabric of the harness to increase the support and distribution of pressure on the body.

Figure 29 ; An example of a typical leg strap style harness by Magic Marine.

The hybrid

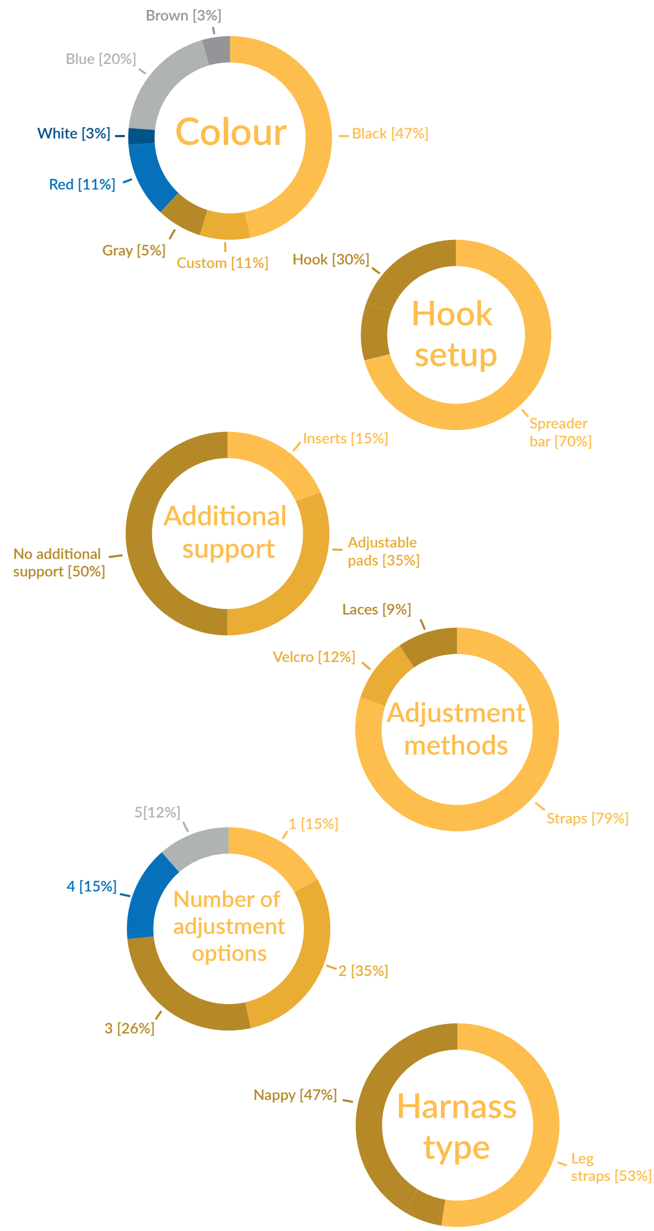
As previously mentioned more harness manufacurers have merged the two distinctive harness designs in to one. In Figure 30 an example of such a harness is provided. Showing the single strap bottom and spreader bar that is adjusted by straps on the side. The harness also has a adjustable plate in the back to provide extra support for the user. Clearly showing that this harness is intended to increase support, but at the same time the freedom of movement.

Figure 30 ; A 'hybrid' harness, mixing nappy and leg strap design elements, by Gill.

The hybrid

Sailors have numerous harnesses to choose from, diverging in terms of design and complexity. In order to generate an overview of the differences between harnesses, 38 harness models were analysed. All harnesses were evaluated based on the same points, such as hook setup and the number of adjustments option. Results have

subsequently the 470. Starting out with just a piece textile wrapped around the hips, it gradually developed into the harness that looks familiar. Fully encapsulating the upperbody and becoming available in the strangest set of colors. Newer more dynamic classes adopted trapeze hiking, increasing the demand for harnesses.



> *Figure 31 ; An overview of the quantified results of characteristics of trapeze harnesses.*

The ratio between nappy and leg strap harnesses is about 50:50

been quantified and visualised in Figure 31. In Figure 32 provides an overview of a selection of harnesses that were used. The results of this analysis showed that the ratio between nappies and leg strap style harnesses is about 50:50, but that the ratio between hook and spreader bar is 30:70. Leading to believe that combination of spreader bar and a nappy-style harness is quite common. Other facts showed that 75% of the studied harnesses are adjusted using straps and the number adjustments option range between 1 and 5.

Other fields

Sailing is not the only domain where a type of harness is used to stay suspended from a line or object. A close relatives are wind- and kitesurfing. These harnesses are focussed on supporting the midsection of the body by stiffening the core. Although sailors use a different type of harness, some overlap can be found in windsurfing and kitesurfing harnesses. Similar to dinghy sailing, a harness is as an aid to increase righting momentum. However, for a wind- or kitesurfer it also a method to relief load on the arms, as the distance between surfer and bar or boom is much smaller and is directly controlling the sail. A windsurfing and kitesurfing harness comes in two types: The waist and seat harness (see Figure 33). The main difference being the location of the support, which in turn alters the mechanics. A waist harness reaches from half way of the back to just above the buttocks, mainly focussing on supporting the back. Whereas a seat harness from the lower back to underneath the buttocks, allowing the windsurfer to take a seated posture. Both harnesses have a large amount of foam padding and are stiffer than trapeze harnesses used in dinghy sailing to have a equal distribution.

> *Figure 32 ; An overview of harnesses currently on the market.*

Apart from sports there are also safety harnesses, which come various shapes and sizes. A modern trapeze harness might also have an insert to stiffen the back and provide extra support when needed. Safety harnesses are used in multiple sectors and designs are therefore diverse. Ranging from professional environments on i.e. oil rigs to abseiling in mountainous areas. Safety harnesses can be categorised in two types: a seat and a full-body harness. Where a seat harness is commonly used in climbing and only supports the legs and lower back (seeFigure 33). A full-body harnesses are generally used in professional environments. Compared to sailing harnesses the safety harness designed to support a more seated posture. In addition the harnesses are in most cases made up from thick padded straps with a limited amount of fabric. Positively contributing to the freedom of movement, light feel and airiness of the harness.

3.2.4 Deconstruction of the harness

The design of harnesses are diverse, but in order to fully understand the working of a harness, the harness was simplified into its most basic form. This chapter will present the analysis that was conducted to obtain a deeper understanding concerning the mechanics of the harness. Resulting in a model that is able to predict the forces that act on the body while fully hiking and an overview of the parameters that determine the magnitude of these forces.

The basics of a harness

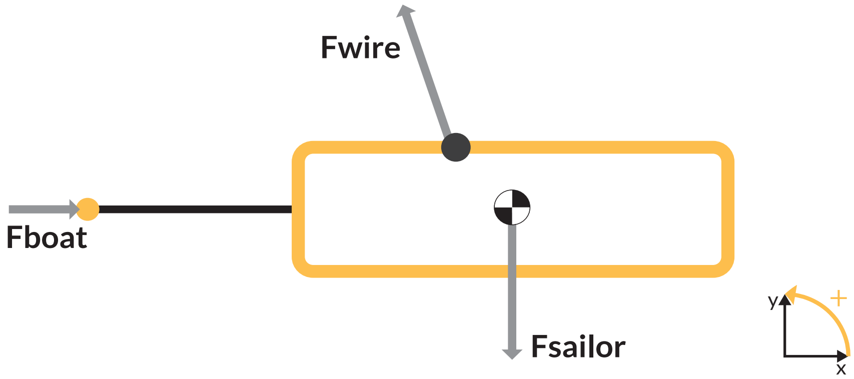
At the start of this report an overview of the entire system was sketched to define the system boundaries and determine the magnitude of the forces acting on the boat as a result of hiking with a trapeze. By zooming further in on the system and working towards the body, parts of the system get replaced or simplified. In Figure 34 a free body diagram illustrates the boundaries of the current static system, which was narrowed down to the harness and the body. From here the system was narrowed down again to the main contact points of the harness. A trapeze harness contacts the body of sailor on numerous points, creating pressure points. The magnitude of the pressure is dependent on the ratio between the force and the contact area.
As complex a trapeze harness design may be, all harnesses derived from the same basic principle of supporting the hips and shoulders (see Figure 35). To simplify the harness, luxurious adjustment options and inserts were left out, bringing the harness to its bare form. The type of hook was not left out of the equation, as this is a decisive design element of the harness. From the hook

Windsurfers (RS-X) like the harness to be as small as possible, only supporting the buttocks.

Figure 33 ; Top-legt a waist harness, bottom right a seat harness, top-right a seat climbing harness and bottom-right a full body safey harness.

Side story: How much does a harness weigh?

Knowing what the limits in terms of weight are for a harness is important, but without sense of how much this is and what factors influence the weight, this information is meaningless. By performing a low key experiment, the weight of four distinctively different harnesses was measured. This was not done according to the method stated in the RRS, but plainly by weiging each harness using a scale. Results showed that a nappy harness is definitely the lightest, weighing just under 800 grams. This harness was made of very thin fabric and had a hook instead of a spreader bar. On the other end there is the leg strap harness, that was just short of 2000 grams, leaving a little margin when soaked in water. Compared to the nappy, this harness had multiple adjustement options, thicker fabric and above all a wide spreader bar. The explorative nature provided a quick insight in the magnitude of the weight for a particular type of harness and the influence of certain elements..



^
Figure 34 ; Free body diagram of the system with sailor and harness.

∨
Figure 35 ; The simplification of the harness applied to two different types of harnesses.

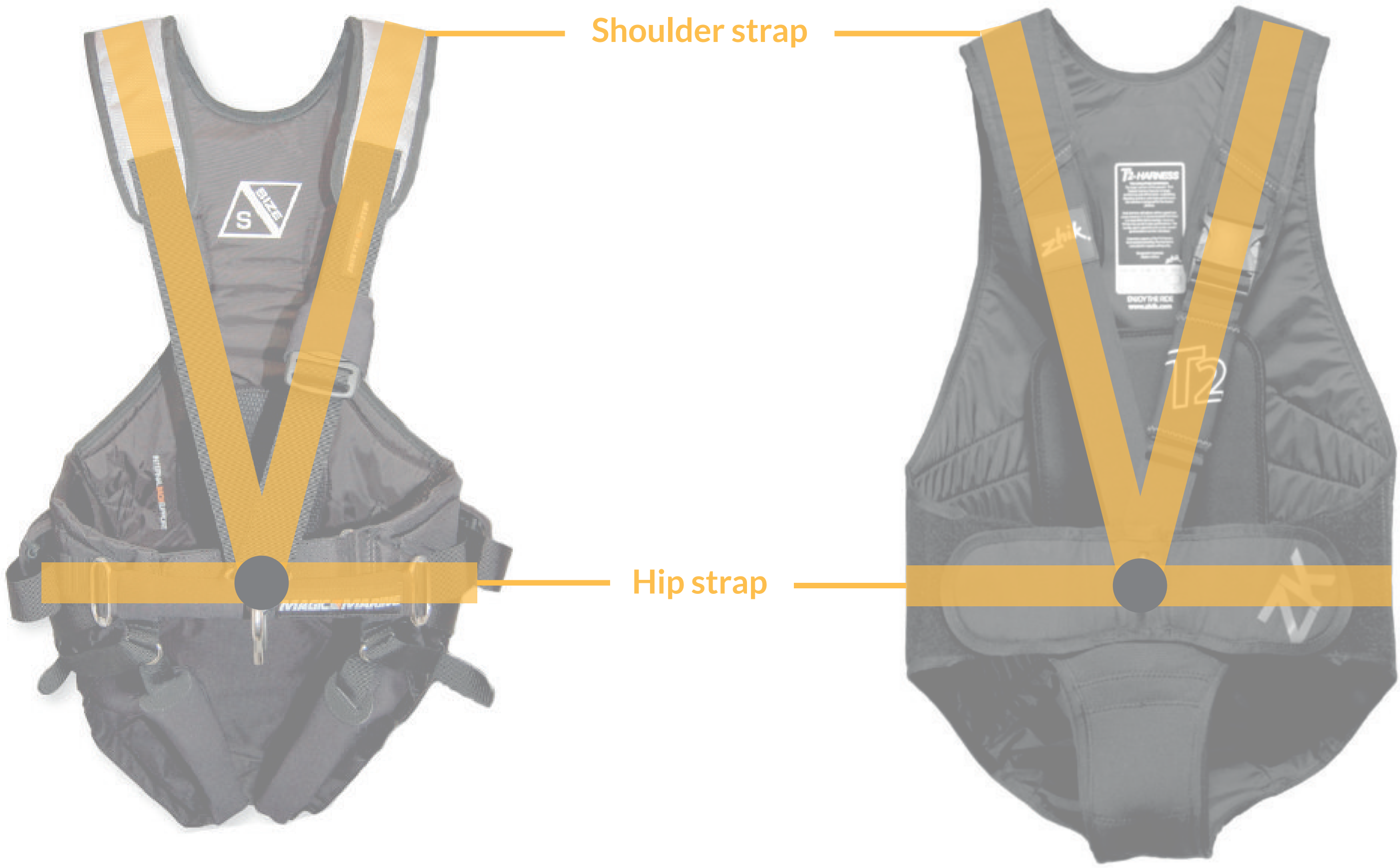
the forces are distributed over the shoulder and hip strap. Which in turn distributes the forces over the body. Why the hip was chosen as a support point could be proven by the anatomy of the body. The design of the hip allows a high a degree of compression as there is little tissue or muscle that could get damaged from excessive pressure. For the shoulders this would be partially true, as the strap for a large part rests on a muscles (trapezius). But its answer could be found mechanics. The shoulder is the furthest away from the main pivot point, the hip. So by support this point the muscle tension should be the lowest and thus most efficient. Additionally, to prevent the body from sliding out the harness and to support the upper body, the shoulders offer the perfect spot. By analysing the situation from different perspectives it was possible to identify parameters that influence the forces on the body and formulate a model to quantify the forces.

3.2.5 Interaction with the body

From the hook the forces are distributed over the shoulder and hip straps. Which in turn distribute the forces over the body. By analysing this situation from different perspectives it was possible to visualise the influence of the spreader bar and how the body is supported.

Side view

The illustration in figure Figure 37 provides an overview of the situation at hand, where a sailor is hanging in the trapeze at 90 degree angle relative to the mast. Fwire engages at the hook where it is divided over the hip and shoulder strap. At points where straps contact the body a force is exerted on the body that in turn develops a reaction (F-normal) from the body to counter the forces of the straps. The magnitude of the F-normal forces at these points are dependent on multiple parameters such as the mass of the sailor, position of the centre-of-mass (COM) and the position of the hook. The figure demonstrates that besides the shoulders, the strap is partially supporting the back. A setup that is not proving itself to be the most efficient method to accomplish that goal. In a neutral posture the spine is not straight and characterised by two curves in the thoracic and lumbar spine (see Figure 36). The degree of curvature is expressed in kyphosis and lordosis angle respectively and is different among the



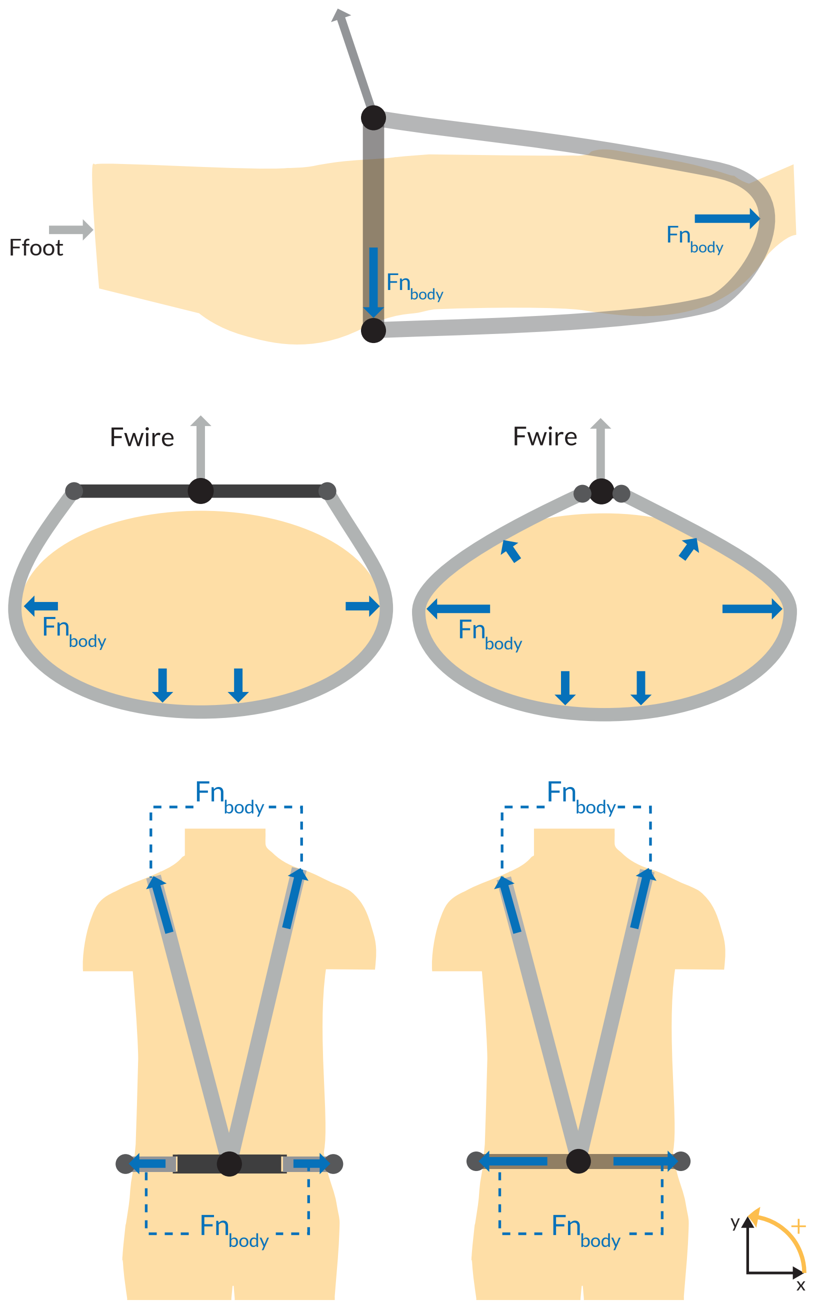
population. Increasing the lordosis angle will result in more inward curvature and vice versa. When a strap is tensioned it will automatically find the shortest distance between two points and not fully support the inward curvature of the lumbar spine region. Indicating that the lumbar area might not be supported to the desired degree. A point that could be validated by the fact that characteristics of the back part of a harness are very similar to that of a strap, as this is also made from one piece and seeking the shortest path between two points.

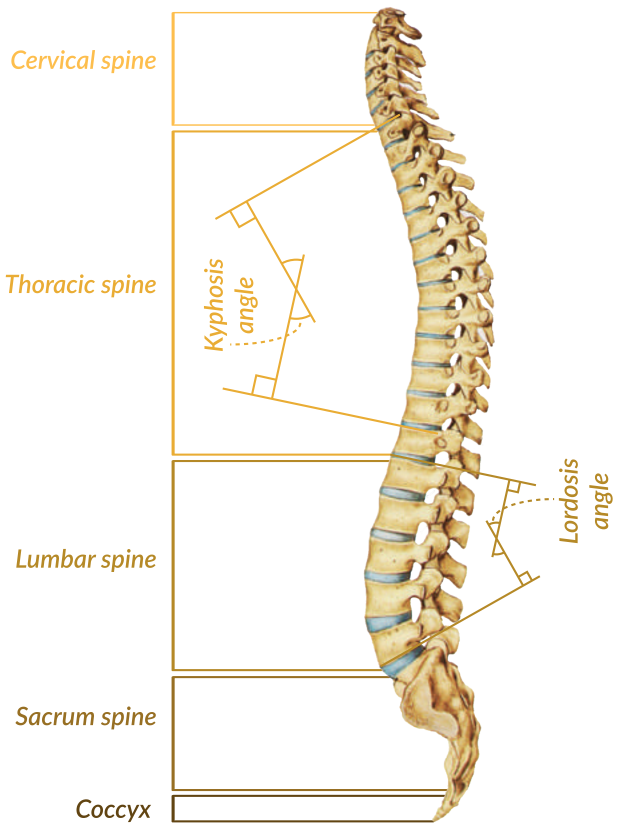
Cross section view

The hip strap wraps fully around the body distributing the tension force and compressing the body at every point of contact. The compression force can be influenced using a spreader bar. In Figure 37 the differences in terms of forces magnitudes are visualised for both cases. In case of a harness without a spreader bar, a simple hook, the compression force is largest. This is caused by the fact that the hook is placed in the middle and that both sides of the belt are connected to the hook. Resulting in a situation where the straps have to wrap around the body, covering a larger surface. Since the straps are more horizontally oriented at the top, where it is in contact with the body, the sailor will experience more of this horizontal force on the hips. This force is countered by the body in the form of a F-normal force. The situation is slightly different in case of a spreader bar. Here the forces in the horizontal direction has the same magnitude, but are for a large part absorbed by the spreader bar. As a result, the F-normal on the hips should be smaller and the sailor should experience less compression. Besides the width of the spreader bar, the distance between the hook and the body is an important factor. This distance determines the angle between the strap and the horizontal component at the hip. If the angle increases the horizontal component will decrease, as more force is directed in the y-direction. The sum of all forces in the y-direction is not affected by the spreader bar width, as in both cases the weight of the sailor remains the same. Producing a similar reaction force of the body at the height of the tailbone.

< *Figure 36 ; Illustration of the spine with the Kyphosis and Lordosis angle pointed out.*

∨ *Figure 37 ; The simplified and body interacting visualised in a side-, cross section- and frontview.*





3.2.6 Modelling the harness

Besides predictions based on touch and appearance, it was possible to create a model that could generate insights in the force that act on the body. The model was based on several dimensions determined by both the harness and the human body identified by simplifying the harness.

Primary model

The path towards the formulation of the model started by going back to the model that was formulated to quantify the righting moment of a 49er depending on the outward position of the sailor [see 1.2.3]. Here was found that the largest force on the wire was generated if the sailor was hiking at a 90 degrees angle in relation to the mast. Using this model as a starting point, the load on the wire could be calculated based on the anthropometric measurements of a sailor and harness characteristics. Figure 38 provides an overview of the input parameters and how these parameters were used to approximate the forces in the desired places. Quantifying the force on the wire was the basis for further approximations, allowing to zoom in on the areas where the simplified harness gets into contact with the body. In this case the shoulders and the hips. The areas that, according to sailors, have to deal with the largest forces. To continue further formulation of the model and calculations, the body was considered to be stiff.

Force on the shoulder

In the deconstructed version of the harness the upper body was supported by a strap that wraps around the shoulder. In a full hiking position the upper body is horizontally oriented. The part of the strap reaching from the hook to the shoulder will, depending on the adjustment, never have a perfect horizontal orientation when fully hiking since there is always space between the hook and the upper body. As the space between the hook and body approaches zero the load on the strap would become infinitely high, which would require materials to be infinitely strong. In order to quantify the magnitude of the normal force of the shoulders, the loads on the strap had to be calculated. Normally the strap would wrap around the shoulder, resulting a distributed force (P(x)) on the shoulder. Due to the complexity to determine the exact distribution of this force, the force was simplified to a point force directly at the top of the shoulders. By zooming in on the shoulders, another consequence of wrapping a strap around a surface is identified, being friction (see Figure 39). Thus, Fs1 and Fs2 must be different, as friction influences the situation. Since friction is a variable that is determined by multiple factors, including the material surfaces, exactly determining the coefficient would be outside the scope of this thesis. Instead, to approximate the force, a conversion coefficient was experimentally established (See appendices A9 - A10). Based on the input variables used to calculate the force on the wire and the conversion coefficient, an approximation of the load on the shoulders could be calculated.

Compression on the hips

Deconstructing the harness simplified the hip part to a strap. Similar to a normal harness the strap is subjected to a distributed force (P(x)) at the point it touched the body. Which posed a problem, as the exact distribution could not be determined

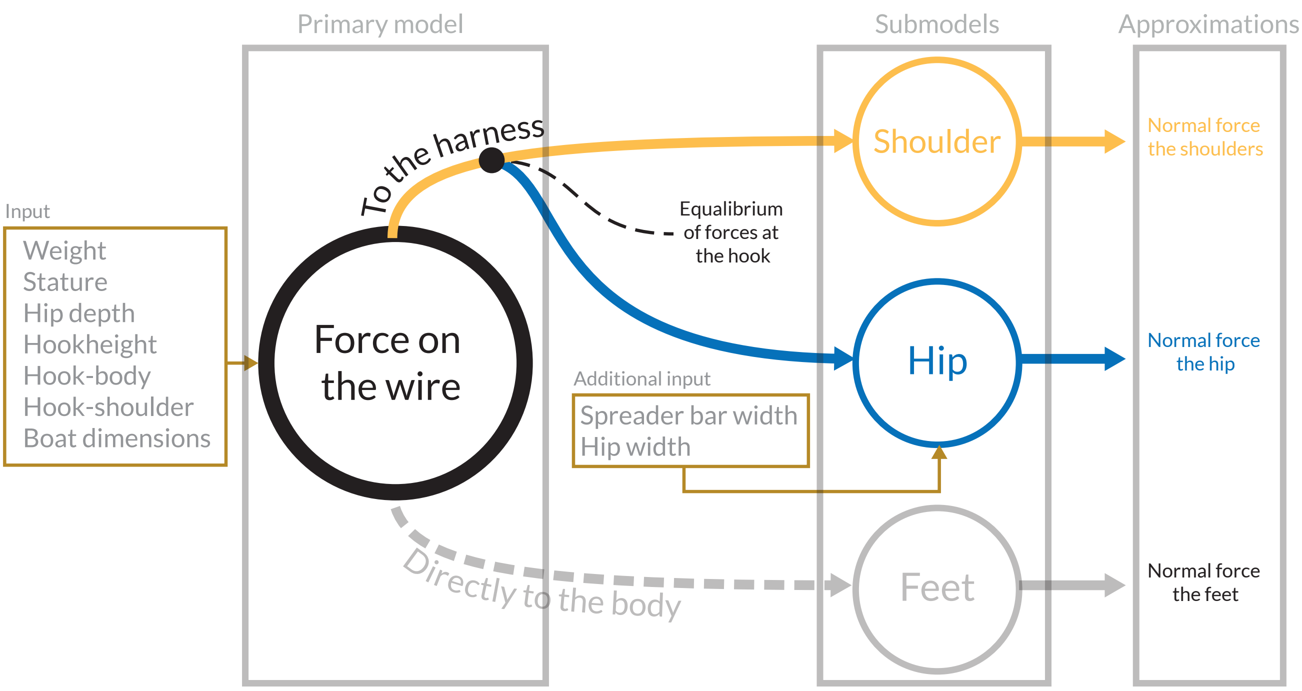


Figure 38 ; *A schematic overview of the input parameters and towards an output of the model.*

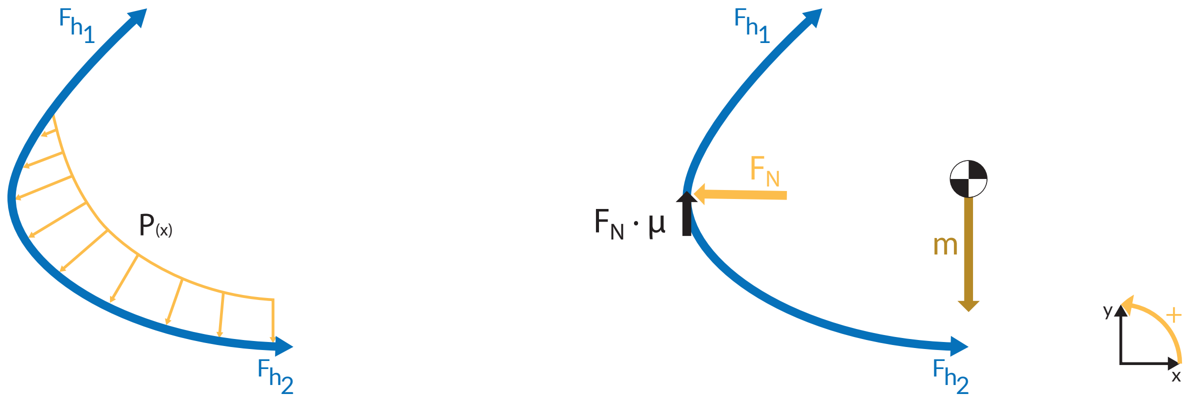


Figure 39 ; An illustration of the forces acting on the shoulder and hip.

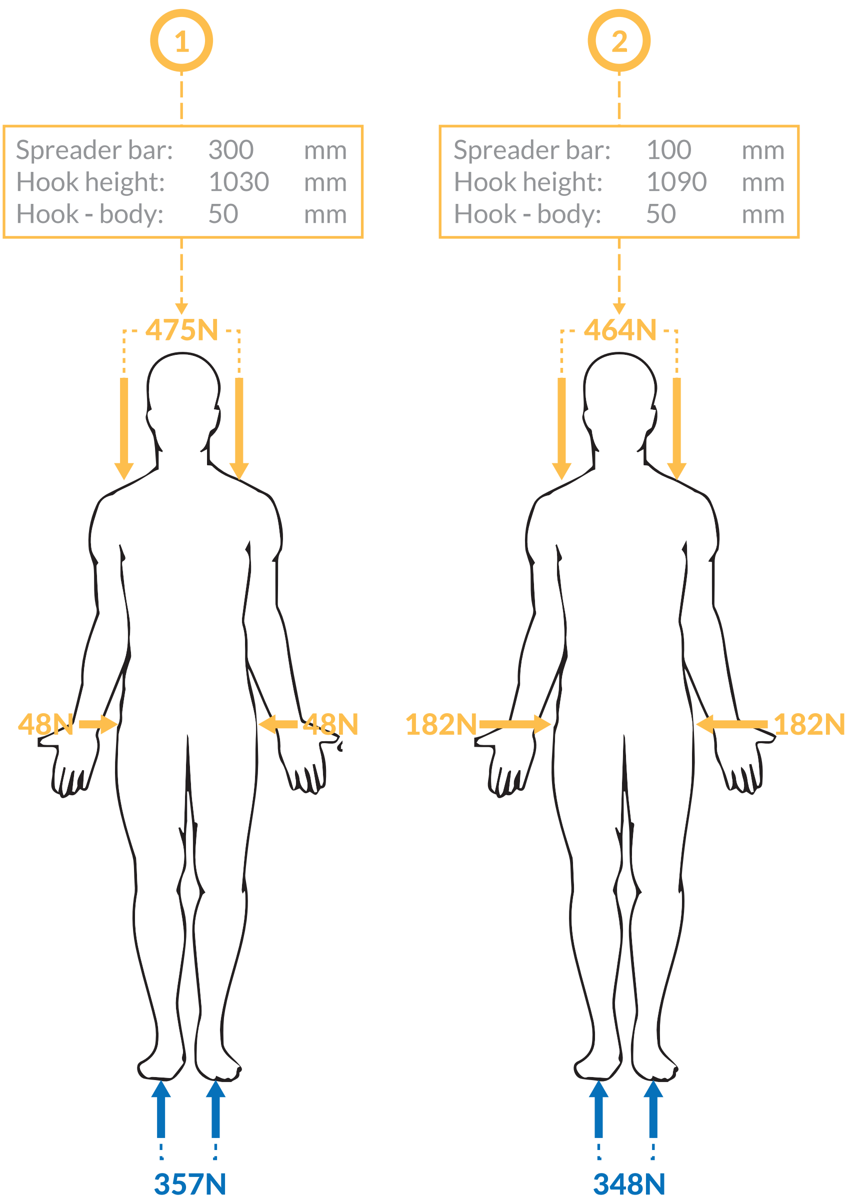


Figure 40 ; Input parameters and output of the model to demonstrate the differences between harnesses.

and is different for every harness and body. To be able to quantify the reaction force of the body on the hips, the force was simplified to a point force (see Figure 39). The point force (Fn) was horizontally oriented positioned at core height. A setup that allowed to calculate compressive force of the harness, an effect of the harness often pointed out by the sailors as being important. Similar to the situation on the shoulders, the harness wraps around an object, meaning friction is involved.

Compression on the hips

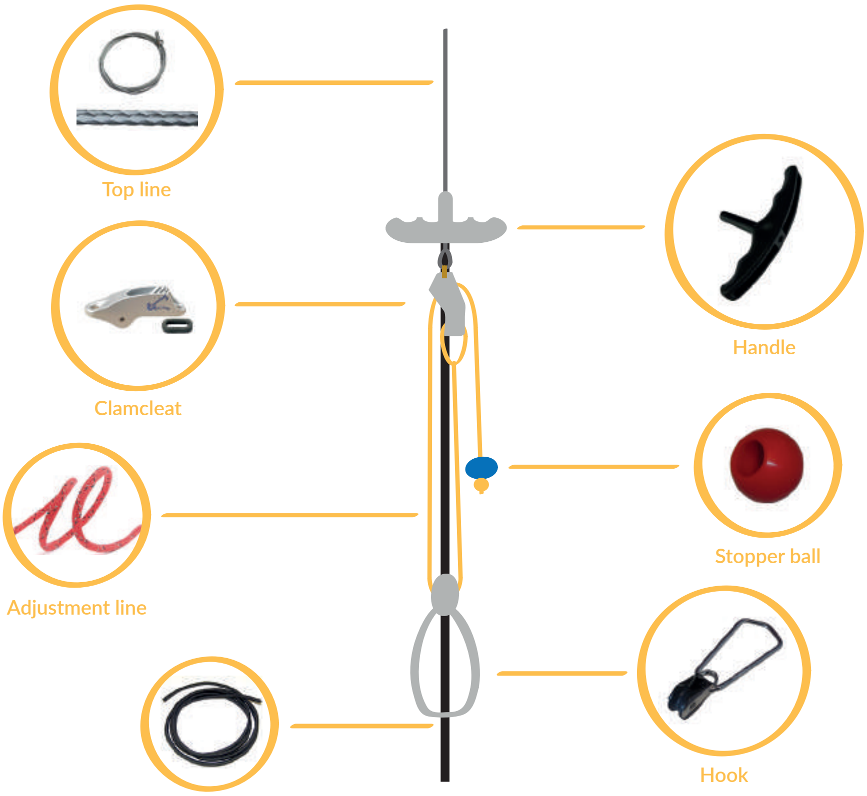
The model is based on the anthropometric data of a sailor. Design details of the harness, hook height and spreader bar width, are main determinants affecting the magnitude of the forces that are transferred from the harness to the body. To demonstrate how design parameters of the harness influence the magnitude of the forces acting on the body, two different harness designs were ran through the model. Anthropometric parameters for the model were provided by using the dummy model as described in appendix A5.
In Figure 40 the input harness specific input parameters are provided supplemented with the outputs drawn at the point of interaction. Harness 1 with a 300 mm spreader bar, a hook height of 1040 mm and distance between hook and body of 50 mm, showed to be subjected to higher forces except for the force on the hips. For harness 2, with a smaller 100 mm spreader bar, a hook height of 1090 mm and distance between hook and body of 50 mm, the force on the hips saw a threefold increase. The force on the feet and shoulders was slightly lower, as the higher hook reduced the distance with the COM.
Putting the calculated forces into perspective to the weight of the sailor, 80 kilograms, shows that the force on the shoulders in both cases is approximately 60% of the body weight. Whereas the compressive force is only 6% for harness 1 and 23% for harness 2 of the body weight.

3.2.7 Trapeze sailing boats

While sailing, a sailor has to perform numerous tasks and adopt different postures to sail the boat at maximum speed, all while wearing a trapeze harness. This chapter discusses some of the boat specific requirements for a trapeze harness. An overview that was generated by closely investigating the differences between the 470 and 49er in terms of movement in the boat, procedures and postures.

Figure 41 ; An illustration providing an overview of all parts and how these parts are put together to create the trapeze system.

Figure 42 ; The crew hiking in a 470 sailing upwind.



Trapeze system

Trapeze systems among different classes are not necessarily similar, the same applies to the 470 and 49er setups. Due to class rules and new designs, trapeze setups can differentiate. For example, according to class rules the 470 trapeze lines should be steel wire, whereas the 49er trapeze line may be a Dyneema line. Nevertheless, systems all derive from a basic setup as is provided in Figure 41. Although, multiple producers have tried to reinvent the trapeze mechanism by altering the connection between the trapeze wire and harness. None of the new systems have seem to have an advantage over the current system using a simple hook.
The hook that is part of the common trapeze setup is made up out of seven or eight other distinguishable parts. Starting up top, at the designated attachment point, the top line is secured to mast. Depending on the class and its rules this can be a metal wire or Dyneema rope. One of the most important parts of the setup is the shock cord, connecting the trapeze line to the hull. The cord ensures that the hook returns to its neutral position after hooking out for a tack or gybe, making it easy to hooking in the next time around.

The 470

Currently the most mature dual-handed Olympic class, making its 12th Olympic appearance in 2020 during the Olympic Games in Tokyo. Recent decisions by the International Olympic Committee (IOC) might have put a hold to the 470's appearance, as it has not been chosen to be part of the Olympic Games of 2024 in [03]. When directly comparing the 470 to the 49er, one of the

first things that arises is the fact that the 470 has a single trapeze setup (Figure 42). When the 470 was first introduced boats this setup was quite new and popular. However, nowadays almost every newly designed trapeze boats have a two trapeze setup, allowing the sailors to generate more righting moment.
The 470 can be specified as a boat with a traditional set up in terms of rigging. Mainly the fact that the boat has a spinnaker, instead of the modern gennaker, is what distinguishes it from modern day classes. The fact the 470 is designed to go downwind slightly reduces the usage of the trapeze. As the boat goes straight downwind it requires almost no righting moment, meaning that the crew spends more time sitting down.

The 49'er

Categorised as skiff, the 49er is a boat that is designed for speed and often referred to as a high performance sailing class. 49ers are characterised by their narrow hull and a high sail to weight ratio, resulting in a racing machine. Sail area of the 49er during a downwind leg is twice as large as that of a 470 in a downwind leg. Proving the point of the sail to weight ratio, as the weight of the hulls are almost similar. Contrasting to other dinghies, modern day the 49er is helmed from the trapeze, requiring a different technique.
As part to renew and make sailing a more exciting sport for spectators, the Olympic Committee chose the 49er as a new class above 15 other submitted classes [04]. Up till 2012 the 49er remained a male class. However, for the 2016 Olympics the 49er's sail plan was slightly adjusted to create the 49er FX (see Figure 43). A new class with a reduced sail area to would better suit female sailors, whom are generally lighter than males. An addition that included two female competitors to the games, which was part of the International Olympic Committee to balance the amount of male and female competitors [05].

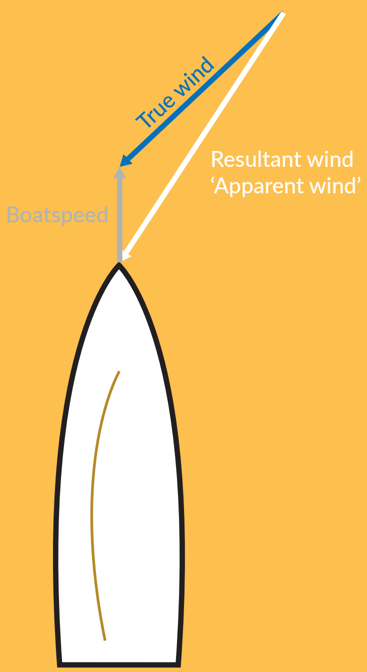
03 WorldSailing. (2018). "Paris 2024 Events confirmed at World Sailing Mid-Year Meeting." Retrieved May 15th, 2018, from http://www.sailing.org/news/86947.php#.WwVYAC-iGL8.

04 Lloyd, B. (1997, April 20th 1997). The 49er Brings a Rush of Sailors to Try It Out. The New York Times. Retrieved from https://www.nytimes.com/1997/04/20/sports/

05 International Olympic Committee. Promotion of women in sport - Statistics. Retrieved from https://www.olympic.org/women-in-sport/background/statistics

Figure 43 ; Two 49ers; on the left the 'male' 49er and on the right the 'female' 49er FX

Side story: Apperent wind explained



The spectacular characteristics of the skiffs are found in the fact that the boats are able to reach upwind speeds that are higher than the windspeed due to combination of low resistance and apparent wind. A principal that is based on the fact that if a object starts moving it also gets to deal with headwind. In this case, a boat is picking up speed from the true wind, similar to what would happen on a bike once you start paddling. The vectors of the headwind and true wind together result in the apparent wind vector (Mason, 2000). To make this work, 49ers have sails that are relatively flat, limiting the loss by drag.

49er Helmsman

Boat trim

The helmsman's movements are kept to a minimum so their main attention can go out to steering the boat. In light conditions the helmsman will stay in and slowly move in and out if need be. It is possible that the helmsman is sitting on the wing and not hooked in. Once conditions start to get heavier the helmsman will start hiking more, but still remain fairly static. While performing basic maneuvers the helmsman will move in sync with the crew and quickly get back in position to focus on steering.

Sheet control

In case of the 49er helmsman controls the jib sheet during upwind legs the helmsman, which is lighter and requires less adjust-ments. Just before a buoy rounding for the downwind legs, the jib is clamped and the mainsheet is handed over to the helmsman. This way the helmsman can stay out hiking while the crew can go in to perform their task. Before heading back upwind the sheets are switched back.

Steering

The helmsman's main task is to keep the boat on track and keep the boat speed at its maximum. Combining steering with trapezing requires exercise to maintain balance and be able to adjust outward position without unnecessary movements of the rudder.

49er Crew

Boat trim

The crew's primary task is boat trim. The amount of movement is largely dependant on the wind conditions. Lighter conditions ask for constant attention to find the sufficient amount counter moment. In these conditions the crew is often positioned in front of the wing to pull out the back part of the hull (stern) to reduce drag from the water. In heavier conditions the crew stands on the gunwale moving in and out or fully stretched, trying to find amount of counter balance. During starts and tacks, the crew is responsible for pumping to help the boat get back up to speed.

Sheet control

Controlling the mainsheet is crew's task in upwind legs. In light wind conditions this might be switched, so the crew can move more freely. The tension on the mainsheet is higher than on the jib sheet, the fact that the crew is able to control the sheet with two hands allows better control. Downwind the crew passes the mainsheet to the helmsman so the crew can take the gennaker sheet. With a higher tension on the sheet the crew is pulled inward, especially during heavier conditions.

Gennaker hoists & drops

Deploying the gennaker is an important manoeuvre that requires timing and agility. In seconds, the gennaker must be able to take wind and help increase boat speed. To perform this task, the crew hooks out of the trapeze and steps towards the middle of the boat, bends over and reaches down for the line. Usually in a explosive manner and with short strokes, the crew pulls the line in hoisting the gennaker. Thereafter, quickly reaching for the gennaker sheet and hooking in the trapeze to get into position. To drop the gennaker the process is reversed.

470 Crew

Sheet control

While hanging in the trapeze the crew the other task is to control the jib. Compared to the mainsail, the jib is trimmed less and requires less force to be controlled. For the crew it is possible to put the sheet in the clamp. In the downwind legs the crew's main task is to control the spinnaker sheets. Depending on conditions and heading, this could be while hiking or in a seated position.

Spinnaker hoists & drops

Hoisting and dropping the spinnaker consists of two parts; setting the pole and hoisting the sail. The crew has to go in to grab the spinnaker pole and set it by reaching towards the front of the boat. Next the spinnaker is hoisted by the helmsman. The drops are a hectic manoeuvre where multiple tasks have to be performed in a very short time. The crew has to guide the spinnaker into the storage bag without damaging the sail. Quickly after the spinnaker pole has to be taken down and put away. In this short period of time, freedom of movement is paramount as the crew has to reach and bend over.

Body pumping

From a steady 8 knots of wind (similar to a very light 3 Beaufort) the race committee may choose to allow body pumping and rocking of the boat to increase boat speed. Body pumping is performed powerfully thrusting the hips up and down while holding on to the trapeze line and standing on the gunwale.

Tasks division comparison

One of the characteristics of the 49er is the fact that both helmsman and crew are using the trapeze to balance the boat, whereas in the 470 only the crew uses a trapeze to do so. Studying the main tasks for every position produced an overview, this overview is provided in figure Figure 44. In terms of boat trim every position is involved, however in both boats its is the crew's main responsibility. Indicating that the harness should not reduce the crew's mobility. A note that was became even more evident when analysing gennaker hoists in the 49er or tacks and gybes in the 470. These tasks required the crew to bend over, squat or make themselves as small as possible to fit underneath the boom. The latter is only applicable to the 470, where crew has to duck between the opening that is created between the boom and centreboard, as is shown in Figure 45. On the contrary, the helmsman in the 49er is more static, indicating that support is an important requirement specifically for a sailor at the helm. Another factor that must not be overlooked is the tensions on the sheet, especially in heavier conditions the tension on the sheet increases and pulls the sailor more inward.

3.2.8 Conclusion

In this chapter the first basic steps towards a better understanding of the trapeze harness were taken. By studying the basics in terms of design, usage and physics, insights in essential requirements were provided. Each of these insights is a valuable.

Carry and support the body

Deconstructing showed that its basic shape consists of two straps that have to carry the weight of the body. Further zooming in identified a basic but valuable fact, applying to all harness designs; Back parts of a harness consist of one piece. The back part has two distinct functions; carrying the weight of the body and supporting specific parts of the body, e.g. the lower back. However, its current setup seems to inefficient at doing so and is dependent on the other. Splitting these functions would allow the specific support in the lower back to be less dependent and even more effective. Raising the question if this provides the best result and the distribution of pressure on the back is experienced by the sailor? In user study 1 the first step towards answering these questions was taken.

Freedom of movement and support

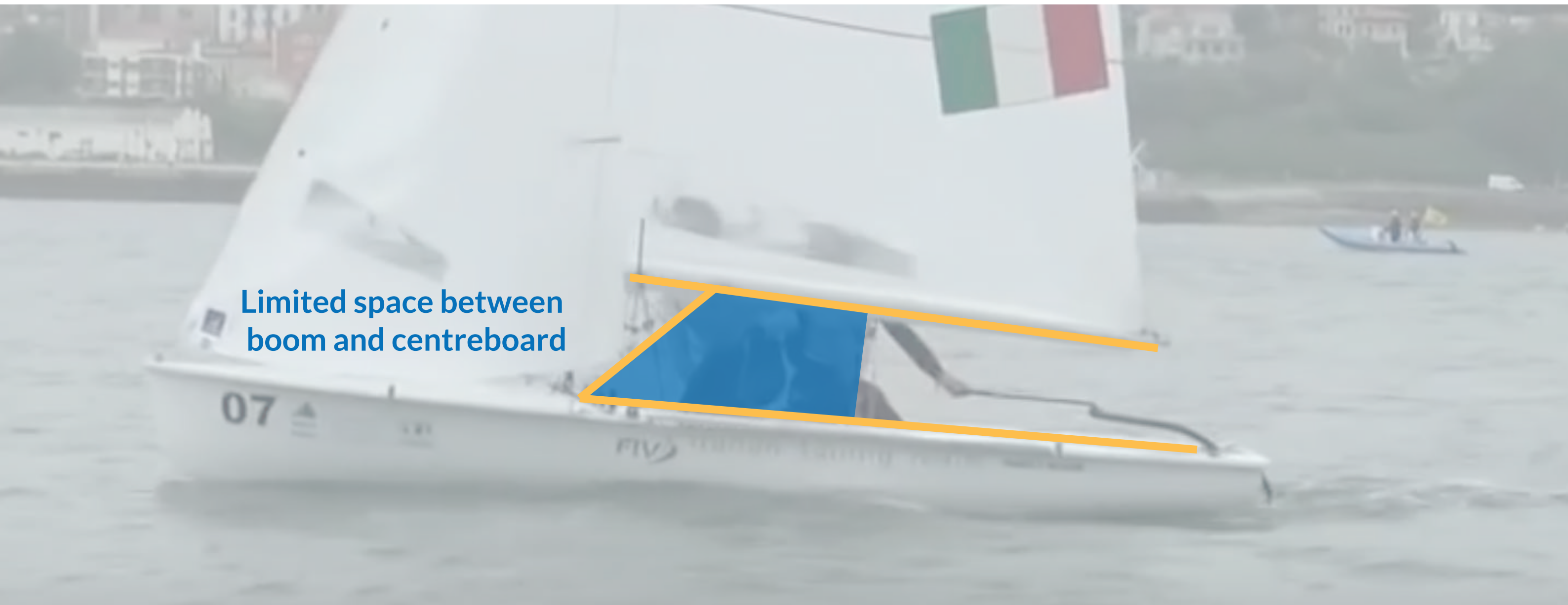
Studying the specific tasks of the sailors in both the 49er and 470 provided important insights in the requirements of a harness, but raised more questions concerning the actual experience, as provided underneath in the box 'Further questions'. One of the main insights that was taken out of the analysis was the need for mobility, freedom to move, while conducting certain tasks in the boat. A requirement that was especially demanded by the crew. On the hand the helmsman was found to be more static, implying that the helmsman would benefit from having a harness that provides more support instead of mobility. However, to what extent are conditions an influencing factor here? And is it possible for a harness to have both qualities?

Question raised from this chapter:

What is the most prefered harness?
Where do you miss support from the harness?
What movements are limited by the harness?
What are the most important parameters when choosing a harness?
What design elements are considered to be crucial from a sailor's perspective sailing at a high level?

< *Figure 44 ; An overview of tasks executed by the helmsman and crew of both the 470 and 49er.*

V *Figure 45 ; An image of 470 sailing upwind with a blue frame highlighting the limited space between boom and centreboard.*



3.3 User study 1

Interviews with sailors

What methods

how

What came out

3.3.1 Introduction

Sailors in trapeze classes have to possess great agility, balance skills and stamina to perform rapid shifts of the body's posture and react to changes on the water (07). Bay et al. (2017) studied the physiological requirements of 49er sailors by studying the movements and performing simulation test, such as tacking and trimming. Further details about the conclusion are outside the scope of this thesis. Nevertheless, it provides an impression of how trapeze sailing must be seen and what is demanded from the sailor while wearing a trapeze harness. The exact experience of and interaction between the trapeze harness and sailor was still unknown. In this user study the main goal was to collect valuable information and insights regarding this interaction to identify important design parameters for a trapeze harness.

3.3.2 Objective

Sailors are the end users of the trapeze harnesses and wear a harness almost on a daily basis. Based on their insights, expertise and personal preferences athletes could pinpoint specific features of the trapeze harness that are either important or ineffective. Identifying the needs of this the target group. In the end the main objective was to find an answer to the following research question: What design elements are considered to be crucial from a sailor's perspective sailing at a high level?

Additionally, finding answers to sub questions such as:

- What harness is most prefered?
- Based on which factors does a sailor choose their harness?
- Where does the sailor miss support from the harness?
- What movements are being limited by the harness?

During the interviews sailors were asked to tell about important aspects of the trapeze harness, irritations, usage and support of the harness.

3.3.3 Method

Obtaining the desired information was achieved by conducting small semi-structured interviews with sailors from both the 470 and 49er (FX) classes. Since most of the sailors were training outside the Netherlands, another option was presented in the form of a questionnaire. The interviews were conducted in Dutch, enabling the sailors to express themselves and not experience language as a barrier. The goal was to have an open discussion about the trapeze harness with the guidance of a questionnaire filled out by the interviewer. During the interviews a harness was laid on the table to kickstart the discussion and help to point out parts of the harness which related to the discussed topic. An overview of the questionnaire is provided in appendix [xx].

3.3.4 Results

In total twelve sailors, four male and eight female, have participated in the user study. All having a different sailing history, five sailors having experience or currently sailing in the 470 and nine 49er sailors who are currently sailing or have experience sailing the class. Due to availability of the sailors six were interviewed directly and six sailors filled out the questionnaire.

Choosing a particular harness

From the interviews it was not possible to point out a specific harness design that favored by all sailors, the diverse personal preferences proved to be an important factor. Five out twelve sailors had two or more trapeze harnesses, one for light weather and one for heavy weather. Providing a hint to the most important decision criteria for a harness. The main decision criteria to choose one of them could be traced back to trading off mobility and support. Dependent on how much support the sailor was willing to trade for freedom of movement a harness is selected. Similar to the trend found in the market the nappy style and hybrid harness are most popular, with a score of eleven out twelve sailors having either a nappy or hybrid harness According to the sailors these harnesses have a better fit and irritate less in the groin region. Other influencers for the type of harness were identified in injury history and sponsoring.

Injuries

Sailors that had previously suffered from an injury in the back, specifically choose a harness they consider to be more supportive in the back. In total five sailors indicated to have experienced injuries in the back, with three them in the lower back region.

Missing support

Although the harness brands and models are diverse among the sailors, six pointed out that support in the lower back is lacking. A missing support feature that reveals it self after spending a longer time on the water. If the ability to maintain a stable posture starts to fade, the body gradually relies more on the shape of the harness to maintain posture. One sailor specifically indicated that for all of the trapeze harnesses in her possession, there is too much space between the body and the lower back part of the harness.

Disliked features

Sailors identified multiple parts of the harness to be essential for the freedom of movement and the fit of the harness. For a nappy style harness pointers were found in the high cut-out of the legs and stiffness of the material. The high cut out of the legs is fundamental for moving and bending the legs freely (see Figure 46). Also the width of the groin piece may in some cases cause irritation if it is too wide. Only four of the sailors had a leg strap harness and pointed out that the biggest irritation involved the strangling of the straps when squatting or bending over, which resulted in less mobility. Also the fact that the legs strap harness mostly used strap to be adjusted was identified as obstructing. Sailors indicated the straps would fly around or get tangled up in the lines of the boat. The distance between the hook and body was in general pointed out to be negative aspect of a harness. Its adjustment however largely depends on the design of the harness, for a harness with a spreader bar this can often be regulated.

Contact points and over stretching

Being able to adjust the harness was considered to be important for all interviewed sailors, also while sailing. Predominantly to increase or decrease the compression at certain points of the body. Especially accurately adjusting the hip part was found to be essential. Six sailors pointed out that compression on the hips is a way of communicating with the boat, feeling how the boat responds to a change in trim or to a wind shift. The amount of pressure on the hips was regulated by choosing between harnesses with different spreader bar widths. Another pressure point is found on the shoulder. The shoulder straps can determine the muscle tension in the core. By tightening the straps the abdominals are slightly less loaded, but the compression on the shoulders will increase. Sailors indicated that if they get fatigued the shoulder strap is tightened. If the sailors were asked about the most demanding postures the subject of over stretching was mentioned by eight of the 12 sailors (not to be confused with stretching of the arm). Here the sailor slightly twists and pushes the upper body into the harness. The posture results in more pressure from the harness on the body, which in turn provides a better feeling of the boat and more stability. According to the sailors this posture is the hardest to maintain as it requires tension on the muscles for a longer period of time, fatiguing the sailors quicker.

Sheet tension

One sailor pointed out that a difference was experienced in load depending the position in the boat. The difference was experienced when switching between the crew and helm position. The helm position demanded more tension on the abdominals than the crew position, as the sailor indicated that the sheet tension pulled the sailor inward. To compensate, the sailor would put more tension on the shoulder strap.

3.3.5 Discussion

The main findings from this study were that (a) a sailor trades off between freedom of movement and support, (b) support is missed in the lower back and (c) contact points are important to feel the boat.

Trading off between freedom of movement and support

Sailors related freedom of movement as a requirement in light conditions, by mentioning that in lights wind they should be able to move freely. On the other hand, sailors desire to have more support from the harness if conditions get more physically demanding and are willing to reduce the degree of freedom. An insights that supposes freedom of movement and support are therefore two opposites and support from a trapeze harness is increased if a sailor settles with a limitation of freedom of movement. For instance, if the sailor has custom made brace

Figure 46 ; *An image zoomed in on the hip part of a trapeze harness pin pointing to the 'high cut-out' of the legs.*

on the back from top to bottom support is increased, but freedom of movement is greatly reduced. Showing that the statement regarding the two being opposites is plausible. To verify this statement the interaction and choice for a particular harness will have to investigated more into detail.

Injuries and the harness

Of the sailors twelve participating in the study, five indicated to have had an injury in the back. Three of which in the lower back region, the part where the spine curves inward. In literature Schultz et al. (2016) studied the reported injuries of Olympic sailors for specific regions of the body, reporting that 23% of all injuries were found in either the thoracic or lumbar spine [06]. Tan et al. (2016) studied the reported injuries of the 2014 World Championship specified for every class and reported that 29% of all injuries reported during this event involved the thoracic or lumbar spine [07]. Additionally finding that the females had a higher injury prevalence than males sailing the same class. Unfortunately, both studies did not identify the trapeze harness as a possible reason for the development or prevention of injuries in the spine. For the injuries related to the spine reduced physical conditioning could be factor. Fatigue or weakness of the abdominal muscles, results in a higher activity and thus load on the hip flexor muscle, which connects the spine to the lower limbs [08]. This causes other muscles to take over in order to maintain posture and create an imbalance in the spine, with the risk of injury as a result. Lock & Allen (1992) already reported that weak trunk musculature was associated with and increase of lower back pain, but also added muscle fatigue and low flexibility to the list of possible causes [09]. A possible initiator of extra strain on the spine could well be pumping. Pumping is a manoeuvre where the upper body is rapidly moved backwards to create extra momentum on the mast and more pressure in the sails to increase boat speed. A pump is performed during starts, tacks and gybes. As the upper body is flexed and extended rapidly the force needed to decelerate the upper body is big and causes a peak load [10, 11]. Which could result in increasing injury risks of the musculoskeletal system.

For further reference the physiotherapist and team doctor of the Dutch Sailing Team were asked to provide their view on possible reasons for the injuries in the lower back regions. According to them this could be traced back to three possible reasons. First the fact of hyperextension of the back, a state of the back that is known as 3D-extension. Due to short fast movements of the upper body the vertebrae and cartilage in the back have to endure hard impacts, maximally loading the back. Which in time could lead to injuries. These statements are in line with the studies of Marras & Mirka (1992) and Besier & Sanders (1999). The second argument could be the physical fitness of the sailor. Physical condition and strength in the core among sailors is different due to physique or training level. Sailors with or having history of a back injury are advised to choose a harness that offers more support to prevent further development or recurring.
The third argument could be the that a harness is not providing enough support, mainly between the lower back and the harness there is often space [12]. Literature reports possible arguments for the development of injuries in the lower back, it does not involve the influence of the trapeze harness as being a possible cause. Both the physiotherapist and team doctor identified the design of the harness as possible reason that increases the development of an injury, but can not substantiate this argument.

06 Schultz, A., Taaffe, D., Blackburn, M., Logan, P., White, D., Drew, M. and Lockie, R. (2016). Musculoskeletal screening as a predictor of seasonal injury in elite Olympic class sailors.

07 Tan, B., Leong, D., Vaz Pardal, C., Lin, C. Y., & Wen Kam, J. (2016). Injury and illness surveillance at the International Sailing Federation Sailing World Championships 2014.

08 Blackburn, M. (1994). The stayed back: Ideas and exercises to avoid problems with the sailing spine.

09 Locke, S. and Allen, G. (1992). Etiology of low back pain in elite boardsailors.

10 Marras, W. and Mirka, G. (1992). A Comprehensive Evaluation of Trunk Response to Asymmetric Trunk Motion.

11 Besier, T. and Sanders, R. (1999). Analysis of dynamic trapeze sailing techniques.

12 Haak, M. & Broekhof F. (2018) Injuries in the Dutch Sailing Team

Side story: Load on the shoulder straps

By wrapping around the body the harness applying a compressive force to multiple points. One of these points is at the shoulder, which is a supported point that is furthest away from the hook. When wearing a harness the compression on the shoulders is felt, but can not be put into numbers. By means of an experiment involving a randomly selected harnesss and a load sensor the load in the shoulder straps was measured. While hiking the load sensor showed that the load on the straps was ranging between 24 ~ 28 kilograms, about a third of the participants body weight. Indicating that a sailor is constantly submitted to a relatively high load, compressing to body.

Feeling from the harness

There are several ways the sailor is able to increase the pressure from the harness on the body. One of them being the width of the spreader another by regulating the tension in one of the adjustment straps, such as the shoulder strap. Still, eight of the sailors pointed out that by over stretching and pushing the upper body into the harness resulted in the best feeling of the boat. The posture that is adopted is very demanding, but in return makes the sailor feel stronger and part of the boat. Although, these are both psychological experiences it enhances the sailors performance.

3.3.6 Conclusion

This user study provided important insights in the most important elements of a trapeze harness according the sailors. Choosing for a particular harness was based on the degree of freedom or support the harness had to provide. The compromise between these two was subsequently determined by at least two factors; the wind strength and physical fitness. The physical fitness is different for every sailor and depends the injury history of a sailor and the physical strength. A sailor with a history of back related injuries benefits from having harness that offers more support. Besides these main factors, four other factors were identified to assess whether the design of a harness is supportive or offers freedom of movement. Sailors individually rate a harness on material thickness/stiffness, type of harness, spreader bar width and contours around the legs.

>
Figure 47 ; A 49er crew sailing in lighter conditions, shown by the crewmember being in front of the wing.

It was not possible to prove whether the harness could be the source of the problem for the development of injuries in the lower back. However, the harness could be the solution for prevention of these type of injuries. As both literature and interviews described, back injuries can be attributed to rapid movements of the upper body and the ability to maintain a certain posture. If the design of the harness were to limit these movements and offer a better support to maintain a posture, the number injuries could decline. In order to do so more understanding of the interaction between the back and harness is required. Raising the question how pressure is distributed over the back while hiking?

Sailors are constantly looking for feedback from the boat. When standing on the gunwale the contact area is limited to the feet, which do not offer the desired amount of feeling. Instead, sailors try to get a feel for the boat by creating pressure points in the harness. As something that is under tension is able to transfer a vibration. Current harness designs transfer this either to the hips or shoulders, which are the main contact points of the harness. The degree of pressure determines the amount of feeling. By tweaking factors such as type and number of adjustments and hook setup, the amount of pressure regulated. Inherently, altering the experience of a harness.

Side story: Load on the wire

Sailors experience the application of extra force on the harness, while over strething, as extra momentum on the mast. From a physics point of view this is a misconception, as this momentum can only increase by a bigger moment arm or increased weight. By applying more force, the bodyweight of the sailor does not increase. From this perspective it is worth wondering whether over stretching is not a waste of energy and only has a psychological effect.
To find out whether the force on the wire does increase when a sailor pushes the shoulders into the harness, a trapeze setup was slightly adjusted by adding a load sensor between a part of the wire. For the experiment a randomly selected harness was used. The results showed that the average load on the wire would on average increase by 500 grams when pushing the shoulders back. Proving there is a difference. Although, this might be caused by the fact that when a sailor starts to push down the shoulders other parts of the body are tensioned as well, including legs pushing the sailor further out and thus increasing the moment arm. The extra energy that is needed could in terms of extra moment on the mast almost be ignored. But, if the stretching increases the feeling of the boat and stability of the sailor with the result of a better performance, then stretching might be worth no matter the initial reason.

3.4 User study 2

Opinion of non sailors

What methods

how

What came out

3.4.1 Introduction

Trapeze harnesses are available in many shape and sizes. Some of them with multiple adjustment possibilities to ensure a perfect customised fit, whereas others seem to be kept as simple as possible. The way the trapeze harnesses are designed should influence the experience of wearing them in one way or the other. With this study more insight was generated in the differences and experience of wearing a harness.

3.4.3 Objective

The study's main objective was to gather the opinion about the experience of wearing a trapeze harness of people without any experience in sailing, or more precise trapeze sailing. Thereby pointing out what factors affect the fit and determine the comfort level of different harness designs. The main research question was: How do non sailors experience the fit of a harness? With the following sub questions:

- What design elements of a trapeze harness are perceived comfortable?
- What are the pressure points of harness on the body?

3.4.2 Method

Nine participants are asked to participate to fit four different trapeze harnesses. Participants preferably did not have any experience in sailing, thereby having no presumptions. Every harness used for the study had either size M or L. According to the size charts, if available for the harness, the harnesses would fit people with a stature ranging between 1760 - 1880 mm.

The procedure started out with taking anthropometric measurements and explaining that they were going to assess four different harnesses with the aid of a questionnaire, explicitly mentioning that sharing their opinion out loud was important. The questionnaire was divided into two parts; one part before wearing and one part while or after wearing the harness. The participants were given the harnesses in random order together with the questionnaire to assess the harness by observing and touching. Subsequently filling out the first part of the questionnaire rating the expected comfort on a 7-scale Likert and indicating what elements the participants based this assumption. Next, the participant was asked to put on the trapeze harness and adjust the harness up to the degree the participant found it had the best possible fit. While wearing the harness, participants asked to move and bend, mimicking real use of the harness. In order to gain insight in comfort as a product experience, it is important to keep in mind that the experience of comfort is achieved when more comfort is experienced than expected [13]. Therefore the second part of the questionnaire assessed the fit and experienced comfort with a 7-scale Likert. This process was repeated for another three times. During the experiment participants were not asked to hike in the trapeze, as the experiment's main goal was to generate an overview of the factors that determine the comfort of a harness for someone who is not biased.

Harnesses used for the study

Participant were asked to wear four different harness designs (see Figure 48). Main differences

13 Vink, P. and M. P. D. Looze (2008). "Crucial elements of designing for comfort." Product Experience: 441 - 460.

Figure 48 ; Overview of the four harnesses used for the study with a short description of their main design features.

Harness A

Harness B

Harness C

Harness D

Features

Harness A
> Thick padding / fabric
> Wide spreader bar
> Leg strap harness
> Strap adjustments
> Support plate cushioning and plate in the back

Harness B
> Thin padding / fabric
> Medium width spreader bar
> Leg strap harness
> Strap adjustments

Harness C
> No padding
> Narrow plate with hook
> Nappy harness
> Velcro adjustments

Harness D
> Wide spreader bar
> Leg strap harness
> No shoulder straps
> Strap adjustment
> Inflexible fabric and thick padding

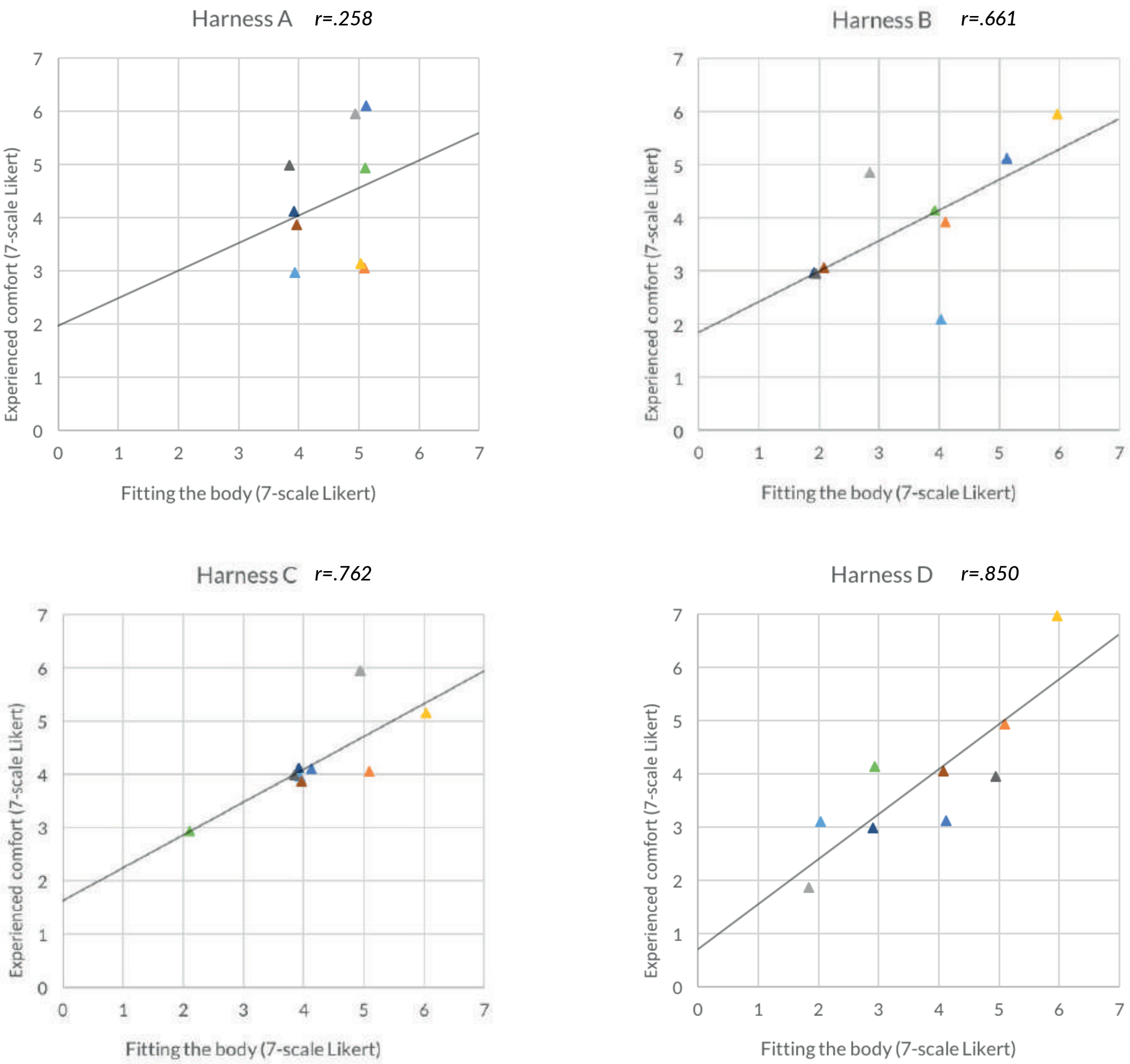
could be identified in terms of flexibility of the fabric, spreader bar width and spreader bar setup. Among one of the harnesses was a harness specifically designed for windsurfing. Compared to a trapeze harness used in sailing, a windsurfing harness does not have shoulder straps and focuses its support on the core of the surfer's body. Arguments for the fact that the windsurfing harness does not have shoulder straps could find in the posture that is adopted while surfing, which is close to upright instead of horizontal posture.

3.4.4 Results

In total nine people participated in this user study, seven male and two female participants. Measuring between 1750 and 1890 mm. The participants all had little to no experience in sailing or trapeze sailing.

Experienced comfort

Participants rated all harnesses before and after wearing on comfort, first assessing the harness based on the knowledge or feeling and afterwards on the actual feeling. Participants rated harness A being the most comfortable upfront. However, three participants rated the experienced comfort of the harness similar or more than expected. Arguments to support the expected comfort were due to the thicker cushioning and stiffness of the harness. Similar to harness A, six participants rated experienced comfort for harness B lower than was assumed. According to six participants the material was found to be the main reason for the expected comfort, materials were too flexible and could therefore not provide support. Five participants mentioned the same reasons for their expectations about harness C, but additionally four participants mentioned that this harness did have a design that would fit the body nicely. For harness C zeven out of nine participants rated the experienced comfort to be higher than expected. Harness D saw an increase of six participants rating the experienced comfort higher than expected, with five of the nine participants pointing out that the absence of shoulders straps was one the reasons to assume it was less comfortable. Participants rating the expecting comfort higher than four, indicated that the material stiffness and harder parts of the harness as argumentation for their expectation.



> *Figure 49 ; Fitting and experienced comfort rating s for every harness.*

Fit and experienced comfort

During the study participants rated to what the degree the harness was matching their body shape and the experienced comfort. Results show that for harness B, C and D a correlation between the matching quality of the harness and the experienced comfort with correlation values of r=.661, r=.762 and r=.850 respectively. In contradiction, the evaluation of the matching shape and experienced comfort shows no correlation for harness A with r=.258. (see Figure 49).

Fit of the harness

While assessing the comfort level of the harness, the shape of the harness was taken as one of the determinants. For harness A, four out of nine participants assessed the fit of the harness with a four or higher, but at same time indicated that the harness did not perfectly fit the back and left a unsupported gap in the lower back. An equal amount of participants indicated to have experienced the same thing for harness B, however in this case the matching quality of the harness was rated with a four or lower. Similar findings could not be identified for harness C or D.

Pressure points

Participants indicated that pressure of the harnesses was most frequently experienced on the shoulders, hips and groin. Figure 50 provides an overview number of times a certain area was indicated by the participants for every harness. Showing that for harness C no pressure was experienced on the hips, whereas this was the case for all other harnesses used for the study. Results showed that participants did not experience any pressure on the shoulders, but instead a peak on the middle of the back.

3.4.5 Discussion

Comfort of the harnesses

Analysing the comfort ratings before and after having worn the harness, showed that after wearing harness A and B participants rated the comfort of the harness lower than initially expected. Upfront harness A was, on average, rated high predominantly as a result of its thick cushioning and stiff materials. Participants indicated that this gave the impression that the harness was providing support and thus should be comfortable, suggesting that support is an indicator for comfort. The same trend was

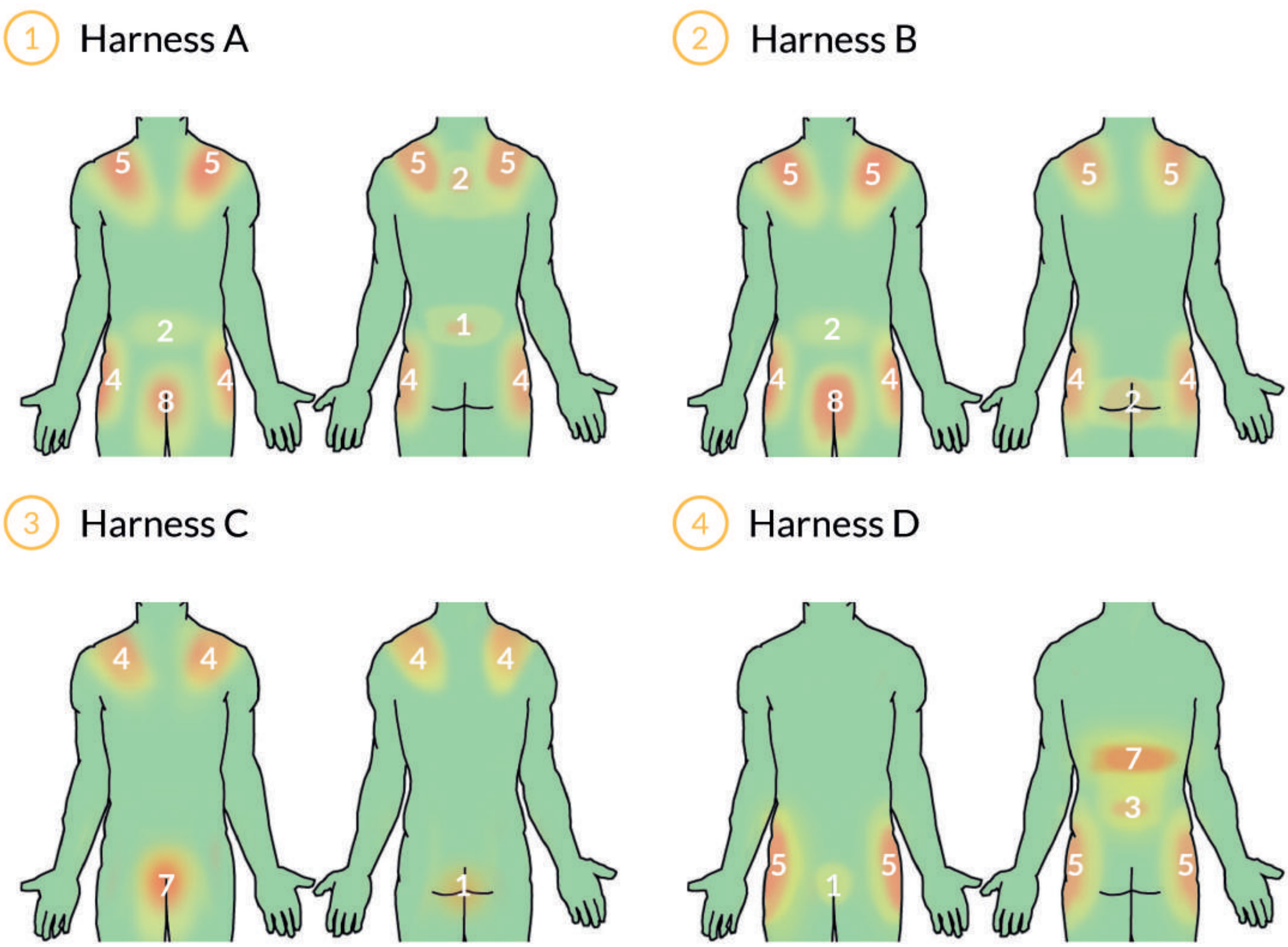


Figure 50 : Pressure points on the body highlighted by the number of times this region was indicated.

identified for harness B. Though, harness B was rated lower on average due to the softness and flexibility of the material. Harness A and B might share the same faith in terms of comfort decrease, their initial arguments are opposite as is reflected in the score. Still, on average harness A scored highest experienced comfort level of all harnesses, leading to believe that there is another reason for the decline. Eight out nine participants indicated that the harness put pressure on the groin area, which was found for all harnesses except D. In user study 1 it was argued that one of the reason for lower back injuries could be as a result of the design of the harnesses, leaving space between the harness and the lower back of the sailor. During the study this very same point was pointed out on multiple occasions, for both harness A and B four participants explicitly mentioned this in the questionnaire afterwards. To what extent this open space remains present when the sailor is hiking requires a more detailed study.

Support as a unit

Participants beforehand rated the expected comfort, using the term support as a unit to express comfort. Subsequently, during the study participants used the term support again to express if the fit of a harness. For instance, participants indicated that the harness did not provide support in the lower back as it left space between the body and harness. Suggesting that contact pressure could be a determinant for support. With the current study setup it was not possible to find a relation between the two, nonetheless it presented an interesting insight.

Moving inside the harness

In the middle of the study one of the participants brought up an interesting fact; “It feels like my body is moving through the harness instead of the harness moving with the body”, participant 2 while wearing harness A. Which at first sight might sound as a logical observation, because this the case for every harness. However, looking more closely reveals that this a design element that limits freedom of movement of a harness, but on the other hand provides support. The design element referred to here is the back part of a harness. In all harness designs this part of the harness is piece that has a set length and does not stretch. Identifying a possible part of the harness that could be redesigned to improve freedom of movement.

Adjusting a harness

Since there was no hiking in this study the pressure point analysis has debatable addition. Nevertheless, it provided a valuable insight in the adjustment options of a harness. During the user study harness C was the only harness to have Velcro as a method to adjust the fit on the hips. The multi-layered Velcro allowed the participant to carefully adjust the hip part to fit around the body, but at the same time did allow the participant to pretension the harness. Figure 50 shows that there are pressure points on the hips for harnesses A, B and D, but not for harness C. The lack of pretension could have a positive benefit while walking around or standing straight up, but while hiking might result in a totally different outcome. Still, this does not take away the fact that the Velcro was a good method to adjust and leftover straps around flying around. Merging the quality of the strap in terms of pretensioning and the cleanness of the Velcro could possibly be an interesting direction to upgrade the design of the harness.

3.4.6 Conclusion

Since the user study did not involve participants an unbiased opinion was given about design elements of the harness. Factors such as material stiffness, flexibility and cushioning were identified to be indicators of comfort. Similar to what was argued in user study 1, the harnesses left a space between the participant and lower back. Further investigation must be conducted to study what happens when the sailor starts hiking and how this affects the support of a harness. Before that, determinants of support have to be identified. Participants used the term support to point out to both comfort and possibly contact pressure.

Additionally, a point was put forward that deserves more attention as it is a design characteristic that applies to every harness design, being the back part. During the study a participant pointed out that their movement were limited due to the fact that the harness does not move and slides over the body while moving, instead of moving along. An insight that led to question the current design of the back part.

Lastly, the study provided an insight for the adjustment methods for a harness. The Velcro adjustment used for one of the harnesses proved to be a good method to ensure a perfect fit, but could not pretension the harness. Straps on the other hand did provide the possibility to pretension the harness, however left the participant with a long piece of residual strap. Merging the two methods could be a way to generate a setup with the positive qualities of both in one.

3.5 User study 3

Observing hiking with a harness

What methods

how

What came out

3.5.1 Introduction

A harness is produced to fit numerous bodies, each having their individual dimensions, curves and volumes. As a result, harnesses may fit one body perfectly whereas another body may not perfectly align with the harness, which could be experienced as discomfort or a lack of support. Current harness designs all fit a certain range of anthropometric measurements, e.g. stature or hip circumference. To demonstrate this point the size chart of a harness manufacturer is provided in Figure 51. The chart shows that size 'L' (large) should fit people ranging in stature from 1820 mm to 1880 mm. Additionally, the manufacturer provides the range for the waist and chest circumferences to choose the size that fits best. Using predetermined measurement ranges, the number of different sizes is limited, but the best fitting harness can not be offered. Therefore, some of the sailors choose to have a custom made harness. The scope of this thesis is not set up a new sizing chart, however it is relevant to find out how a harness fits the body.

3.5.2 Objective

The previous studies have identified multiple important design features, but up till now did not investigate the interaction between body and harness. So in order to obtain a better understanding the first steps were taken in this experiment by studying the interaction upclose. The main research question for this study was: How is the fit of the trapeze harness influenced by the interaction with the body of a sailor while hiking? Additionally, the study tried to find an answer to the following sub questions: What role do design elements of the trapeze harness play in this interaction?

3.5.3 Method

To identify differences, the harnesses were tested in a simulated trapeze setup. The setup was not an exact replication of an existing trapeze system, which was outside the scope and main goal of this study.
The study was split in two parts. The first part was conducted using a dummy to obtain reference material. The dummy matched the human figure and left out the variable of tissue deformation as as a result of contact pressure, since the surface of the dummy was hard and would deform. Before dressing up the dummy with one of the harnesses, anthropometric measurements were taken. Next, the dummy was dressed with the first harness, making sure the harness would fit tightly. Once wearing the harness it was attached to the hook and the dummy was put into a hiking position of 90 degrees. The setup allowed to walk around the dummy and study the situation from multiple points of view. Meanwhile pictures of the back, spreader bar and hip part were taken for later comparison. This process was repeated for the other harnesses.
For the second part, a sailor that shared the same anthropometric measurements was asked to participate in the study, repeating the steps as described for the dummy. The participant was asked to share thoughts about their experience while hiking out loud, so these could be documented by the observer.

Magic Marine size chart

	Starure (mm)		Chest circumference (mm)		Waist circumference (mm)	
	Min	Max	Min	Max	Min	Max
XXS	1620	1670	813	838	660	711
XS	1640	1690	838	889	711	737
S	1700	1750	889	940	737	787
M	1760	1820	940	991	787	838
L	1820	1880	991	1041	838	889
XL	1860	1960	1041	1118	889	965
XXL	1880	1960	1118	1194	965	1041

Figure 51 ; Size chart of Magic Marine's trapeze harnesses.

Harnesses used for the study

For the experiment three types of harnesses were used, that all have an unique design element. In Figure 53 (next page) images of these harnesses are provided. The harnesses used for the experiment were simplified allowing the harnesses to be compared at the same level. Illustrations of these simplications are provided in figure [xx]. Harness A is characterised by the stiff material, wide spreader bar and hard plate in the back. Similar to harness A, harness B has a spreader bar setup, but has no protective padding around the straps and is made from flexible material. Harness C is made from a flexible material with little padding throughout the harness and has a narrow spreader bar setup.

Dimension	*Dummy*	*Sailor*
Length (mm)	1860	1850
Circumference hips (mm)	890	900
Circumference buttocks (mm)	950	1000
Body depth at the hips (mm)	190	200
Body depth at the chest (mm)	225	270
Weight (kg)	9,65	78

Figure 52 ; Table providing an overview of the dimensions of the dummy and participant.

3.5.4 Results

Disregarding weight, anthropometric data show no large differences between the participant and dummy (see Figure 52). Using the adjustment options of the harnesses anthropometric differences were reduced. In terms of weight the participant was eight times heavier than the dummy.

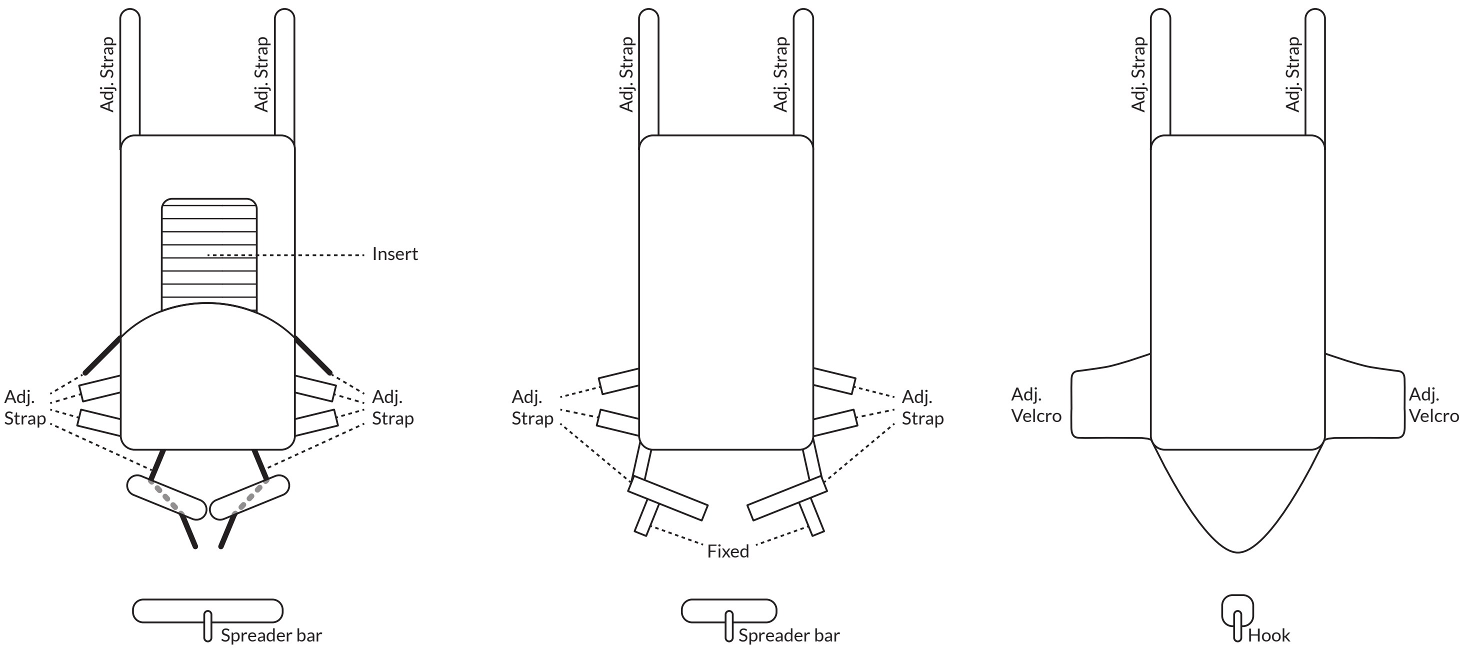
Harness A`

For both situations harness A showed to have too much material in the lower back in full hiking posture. Also, the semi-rigid plate in the back did not bend enough to match the curvature of the back, even with the extra weight of the participant (Figure 54).

Harness B

Initially, the dummy caused the harness to slight deform as was demonstrated by the small wrinkles on the hips pointing towards the anchor points of the straps. The same phenomenon occured to a greater extent for the participant, here the harness demonstrated more deformation and deeper wrinkles with the straps digging into the body. On the back the harness was not fully contacting the dummy's body and left space in between. In case of the participant the back was in full contact with the harness, but showed deep wrinkles.

Figure 53 ; Overview of the harnesses used for the study and their simplified schematic versions.



Harness A

~ Magic Marine Ultimate II

A leg strapped harness with thick padding around the hips and leg straps. In the back the harness has a hard plastic insert. Using multiple straps positioned around the spreader bar the harness can be adjusted. Back is slightly curved to follow body contours.

Harness B

~ LA

Leg strap harness with very limited padding throughout. Straps are not padded, except for the shoulders straps. The harness features a spreader bar that does not cover the full width of the harness. The back of the harness is modelled straight.

Harness C

~ Magic Marine Viper

A lightweight nappy-style harness featuring a hook. The harness has two adjustment options: Big Velcro bands around the hips and shoulder straps. Padding is very limited. The groin part is made of neoprene, allowing the part to stretch. The back of the harness is straight.

Harness C

In contrary to the participant's situation, the back part of harness C was not in contact with the lower back. This was demonstrated and felt by the excess material in this area. On the hips a high degree of deformation was found while the participant was hiking. A large gap between the harness and the hook was created and according to the participant resulting in high compression on the hips.

3.5.5 Discussion

From the observations multiple insights could identified, starting with the fact the spreader bar has a large influence on how the fabric of the harness wraps around the body. Of course, there is also the positioning of the straps on the harness and shape of the harness that influences how the fabric wraps and stretches. This differences can be found back in the difference between harness A and B (Figure 54). Both harnesses have a

< Figure 54 ; *Selected photographs taken during the observation, showing the differences in deformation between the harnesses for the dummy and participant.*

spreader bar, but due to the design of the harness the tension is distributed differently. On the other hand there is also the factor of type of padding and fabric. Harness A has quite a thick padding and stiffer material, e.g. on the hips, that result in a different distribution and significant less deformation of the harness. In harnesses B and C this deformation is clearly visible in the wrinkles and tensioned fabric that pulls from the hook around the body, resulting in concentrated areas of higher pressure on the body.

The dummy was not heavy enough to generate a load in the harness that would ensure the harness to fit the contours. Once weight is added all harnesses wrap around the body. However, it might be possible that this not the harness, but the body that is altering to fit perfectly into the harness. With the current experiment setup this argument can not be underpinned. But the fact that the back parts of harness B, and to some extend harness C, are flat leads to question if the harness is wrapping around the body. Striking is the fact that the insert in harness A does not bend enough the follow the contours of the body. In essence, this makes the insert unnecessary.

At first sight the Velcro is easy to use and perfect method to follow the contours of the body, but with one downside. In contrast to the straps, the Velcro can not be pretensioned enough. As a result, once a sailor starts hiking the distance between hook and body increases, resulting in a sack-like harness around the hips which nullifies the designed shape of the harness. Whether the shape was intentionally designed can not be determined without consulting the designers.

3.5.6 Conclusion

From the observations it is possible to conclude that all harnesses have a certain aspect that does not produce the best result in terms of fit or support. It remains open for discussion whether the designed elements were even designed to produce these results. However, it is very clear that the three harnesses share very limited design elements, exposing the differences even more. For instance, the influence of the spreader bar on the tensioning in the harness or the type of fabric in combination with the padding. Both of these design elements influence how the harness fits and tensions around the human body. Important design features that are helpful when redesigning the harness.

14 *Besier, T. and Sanders, R. (1999). Analysis of dynamic trapeze sailing techniques.*

3.6 User study 4

Interaction of harness and the body upclose

What methods

how

What came out

3.6.1 Introduction

Currently, studies that have been researching the topic of the trapeze harness in terms of design requirements, influencing factors or load distribution is either limited or has not yet been researched. Studies that have been conducted researched muscle tension using electromyography (EMG). Among them are the studies of Marchetti et al. (15) who primarily looked at muscle activity differences between foot-strap hiking and trapeze hiking. Marchetti et al. concluded that trapeze hiking primarily activated muscles in the neck and calves and only very little activation was seen in the abdomen and leg region. Hereafter, Hall et al. (16) studied different trapeze harness designs to see whether differences in trapeze harness designs could be linked to muscle tension. The study showed that trapeze harness designs should include heavy, rigid padding throughout the harness and have adjustable leg straps instead of a crotch strap. It should be noted that these are general design features. Results showed that there was no harness that stood out from the rest in terms of personal preference. Implying that the aforementioned design features are generally effective and that other features may vary according to personal preferences. In addition, Hall et al. also found that a positive evaluation about the comfort of the harness was also reflected in lower levels of muscular tension.

Whereas Hall et al. studied static trapeze sailing, Besier and Sanders (17) studied dynamic trapeze sailing using EMG data. Besier and Sanders concluded that there are stresses on the musculoskeletal system due to constant tensioning of the muscle in the core region to stabilise the trunk. A conclusion that was not drawn from the study done by Marchetti et al. Also, Besier and Sanders claimed that the muscle activations to stabilise the trunk in light wind are just as high as strong wind sailing postures. Nowadays trapeze sailing require sailors to have the ability to execute rapid shifts of the body and high intensity rope-pulls with high power and speed (18). Suggesting that stabilisation of the trunk and balance is even more important. None of these studies have investigated how the harness transfers the load from the wire on the sailor's body and what design factors are important influencers for the distribution and the magnitude of the compressive force. The purpose of this is study is to identify what design parameters of a trapeze harness influence the magnitude and distribution of the load on a sailor's body.

3.6.3 Objective

A topic that emerged on multiple occasions as some harnesses left a gap between the body and fabric when standing or not fully hiking. It remained unclear how this would develop once the harness is under full load.
Based on these expectations further question were formulated to gain a better understanding of the workings of the harness.

1. What is the value of pressure on the hips from a sailor's perspective?
2. To what extent is a harness with a back part that matches the contours of the human back considered to be more supportive?
3. What harness design is preferred by sailors? And Why?
4. What elements of the harness influence the experience of a harness?

3.6.2 Method

To gather quantitative and qualitative data, three measurement methods were used while the participant was hiking. One constantly monitering the load in the shoulders straps, one measuring the pressure between the harness and the body in six predetermined places and a questionnaire about the experience. The pressure between harness and body was measured using a pressure cell, that was positioned under the shoulder strap, on the hip and in four regions of the back.
For the experiment five experienced sailors were asked to participate either sailing in the 470 or 49er. Participants were asked to hike in a 49er simulator with each harness and share their thoughts while measurements were conducted. Afterwards the participants were asked to fill out the questionaire rating the support of the harness.

Harnesses used during the study

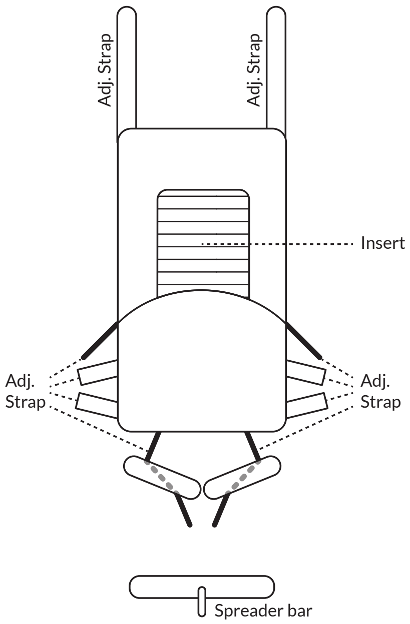
During the experiment three distinctly different harness were used. The harness differed in methods of adjusting, supporting elements, material and hook setup. In Figure 55the harnesses are presented, providing a basic overview of the harness designs and their features. To create a better understanding of the designs and to compare the harnesses on the same level, each harness was simplified and a schematic illustration was composed. Harness A could be considered to be the most technical harness of the three. Throughout the harness there are different thicknesses of foam used and in the back the harness has a convex shaped flexible insert. The harness features the widest spreader bar of the three harnesses that are used for the experiment. Harness B, on the

15 Marchetti, M., Figura, F., & Ricci, B. (1980). *Biomechanics of two fundamental sailing postures.*

16 Hall, S. J., Kent, J. A., & Dickinson, V. R. (1989). *Comparative assessment of novel sailing trapeze harness designs.*

17 Bessier, T., & Sanders, R. (1999). *Analysis of dynamic trapeze sailing techniques.*

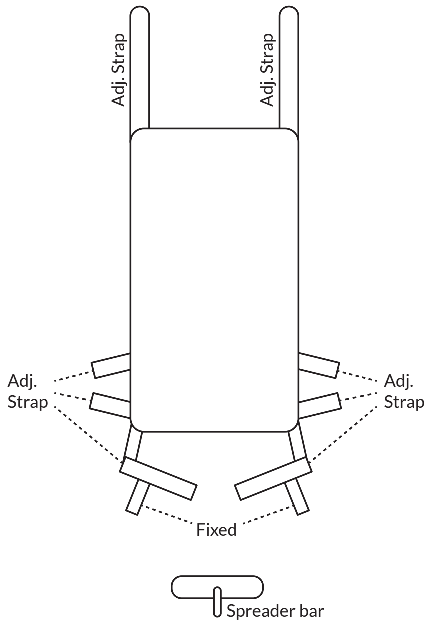
18 Bay, J., Bojsen-Moller, J., & Nordsborg, N. B. (2018). *Reliable and sensitive physical testing of elite trapeze sailors.*



Harness A

~ Magic Marine Ultimate II

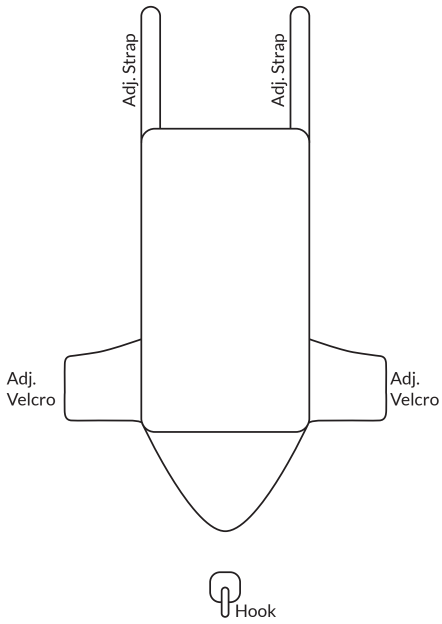
A leg strapped harness with thick padding around the hips and leg straps. In the back the harness has a hard plastic insert. Using multiple straps positioned around the spreader bar the harness can be adjusted. Back is slightly curved to follow body contours.



Harness B

~ LA

Leg strap harness with very limited padding throughout. Straps are not padded, except for the shoulders straps. The harness features a spreader bar that does not cover the full width of the harness. The back of the harness is modelled straight.



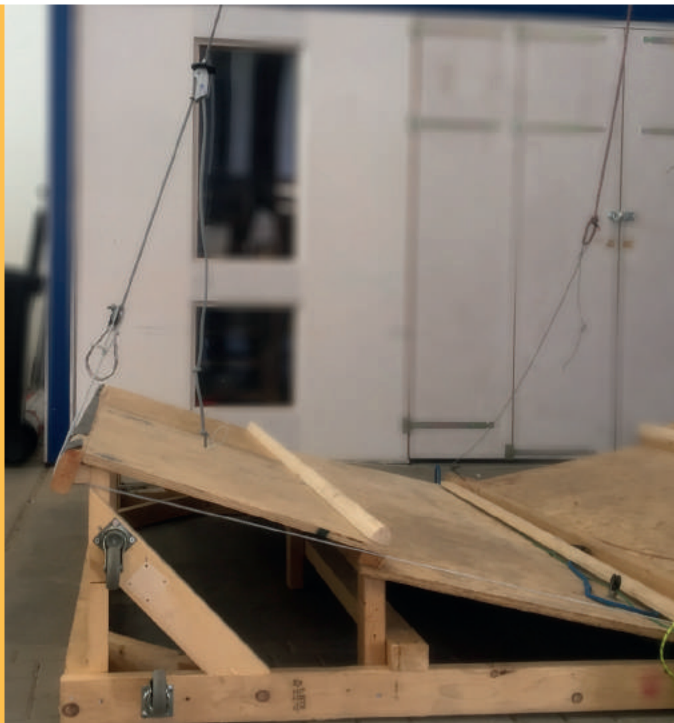
Harness C

~ Magic Marine Viper

A lightweight nappy-style harness featuring a hook. The harness has two adjustment options: Big Velcro bands around the hips and shoulder straps. Padding is very limited. The groin part is made of neoprene, allowing the part to stretch. The back of the harness is straight.

Side story: 49er simulator

Realistic experiment conditions required a boat and complete rig to be available. Due unavailability of either of these and the wish for a 49er simulator, a wooden model was built based on the exact measurements of the 49er hull (see Figure 56). The simulator was set up inside a warehouse with trapeze wires hanging down from the ceiling at the correct height and angle. Since it has been built, the simulator has seen gradual upgrades, such as more trapeze wires, a boom and to top it off a gennaker hoist and drop system. Fully functioning as a valuable extra training instrument to polish the execution of standard maneuvres .



other hand, is far less technical. The harness has no foam covering the straps and in general the harness could be described as being flexible. Similar to harness A, B features a spreader bar, but is narrower. Both A and B are leg strap-style harnesses, whereas C is a nappy-style harness. Also, harness is C has a simple hook instead of a spreader bar and features big Velcro bands that cover the surface of the hips.

3.6.4 Results

Experience of pressure on the hips

During previously conducted interviews multiple sailors indicated that pressure on the hips was an important factor for a harness as this allows a sailor to feel what the boat is doing or how it is reacting to changes in conditions. Though, it could not be determined whether the pressure that was caused was experienced as supportive or what the magnitude of this pressure is compared to other parts of the harness where it is in contact with the body. Experiment results helped to provide these insights answer the following research questions (RQ):

RQ : What is the value of pressure on the hips from a sailor's perspective?

Sub-RQ: What is the effect of the spreader bar on the pressure on the hips?

Importance of pressure on the hips

Figure 56 provides an overview how quotes and data were used formulate an answer to this question. Pressure on the hips is experienced as a positive feature of a harness. According to the participants, pressure on this region provides feedback. Feedback that helps the sailor to feel what the boat is doing, if it is under- or overpowered or luffing or bearing away. A point that was mentioned several times during interviews with sailors and was proved once more while conducting the experiments. Additionally, feedback provides a feeling of control and of being one with the boat. All contributing to concentration. Although, these qualities are psychological, these do have a direct effect on the experience of harness. For instance, when a sailor experiences less pressure on the hips, this could result in reduce the connection with the boat and thereby lead to depreciation of the harness. From an anatomical point of view, the hip region is able to handle a compression force. The hip region is formed by the pelvis and the femur (thigh bone). A composition that covers the full width of the body and thus can provide a reaction force without unnecessarily putting stress on parts of the body that need a constant flow of blood. In general, the sailors value pressure on the hips as an essential element of the harness.

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Figure 55 ; Overview of the harnesses used for the study and their simplified schematic versions.

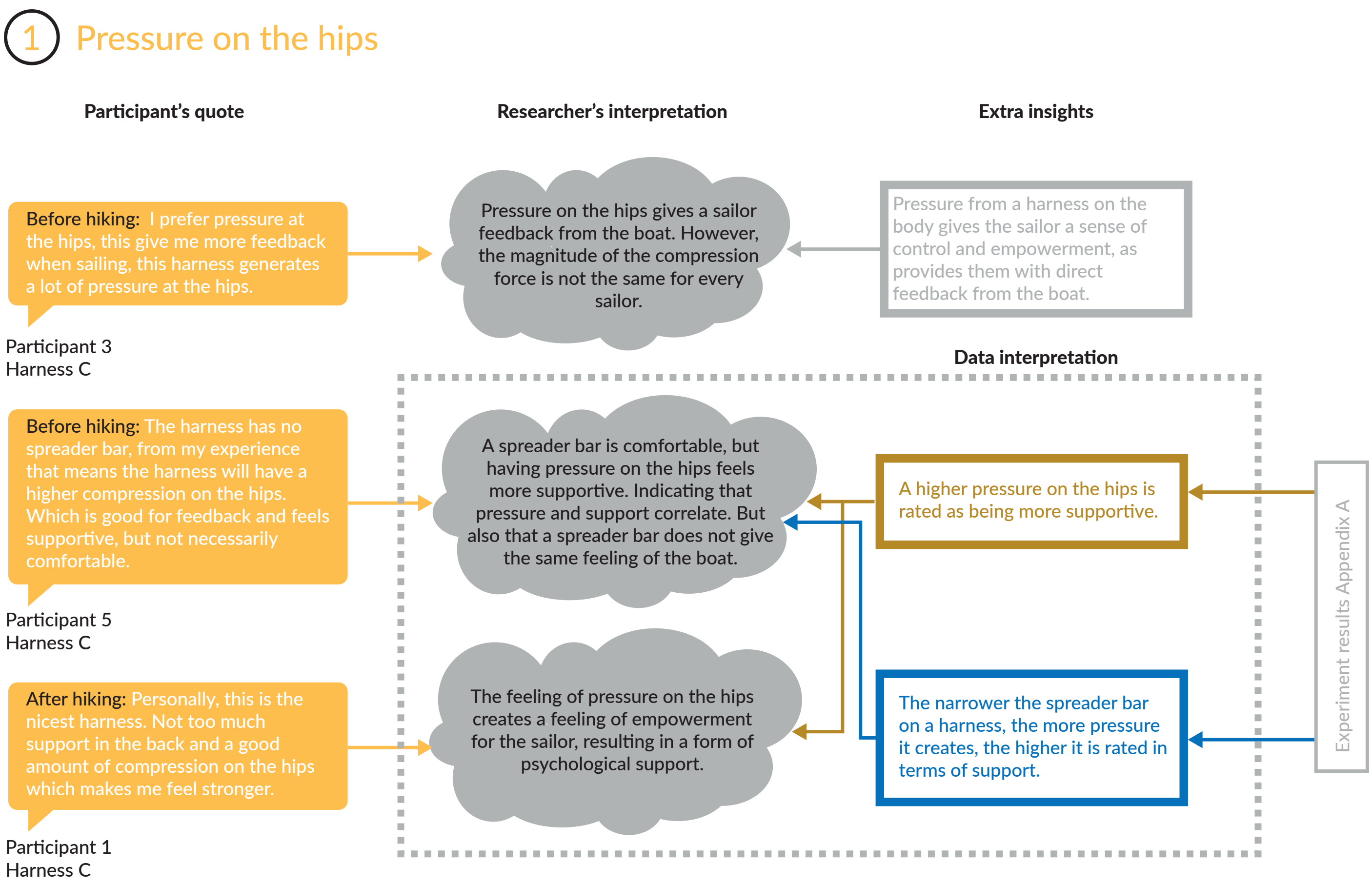
Pressure on the hips is an essential element of trapeze harness.

A spreader bar is only preferred when a sailor wants to have more comfort.

Peak pressures are not necessarily more supportive.

V

Figure 56 ; A schematic figure presenting how participants quotes and data led to insights for the hip area.



2 Fitting the back

Participant's quote | **Researcher's interpretation** | **Extra insights**

While hiking: While sailing I normally push myself in my harness to get more feedback and feeling of speed.

Participant 2
Harness A

Similar to pressure on the hips, pressure from the harness on the body provides feedback and results in a feeling of control. Proving to be important points for a harness and that the participant is missing this pressure.

While hiking: Now I am hiking I feel support in the upper and lower back, but not in the middle region of my back.

Participant 5
Harness B

While hiking: The harness does not support the back, only at the top and bottom of the back you can feel the harness pushing on the body.

Participant 1
Harness B

This harness does not support the middle region of the back, which could be caused by the fact that back is flat and does not follow the contour of the spine. As result the pressure is not equally distributed

While hiking: I do not feel much pressure or support in the upper back from this harness

Participant 1
Harness A

The 'supportive' plate does not seem to generate the desired result. In addition, the participant uses terms pressure or support as if they are the same.

While hiking: Nice and comfortable harness, I can stay in the wire for quite some time with this harness without getting fatigued.

Participant 2
Harness A

Pressure distribution of this harness seems to be about right. Implying that shape and stiffening of certain parts are creating a harness that ensures there are no peak pressure points.

While hiking: I do not feel the effect of the plate in the back, it does not seem to give any support. If you push the plate it still flexes inward.

Participant 4
Harness A

Again the 'supportive' plate does not seem to provide any support. The pushing of the plate indicates that there is too little pressure from the body to bend the plate to match the figure of the back.

While hiking: I do not feel much support in the lower back, I feel no pressure here. Normally I would feel pressure.

Participant 3
Harness C

Pressure and support are considered to be the same for this participant. A harness with a back part that is straight does not provide an even support on the back, which leads to a negative experience of the harness.

Before hiking: I do not expect this harness to be comfortable, because it is basically a big bag that does not have the shape that matches my body.

Participant 5
Harness B

Pre-judging the harness based on the experience with other harnesses. The flat design of the back supposedly results in the experience of uneven distribution of the pressure on the back.

Extra insights

Pressure from a harness on the body gives the sailor a sense of control and empowerment, as provides them with direct feedback from the boat.

If a harness has an insert in the back part with the intention to provide extra support, then this should be made to fit the sailor.

An equal distribution of pressure is experienced as more comfortable.

Data interpretation

Harnesses with a back part that is not designed to follow the contours of the spine, result in peak pressures in the upper and lower back and drop in the middle region of the back.

An uneven distribution of the pressure on the back is experienced and rated as being less supportive.

Harness A is the harness is rated the highest for support on the back. Compared to other harnesses the back part is designed to match the curves of the human spine.

Experiment results Appendix A

3.6.5 fitting the back

During the fit experiment discussed in 2.2.4 the extent to which the harnesses were designed to fit the contours of the back was questioned. The fact that most harnesses are designed to fit the human body was also questioned by sailors and the medical team. According to both groups, harnesses often do not completely support the back and leave a space between the body and parts of the back, mainly the lower back. Considering that the experiment was limited to an observation and sailors were not specifically questioned about this subject, the argument could not be substantiated. With this thought in mind, the following research question was formulated:

RQ: To what extent is a harness with a back part that matches the contours of the human back considered to be more supportive?

Harnesses pressing on the back

Curvature and dimensions of the back is different for every participant, which is proven by the difference in measured pressure and the rated of experienced support (see Figure 59). An overview of these measurements is provided in appendix [xx]. However, using the quotes and data allowed to identify a couple of trends that distinct the harnesses and their experiences. Especially harness B causes peak pressures in the upper and lower back. The pressure peaks are rated high in terms of support, suggesting that pressure and support are correlated. The middle back regions are rated lower and have a lower measured pressure. For Harness C this point is less evident. In general the pressures on the back for harness C are higher, but are not rated significantly higher. During the experiment harness A showed less fluctuating values in terms of measured pressure and rated support. Participants rated harness A to be the most supportive in the back without big differences between the different sections. Which can be related to the fact that harness A has a back part that is slightly curved to align with the curvature of the back. Implying that a harness with a back part that matches the contours of the back is providing more support and a better distribution of the pressure over the back. This same trend was found in the quotes of the participants, who indicated that harnesses B and C both provided less support in the back, specifically the middle region. The combination of measured pressure, rated support in the regions of back and quotes, led to the conclusion that an uneven distribution of pressure on the back is experienced as being less supportive.

3.6.6 essential design features

Most harnesses on the market are made to fit the masses and are not designed to fit one specific body. A problem that is partially solved by the harness adaptable (or able to adjust) in a predefined range. Trading off between ease-of-use and fitting capabilities. Based on the analysis in [harness market], outcomes showed that more than 75% of the harnesses are adjusted using straps and that all harnesses have between one and five adjustment options. Results from the interviews showed that 90% of the questioned sailors in the Dutch Sailing Team have a nappy style harness for comfort and mobility reasons. Design features that determine the fit and thus also the experience of a harness.

RQ: What harness design is preferred by sailors? And Why?
Sub-RQ: To what extent do additional supportive element influence freedom of movement?

Using straps on a harness

The most common harness adjust method is a strap. A reliant and tensionable method that was not preferred by every participant. Especially when used at the legs. According to the participants the leg straps irritate, strangle the legs and reduce freedom of movement (see Figure 60). The irritation might find it origins in the fact that the straps did not have any padding to increase the surface area and distribute the pressure, which was the case for Harness B. Yet, strangling and limited freedom of movement were identified for both Harness A and B. In some cases the comments were made before wearing the harness, indicating that the negative attitude towards a leg strap harness was already based on previous experiences.
This reveals that the true reason why most sailors choose a nappy style harness above a leg strap harness is based on freedom of movement.

Padding and material thickness

Whereas the pressure on the hips for harness A were generally the lowest, the support was rated quite high. An outcome that could be explained by the distribution of the compressive force on

Equal distribution of pressure on the back leads to a more supportive harness and is experienced to be more comfortable.

A harness with a curved back part could result in a better distribution of the pressure on the back.

Pressure on the lower back is important and often missing.

Harness B looks like a torturing device...

Adjustment straps generally have a bad reputation.

Figure 57 : A schematic figure presenting how participant's quotes and data led to insights for the back region.

Freedom of movement is a primary decision criterion.

A harness' mobility easily influenced by adding or removing stiffening parts.

For men, a nappy harness always requires some organising down below.

Deformation of a harness has a negative influence on the experience.

Nappy harnesses are preferred over leg strap harnesses.

A harness should have no loose elements.

Figure 58 ; A schematic figure presenting how participant's quotes led to insights for the design features.

the hips. Directly comparing the hip part of each harness, revealed that Harness A is more padded, stiffer and that the straps are directly located above the hip region. Eliminating deformation and ensuring a evenly distributed compressive force. Implying that in areas where the harness is in contact with the body it is better if the harness is more padded and stiffer than other parts. Keeping mobility in mind. Something that was pointed out by one the participants, mentioning that harness A was too much in terms of padding thickness and therefore limited freedom of movement.

Stiffening inserts

During the interviews with the sailors some mentioned the use of inserts in the back of their harness as positive property of their harnesses. Mainly when sailing in heavier conditions (+15 knots ~ 4 beaufort) an insert provides more support and comfort for the sailor. Harness A had a flexible plate integrated in the harness, but this did not necessarily result in a more equal distribution of the pressure on the back. For a large part this could be attributed to the fact that the plate did not bend enough to match the curvature of the back. Another reason was the fact that the plate was not in the correct position, due to sizing issues or a poor design. Similar to the material thickness, adding something that adds stiffness might reduce mobility.

3.6.7 Experiential factors of a harness

The overall experience of a harness is based on the expected experience and the actual experience. Two states that might be opposing. A sailor's expected experience is observational formed based on previous experiences with a harness that had similar design elements. By using the harness to move and hike, the actual experience is formed.

RQ: What elements of the harness influence the experience of a harness?
Sub-RQ: To what extent does the harness have a mental effect on its user?

Influencing the experience

Quotes and comments of the participants revealed that the expected experience for Harness A and B were predominantly negative. (see Figure 61) Both harnesses have leg straps, elements that led the participants that the harness was limiting their freedom of movement or would irritate. To a certain degree the same applied to straps in general. Participants indicated that in many cases straps were too long and would get tangled up or get in the way while moving.
In most cases these comments were made before wearing the harness, suggesting that the experience is largely determined by comparing the harness to previous experiences with harnesses that shared design elements. Affecting the current experience. The Velcro adjustment on harness C was only criticised once, as it did not allow to be pretensioned as much as the straps. Resulting in deformation of the harness once the participant started hiking. Deformation was indicated more often by the participants, especially for Harness B. The attachment of the straps and design of the harness led to deformation of the harness and in one case the spreader bar started tilting.
The experiment setup did not allow to replicate actual movements of the boat. Still the participants pointed out that while hiking feedback of the harness is an important factor and resulted in a positive attitude towards a harness. Particularly Harness C was praised, as the harness' design provided more pressure and so more feedback.
Overall, a positive experience is accomplished by the degree of freedom of movement and feedback from the harness. Which in turn derived from design elements such as harness type, adjustment methods and material usage.
Feedback, on the other hand, might result in a positive psychological experience. The harness offers multiple ways to create extra pressure (and thus feedback), e.g. leaving out a spreader bar or pushing the body into the harness, giving the sailor a feeling of control and empowerment. Both positive experiences that could directly influence the sailors performance.

Where there is pressure there is support

Participants indicated that if the harness offered no pressure, there was not support. A trend that was also found when comparing measurement data with the rated support on the back and hips. In general, if the pressure was higher the rated support was also higher.

3 Design features

Participant's quote | **Researcher's interpretation**

Before hiking: The straps of this harness are somewhat annoying to adjust it takes some steps to get it right. Straps also can't be changed in terms of supportive direction, so moving it slighty up or down.

Participant 2
Harness A

Multiple adjustment possibilities might improve the hiking comfort and experience, but it also has a negative influence on the overall experience of the harness. This sailor wants harness with a limited number of adjustment options, preferably no straps.

Before hiking: This harness looks quite comfortable, but in my experience the straps always fly around or get tangled up in some way. So, I don't really like straps.

Participant 1
Harness A

A first look at a harness can influence the overall experience, which is also depending on previous experiences. For this sailor the harness looks comfortable, but the fact that the harness has straps is a bad influence for the overall opinion.

While hiking: The straps of this harness are easy to adjust, however they really dig into the body when standing in the wire and deform the harness.

Participant 3
Harness B

The concentrated pressure at the attachement points of the straps in combination with the flexibility of the harness result in a negative experience. Again giving the sailor the feeling that the harness is failing.

While hiking: I think the straps are hard to adjust and I am not a big fan of leg strap harnesses, they always strangle my legs when squatting.

Participant 5
Harness A

In the opinion of the sailor a harness with leg straps limits the freedom of movement. Previous experiences with strap adjusting harnesses seem to have negatively influenced the sailor about straps. So the sailor already had a negative expectation about the harness.

While hiking: In my opinion this harness has very uncomfortable leg straps, the have no cover. Also the spreader bar is tilting, which is strange to see.

Participant 4
Harness B

The fact that the sailor mentions that it is strange to see that the spreader bar tilt, indicates a negative experience. Adding to the fact that the straps are very uncomfortable.

While hiking: The straps squeeze and cut into my buttocks and legs. Especially when moving in and out of the boat. I don't like this harness.

Participant 1
Harness B

Again here, the straps limit the freedom of movement of a sailor. Leg straps tend to result in too much concetrated pressure around the legs.

After hiking: The harness was surpisingly more comfortable then you would expect. However, the leg straps have a strange attachment on the side and cut hard into my legs.

Participant 2
Harness B

A harness with leg straps proves to be interpreted more negatively beforehand, as the sailor says "then you would expect". But the leg straps for this harness are still experienced as being irritating.

Before hiking: I think this harness is too much for me. It's padding is too thick which reduces the mobility and has too many supportive elements that could block movements.

Participant 4
Harness A

For a large part a harness' experience is based on the visual characteristics of the harness upfront. For this sailor a harness that is considered to be very supportive is experienced as an obstruction for moving freely.

Extra insights

The opinion of a harness is largely deteremined by the characteristics of a harness and the sailor's previous experience with a harness that has similar design features.

A harness with leg straps limits the freedom of movement of a sailor.

Harnesses using straps to adjust tend to have a bad reputation due to the fact that the straps are in fixed places, create a concentrated pressure or in some cases are not padded.

4 Harness experience

Participant's quote / **Researcher's interpretation**

While hiking, participant indicated that no support was felt in the lower back. Why not? : I don't feel any pressure from the harness in the lower back.

Participant 3
Harness C

A quote that indicates that pressure and support are perceived to be the same for a sailor.

While wearing: I find it annoying that when bending over and crawling a harness never seems to move with the body, instead, the body moves in the harness, which limits freedom.

Participant 5
Harness -

Important comment that describes exactly what is the problem with current harness designs. Since the back part in most cases is one piece of unstretchable material it can't shorten or lengthen when needed.

Before hiking: I do not expect this harness to be comfortable, because it is basically a big bag that does not have the shape that matches my body.

Participant 5
Harness B

The sailor explains why the harness will be uncomfortable, which must be the result of an unpleasant experience. Which also has an effect on the pshycological experience of the harness.

Before hiking: The harness has no spreader bar, from my experience that means the harness will have a higher compression on the hips. Which is good for feedback and feels supportive, but not necessarily comfortable.

Participant 5
Harness C

In this quote the similarity between support and pressure is again emphasized. It also demonstrates that a sailor is willing to suffer in order to get more feedback from the boat.

While hiking: I have adjusted the Velcro on the hips quite tight, but now I am hiking there is a big gap between the hook and my body. Which looks odd.

Participant 4
Harness C

Through the eyes of the sailor the gap between the body and the hook is not right. It shows that the harness is not able to maintain its form. To a certain extent this might also have a pshycological effect, affecting the concentration of the sailor.

While hiking: I think this is quite something, I feel like the load on the shoulders for this harness is higher than the other harnesses, which makes it quite heavy. Could that be due to thin fabric of the harness?

Participant 2
Harness C

Interesting comment by the sailor. However, the higher load could also be caused by the absense of a spreader bar. It does influence the experience of the harness, even affecting concentration if it starts to irritate.

While hiking: What I like about this harness is the high cut out of the legs. Now I can go in and out with my legs being strangled or irritating.

Participant 1
Harness C

Moving freely with a harness is an important factor for a positive attitude towards a harness. Largely caused by a previous negative experience.

While hiking: The straps of this harness are easy to adjust, however they really dig into the body when standing in the wire and deform the harness.

Participant 3
Harness B

The concentrated pressure at the attachement points of the straps in combination with the flexibility of the harness result in a negative experience. Again giving the sailor the feeling that the harness is failing.

Before hiking: I think this harness is too much for me. It's padding is too thick which reduces the mobility and has too many supportive elements that could block movements.

Participant 4
Harness A

A negative attitude towards the harness due to a previous negative experience of the limited freedom of movement.

While hiking: In my opinion this harness has very uncomfortable leg straps, the have no cover. Also the spreader bar is tilting, which is strange to see.

Participant 4
Harness B

The fact that the sailor mentions that it is strange to see that the spreader bar tilt, indicates a negative experience. Adding to the fact that the straps are very uncomfortable.

Extra insights

A harness design that is perceived to be uncomfortable has a big influence on the psychological experience of a harness.

When the harness and body are in contact, pressure and support are perceived to be the same. More pressure is more support.

Freedom and mobility while wearing a harness are important contributors to the psychological experience of a harness.

Feedback from the boat through the harness results in a positive attitude towards the harness.

Deformation of a harness due to a bad adjustment, creates the idea of a failing product which has negative influence on the experience of the harness.

the actual load on the shoulders

The load on the shoulders is primarily based on the weight and stature of a sailor. The model outputs showed that differences among participants should be detectable, but that difference between harness would be in the range of 1 ~ 10 N. During the experiment the shoulder load has been measured using two methods. Participants were explicitly asked to hang straight with the trapeze wire in the middle, assuming that the load on the shoulders would then be equally distributed. The first was the load sensor between the hook and shoulder strap, measuring the total load in the front part of the strap. Since this load was measured six times it was averaged for every participant to be used for further analysis. The second method was using the pressure cell, by placing the cell between the shoulder and the strap and measuring the load on one part of the shoulder. Both measurements were compared to the predicted data to determine whether the model's output is in line with the actual situation.

The front part of the shoulder strap

With the load sensor only the load in front of the shoulder strap was measured. Therefore the data was compared to the calculated load in the strap instead of the total load on the shoulders. In table xx the results are shown in bar charts specified for every harness and participant. Results showed that the differences between the model output and measured loads are harness dependent, visualised in the bar charts in Figure 62. For Harness A and B the measured load in general was lower than the load calculated by the model, ranging between 15 ~ 150N. Harness C shows a different trend, here the measured load for two participants is even higher than the calculated loads, 80N and 100N to be precise. Measurements for the other three participants were lower, ranging from 20 ~ 50N. These differences could be partially attributed to the fact that the hook heights for Harness C in on average was lower than for the other two harnesses. As the sensitivity analysis for the shoulder model (appendix XX) showed that the hook height from the ground had a significant influence on force that is directed to the shoulder. Other arguments could be harness design, spreader bar width, material stiffness or muscle effort that reduced a part of the load on the shoulders. The last argument could stand, but then Harness C should show a similar trend. With the current data it is not possible to determine what factor could explain the differences.

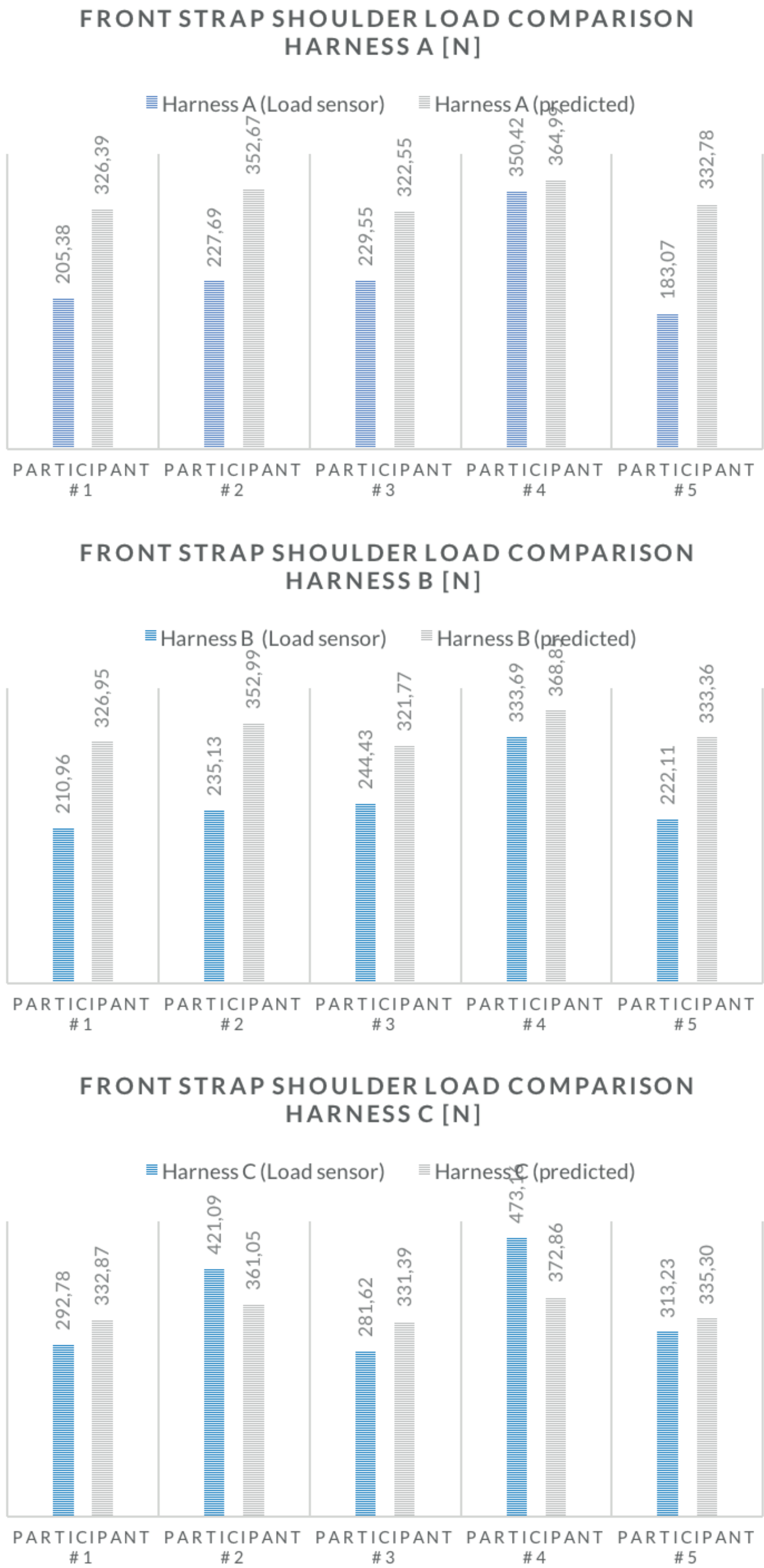
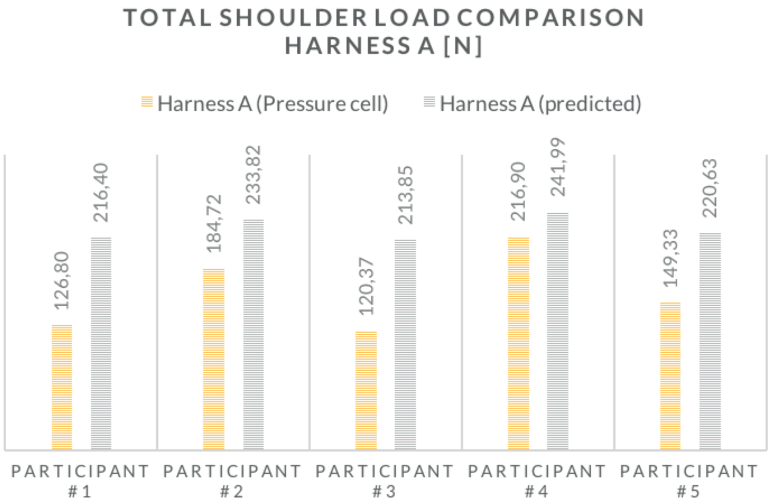
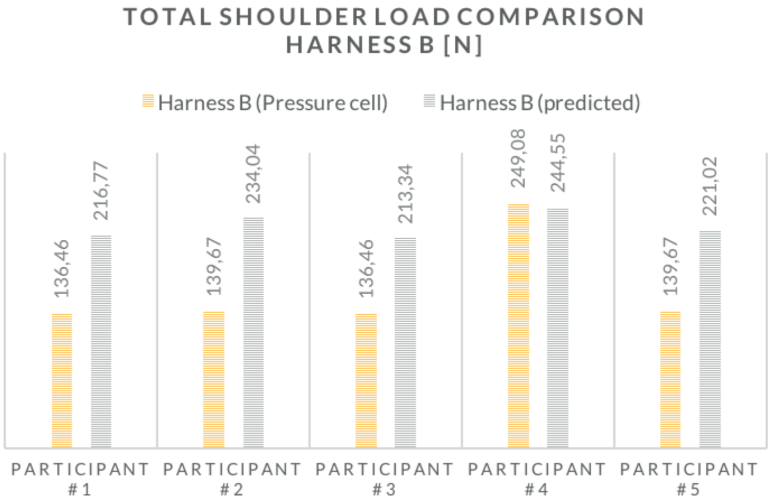


Figure 60 ; *Bar charts presenting the measured load in the shoulder strap for every participant sorted for every harness.*

Figure 59 ; *A schematic figure presenting how participant's quotes led to insights for the experience.*

A harness that is considered more supportive has a lower shoulder load.





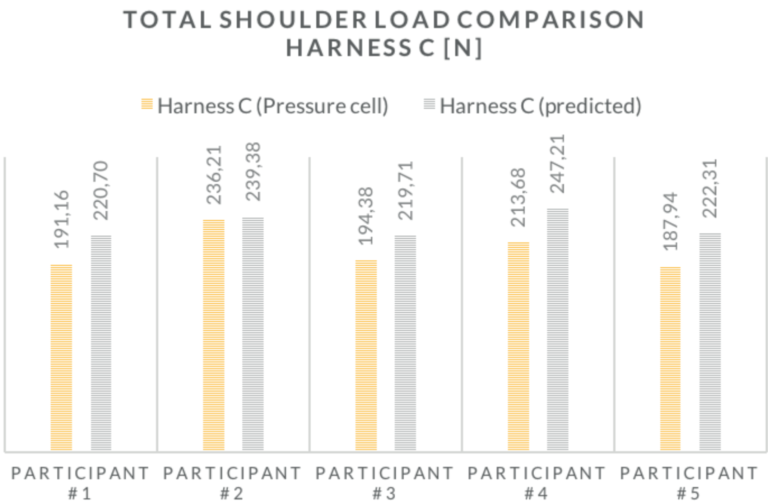


Figure 61 ; Bar charts presenting the measured total load on the shoulder for every participant sorted for every harness.

Hook height is an important influencer of the shoulder load.

Total load on the shoulder

The pressure cell granted another possibility to examine the shoulder. To compare data outputs generated by the model and the outputs of the pressure cell, the model output had to be halved as the pressure cell only measured the pressure at one side of the shoulder and the model calculated the sum of the load. The results are shown in Figure 63.

Similar to the measurements in the front strap, the total load on the shoulder in general is lower for Harness A and B than the calculated loads. For Harness C the measurements are still lower, however the difference is smaller ranging between 30 ~ 50N. Whereas for Harness A and B the measurements differ between 5 ~ 100N. Measurement fluctuations might be caused by the fact that in some cases the pressure cell was not placed exactly in middle of the shoulder or not covered entirely. Reducing the pressure.

the actual load on the hip

Model predictions showed a gradual increase if the spreader bar width was decreasing in width and an increase if the width of the body increased. Both parameters were identified as the biggest influencers for the load on the hip. Hip load was measured by placing the pressure cell between the hip part of the harness and the body, resulting in a pressure read out of that particular at one side of the hip.

Spreader bar differences

The model output showed a clear increase as the spreader bar width decreased. Unfortunately, this trend was less evident in the measurements (see Figure 64). Measured pressure for Harness A was the lowest for every participant, but in all cases close to twice the model's output. For harness B and C the differences were smaller, staying within a 20N margin for 5 out 10 measurements. Suggesting that the spreader bar is the only reason for the difference of Harness A would not stand. A possible argument could be found in the fact that Harness A is pretensioned using straps positioned directly above the hip. Another possible reason for a higher load for Harness A could be traced back to the stiffer hip part of the harness in combination with the positioning of the pressure cell. With current data it was possible to conclude that a spreader bar has a direct influence on the load on the hips. But that factors such as harness design in terms of distribution and positioning of the adjustments could affect the load.

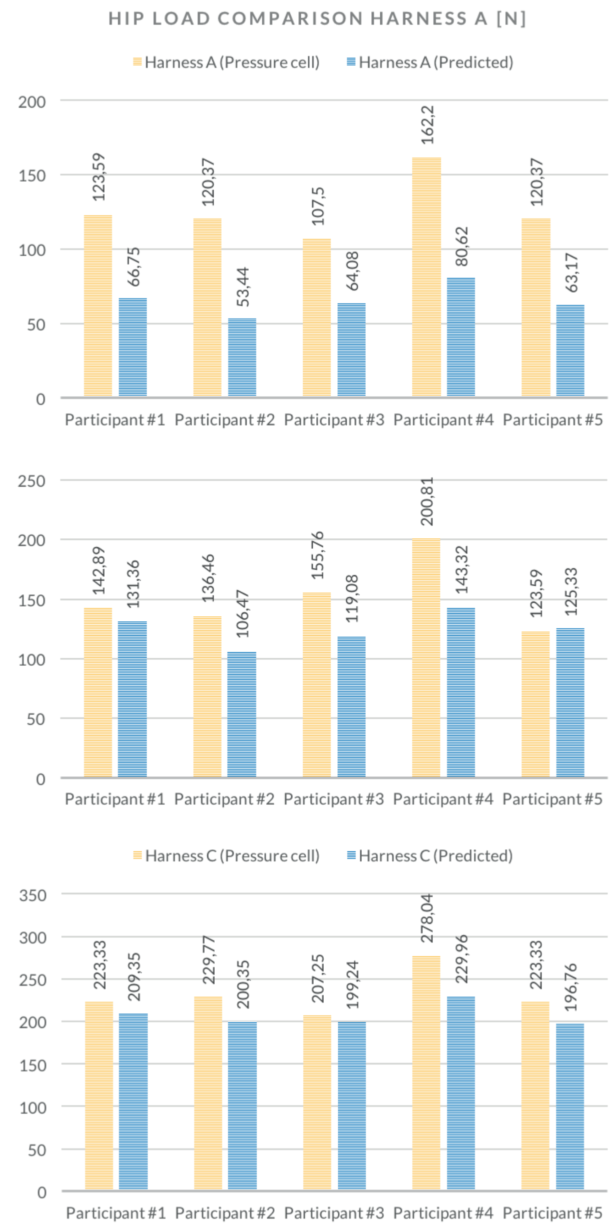


Figure 62 ; Bar charts presenting the measured load on the hip for every participant sorted for every harness.

3.6.8 Discussion

The influence of a spreader bar

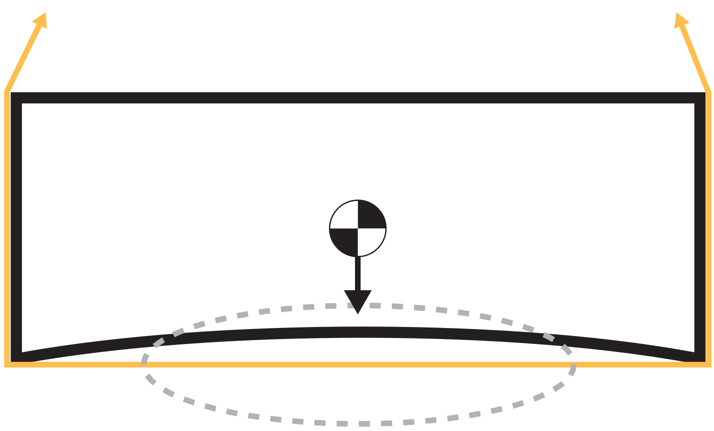
One of the participants identified a harness with spreader bar as 'being more comfortable'. An interesting point of view, suggesting that comfort and pressure are related. However, the same participant also mentioned that more compression on the hips means more feedback from the boat. Preferring a harness without a spreader bar. This opinion was confirmed by the data from the other participants. Harness C is designed without a spreader bar and generated in all cases the highest pressure. Demonstrating that a spreader bar indeed reduces the pressure on the hips. For all participants the pressure was experienced as supportive. Though it does not mean that the support of a harness with spreader bar is less. A point that was validated when examining the rated support on the hips of Harness A. The harness with the lowest average pressure was still rated positively. With current data it was possible to conclude that a spreader bar has a direct influence on the load on the hips. But that factors such as harness design in terms of distribution and positioning of the adjustments could affect the load.

The actual effect of the spreader is less than evident than expected.

Design of the back

One participant described harness B as: "A big bag". A quote that actually hits the nail on its head. To illustrate this a different situation is sketched. For example, when hoisting a crate with a slight concave bottom with a cargo net (see Figure 63). Once the hoisting starts the net will tension and compress the crate from multiple directions. However, on the bottom of the crate the net will only provide support near the edges. An obvious result as the net is tensioned and thus covering the shortest distance around the crate. If it were to fill the concave part, the length of the net around the crate would increase. Of course, the situation described is far more simplified than what actually happens when a harness wraps around the human back, which is not as rigid as a crate. Nevertheless, it illustrates that if a material gets tensioned it will always follow the shortest path. In order to, partially, compensate this a material can be designed to match the object it has to support. This argument would also suggest that it is not the harness that adjusts to the body, but the body to the harness. In current harness designs, sailors push their backs into the harness to create more pressure. The pressure and the extra force that is exerted gives them a feel of control. Again a psychological effect of the harness. By having a harness that matches the contours of the back the positive effects of (over-) stretching could be realised, making a harness both more supportive and increasing feedback.

Figure 63 ; Hoisting crate example, demonstrating the gap between the concave bottom and net.



19 Adeyemi, A. J., Rohani, J. M., & Abdul Rani, M. R. (2017). Backpack-back pain complexity and the need for multifactorial safe weight recommendation.

20 Dreischarf, M., Shirazi-Adl, A., Arjmand, N., Rohlmann, A., & Schmidt, H. (2016). Estimation of loads on human lumbar spine: A review of in vivo and computational model studies.

Psychological influences of the harness

During the experiment Harness B and C both showed that due to design and adjustment options the harness could deform. Form the reaction of the participants it was possible to conclude that this was interpreted as odd, irritating and even distracting. In the eyes of the sailor this seems as if the product that is used is failing or something is wrong. Sailors might find this very distracting while sailing and take away concentration from their main tasks. Similar to something that is off about the boat. For instance, a line that is wrapped around the mast or a gennaker that has a small tear. Things that lead to believe that a sailor (or any other athlete) can not perform up to standard, because their material is letting them down. A harness induces the same feeling.

Shoulder load effect on the body

The load on the shoulder was measured in with two methods, both showing similar trends with regard to the differences between the harnesses. Arguments that could support the differences are limited to speculations and could not be backed up with the current available data. The results showed that total load on one side could reach 250N. To put this in perspective, assuming that the load on the shoulders is equally distributed, the total measured load of a participant weighing 80 kilograms and measuring 1810 mm (participant 4) wearing Harness B would be equivalent to carrying a person on the shoulders or backpack weighing 50 kilograms. According to Adeyemi et al (19) an advised backpack weight is ranging between 10 ~ 15% of the body weight of its carrier, to limit the prospect of obtaining a back injuries. Unfortunately, this comparison leaves out the fact that the sailor is in a prone position and that the overall load on the spine is lower than in a standing posture (20). In order to find a well founded answer on the spinal load while hiking with a trapeze harness, more specific research would have to be conducted. Nonetheless, pressure from the load on the body can be reduced. For instance, by increasing the shoulder strap width or increasing the standard hook height of a harness.

A harness should make the sailor feel stronger.

3.6.9 Conclusions

Validating the model and being able to express the forces acting on the body in numbers, proved to be a valuable method to obtain a deeper understanding of the harness. The results of this experiment was far greater than just numbers and figures. It also allowed to put every insight that was gathered so far to the test. Answering the question: What is the magnitude of the forces that the body has to deal with?

The trapeze harness is complex product that due to its design and diversity in human physique has a different fit for everyone. Measurements showed that for a large part loads on the body can be reduced or better distributed by changing the design or materials used in that specific area. For example, material stiffness was identified as a possible influencer for supportiveness of a harness, however by making something stiff

Side story: Loads while overstretching

In appendix A11 additional pictures of the simulator are provided.

Besides a neutral hiking posture, the participants were also asked stretch as they normally would to push into the harness. Thereby identifying and quantifying the differences with a neutral hiking stance. Results showed that this posture resulted in a higher load on the shoulder for every participant. Increases of the load for Harness A proved to be the highest ranging between 33% ~ 57%. Showing that stretching also increased the strain on the body and could negative effects for the endurance to maintain the posture and injuries on the long run. For the hip area the results showed the opposite trend. Loads in the hip area were found to be lower than the loads measured while hiking neutrally. For all harnesses the loads difference ranged between 1 ~ 90 N. Which could be identified as a negative side effect, since sailors indicated pressure at the hips as an important factor for having feeling for the boat.

Regarding the back, which measurement data has not been explicitly discussed, the loads tended shift more towards the upper back and in some cases got close to zero in the lower back. A clear indication of the pressure points that are created whilst stretching. Although, the increase on the shoulders and upper back could have been expected, the increase of the load is very much dependent of the amount of effort the sailor puts in.

the freedom of movement is reduced. In order to incorporate and make use of the beneficial effect of material stiffness it would have to be used in areas where material stiffness is not going to be an issue. An area such as the hip. Material stiffness was among other design parameters that influence the interaction between harness and body but also the experience. Other than the physiological effects, it was also possible to identify that a harness has a psychological effect on the sailor. Certain design elements or deformation of the harness could give the interpretation that the harness is not up to expectations or affecting the performance of the sailor.

With regard to the distribution of the load on the body, the experiment provided superficial information. Nonetheless, it was enough to conclude that the design of the back part of the harness has a direct influence on the distribution of the load on the back. Flat and straight designed back parts resulted in peak pressures in the upper and lower back. A deeper analysis of this fact also revealed it is very likely that the body adjusts to fit the harness instead of the harness fitting to the body. An important insight, as this indicates that in order to design a harness that equally distributes load it would have to match the body perfectly.

The measurements of the load on the shoulders and hips also helped to reveal to what extent the model outputs were in line with the actual situation. In some cases the difference was bigger than expected, which could be caused by the fact the model considers the system to be perfectly static. Whereas in practice participants might have exerted or reduced force on the harness when stabilizing using their muscles. Of course there remains the influence of measuring, which could be a partial source for measurement errors. The experiment setup and measurements made the data relatively susceptible to inaccuracies. Factors such as positioning of the pressure cell or sizing of the trapeze harnesses, influenced the measurements and allowed small errors to occur. Nevertheless, the main objective of the experiment was to develop a better understanding of exactly happens between the harness and the body. An understanding that has been developed and could form a basis for more specific studies. With the current used setup the distribution of the force on the back has been mapped, but is still very superficial.

3.7 Design research

Improving support and freedom

What methods

how

What came out

3.7.1 Introduction

The design of a harness determines the mobility of the sailor while wearing it. In previous studies the fact that the fabric on the back has a set length and is not flexible reduces the freedom sailor has. In this chapter the path towards more freedom is presented. Besides freedom of movement, this chapter also addresses methods to improve the support of a harness.

3.7.2 The strap as the harness basis

Together with the hip strap, the shoulder strap forms the foundation of the harness. Current harness designs all have a similar shoulder strap orientation which starts from at the hook, wrapping around the shoulder covering the entire length of the back and subsequently attaching to the hip strap. From here the bottom part passes between or around the legs to reach back to the hook, fully enclosing the upper body. The length of the shoulder strap determines the freedom of movement for the upper body. If the length of the strap is increased the degree freedom of movement is enhanced, but at the cost of support and demanding a higher physical input from the sailor. With a different orientation of the straps the negative side effects of the trade-off could be minimised. In order to find if this could be accomplished, different orientations of the shoulder straps were examined by means of sketches and strap models, as visualised in figure xx. The starting point of the search was by taking taking the hook as the centre of the harness and working from to find new orientations of the strap. For example, by adding an extra strap or cutting the strap in half and bringing it directly to the front after it wrapped around the shoulder. From the investigation it was found that if the attachment point of shoulder strap on the hip strap on the back was gradually brought to the front (or more towards the hook), then the freedom of movement was increased. In Figure 64 two examples are provided that demonstrate different setups. One version with shoulder straps crossing on the back and directly attaching at the hook and one setup with shoulder straps attaching on the hips of the sailor. The setup on the far left leaves a large open space on the back, thereby greatly reducing possible support options. Nonetheless, it provides a possible path towards a new harness where the right position of the attachment point of the shoulder strap has to be found.

Figure 64 ; Strap iterations tried out on a dummy.

3.7.3 Adding material

With the harness' strap setup determined the next step towards a harness would be to determine where the body needs support. Depending on the place the material characteristics can alter. For instance, on the hips materials are preferably stiffer to limit deformation.

[more elaborate]

21 Cholewicki, J., Juluru, K., Radebold, A., Panjabi, M. M., & McGill, S. M. (1999). Lumbar spine stability can be augmented with an abdominal belt and/or increased intra-abdominal pressure. Eur Spine J, 8(5), 388-395.

22 Meakin, J. R., Gregory, J. S., Aspden, R. M., Smith, F. W., & Gilbert, F. J. (2009). The intrinsic shape of the human lumbar spine in the supine, standing and sitting postures: characterization using an active shape model. J Anat, 215(2), 206-211. doi:10.1111/j.1469-7580.2009.01102.x

23 Vink, P., & Lips, D. (2017). Sensitivity of the human back and buttocks: The missing link in comfort seat design. Appl Ergon, 58, 287-292. doi:10.1016/j.apergo.2016.07.004

3.7.4 Supporting the body

While investigating the basics of a harness it was found that the harness essentially carries the weight of the body by supporting it on two points: The hips and the shoulders. For an improved base the other support points can be added, such as the lower back, the spread the load. In current harness designs multiple methods are used to create more support in the lower and middle region of the back, ranging from a inserted stiff plates to adjustable cushions. Other designs have a curved back part to follow natural curves of the spine and create an even distribution along its length. All using the back part as a basis. In other words, the back part is both connecting the top with the bottom of the harness and providing specific support. Splitting these functions could lead to a more efficient support system that can specifically provide support points and alter its level of support without comprising other functions of the harness.

Support and stability through compression

Improving stability and support in the back can be achieved by in multiple ways. Looking at other disciplines, such as weight lifting where the (lower) back subjected to a high load, stability in the lower regions of the back is provided by a lifting belt (or abdominal belt). According Cholewicki et al. (1999) lumbar spine stability is improved by wearing a abdominal belt [21]. Cholewicki et al. researched the use of an abdominal belt by using a EMG analysis measuring the activity of 12 trunk muscles.

Supporting body contours

The human spine is not a standard part of the body. Although the structure is the same, the curvature of the spine in the sagittal plane can be very different among people [22]. For instance, Meakin et al. (2009) found that lumbar spine shapes can vary considerably between people when standing, seated or in a supine position. Indicating that to perfectly support a back with an insert or by means of 3D shaped fabric, the part should be made individually match the user's back curvature. Having parts that align with the curvature of the body should result in more equal distribution of the pressure on the back and also keep the spine in its neutral position. Which in turn could lead to less injuries in the (lower) back region as muscles are less fatigued to maintain posture.

Sensitivity in the back

In user study 1 the conclusion was drawn that pressure from a harness is experienced as support and that pressure on the body is an important feature of a harness to feel what the boat is doing. The pressure is experienced on the hips and partially on the back. Vink and Lips (2016) found that the upper region of the back and shoulders are significantly more sensitive than the lower part of the back [23]. Especially the shoulders were more sensitive, which is an important fact to keep in mind when designing a harness.

3.8 User study 5

Validating the redesign proposal

What methods

how

What came out

3.8.1 Introduction

While investigating the basics of a harness it was found that the harness essentially carries the weight of the body by supporting it on two points: The hips and the shoulders. For an improved base the other support points can be added, such as the lower back, the spread the load. In current harness designs multiple methods are used to create more support in the lower and middle region of the back, ranging from a inserted stiff plates to adjustable cushions. Other designs have a curved back part to follow natural curves of the spine and create an even distribution along its length. All using the back part as a basis. In other words, the back part is both connecting the top with the bottom of the harness and providing

3.8.2 Objective

Having produced a prototype of the redesign, the next step was to find out if the intended design objectives were met with this design. The design predominantly focussed on freedom of movement and supporting the lumbar area. Design features that were achieved by opening up the back part and creating an seperated support strap in the lumbar area. The main objective for this experiment is to find out how sailors experience the harness and in what ways it differs from their current harnesses.

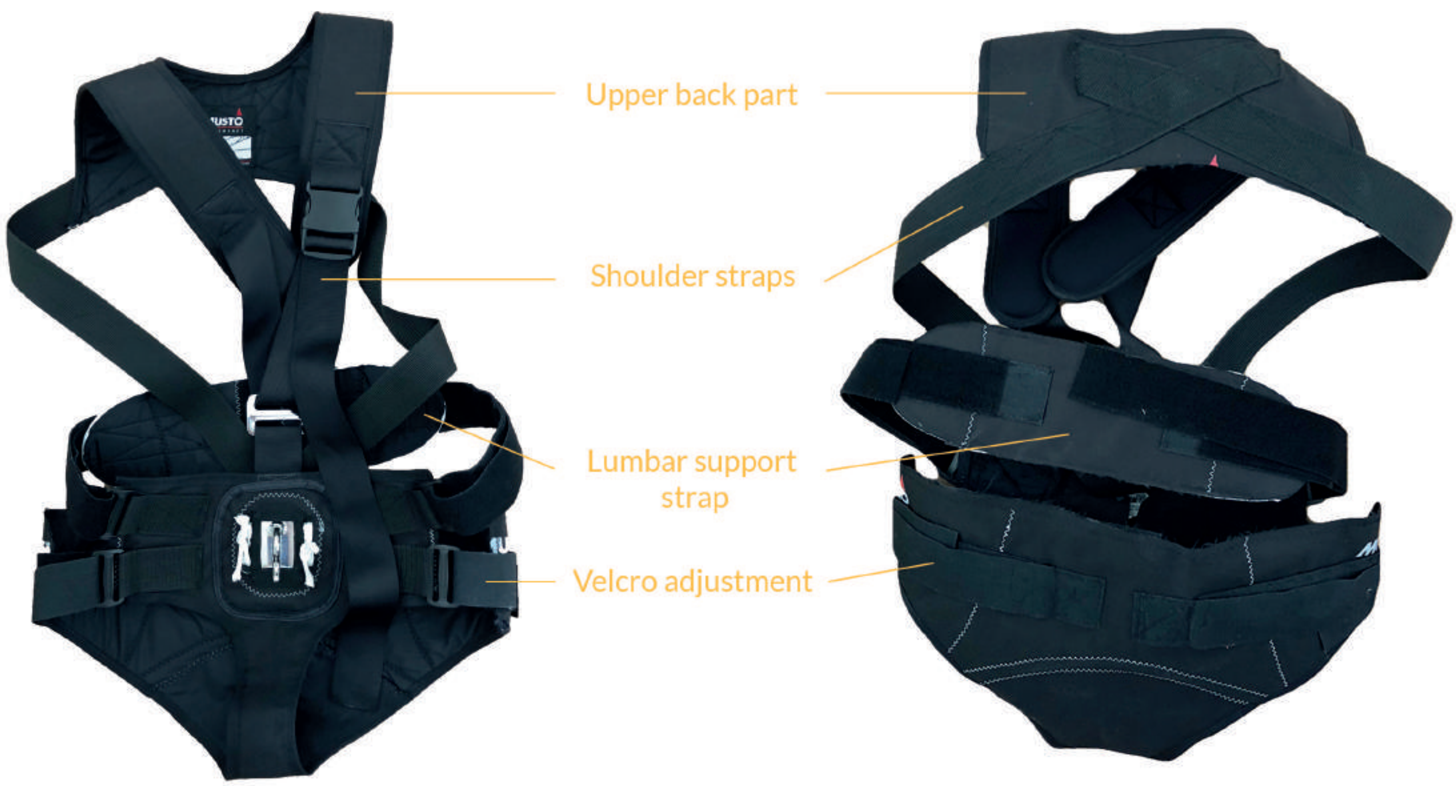
Research question:
To what extent does the harness improve freedom of movement?

Sub questions:
- What are positive qualities of the harness redesign?
- To what extent is support in the lumbar region improved by the separate lumbar strap?
- What alterations would improve the harness support?
- How does the design affect the basic function of carrying a sailor?

3.8.3 Method

The experiment consisted of two parts; onshore hiking session and one on water session. For the onshore session four sailors (two female and two male) participated and gave their opinion about the harness. Before starting out with the prototype the sailor was asked three questions about their expectations and afterwards the sailors were asked eight detailed questions about their experience. It was pressed not to directly compare the prototype to their own harnesses, unless this was specifically asked (see Figure 65).
For the on water session one 49'er sailor used the prototype harness to assess its use, indicate what improvements work and what changes should be made in order to create a better harness.
The sailor was asked to wear the prototype and perform their regular training exercises. After 10 - 15 minutes the sailor would change back to their own harness to directly compare the harness. Before sailing the harness was inspected and tested onshore with high peak loads to make sure the harness would not suddenly fall apart while sailing. These peak loads were applied by shocking and pumping with the body.

Figure 65 ; Prototype used to validate the design.



3.8.4 Results

Quote before sailing: Once I was wearing the harness and walking towards the boat I really liked the feeling of support the lumbar strap gave, but once hiking it started to hurt just above the strap.

Quote while hiking onshore: I feel the strap digging into my body, the attachment and dimensions of the strap does not seem right.

Quote while looking at the harness: The harness misses a lot of fabric, so I guess it will also miss a lot of support.

Quote while hiking onshore: I can feel the extra pressure the lumbar strap provides, but it is not feeling right. Above the strap it misses support.

Quote while adjusting the harness: The Velcro is better this way! It has the same qualities of traditional straps, but then with the clean design properties of Velcro.

Quote while hiking on water: The upper back part is too small and in this case the fixed shoulder strap is slightly too long.

Onshore

All sailors disliked the degree of pressure that was created by the lumbar strap and indicated that it lacked support in the desired places. Which would be more towards the middle of the back. The orientation of the shoulder straps together with the open back was received with amazement, as the sailors could not imagine that this would result in a comfortable harness. These thoughts were demonstrated with the following quotes: “Where is the rest of the harness?” or “The harness looks very different and not very comfortable, so I am expecting it will hurt!” While putting on the harness it was pointed out that the Velcro straps adjustments were a positive feature of the harness. As soon as the sailors started hiking the opinion of the sailors all resulting in an opinion which was inline with the initial thought the sailors had about the harness: The harness was too rough and the lumbar strap was not functioning as was expected. Resulting in a high load just above the support strap. Sailors indicated the lumbar support strap was too narrow and that the gap between the lumbar support strap and the upper back part was too big. The freedom of movement while standing was positively assessed by all sailors and allowed to bend and move the shoulders freely. A feature that was intensified by the fact that both straps of the shoulder straps are able to slide freely through the buckles where the straps attach to the hook.

Figure 66 ; Photograph of the on water validation session, with the helmsman is wearing the prototype.

On water

Before sailing the sailor indicated that the fit of the harness was good and the lumbar strap already provided support in the lower back. The only comment was the upper back part, which was slightly too high and thereby pressing on the neck. The sailor started wearing the harness right from the start of the training session and worn it for about 10 - 15 minutes during an upwind leg, performing numerous tacks (see Figure 66). After 10 - 15 minutes the sailor wanted to change back to her own harness to continue training. Her comment was primarily that the load on the back was to high and too demanding that it resulted in pain and discomfort. The sailor indicated that the strap should be reaching higher and be stiffer. Additionally, the upper back part was too high and pressing on her neck as tension on the shoulder strap was increased.

3.8.5 Discussion

Based on the feedback of the sailors, from both multiple onshore and one water hiking session, a couple of suggestions could be given for the further development of the harness. The prototype was not comparable to a finished product, far from it, and should therefore not be regarded as one. In theory this sounds easy, however while wearing the prototype harness sailors found it hard to set their mind to this thought and they were rapidly comparing the prototype harness to their own harness. Due to the fact that the prototype harness was quite different from an ordinary harness and was interpreted as being a highly demanding and unsupportive harness, the experience of the harness had to make up for a lot. Proving what an impact previous experiences and assumptions have on the harness. Which may sound conservative, but if their regular harness is working fine and provides a great feeling why change it? The challenge is to break through this by providing an alternative which is able to provide a similar feeling with an extra feature. In order to accomplish this a few alterations or adjustments could lead towards a next prototype which could close the gap.

First of all the upper back part. Sailors pointed out this was to small and did not provide enough support. Enlarging this should cover a larger part of the back and thereby provide more support. Next there is the lumbar strap. The strap provided support, but not with the desired effects. The sailors pointed out that the strap was to narrow in terms of both the height and width, thereby cutting in the side of the body and creating a high load on the back just above the strap. Keeping the first point in mind, a possible alteration could be to simply to reduce the open space on the back and bring the parts further together to cover a larger part of the back. This would require more stiffening of the harness, especially in the lumbar area.

The shoulder straps required a different way of putting the harness on, but were experienced to create to more freedom of movement. In a next design the straps could be slightly wider and padded to create a more finished product. Last, the adjustment straps, these were regarded to be a positive improvement. Currently, most harnesses that use Velcro adjustments can not be tensioned tightly, with this design that is possible and can provide a better fit.

3.8.6 Conclusion

In the end the experiment provided valuable insights and information, where new information was gathered for further development of the harness. The on water conditions were not in line with the intended conditions for the harness, but was an important part of the experiment. Among other things, it showed that the difference between on water and on shore hiking is very different and can not be regarded the same.

Of course this statement has to be proven with further experiment to create a sufficient foundation. However, during the experiment it showed that the dynamics involved while hiking on water a bigger than during a on shore hiking session. The experiment showed that the harness indeed improved freedom of movement, but that the transition from current harness designs to the design presented by the prototype is a big leap. Instead, the idea of separation should be maintained, yet be transformed into a harness that provides more support in the back. Besides this feedback the prototype also had a specific Velcro adjustment setup that was regarded as a positive upgrade of regular Velcro adjustment options. Unfortunately, the lumbar support strap did not provide the intended results and will have to redesigned to provide more support, which could be achieved by enlarging the width and height of the strap and even by adding stiffening parts. Basically bracing the back and core, possibly resulting in a harness that is leaning more towards a kitesurfing harness.


MARINEPOOL
kelag
kelag

Closing

Introduction to closing

4.1 Recommendations

4.1.1 Research opportunities

By means of user studies the interaction between sailor and harness was investigated closely. Early on in the project support was identified as a unit to express comfort of a harness. However, a further relation good not be found or substantiated. For further development of the trapeze harness, and especially its supportive elements, finding this relation could be valuable. The largest contact area between harness and the sailor's body is the back. Throughout this thesis, the back of the sailor has been a discussion subject more than once. Finding that pressure distribution over the back is irregular and support in lower back is often lacking or not designed to be most efficient. The redesign has provided an element that can improve this support. Still, there is room for more specific research on the interaction between the back and the harness. E.g. to what extent does a optimal shaped back part of a trapeze harness improve stability of a sailor?

4.1.2 Programming board limitations

The programming board is method to make the effect of changing the design parameters more insightful, its initial setup works and provides a clear overview. Its current design is still conceptual and its output should be treated as an indicative design direction.
Even so, zooming in on the workings exposes flaws. First of all, the 3D characteristics of the cube are not used, as a result the distribution differences are not used up till their full potential. Best illustrated with the clustering of the cube layouts towards the middle of the scale, where layouts are different but due the 2D assessment can not be distinguished. This could be solved by adding a third dimension that prioritises the rows. The number of possible configurations will remain the same, though it will require a different clustering.
Secondly there is the ratio between hiking and performing other tasks. On water conditions are the biggest influencer for the time a sailor is hiking. In light conditions a sailor might not even be hooked in and benefit a lot from extra freedom of movement, but a slight increase in breeze might multiply the time spend hiking by factor two. In that case freedom of movement becomes far less important and support will gradually start overruling. This influence has not been taken into consideration when designing the programming, however does earn attention.
Thirdly, the influence of the secondary layer on the cube configuration is linear, whereas a design specific parameter could have a bigger influence on certain cube configuration. For example, if the output based on the primary layer is at the far end of the freedom of movement side of the scale and in the secondary the type of harness is set to "Leg strap", then the outcome is not a leg strap harness. The same applies to material thickness, which is a highly personal preference and not harness specific.
Although, it is design is conceptual and far from definitive the points mentioned above provide the first towards a programming board that provides well founded output.

4.1.3 Programming board limitations

The proposed redesign was characterised by a unique strap setup and as a result an open back. Developed by taking the strap setup as the harness' basis, allowing to carefully determine where a harness should provide support. Additionally, providing clear overview for the assessment of freedom of movement. A method that could be used for further trapeze harness development. One of the unique features of the proposed redesign was the separation of functions, best exhibited by the lumbar support strap. An individual part of the harness and could adjusted without influencing other parts of the harness. While testing the prototype this feature was embedded, unfortunately it was found too small and not positioned in the right place. In the redesign the strap's height was increased and the a curvature was added to ensure a right fit. To what extent this feature will produce the intended result requires a further development step.
While developing trapeze harness concepts, one of the designs had tensioning system embedded into the harness. Once the sailor started hiking the harness would tension as weight was exerted on the hook. In this case, the entire harness was depending on the system. A dynamic element in a harness is new and needs to be reliable. For a first step this setup could be scaled down and embedded in a smaller part of the harness, such as the lumber strap or other back support.
During the project a prototype was fabricated to find out if the harness design would provide the intended features. The prototype was able to do so, however outcomes were limited by the appearance and finishing. Participants indicated that parts of the harness did not fit well enough and were cutting in the body. If a next prototype is going to be fabricated that embodies the features and layout of the proposed redesign, then the finishing of the prototype should get extra attention.

4.2 Recommendations

Finally, the end! Looking back the project I can say that it has been quite journey, where I have bumped into myself numerous times. However, all contributing to the end result of this thesis, which I consider to be a good base for further development. In my opinion, the harness with the open back is definitely a feasible idea.

4.2.1 Project outcomes

The trapeze harness has been part of sailing for 60 years, however up till now little knowledge about the piece of technical clothing was documented within the Dutch Sailing Association. Of course, sailors and coaches have thought about new ideas and might have tried them out. Unfortunately, these ideas were either basic adjustments or were not documented and still floating around somewhere. A similar trend was found in literature, where conducted research concerning the trapeze harness was very limited. In most cases literature concerned the physical requirements of a sailor, an interesting subject though only partially entirely relevant for this project. During the project knowledge in terms of pressure or load on the body and important design parameters to improve freedom of movement or support were obtained. Some insights could be considered logical conclusion and previously known, but they all contributed to the end result of the project.

Due to the fact that the Sailing Innovation Centre is located at the National Training Centre contact with sailors, coaches and other staff members could be easily established. Resulting in several interesting discussions where light was shed on problems and solutions. Unfortunately, the sailors were often away on trainings sessions or races, which at the start of the project was not always ideal.

Looking back at the end results, I was surprised with the outcome and think that this harness redesign definitely has potential for the future. Only if the next iteration focuses more on making it feasible product. For now the first steps towards a totally different harness design have been taken, where the sailors have to be more involved into the process.
The other end result, the programming board, is a typical example of brainchild that got out of hand. The initial idea was to produce a way to demonstrate how certain design parameters influence the design and choice for a particular harness. Eventually, resulting in a conceptual tool that generates an trapeze harness design with according to a set of design requirements. Since the programming board was a creation produced shortly before handing in, the designs could not be physically tested by means of simple prototype.

4.2.2 What I experienced

Structure, no that is not one of my strengths. Instead, I consider the absence of structure to be one. It is more than safe to say that my way of working is absolutely not characterised by strict planning, rather by impulsive decisions, a lack of concentration and always the urge to find an answer. The last 'quality' was only sparked towards the end of my masters, it has always been there but never found its way to the surface. Which I find unfortunate. The combination of these traits have helped and blocked me during this project, as I might have spent too much time on unnecessary reading totally irrelevant articles or conducting experiments that were far outside the scope of this project. In some cases I felt like a blind wild horse storming through a town. Still, it all contributed to the end result, yet not very much too efficiency.

Somewhere in the middle of the project it struck me how far I had gone off track and found myself far outside my area of expertise as I was reading articles about all muscles supporting the lower back. At some point I was doubting if was still being a designer and not a human movement scientist. Though, I think this exactly what an industrial designer is supposed to do, getting to know as much as possible. I consider knowing a little about a lot things to be more valuable than knowing a lot about a little things. Enabling a designer to understand people with different areas of expertise and merging their ideas.

4.2.3 What I learned

Well, there are definitely a few things I have learned, maybe even more in these last months than ever before during my time as a student. While tackling problems always took the difficult path, keeping things to complicated. During the project I have seen how simplifying problems allows easy understanding and still maintains a certain degree of accuracy to the outcomes. For example, during the project I was fighting to formulate a working model to quantify the forces the sailor experienced on the body while hiking. I kept using a too complicated approach for far too long, wasting a lot of time. Once I simplified the harness to its most basic shape I was able to understand what was going on. Shortly after I could formulated a working model that put out numbers that were largely in line with measurements. So, for future projects, analyse the situation and simplify it to its most simple form.

Throughout the project I have found myself totally lost in information quite a few times, mixing up minor details with the big and important insights. In most cases I just went on diverging further until someone just asked me: “Why is this relevant?” The solution is easy: I must harness* my impulsive way of working and urge to finding an answer, but more often take a step back and create an overview.

I have learned that I am not a designer, but a thinker. By this I mean that I can not spent months on designing a small part of product, I want to design the bigger picture. What should it do, why and how. Big lines. Similar to my drawing skills. I can draw the outlines of a car, but do not dare to ask me to draw its interior.

Prioritising. I dare to say that I did a lot, however I did not prioritise my tasks. I gave a lot things more attention than it deserved, things which were relatively unimportant. Affecting the quality of my work and reducing the thoroughness of the research.
Last, I have learned how much I dislike scientific writing, as you might have experienced while reading this thesis. I need, or maybe want, to use too many words to describe a finding or argument.

*I have avoided to use this word as a verb in the thesis, but here it seems suiting.

Appendices

A1: References

Orientation:

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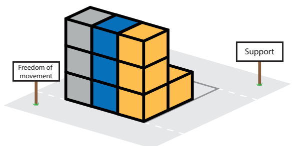
Images

alkasjf

A2: Programming board



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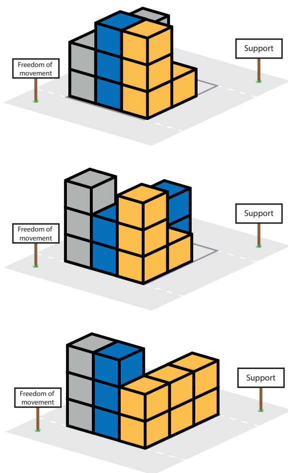

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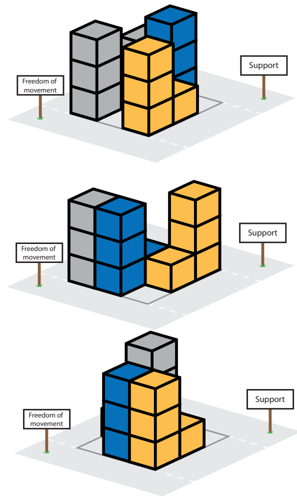

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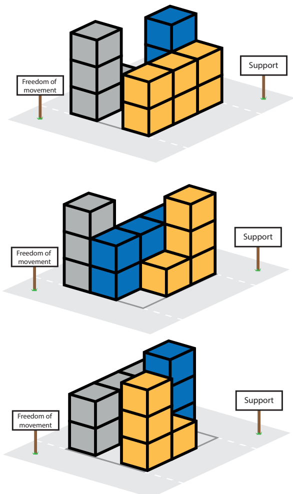

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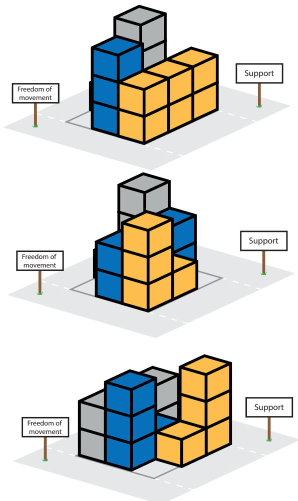

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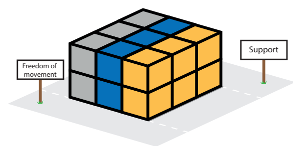

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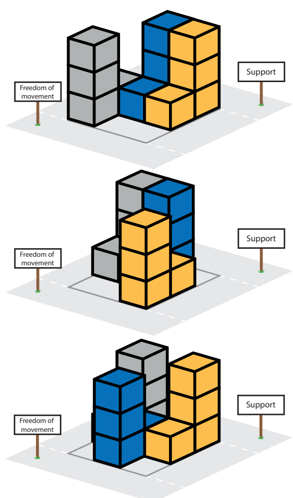

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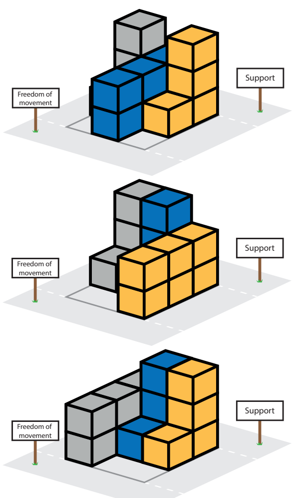

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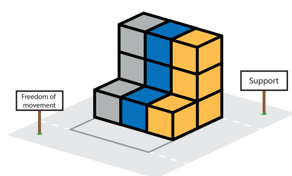

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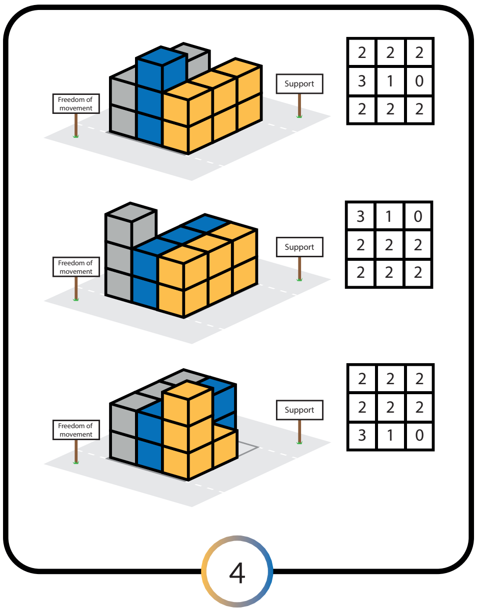
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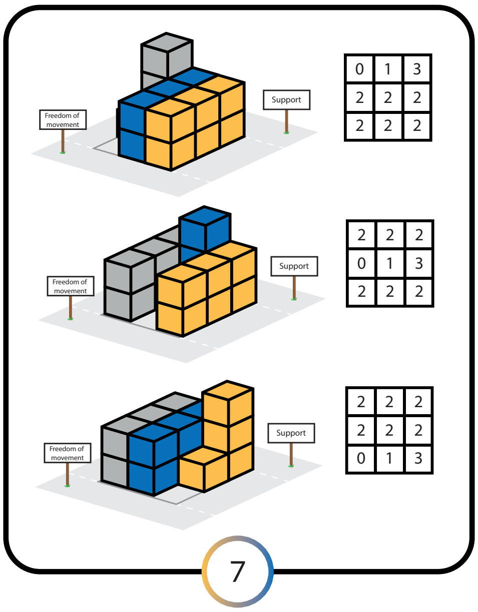
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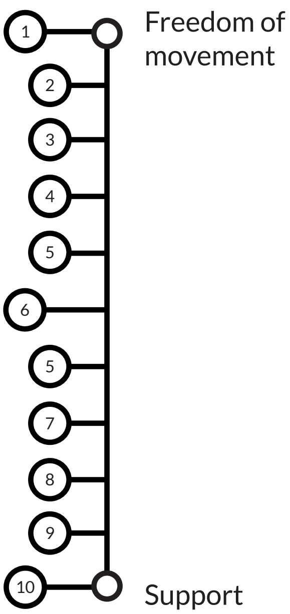
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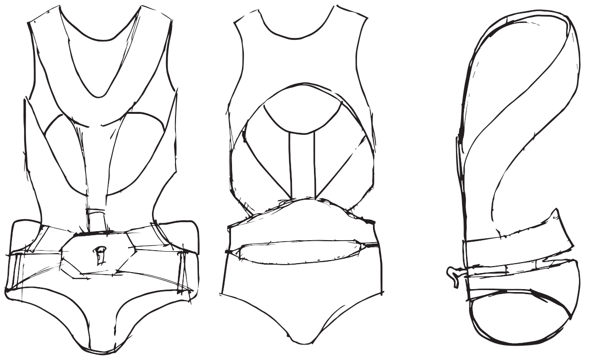
A2: Programming board



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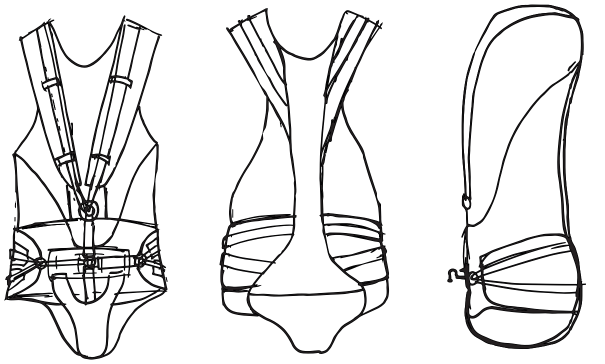

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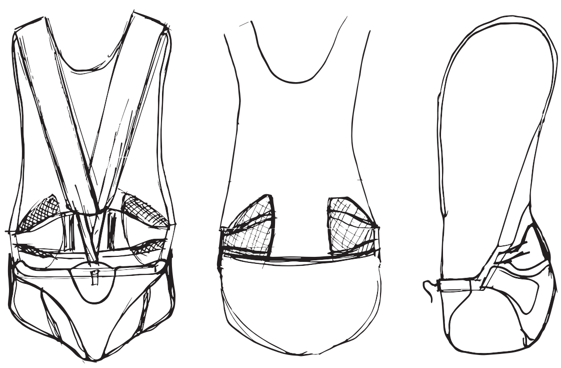

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A3: User test 2

Naam:
Datum:
Geslacht: Man / vrouw

Hoeveel verschillende trapeze harnassen heb je?

▢ 1 ▢ 2 ▢ 3 ▢ 4

Wat zijn de belangrijkste verschillen tussen deze vesten en waarop baseer jij je keuze voor een bepaald vest?

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Aan welke onderdelen of punten van het trapeze vest stoor jij je het meeste en waarom? (Bijvoorbeeld: Wat zou je willen instellen, maar kan nu niet?)

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Welke afstelling van het pak vind je het belangrijkst? En welke pas je het meeste aan?

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Welke houding(en) zijn tijdens het zeilen het zwaarst?

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Wat doe je bij vermoeiing anders met het vest of qua houding?

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Bij welke handeling zit het trapeze vest het meeste in de weg?

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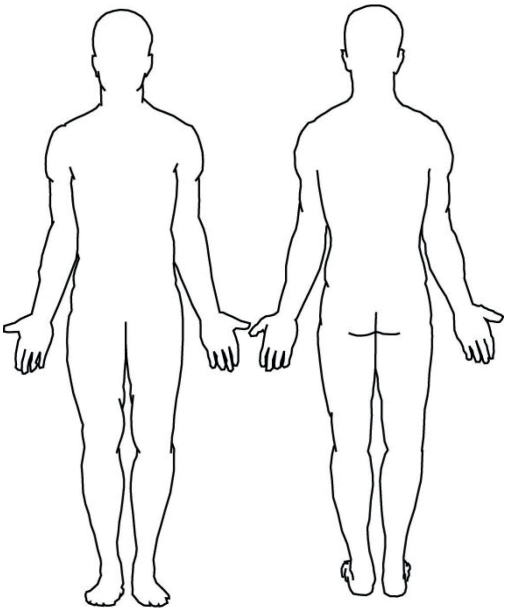
Op welke plaatsen je lichaam ervaar je de meeste druk van het vest? En welk hiervan is het minst fijn?



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Wat heb je gedaan of doe je om op deze probleemgebieden de druk te verlichten?

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Op welke gebieden mis je juist ondersteuning van het vest?

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Heb je ooit lichamelijk klachten gehad? Zoja, welke?

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	Gender	Boat	Aantal trapeze harnassen	Merk en model	Type harnass	Op basis van welke eisen kies je een harnas?	Welke onderdelen aan het harnas ervaar als zijnde storend?	Wat vind je de belangrijkste afstelling van een harnas?
Participant 1	Female	49'er FX	1	Magic Marine Team	Nappy	Dit harnas heeft extra rugondersteunende pads en is zacht bij de liezen. Ik heb maar één harnas dus maak verder onderscheid voor een bepaald weertype, ik weet dan andere dat wel doen.	Slijt snel op de billen	De schouderband. Als het harder waait zet ik deze wat strakker. Dan heb ik meer support
Participant 2	Female	49'er FX (Voorheen ook 470 en Nacra 17)	1	North sails Japan	Leg strap	Het harnas heeft 2 battens in de rug voor ondersteuning.. Het houdt de rug recht en het heeft verstelbare straps bij de heup, schouders en liezen. Eenmaal één dag een andere gebruikt 3 jaar geleden (Zhik) resultaat hiervan was een Hernia.	Niets. Is wel vrij licht. Iets zwaarder zou beter zijn	De schouder en heup afstelling zijn belangrijk en moeten goed strak zitten. Schouders mogen niet te ver naar achteren kunnen in verband met overstrekking.
Participant 3	Female	49'er FX en voorheen ook 29'er	1	Zhik T2	Hybrid	Klittenband bij de heup en grote draagplaat in rug zijn fijne features van dit harnas. Mijn coach zei dat dit een goed harnas was, dus deze heb ik toen geprobeerd en eigenlijk beviel dat goed.	Niets.	Bij mijn heupen voor de juiste druk en gevoel
Participant 4	Female	49'er FX en voorheen ook 470	2	Zhik T2 en een zelf gemaakte uit Duitsland	Hybrid en nappy	Het harnas van Zhik heeft een plaat in de rug, brede banden en zacht rubber in de liezen. Dit is fijn. Het licht gewicht trapeze harnas weegt maar 400gr en is veel minder ondersteund. Met weinig wind gebruik ik het lichte harnas omdat het minder weegt, makkelijker in te bewegen omdat de stof dun is en er is minder ondersteuning nodig als niet veel hangt. Met meer wind het harnas van Zhik omdat het iets zwaarder is en meer ondersteuning geeft	Zhik: Het klittenband rond de heupen en middel. Als het harnas iets ouder wordt kan dit los gaan tijdens het zeilen. De lichte broek snijdt in de liezen en het is een soort zak waar je in stapt. Dus als de zak als vrouw over je heupen pas, dan zit die bij je middel los..	Geen specifieke afstelling
Participant 5	Female	49'er FX, Matchrace, 29'er	2	Zhik T2 en Magic marine	Hybrid	Zhik: Dit harnas geeft goede versteviging in de rug. Magic: Snijdt in de lies. Bij het kiezen van harnas kijk ik naar rugversteviging, de druk in de liezen en hoe strak het kan worden gezet bij de heupen.	Ik zou het strakker willen zetten rond mijn middel en heupen, maar dan zonder te veel banden. Die banden zitten vaak in weg en fladderen rond.	-
Participant 6	Female	470	3	?	Leg strap en nappy	Voor mij zijn bewegingsvrijheid, pasvorm/comfort, gewicht en back-support belangrijke onderdelen. In licht weer kies ik een harnas waarin ik makkelijker kan bewegen, bij meer wind een harnas dat meer ondersteuning geeft.	Het opruimen van de straps waarmee je het harnas hebt aangetrokken is belangrijk. Gewicht vs duurzaamheid. Looks (kleurstelling) en back-support	Voor mij zin de shoulder straps het belangrijkste, hiermee creeer je gevoel richting de boot.
Participant 7	Female	470 and Nacra 17	3	?	Leg strap en nappy	Gewicht en comfort zijn voor mij de belangrijkste eisen bij het kiezen van een harnas. Hoe harder het waait hoe meer comfort en support ik wil hebben.	Bij sommige harnassen komt de haak heel ver van het lichaam vandaan te zitten. Dat is erg vervelend. Andere trapezeharnassen beperken de bewegingsvrijheid van je benen wat op een catamaran heel vervelend is (hier zit je op een vlakkere ondergrond).	De schouderband pas ik het meeste aan. Verder vind ik het belangrijk dat de trapezebroek goed aansluit om zo gevoel tussen mij en de boot te creeren
Participant 8	Male	29'er en 49'er	2	Shock	Nappy	Een tweetal shocks op maat laten maken in twee kleuren. De laatste is bijna 2 kilo, het maximale gewicht en dus verzwaard, en heeft een tweetal strips op de rug. Ben erg tevreden met dit harnas. Daarnaast vind ik het Zhik harnas ook fijn, maar die heb ik niet.	Schouders worden soms wat naar binnengedrukt. Daarnaast heeft het harnas weinig beschermend schuim. Het comfort bij het kruis blijft altijd wel een dingetje. Het is belangrijk dat dit goed breed is en het liefst toch wel van iets zachts of stretch.	Voor een trapezeharnas is de binnenkant van het bovenbeen belangrijk, dat wil zeggen de juiste uitsnijding zodat er genoeg bewegingsvrijheid is zonder dat het afkneld. Lengte van het harnas over de rug is belangrijk want dit bepaald ook de compressie. Heupomtrek blijft toch wel één van de belangrijkste doordat dit omsluiting en compressie op de heup bepaald. Die compressie is belangrijk voor het gevoel
Participant 9	Male	Laser en 49'er	1	Magic Marine Team	Nappy	Deze heeft latten in de rug de ondersteuning geven en dat is voor mij voldoende. Ik wil niet het gevoel hebben dat ik compleet gebraced word. Het blijft sport en daar moet je gewoon voor werken. Ik heb gewoon één harnas die ik in iedere omstandigheid kan gebruiken. Zelfs met weinig wind hang je toch al snel in de draad.	Soms zou ik de heupdruk wel iets willen aanpassen tijdens het varen, maar met klittenband gaat dat niet. In de rug vind ik het belangrijk dat ik de latten erin en eruit kan halen en eventueel wat gewicht kan toevoegen als dat nodig is.	Heup afstelling wil ik altijd kunnen aanpassen afhankelijk van de omstandigheden. De schouderband staat bij mij eigenlijk altijd hetzelfde
Participant 10	Male	29'er en 49'er	2	Magic Marine Aurelian en Pro racing	Hybrid en nappy	De team heb ik als licht weer harnas, deze heeft twee strips in de rug die even wat extra ondersteuning geven. Met zwaar weer ga ik dan voor het zwaardere harnas zodat ik nog meer ondersteuning krijg, ook is het materiaal gewoon stijfer waardoor het meer ondersteuning geeft. Dit heb ik ook echt nodig vanwege mijn rugblessure (hernia). De laatstgenoemde heeft pads en latten in de rug.	Ik het vind het belangrijk dat het harnas mijn bovenlichaam goed bij elkaar drukt en dat het harnas een soort stoel gevoel geeft zodat ik goede support heb in de onderrug. Voor mij is ook belangrijk dat ik kan bewegen met de haal	Mijn onderrug vast kunnen zetten is heel belangrijk, maar dan moet ik wel genoeg bewegingsvrijheid behouden. Het klittenband op de heupen is dus ook heel fijn, dan kan ik het harnas echt naar mijn lichaamsvorm aanpassen per dag.
Participant 11	Female	470	3	Magic Marine Team, Magic marine Pro racing (adjusted)	Leg strap en nappy	Allemaal zonder spreader bar. De haak moet dicht bij mijn lichaam zitten anders zit het snel in de weg met de fokkenschoot. Ik ben erg kritisch met harnassen, als het niet lekker zit dan gooi ik het meteen weg. Daarnaast moet ik door het harnas de boot goed aanvoelen. Hierdoor is de heupafstelling dus belangrijk. Daarnaast is bewegelijkheid gewoon belangrijk, in de 470 heb je weinig ruimte om overstag te gaan. Eigenlijk kies het lichtste harnas met licht weer en een zwaarder harnas met zwaar weer. Zonder dat ik het zelf doorheb kies ik dan ook een harnas dat meer ondersteuning geeft.	Snijden bij de liezen is gewoon vervelend en irritant, maar ik kan er weinig aan doen. Is ook afhankelijk van de omstandigheden.	Schouderbanden vaak niet te strak anders krijg je te veel compressie. Heupafstelling is ook belangrijk voor het aanvoelen van de boot.
Participant 12	Male	Nacra17 & 49er	1	Shock harness	Nappy	Ik wilde een harnas dat helemaal voor mij gemaakt is en waarbij ik vrij in kon bewegen, de shock was een mooie middenweg in alle harnassen. Ik heb gekozen voor een allround harnas waarin ik zowel vrij kan bewegen als ondersteuning krijg. Daarnaast is het gemaakt van een redelijk soepele stof waardoor bewegen makkelijk gaat.	Die heb ik eigenlijk niet echt	Onderrug is eigenlijk altijd het belangrijkst voor mij. Hier moet het harnas goed drukken. Niet alleen voor een gevoel van ondersteuning, maar ook om de boot te voelen. Verder heupen, het moet gewoon goed aansluiten

Wat is volgens jou de zwaarste houding met het harnas als je in de trapeze staat?	Wat verander je aan het harnas in geval van vermoeiing?	Bij welke handelingen in de boot kan het harnas in de weg zitten?	Op welke punten op het lichaam ervaar je de meeste druk van het harnas?	Welke aanpassingen doe je om deze druk te verlichten?	Op welke gebieden mis je juist ondersteuning van het harnas?	Heb je ooit lichamelijk klachten gehad? Zoja, welke?	Extra notities
Constant gestrekte houding is zwaar op de nek en de rug. Of constant van binnen naar buiten is zwaarder op de benen, maar dit zorgt wel voor stabiliteit.	Ik doe niets anders	Eigenlijk niet echt.	Op het sleutelbeen drukt de band soms wat en achter bij de trapezius spier als de ban strak heeft gezeten doet dat soms pijn.	Niets	Soms bij de onderrug bij lange dagen	Rug/onderrug	Staat op het punt om een Shock adjustable harnas te gaan proberen vanwegen slijtage en rugklachten
In extension en ingedraaid pompen (470). Indraai posities in het algemeen. Soms is het hijsen en droppen van de gennaker zwaarder door de squad.	Afstelling van het harnas blijft hetzelfde. Het zit meer in de houding. Ik haal dan meer kracht uit mijn benen in plaats van mijn armen.	Lang rechtop staan dan staat het harnas strak en is de bewegingsvrijheid is beperkter	Op de schouders, heupen en waist van de banden, maar geen extreme krachten	Niets	In de indraai posities en eigenlijk ook bij de extentie	Hernia onderrug	470 heeft een hogere belasting vergeleken de 49'er en Nacra. De bemanning staat in overextensie en staat te pompen in de draad.
Er is niet één houding die er boven uit schiet	In sommige gevallen zet ik mijn schouderbanden wat strakker	Niet echt iets	Bij mijn rug vind ik het fijn, mijn schouder wat minder. Maar ik heb nergens echt last	Niets, want ik vind het niet echt vervelend	Nergens erg	Geen	
In de trapeze staan zelf niet echt	Niets	Het Zhik harnas heeft een best wel brede plaat voorop die kan in weg zitten met diepe squats, bijvoorbeeld bij de start. Ik probeer het klittenband altijd zo te doen dan de plaat wat hoger zit.	Soms snijden de harnassen in mijn liezen	Op tijd een nieuwe broek kopen met zachter materiaal op de plek waar de druk verlicht moet worden	Niets	Stijve bovenrug	49'er bemanning: Je staat rechtop en hangt gedeeltelijk op de schoot van het grootzeil of kite 49'er stuur: Je hangt meer op je buikspieren. Als ik stuur heb ik mijn schouderbanden veel strakker 470: Hier sta ik vaak veel meer ingedraaid.
-	-	-	Bij de liezen en schouders. Bij de schouders kan het harness best gaan drukken als je strekt of langere tijd in de trapeze staat.	-	-	Rug	
Een soort stoelhouding in trapeze zitten bij een medium windje en bij maximaal strekken, maximale druk geen bewegingen naar binnen en naar buiten.	Even anders gaan zitten	De straps op je benen gaan na een tijdje enorm knellen	Straps over de schouders	Het harnas even uit en aantrekken	Geen	Geen	
Van in de trapeze staan naar binnen de boot is zwaar voor je arm. Verder light het aan de afstelling van je trapezebroek in hoeverre je je buikspieren moet gebruiken wanneer je gestrekt in de trapeze staat.	De schouderband strakker	Op de trampoline/boot zitten	Op de heupen	Gewenning en het ene harnas heeft het veel minder dan de andere	Afhankelijk van het harnas, maar als je ondersteuning mist dan is het voor de onderrug.	Last van de nek, maar hier heeft het harnas wening mee te maken gehad.	
Vol strekken. Blijft gewoon zwaar omdat je je indraaid en ook wel overstrekt waardoor er veel spanning op je spieren en core komt. Het geeft mij het gevoel dat de boot dan beter reageert en dat ik voel wat er gebeurd.	Schouderband strakker, maar dit gaat dan wel snijden	In principe nooit. Zelfs bij het bukken gaat het vaak goed. Omdat je je zwemvest over je harnas draag word alles in principe naar beneden gehouden.	Eigenlijk alleen op de schouders	Schouderband iets losser	Dikker foam op de rug en iets meer ondersteuning in de onderrug. Ik heb zelf geen rugklachten op dit moment, maar kan mij goed inbeelden dat andere zeilers dat wel hebben.	-	Je ziet bij sommige pakken dat ze een kussentje op de rug hebben zitten, maar dit is eigenlijk vrijwel nutteloos. Dit is puur voor comfort en niet voor ondersteuning zoals strips of een plaat dat wel doet. Ik wil eigenlijk dat mijn haak zo laag mogelijk zit, zodat ik makkelijk kan inhaken. Daarnaast wil ik de haak dicht op mijn lichaam hebben.
Met weinig wind naar binnen en naar buiten	Wat meer gaan hangen in het pakken, dus minder stabiel en schuin naar achteren	Bij licht weer kan dat wel eens voorkomen, maar dat is echt uitzonderlijk	Ik heb niet specifiek te veel druk op één punt op het lichaam, maar op de schouders houd je altijd de druk.	Schouderband iets losser om de druk er een klein beetje af te halen.	Wellicht in de onderrug, maar opzich werken de strips al best aardig.	-	Vol strekken doe ik om meer druk te krijgen tussen mij en het harnas. Hierdoor krijg ik het gevoel dat de boot harder gaat en dat ik meer controle heb.
Overstrekken en indraaien zijn het zwaarste.	Schouderband iets strakker en een rechtere houding in plaats van overstrekken. Ik merk dat ik dan wel onstabieler in de draad sta.	Niets	Schouders en de heupen	Kussentje in de rug	Onderrug blijft een ding	Rugklachten	Shocken van de boot en klappen van de golven zijn goed te voelen en kunnen zorgen voor extra spanning op het harnas en lichaam
Vol gestrekt en het pompen los van de broek	Toch de band iets strakker zetten	Niet echt iets, maar het zou kunnen bij overstag en in licht weer als je een rare houding moet aannemen	Schouder en kruis	Niets	Soms in de onderrug, want daar ontstaat dan een gat tussen het harnas en het lichaam. in veel gevallen wordt dit opgelost met een kussentje of gewoon harder trainen in sportschool.	Irritaties door wrijving maar verder niet	
Vol gestrekt en dan indraaien.	Niets	Bij de Nacra was dat vooral tijdens overstagen, maar bij de 49er eigenlijk alleen bij naar binnen en naar buiten	Shouders en kruis	Niets	Niet alle harnessen leveren de juiste support in the onderrug. Ik heb in mijn harnas een extra kussen zitten om het op te vullen. Maar dit zou beter opgelost kunnen worden met een stel banden.		Bij de Nacra werd ik harder naar binnen getrokken, bij de 49er is dat minder erg het geval. Hierdoor heb ik nu meer spanning op mijn buikspieren, dus het is iets zwaarder.

A4: User study 2

1. When looking at the harness how would rate the comfort of this harness?

Not comfortable 1 2 3 4 5 6 7 Very comfortable

2. What features or design elements makes you think that this harness earns this score?
……
……
………………………………………………………………………………………………

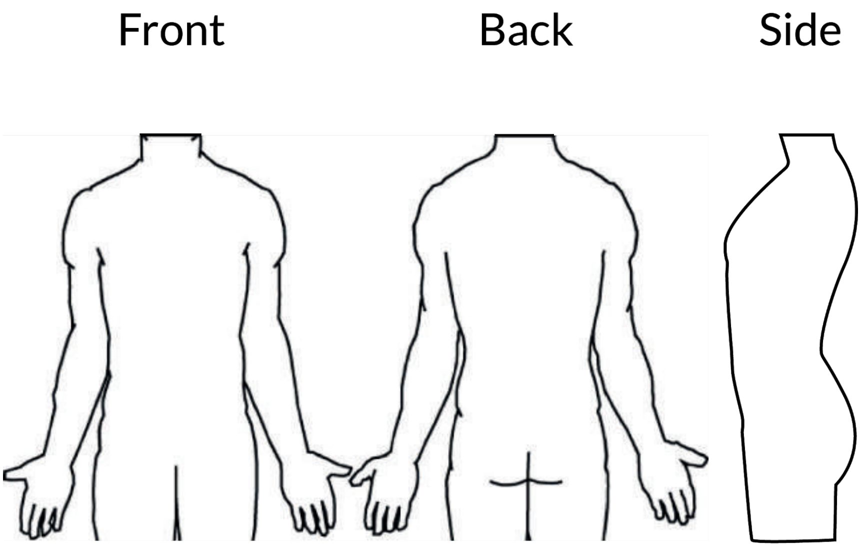
Next, the participants were asked to put on the harness and adjust it to their personal preference using the straps or other adjustment options. Once they were wearing the harness they were asked to fill out the second part of the questionnaire focussing on the experience and fit of the harness.

3. Do the adjustment possibilities are enough to ensure a good fit? Why?
……
……
………………………………………………………………………………………………

4. How would you rate the extent to which the harness matches the contours of the body?

Not all 1 2 3 4 5 6 7 Perfectly

5. Please identify the places with a cross where the harness exerts pressure on the body.



6.How comfortable would you rate this harness?

Not comfortable 1 2 3 4 5 6 7 Very comfortable

	Harness A									
	Beforehand		*After*				*Participants*			
Participant	Expected comfort	Arguments for expected comfort	Adjustment and fit of the harness	Matching human figure	Pressure on the body	Experienced comfort	Stature	Hip circumference	Age	Gender
1	6	Multiple straps to adjust the harness Quality fabric Less comfortable due to back protection	Good shoulder support Not sure if the back protection offers support in the way it should	5	-	6	1770	900	24	Male
2	6	Wide straps on the shoulders Feels like good back support	Amount of possibilities is OK, but kind of inconvinient to handle It feels like your body is moving through the harness instead of the harness moving with the body	5	Shoulders, crotch and hips	3	1870	1000	24	Male
3	6	The harness feels heavy and robust It seems as if the harness is shaped and therefore it looks comfortable	The support can be felt, but when I bend over the harness does not move and feels stiff. However, in an upright position the harness offers much support but little in the back	5	No support in the back Pressure just under the buttocks	6	1890	950	24	Male
4	2	Looks hard and hard materials are used	A lot of possibilities to adjust	5	Upper back, crotch and hips	3	1890	990	23	Male
5	4	Fabric seems a little rough and the spreader bar has a sharp side on the inside. The model seems to fit	No support in the back and hips spreaderbar presses on the belly	4	Shoulders, belly and groin	3	1840	1010	26	Male
6	6	Good support in the lower back and no unnecessary fabric at the groin	Yes, best of all the tested harnesses. Can be improved with extra pieces just above the hip.	5	Lower back, belly, groin and hips	5	1830	910	24	Male
7	5	Looks comfortable due to cushioning and pre shaped form	Does not give any support in the lower back. Hard piece in the back is misplaced. The harness is quite narrow at the upper back.	4	Shoulder, groin and upper back	4	1850	900	27	Male
8	6	Harder harness and every part seems well cushioned	Long bands, adjusting the harness is quite a job.	4	Shoulders and groin	4	1790	910	25	Female
9	6	Feels rigid and probably quite supportive	Adjusting is quite hard, the bands not always work properly and are quite long. The harness has a hard piece that does not align with the lowerback	4	Shoulders and hips	5	1750	920	28	Female

	Harness B									
	Beforehand		*After*				*Participants*			
Participant	Expected comfort	Arguments for expected comfort	Adjustment and fit of the harness	Matching human figure	Pressure on the body	Experienced comfort	Stature	Hip circumference	Age	Gender
1	6	Light weight.	Shoulder strap support is good Leg strap not comfortable Straps are too long	5	Crotch (groin)	5	1770	900	24	Male
2	3	It seems like there is no form to the body	The lower part is OK The upper straps only give support in one specific position When you move slightly the support is gone	4	Shoulder, crotch (groin) and buttocks	4	1870	1000	24	Male
3	3	Looks very flexible and loose Does it match good?	I can not adjust the lower back part of the harness and it now leaves space between my body and the harness.	3	Misses support on the middle of the back	5	1890	950	24	Male
4	6	There are not hard objects, everything feels mobile en soft	Fine, I have the feeling that I am strapped into the harness, except for my back there it has too much space left	6	Crotch and buttocks	6	1890	990	23	Male
5	3	Thin fabric limited support and the back part of the harness is quite straight. Shoulder belts seem annoying	Belts irritate on the body Bar presses on the belly No support	4	Shoulders, belly and groin	2	1840	1010	26	Male
6	3	No hard support points (lower back)	Yes, good compression around the hips, except for the lower back	4	Shoulder, hips, groin and buttocks	4	1830	910	24	Male
7	3	Feels not very supportive as the material is thin and very flexible.	Narrow spreaderbar and the belts have no protective or cushioning layer	2	Hips, shoulders and groin	3	1850	900	27	Male
8	4	No hard inserts to improve support, but the top part is quite broad	The bands around the spreader bar are annoying and spreader bar pushes hard on the human body. Bands and the groin are irritating	2	Hips and groin	3	1790	910	25	Female
9	2	Looks really outdated and doest not feel very supportive	No support in the back. The harness is straight on the body. Spreaderbar is pushing on the belly if the bands are tightened	2	Hips, belly, groin and shoulders	3	1750	920	28	Female

Harness C

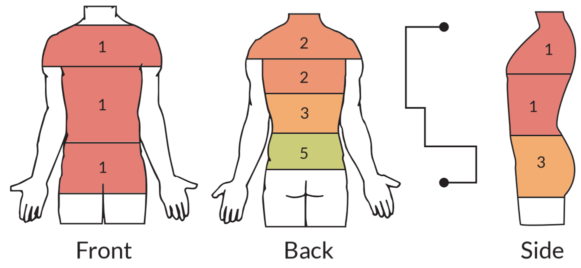
	Beforehand		*After*				*Participants*			
Participant	Expected comfort	Arguments for expected comfort	Adjustment and fit of the harness	Matching human figure	Pressure on the body	Experienced comfort	Stature	Hip circumference	Age	Gender
1	4	Limited possibilities to adjust the harness, does appear to fit good	The harness is not easy to adjust especially around your middle. Not much support when leaning backwards	4	Chest from the belt and crotch	4	1770	900	24	Male
2	5	Looks like the fabric is formed better and varies in thickness in the places you might need it	Lower adjustment gives good support The upper adjustment is very dependent on the position of the body I prefer this way of adjusting over all the seperate straps	5	Shoulders, buttocks and crotch	4	1870	1000	24	Male
3	6	It looks like it is going to fit the body pretty good	The mobility is good If I move the suit does too	5	Crotch (harness is a size too small)	6	1890	950	24	Male
4	3	Material looks harder and more coarse in comparison to the LA	Slightly to small, velcro is a nice option to adjust	6	Crotch (harness is a size too small)	5	1890	990	23	Male
5	4	Thin fabric No supportive materials Hook seems to be integrated nicely	Annoying at the crotch No support	4	Shoulders and crotch	2	1840	1010	26	Male
6	2	No hard support points Wide piece between the legs	Not enough support around the hips, mostly vertical	2	Shoulders and groin	3	1830	910	24	Male
7	2	Loose and thin fabric. The harness looks quite flat and not similar to the shape of the body, what I would expect.	Velcro is a nice way to adjust the harness, it gives a more equal distribution of the support. Part between the legs is to narrow	4	Shoulders and groin.	4	1850	900	27	Male
8	4	Light harness with no supportive elements, but the shape to my body seems supportive and therefore comfortable	Velcro has to be adjusted a few times before it fits perfectly	4	Shoulders	4	1790	910	25	Female
9	3	Thin fabric and very flexible, not very comfortable on first sight	Adjusting with the velcro works fine. Fits nicely around the hips.	4	Shoulders	4	1750	920	28	Female

Harness D

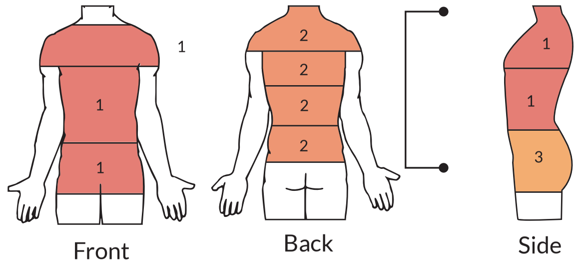
	Beforehand		*After*				*Participants*			
Participant	Expected comfort	Arguments for expected comfort	Adjustment and fit of the harness	Matching human figure	Pressure on the body	Experienced comfort	Stature	Hip circumference	Age	Gender
1	3	Not flexible No shoulder support Piece of foam sticks out in your back	Harness sticks in the back when leaning backwards Metal bar presses into the belly	4	Middle of the back Lower back	3	1770	900	24	Male
2	4	Seems like a good support around the waist, but none to the upper body/back	Better than expected Only the upper strap provides support when standing up straight	5	Groin, just under the buttocks and just above the hips	5	1870	1000	24	Male
3	2	The shape looks good, no shoulder straps	The harness is pre shaped. While wearing in an upright position it feels not so good at the buttocks	2	Middle of the back and at the legs	2	1890	950	24	Male
4	6	Fabric and material feels nice and stiff No shoulder straps	Yes, enough straps to make sure the harness fits nicely	6	Lower back	7	1890	990	23	Male
5	5	Limited annoying fabric Thick material (sturdy) No support in the shoulders	Hard piece in the back No distribution over the body Feels better in the groin	2	Middle of the back	3	1840	1010	26	Male
6	5	A couple of hard pressure points to support Little horizontal surface area between the legs	No room to squat	3	Middle of the back and hips	4	1830	910	24	Male
7	4	Hard casing and looks quite big	It really pushes in the middle of the back	3	Middle of the back and hips	3	1850	900	27	Male
8	5	Looks robust and wrapping around the body	A lot of long bands, little tough to adjust every band	4	Middle of the back and hips	4	1790	910	25	Female
9	4	Big harness and quite hard material	A lot of adjusting with the bands, though harness wraps around the body nicely	5	Hips and middle of the back	4	1750	920	28	Female

A5: User study 4

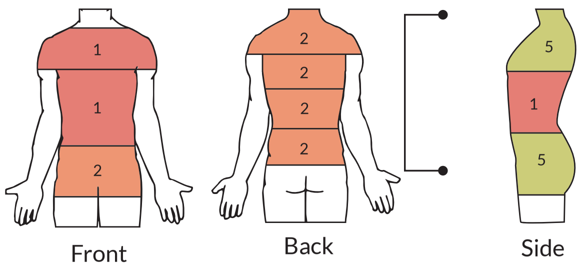
Harness A



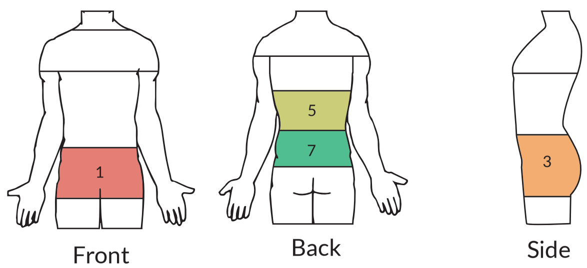
Harness B



Harness C



Harness D



Harness A

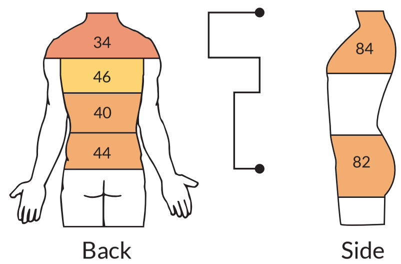
Quotes:

(3) This harness looks quite comfortable, but in my experience the straps always fly around or get tangled up in some way.

--> Straps need to be tucked away or shortened

(3) I do not feel much pressure or support in the upper back.

--> Data shows a similar trend



Harness B

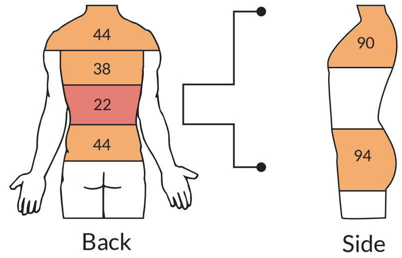
Quotes:

(3) The straps squeeze my buttocks and the harness does not support the back

--> This is proved by the data, showing a slight dip in the middle region.

(3) Straps are way too long and the leg straps make squatting hard

--> Leg straps limit freedom of movement



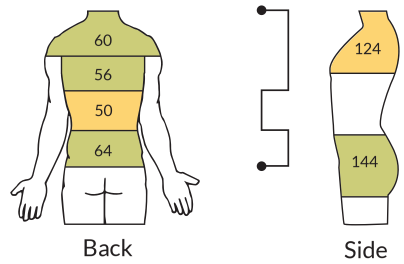
Harness C

Quotes:

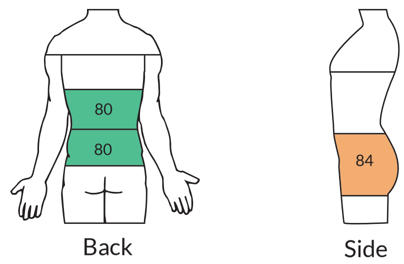
(3) For me this is the nicest harness. Not too much support and a good amount of compression. Much more freedom.

(3) More freedom because of the higher cut out of the legs, which is nice.

--> High cut out of the legs is important for agile movement and squatting.



Harness D



Insights

Harness A:

+ Support is experienced the most in the lower regions, however the pressure is almost equally distributed over the back.

+ There is a small increase in pressure at the position of the plate in the back

Harness B:

+ The support is experienced to be equally distributed over the back, the measured data shows that this the case with a dip in the middle lower region.

Harness C:

+ Similar to Harness B the support is experienced to be equal of the back. Measured data shows that is the case. However the measured pressure is significantly higher than for the other two harnesses.

+ Higher measured pressure at the hips and shoulders is experienced as more supportive

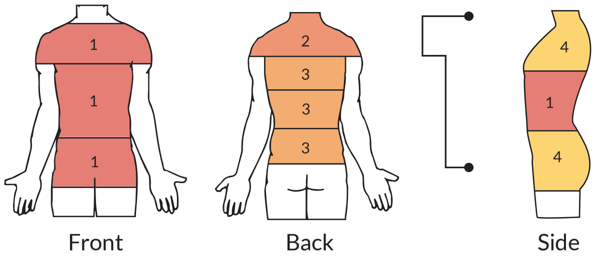
--> Shape or flexibility?

Overall

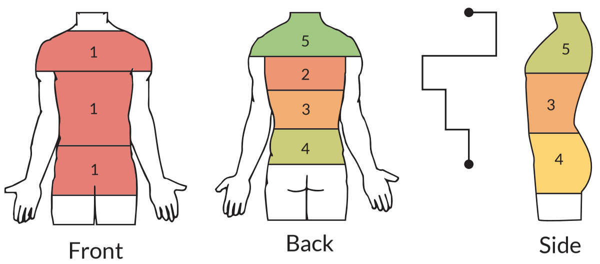
+ Hip compression is lowest for the harness with the widest spreader bar. The same is true for the pressure at the shoulders.

+ Harness C has the highest measured pressure in every region

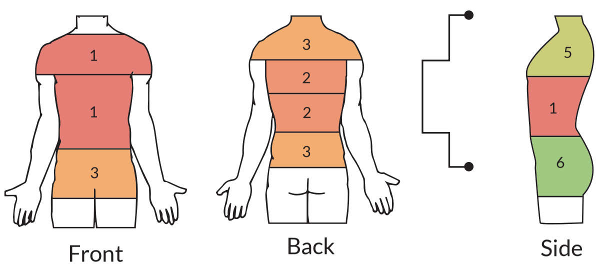
Harness A



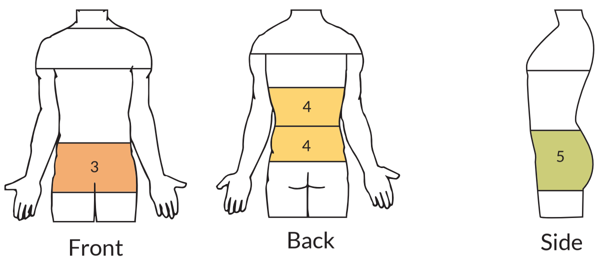
Harness B



Harness C



Harness D



Harness A

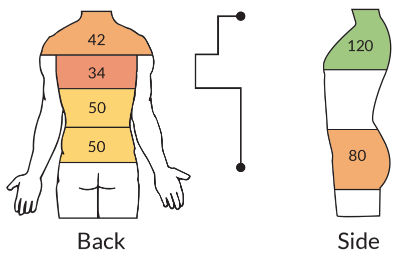
Quotes:

(5) Nice and comfortable harness, I can stay in the wire for quite some time with this harness without getting fatigued.

--> No annoying pressures, the combination of padding, foaming and material stiffness must have a positive influence here

(5) The straps are somewhat annoying to adjust, it takes some steps to get it right.

--> Straps are crossing each other, so there is specific order

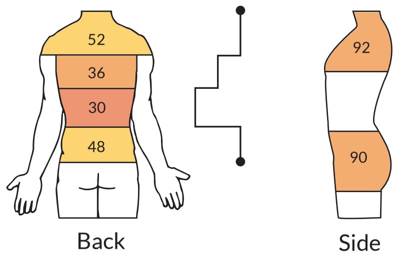


Harness B

Quotes:

(5) The harness is surprisingly more comfortable then you would expect. How the straps at the legs have strange attachment and cut hard.

--> The leg straps are not covered, resulting in a oncomfortabel experience



Harness C

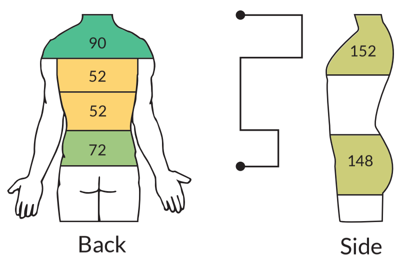
Quotes:

(5) The load on the shoulders is higher than with the other harnesses, which makes it quite heavy.

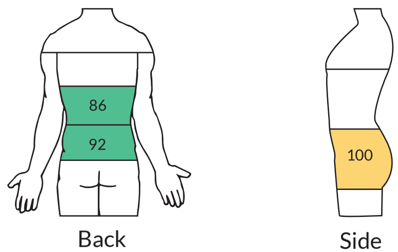
--> Data proves this point

(5) (Why do you think that is the case?) I think due to the flexibility of the fabric

--> In that case Harness B should show more or less the same trend, how ever this is not the case. Spreader bar influence?



Harness D



Insights

Harness A:

+ The experienced support is about equal with a slight drop in the upper back. The measurements show that the pressure is about the same over the back, with a drop in the middle upper region. Which is where the plate is positioned.

Harness B:

+ The experienced support and measured pressure show the same trend. In the upper and lower back the pressure and experienced support is higher, whereas in the middle region both drop.

Harness C:

+ The support and measured pressures show the same trend. Higher in the upper and lower region, and being lower in the middle region.

+ High pressure at the hips and shoulders is also experienced as more supportive.

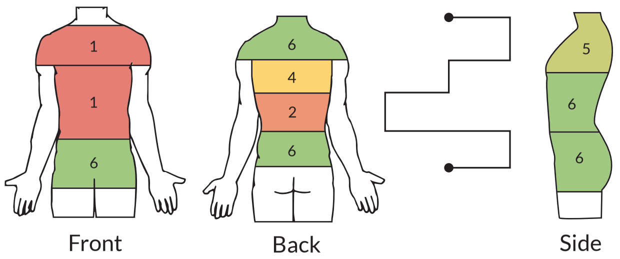
--> Flexibility the reason for an overall pressure increase?

Overall

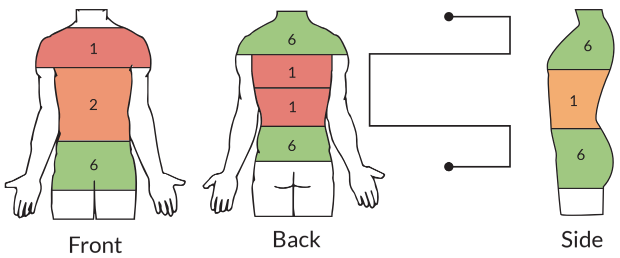
+ Hip compression is lowest for the harness with the widest spreader bar.

+ Harness C has the highest measured pressure in every region, especially the upper back region is high.

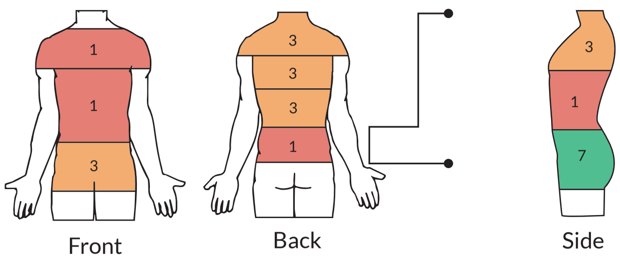
Harness A



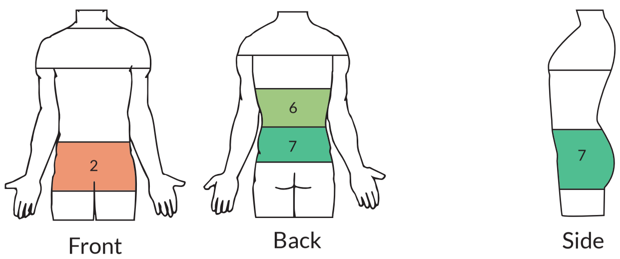
Harness B



Harness C



Harness D

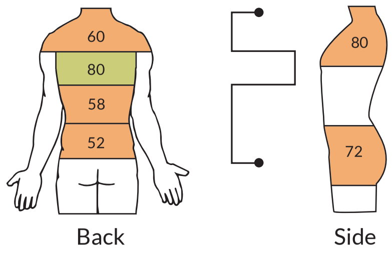


Harness A

Quotes:

(8) I do not really feel the effect of the plate in the back.

--> Measurements do show an increase at the position of the plate

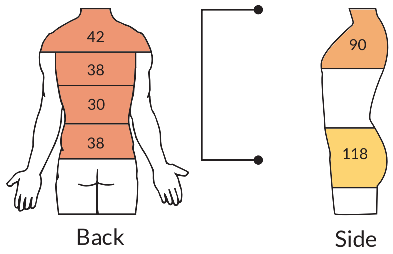


Harness B

Quotes:

(8) The straps are easy to adjust, however they really dig into the body when standing in the wire.

--> Too little padding and stiff material underneath the straps to distribute the pressure. Harness A does have this.



Harness C

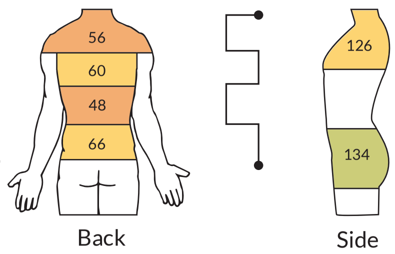
Quotes:

(8) Not so much support in the lower back, but I do prefer some pressure at the hips. This gives me more feedback.

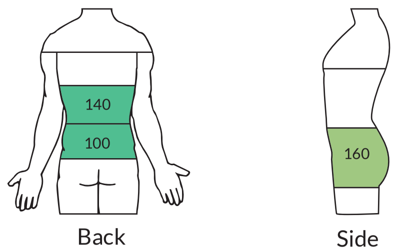
--> Pressure means feedback, pressure is higher for this harness

(8) (Why is there no support in the lower back?) I do not feel any pressure from the harness here.

--> Results show that something different



Harness D



Insights

Harness A:

+ Measured pressure and experienced support do not show the same trend. The participant rates the support highest in the upper and lower region, whereas the pressure is about equal.

+The middle upper region shows a peak where the plate is positioned.

Harness B:

+ Measured pressure along the back can be considered to be about equal. But this is not in line with the experienced support which are rated highest in the upper and lower region.

Harness C:

+ Experienced support of this harness is lowest in the lower back, but in the other regions of the back the same. The measured pressure does not show a drop in the lower back, but is quite constant.

+ High pressure at the hips is experienced as supportive.

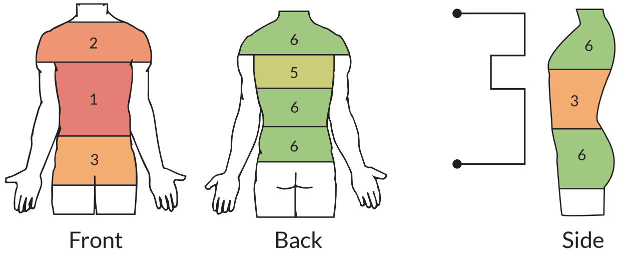
Overall

+ Hip compression is lowest for the harness with the widest spreader bar. The same is true for the pressure at the shoulders.

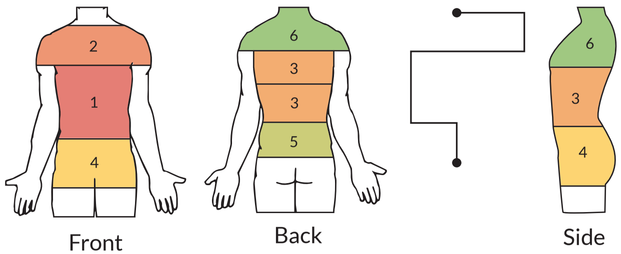
+ Harness C has the highest measured pressure in every region, especially the upper region is high.

+ Support at the shoulders and hips is rated relatively high for all harnesses. However the high pressure at the shoulders for harness C is rated lower than the other harnesses.

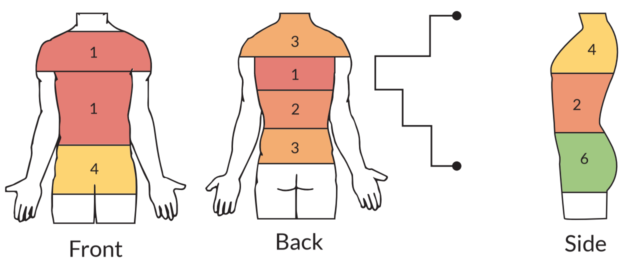
Harness A



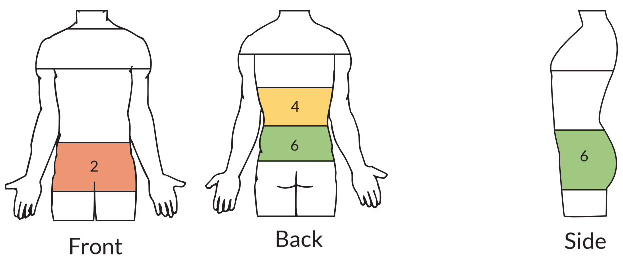
Harness B



Harness C



Harness D



Harness A

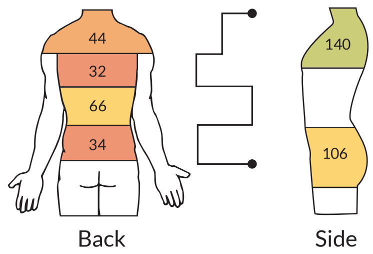
Quotes:

(9) The harness is too much for me. It is to thick which reduces the mobility and has too many supportive elements.

--> Material can be decisive in freedom of movement

(9) I do not feel the plate in the back, it seems to be in the wrong place.

--> Measurements show a partial truth to this



Harness B

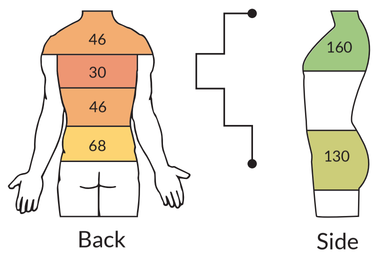
Quotes:

(9) Very uncomfortable leg straps and the spreader bar is tilting when hiking.

--> No coverage of straps is uncomfortable
--> Tilting means that there is no equal distribution of the forces acting on the bar

(9) I do feel quite some support in the upper and lower back.

--> Data show a peak in the lower back



Harness C

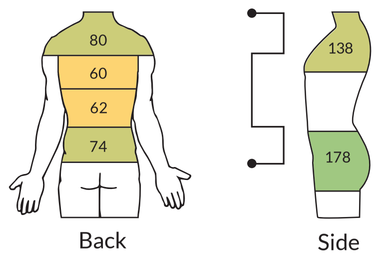
Quotes:

(9) I like the Velcro, but it the downside is that I can not adjust it while sailing and it usually is too loose.

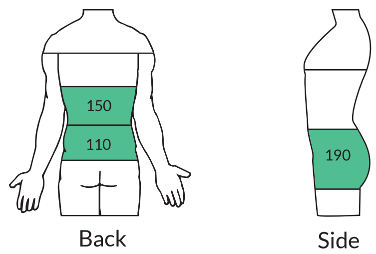
--> Does not allow pre-tensioning

(9) Now there is a big distance between the hook and my body

--> In theory this should reduce the compression force, however this is still relatively high



Harness D



Insights

Harness A:

+ The experienced support is rated relatively high, however the measured pressure is not higher than for other participants. The lower and upper middle region of the back show a drop. For the latter, this is where the plate is positioned.

Harness B:

+ The experienced support is high in the upper and lower region of the back, with a dip in the middle. Measurements show a similar trend, with the highest pressure in the lower back.

+ Shoulder pressure is high and experienced as being supportive.

Harness C:

+ Measurements and experienced support show similar trend in terms of peaks and drops. However, more pressure does not mean more support.

+ High pressure at the hips is experienced as supportive.

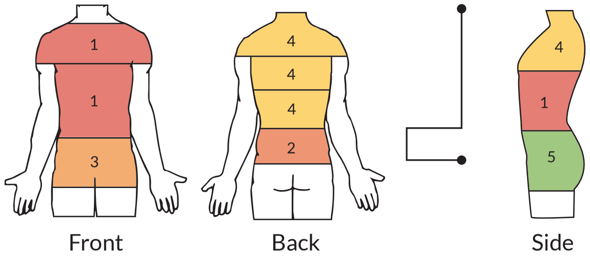
Overall

+ Hip compression is lowest for the harness with the widest spreader bar. The same is true for the pressure at the shoulders. The pressure at each of these points is the highest of all participants.

+ Harness C has the highest measured pressure in most regions which is only experienced as supportive on the hips.

+ Support at the shoulders and hips is rated relatively high for all harnesses. However the high pressure at the shoulders for harness C is rated lower than the other harnesses.

Harness A



Harness A

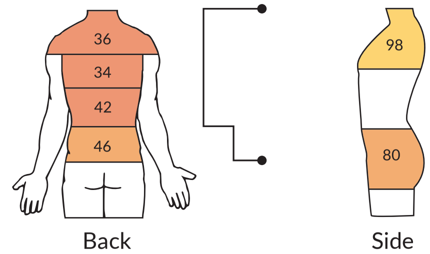
Quotes:

(10) The straps are hard to adjust and I am not a big fan of leg straps, they strangle my legs.

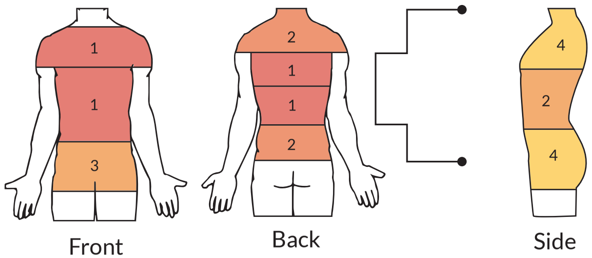
--> Leg straps are not favoured

(10) When bending over and crawling a harness never seems to move with the body, instead the body moves in the harness. I find that annoying, because it limits freedom.

--> Interesting quote, which is true since the back is not flexible and made from one piece



Harness B



Harness B

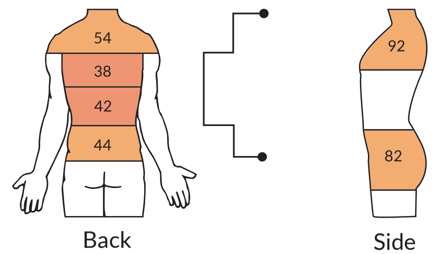
Quotes:

(10) I do not expect this harness to be comfortable, because it is basically a big bag without a shape that fits my body.

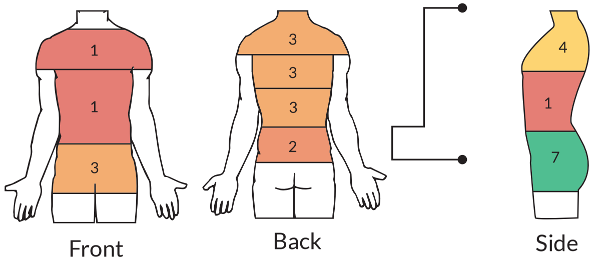
--> Indicating that the pressure should be highest at the upper back and lower back.
--> Visual comfort

(10) My expectation is about right, there is only support in the lower and upper back.

--> Measurements underpins this quote



Harness C

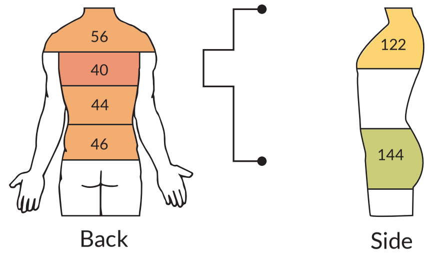


Harness C

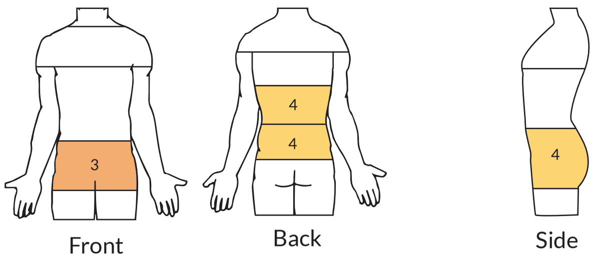
Quotes:

(10) No spreader bar, so the harness will compress on the hips, when standing in the wire the entire day this will start hurting, but it is good for feedback.

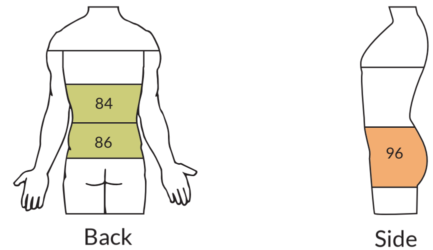
--> Data underpins the higher pressure at the hips



Harness D



Harness D



Insights

Harness A:

+ From the participant's perspective the support is equal along the back with dip at the lower back. The measured data shows the opposite trend, but the distribution can be considered to be even.

+ The insert can not be found back in the measurements or experienced support

Harness B:

+ The participant's expected and experienced outcome were similar. This was also backed by the measurements, which show a drop in the middle region of the back

Harness C:

+ Measurements and experienced support share a similar trend. Lower back support was rated lower, but this was not found back in the data

+ High pressure at the hips is experienced as supportive.

Overall

+ Hip compression is lowest for the harness with the widest spreader bar.

+ Shoulder pressure is the highest for harness C.

+ In gerenal this participant rates harness A as having the best back support. Though, the data shows that every harness has an equally distribution over the back.

+ Support at the shoulders and hips is rated relatively high for all harnesses. However support at the shoulder is rated the same for every harness, while there is a difference in the measurements.

Appendix B: Experiments

B1 - Weighing

Q: What design factors have the largest effect on the weight of a harness?

M: Using a portable weight scale the weight of harness could measured in grams. The weight scale was attached to the hook of the harness and read off until the scale showed a constant value. This process was repeated five times for each harness, in the end calculating the average weight of each harness. The weight of a harness is for many sailors an important factor when choosing a harness, especially in light conditions where weight has a large influence. Comparable to an aeroplane, a sailor wants to be as light as possible and carry unnecessarily heavy things. A few grams can already make a difference. The weight of a harness is determined by the design and materials. Having an overview what features of a harness could influence the weight, might be useful for later design choices.
For the test four harnesses were assessed based on their weight and appearance:

Brand	Model	Type	Discipline	Features
Magic Marine	Viper	Nappy style	Sailing	Simple harness with a Velcro hip adjustment, no spreader bar
Musto	-	Nappy style	Sailing	Adjustable cushion in the lower back and only adjustable using the shoulder strap. No spreader bar.
LA	-	Leg strap style	Sailing	Older model harness without any stiffening parts in the fabric. Has three points to adjust the fit
Magic Marine	Ultimate II	Leg strap style	Sailing	Robust and stiffer harness with four points where the harness can be adjusted. In the back there are 2 adjustable thin cushions. The harness has a spreader bar

[Image of the harnesses]

R: Each harness was weighted using the previously described method, showing that the Magic Marine Viper is clearly the lightest harness of the four and that all harnesses do not exceed the two kilogram weight limit. However, the harnesses were not measured according the to RRS prescribed measuring protocol where the harnesses are wet.

Looking more closely at each harness weight differences can be easily attributed to certain design choices. The Magic Marine Ultimate II is the heaviest harness. Which can be partially traced back to the spreader bar, but also to the fact that the harness has significantly more parts than the other lighter harnesses. Crucial points, where straps attach to the harness, of the harness have been stiffened with semi-flexible material (plastics). Overall the harness has more padding throughout and is stiffer than any of the other harnesses. The Musto harness is closest to the Ultimate II in terms of stiffness. The harness has a stiffer material in the back which is sandwiched between the fabrics. Further features are limited. There is only padding underneath the shoulder straps, an adjustable cushion in the back and the harness has no spreader bar, but a simple hook. Compared to LA harness the Musto is slightly heavier. If material stiffness is a main contributor to the weight of the harness, then the fact that the Musto is heavier than the LA can be attributed to that fact. The LA has a spreader bar, but has a very thin padding and the straps are not covered with a foam or other fabric. The lightest harness, Magic Marine Viper, is specifically designed to light. The design is simple and the material is kept as thin as possible. Again, the flexibility of the material seems to have a large influence on the weight of the harness. The material thickness at the hips of the Magic Marine Ultimate II is roughly four times thicker than for the Magic Marine Viper.

Brand	**Model**	**Weight [grams]**
Magic Marine	Viper	780
Musto	-	950
LA	-	900
Magic Marine	Ultimate II	1820

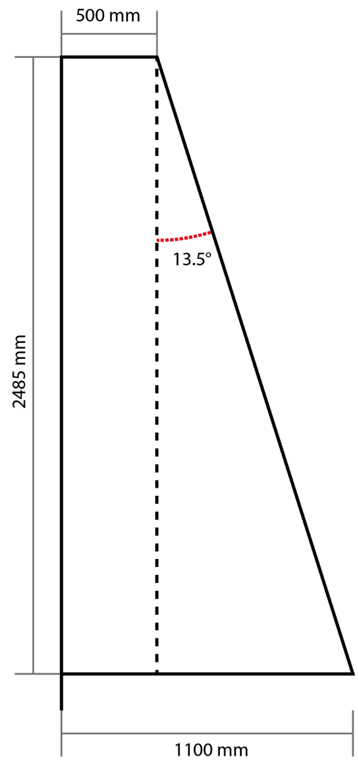
C: Besides the fact that having insight in the exact weight of existing harness, it also provided explorative insights in what factors might be the largest contributors to the increase or decrease in weight of a harness. These insights showed that a spreader bar can have a large influence on the weight, but that material stiffness might be even a bigger contributor. In order to stiffen the fabric or material other materials are added. As a result the harness gets heavier. This might be interpreted as an obvious conclusion, but could not be proved without putting it into numbers.

B2 - Load on the shoulders

Q: What is the load on the shoulders under static conditions when hiking at 90 degrees with a trapeze harness?

The purpose of this small test is to get insight in the magnitude of the force that acts on the shoulders. With this information further decisions can be based upon the data that is gathered from this test.

S: The setup of the test was kept as basic as possible. Using one of the harnesses, a weight scale (load sensor) and a long rope. To measure the load on the shoulder straps, a load sensor was placed between the shoulder strap and its normal attachment point on the hook plate (figure 1). With this setup the load sensor measures the tension in both shoulder straps at once. Thereby neglecting the possible load difference. To simulate a possible trapezing position a small setup was constructed as visualised in figure 2. A rope was connected to a support beam.



R: The test was performed with one test subject (weight: 78 KG and stature: 1850 mm). The load sensor showed a readings between 24 and 28 KG (235 - 275 N). Assuming that the load is evenly distributed on the two straps, the load on each shoulder would be roughly 13 KG.

D: Other than the result of a value, the test also gave an insight for further testing. In this case the harness' shoulder strap was tensioned to level where it was comfortable and gave enough support. The pre-load was not taken into consideration. When comparing different harnesses the pre-load should be the same in order to compare results. The load sensor could serve as a calibration instrument. For further testing the load sensor does not always supply the most accurate data. If a test subject slightly hangs twisted (quite normal) or stands at a relatively large angle from the trapeze attachment point, then the difference can not be measured.
The testing method could be considered quite basic as only one test subject was used. Thereby it was not possible to compare the influence of weight and height in the tension of the straps. Which probably does influence the data, but maybe not significant enough with this setup.

C: The tension on each shoulder belt in this case was about 13 KG. Comparable to carrying a 26 KG bag pack. If a sailor is standing in trapeze for about 3 hours, the exhaustion and irritation seem to be a logic result.

B3 - Load on the wire

Q: How much tension is there in the wire when a sailor is standing in the wire? (And how does this compare to their weight)

M: When a sailor stands in the trapeze this results in a tension in the wire. Among sailors it is believed, psychological effect, that when stretching and pushing their body more into the harness they create a bigger moment. In this case stretching is not moving above the head, but arching the back and pushing the shoulders in the harness. From a physics point of view this is wrong, as a moment is dependent on to factors: The arm and the weight. By increasing one of the two or both this can be accomplished. Stretching has been an point of discussion in the medical team as it also involves creating more strain and pressure on the spine. Initially to check calculations, a simple test setup was created that was able to measure the load on the wire. A test subject measuring 1850 mm and weighing 78 kilograms was asked to step into the Magic Marine Viper harness (0,78 kilograms) to measure the load during normal hiking posture and stretched hiking posture, as described above. The test setup involved a existing trapeze wire in a simulator of a 49er hull, that was equipped with a weight scale between the clamp and top wire. To stay within the range of the weight scale the top line was made out of two lines, so the weight scale would measure half of the tension (figure A2-01). The test subject was asked to hang in each position for 10 seconds so the display could read off and value stabilise. The measurement was carried out five times.

Figure A2-01; The weight scale placed between the clamp and topline.

R: In the table underneath the five measurement results are provided. It shows the average difference in load on the wire between a normal and stretched posture. On average this is 500 grams.

Bodyweight [KG]	Harness weight [KG]	Measured normal posture [KG]	Normal posture [KG]	Stretched posture [KG]	Measured stretched posture [KG]	Difference [KG]
78	0,78	41,25	82,50	41,50	83,00	0,50
78	0,78	40,70	81,40	40,95	81,90	0,50
78	0,78	41,40	82,80	41,90	83,80	1,00
78	0,78	40,30	80,60	40,50	81,00	0,40
78	0,78	41,30	82,60	41,40	82,80	0,20
			82,0		**82,50**	**0,52**

Table A2-01; Overview of the measured results and the averages on the bottom

Figure A2-02; Screenshots of the weight scale during a normal posture (left) and a stretched posture (right)

C: Going back to the research question, for this participant with this harness the load in the wire is roughly 4% bigger than the body. The purpose of this experiment was not to determine an overall factor to calculate the load on the wire based on bodyweight. This would also require to incorporate the hook height and centre of mass in the calculation. Instead, it was to create a general insight in the order of magnitude and later to compare this with calculation outcomes.

1. When looking at the harness how would rate the comfort of this harness?

Not comfortable 1 2 3 4 5 6 7 Very comfortable

2. What features or design elements makes you think that this harness earns this score?
……
……
……………………………………………………………………………………………………

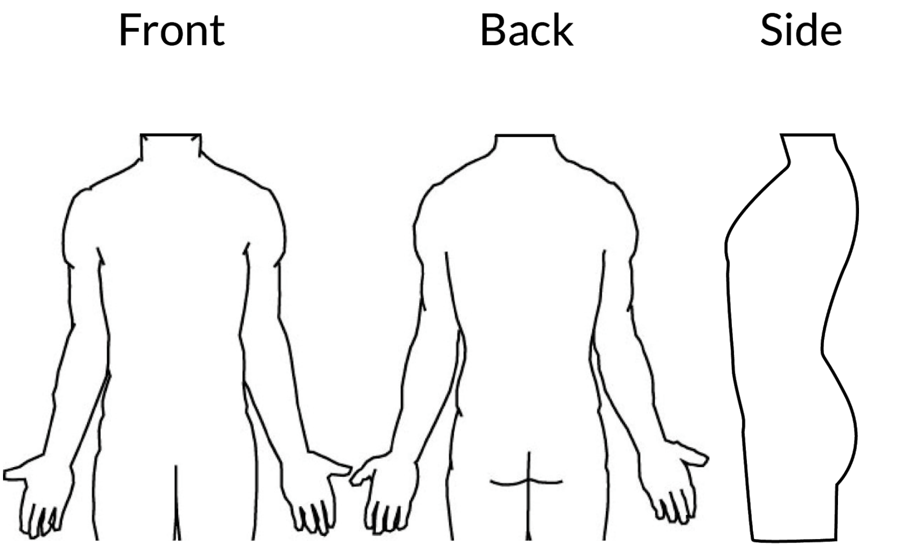
Next, the participants were asked to put on the harness and adjust it to their personal preference using the straps or other adjustment options. Once they were wearing the harness they were asked to fill out the second part of the questionnaire focussing on the experience and fit of the harness.

3. Do the adjustment possibilities are enough to ensure a good fit? Why?
……
……
……………………………………………………………………………………………………

4. How would you rate the extent to which the harness matches the contours of the body?

Not all 1 2 3 4 5 6 7 Perfectly

5. Please identify the places with a cross where the harness exerts pressure on the body.



6.How comfortable would you rate this harness?

Not comfortable 1 2 3 4 5 6 7 Very comfortable

B4 - Standard anthropometric model

For every calculation or experiment where an example model was required, the following measured data served as a basis. In the report the reference 'dummy' is used to indicate that these anthropometric measurements are used.
The measured is a male subject that is comparable to a P50 model in Dined table Dutch adults, dined 2004 male ranging between 20 - 30. Measurements are shown in figure xx.

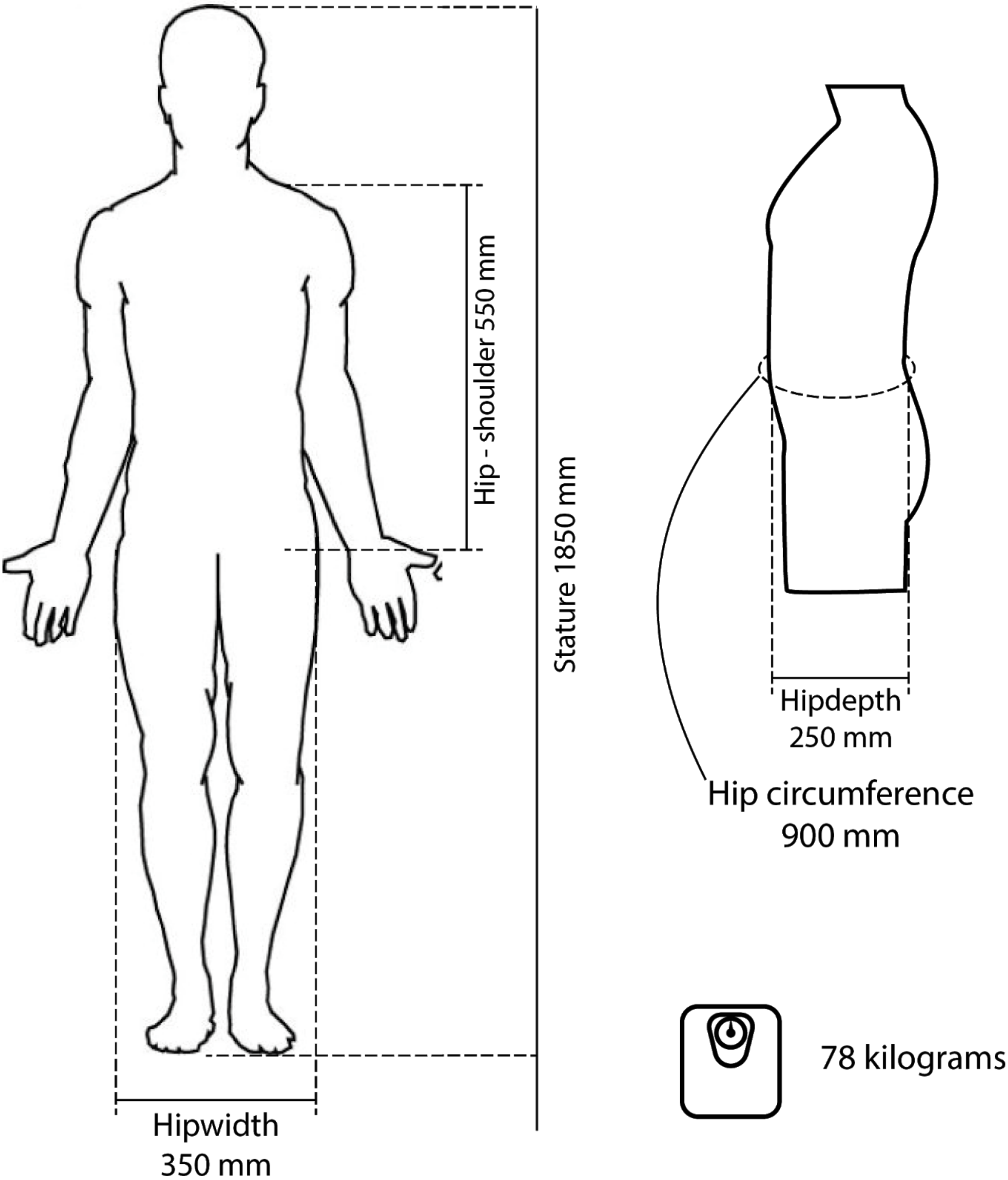


Figure xx; Overview of the measurements of the dummy.

B5 Determining load sensor correction coefficient

I: The load sensor (type: WeiHeng WH-A03) used during most experiments did not provide consistent read outs especially in a horizontal orientation. To make up for the effect of the horizontal orientation an experiment setup was designed to measure the difference and determine a correction factor.

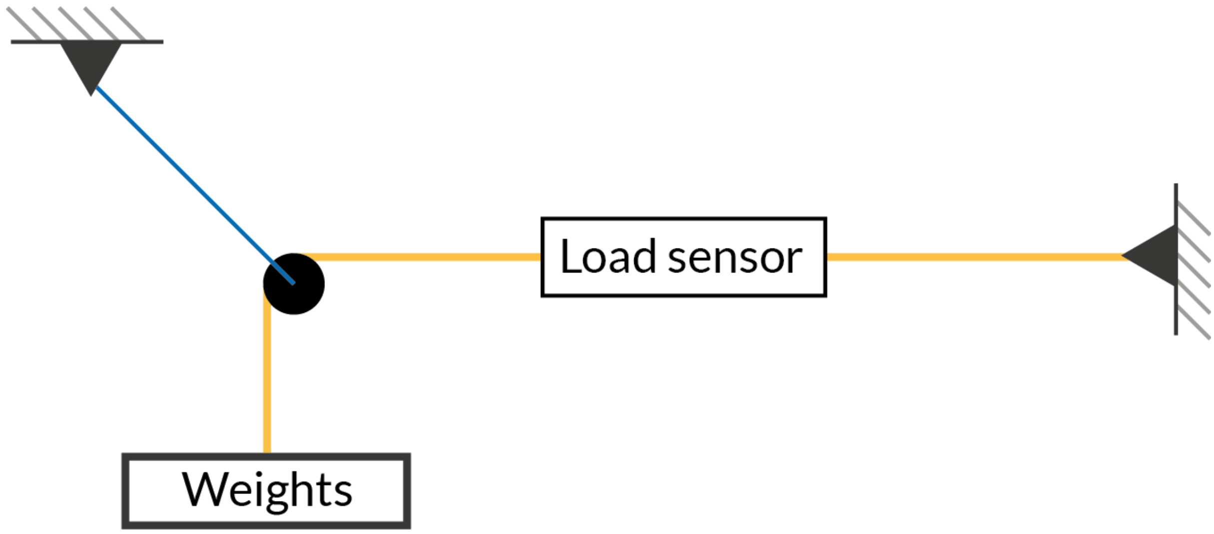


Figure xx; Illustration of the experiment setup

M: A special setup was put in place to ensure that the load sensor was oriented horizontally (see figure xx). On both sides the load sensors had ropes attached to it. One side fixed to a pole and the other side was not fixed, but instead ran through a pulley directing it downward and allowing weights hang down. The load sensor had a weight range from 0 - 50 kilograms with a deviation of 10% and an accuracy of 10 grams. Using weights ranging from 2,5 to 55 kilograms, a complete overview of the load sensor's weight range could be generated. From 0 to 10 kilograms the weight was increased with 2,5 kilograms increments, from 10 to 55 kilograms a step size of 5 kilograms was used. Each weight was measured five times and documented to provide an average overview. Afterwards the test was repeated, but with the load sensor in a vertical orientation. Which is similar to its intended orientation.
With all data measured the average measured value were determined and compared to the actual weights.

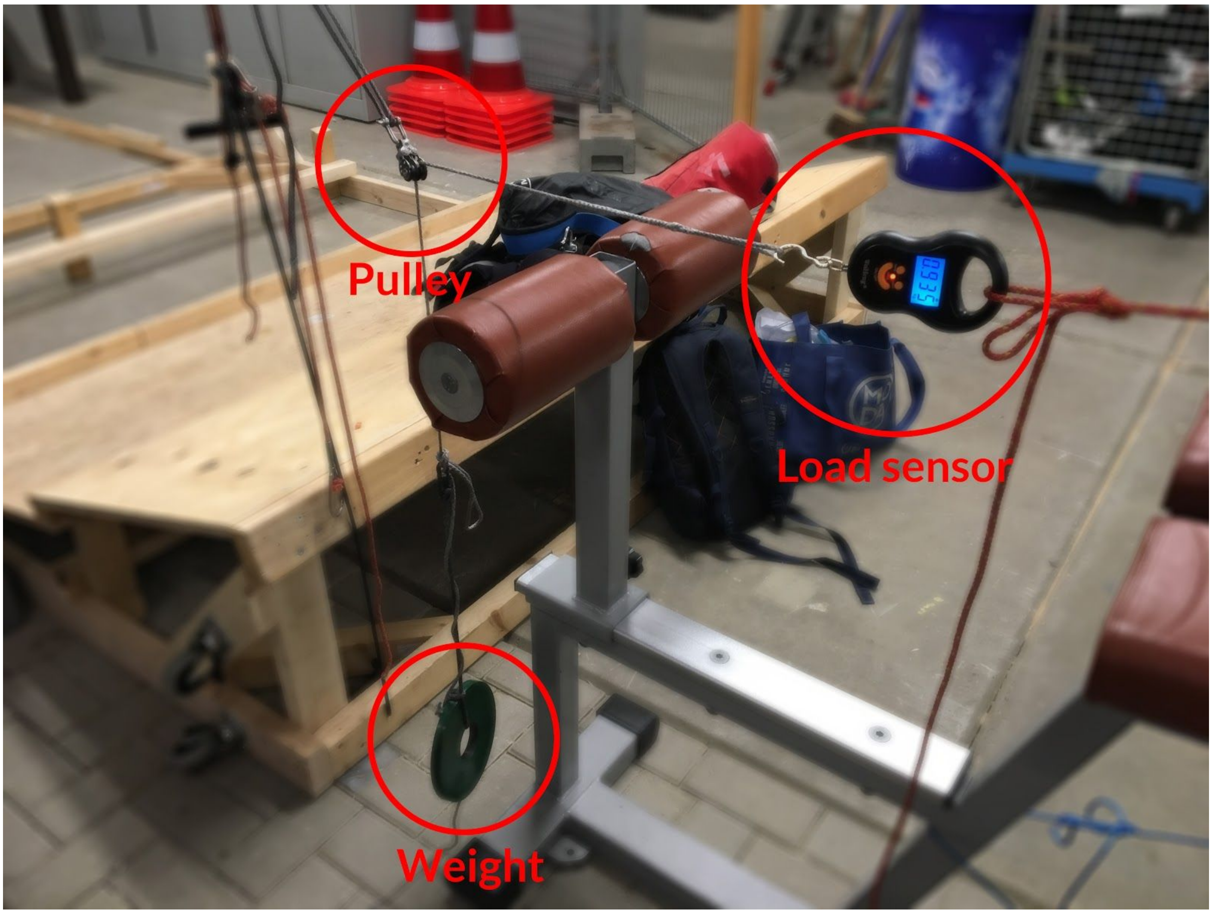


Figure xx; Actual experiment setup to measure horizontal load.

R: In table A6-xx the average measurement results have been provided, complemented with the formulas to correct the measured data to actual weight. Since different weights were used to measure, these were also weighed to measure deviation. Using the functions for linear trend lines of the actual weight, 0-degree angle and 90 degree angle (see figure xx). A correction coefficient (formula) was determined for both straight measurements and measurements at angle.

Weights	Actual weight [KG]	0 degree angle [KG]	*Converted 0 to 0 [KG]*	Difference from actual weight [KG]	*90 degree angle [KG]*	Converted 90 to 0 [KG]	Difference from actual weight [KG]
2,5	2,5				*2,24*	2,26	-0,24
5	4,98	5,12	*4,89*	-0,09	*4,75*	5,10	0,12
7,5	7,46	7,63	*7,50*	0,04	*7,20*	7,88	0,42
10	9,92	10,38	*10,34*	0,42	*9,40*	10,38	0,46
15	14,9	15,40	*15,55*	0,65	*13,90*	15,50	0,60

20	19,84	18,72	*19,01*	-0,83	*17,06*	19,10	-0,74
25	24,82	23,73	*24,21*	-0,61	*21,38*	24,01	-0,81
30	29,76	28,84	*29,53*	-0,23	*25,61*	28,81	-0,95
35	34,74	34,14	*35,04*	0,30	*30,83*	34,76	0,02
40	39,68	38,65	*39,72*	0,04	*34,87*	39,35	-0,33
45	44,66	43,54	*44,81*	0,15	*40,08*	45,28	0,62
50	49,6	48,50	*49,97*	0,37	*44,10*	49,85	0,25
55	54,74	52,78	*54,41*	-0,33	*48,46*	54,81	0,07
Formula 90 naar 0 =((0,993*measured)+4,35*10^-3)/((0,873*measured)+0,235)* measured							
Formula 0 graden = ((0,993*measured)+4,35*10^-3)/((0,955*measured)+0,425)*m easured							

Table A6-xx; Overview of the measured data and converted data.

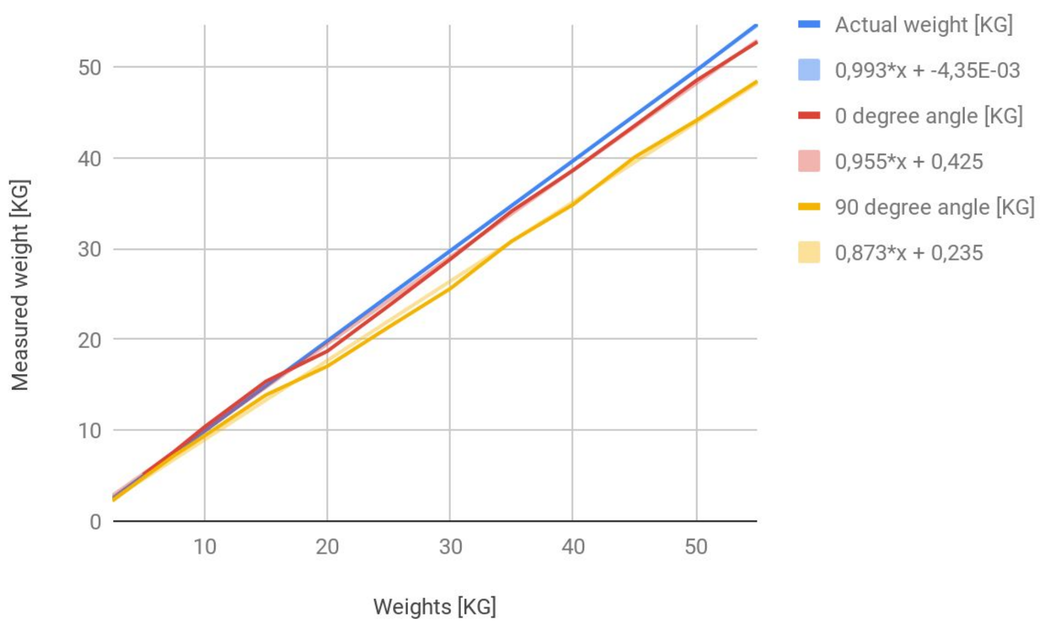


Figure xx; Graph weight versus measured data in kilograms.

C: The correction formula helped to normalise the measured data. However, it still resulted in deviating values from the actual weights. The inconsistency of the load sensor is largely the reason for this deviation, since there was no consist trend of always measure too little or too much. How and for what purposes the load sensor was used before the experiments is unknown.
In case of the 90 degree measurements, the corrected value are significantly closer to the real values. In further experiments the correction formula will be used to correct measured values when the load sensor is horizontally oriented.

B6 Determining stabiliser’s conversion formula

I: To measure the pressure between the human body and the harness a pressure cell was used (type: Chattanooga Stabilizer Pressure Bio-feedback, accuracy 3 mmHg), as shown in figure xx. The pressure cell is connected to a pressure gauge measuring pressure in mmHG, a common pressure unit. Though, this does not provide the desired information and does not allow data to be compared to the model’s output. Therefore a formula that converts mmHG to Kilograms has to be formulated based on pressure gauge outputs.

Figure xx; Chattanooga stabiliser pressure cell.

M: In order to determine a conversion formula for the pressure cell an experiment setup was designed to measure the pressure in the cell when loads where put on to the cell. To recreate the ‘sandwich’ situation when the pressure cell is placed between the body and harness, the pressure cell was laid down on a flat surface. By laying disc weights, that covered the entire surface of the pressure cell, ranging from 0,5 to 20 kilograms with a step size ranging from 0,5 to 2,5 kilograms the cell was loaded. The cell folded over its long side as this proved to provide more consistent read outs and limited the required surface area when it was put between the body and harness. Every weight was put on the cell five times to provide an average read out. Next, the data was put into a graph to find the function of the matching linear trendline.

R: Table A7-xx provides an overview of the measured data. Similar to the conversion formula for the load sensor, the actual weight of the weights slightly deviated. This deviated weights were used when determining the conversion formula.

Starting value	***2***	***mmHG***	
Weights [KG]	Actual weight [KG]	Average pressure [mmHG]	Converted pressure to load [KG]
0	0	2,00	-0,52
0,5	0,50	6,10	0,15
1	1,00	11,20	0,99
1,5	1,49	14,18	1,47
2,5	2,50	21,82	2,73
5	4,98	38,38	5,44
7,5	7,46	52,23	7,71
10	9,92	68,40	10,37
15	14,91	97,05	15,07
17,5	17,47	110,55	17,28
20	19,84	123,25	19,36
Formula from mmHG to KG = 0,164*measured-0,850			

Table A7-xx; Overview of the average measured data used to determine the conversion formula

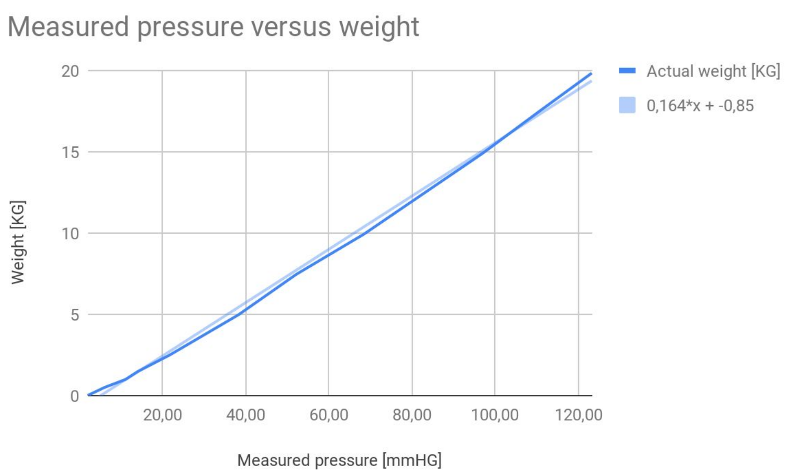


Figure xx; The graph with the measured pressure versus the weights load on the cell.

C: With the conversion formula a the readouts from the pressure gauge can be converted into kilograms. Allowing to compare the data from the test to the output of the models. The pressure is not designed for measurements, only to give the user insight on their posture when doing physiotherapeutic exercises. The readouts that the gauge provide, might therefore not be as accurate as desired.

B7 Shoulder coefficient - (1/2)

I:In the situation where a sailor is wearing a trapeze harness and hangs at a 90 degree angle the shoulder strap is under load. The force in the strap is not evenly distributed due to friction of the strap on the shoulder and distribution of the load caused by the mass of the body (figure [xx]).

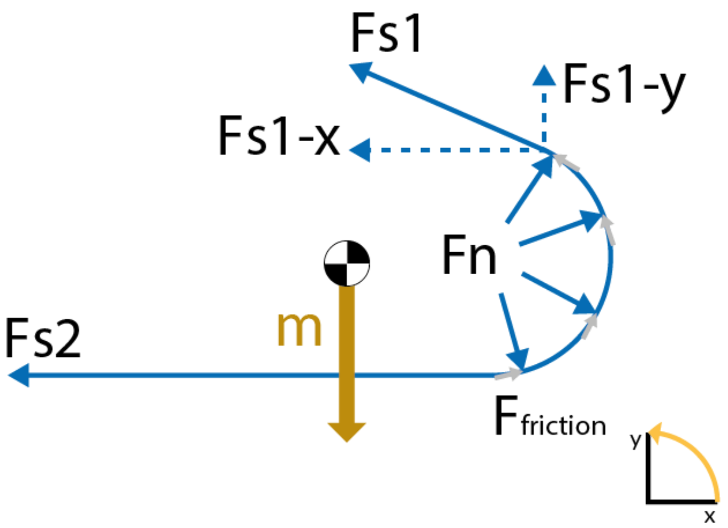


Figure [xx]; The force distribution around the shoulder as a result of the strap wrapping around.

Without determining the friction coefficient between the shoulder and the harness, the magnitude of Fs2 can not be determined. Unfortunately, a friction coefficient, normally known as μ, can not be determined by one experiment as it is dependent on multiple factors such as surface area, surface materials and weight. Which are different for every sailor and every harness, meaning that every situation would have to determined individually. In order to be able to predict and approximate the force on the shoulders a coefficient has to be determined that expresses the ratio between the forces of the shoulder strap before and after it wraps around the shoulder. By simplifying the situation and by analysing the system statically, a coefficient can be obtained. The shoulder strap in essence makes a 180 degree turn by wrapping around a circular shape, the shoulder. If the load before and after passing around the circular object can be measured or calculated a coefficient between the two loads can be calculated. Eventually ending up with an average coefficient that is an estimation of the real situation.

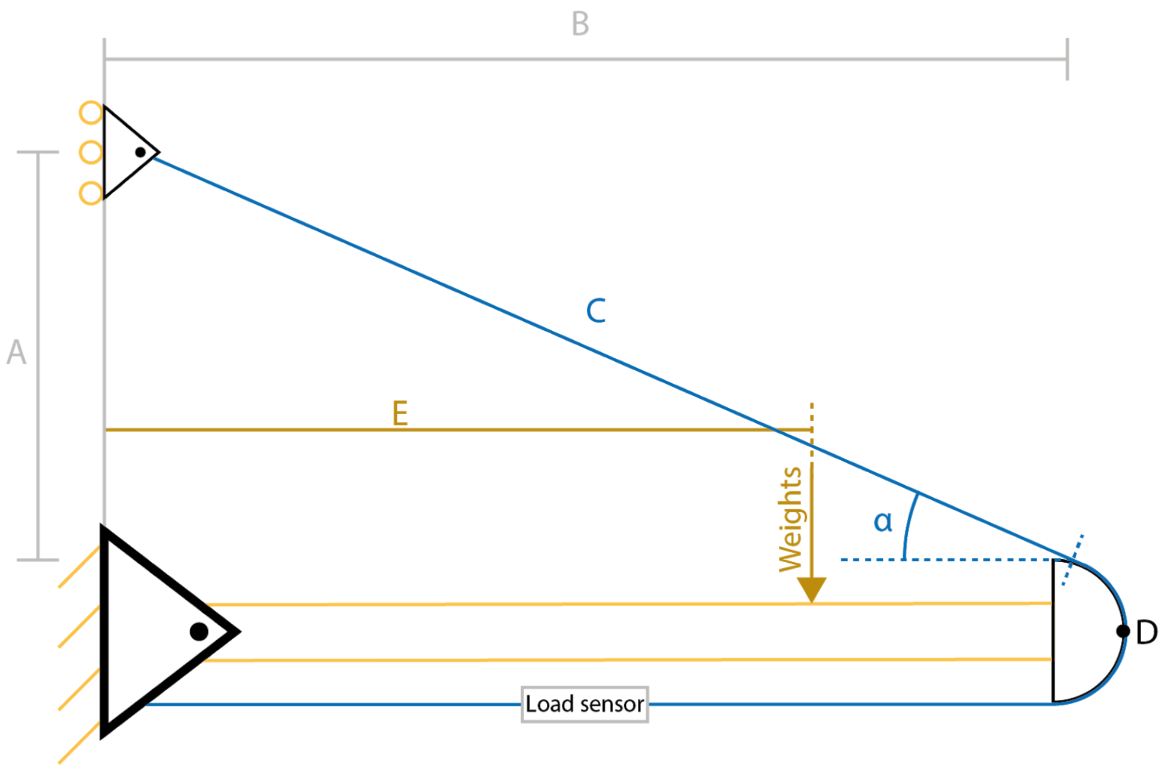


Figure [xx]; A simplified overview of the experiment setup.

M: In figure [xx] an overview of the simplified experiment setup is given. The sailor and harness have been replaced by a beam and rope. A Dyneema rope is attached to a pole at a variable height, enabling to adjust angle α. The rope is used to suspend a beam in the air that is attached to a pivot point on the pole. Starting at the pole, the rope runs down to the other end of the beam and is guided over a round shape on the top of a beam. From the rope is guided underneath the beam to an attachment point on the bottom. The piece of rope that runs between the rounded top and the attachment point on the beam is separated to place a load sensor in the created opening. The load sensor's centre of mass (COM) and the beam's COM are placed directly above each other.

Procedure

The setup is altered by adjusting the lengths of A and C, which in turn changes the angle α and the force in Fs1. By measuring the weight at the end of the pole at D, the load on the rope in C can be calculated using α. The values for A ranged from 30 to 170mm with a 40mm step size. The round shape was a PVC tube cut in half. For each value of A weight was added to the system ranging from 0 to 7,5 kilograms. The weights were positioned at point Resulting in five different loads for each value of A.

Parameters

Before conducting the experiment the length of the beam (B), the weight of the beam at D is measured using the portable scale. This allows to measure the total setup in one go. With these parameters the load (Fs1) could be calculated. Table 1 provides an overview of the parameters known upfront. The load on Fs1 is determined by α. If α gets closer to zero, Fs1 will become infinite.

R: Figure A4-01 provides an overview of the experiment setup used to collect the data as is documented in table 1. Using these results the load in Fs1 could be calculated for every value of A and the added weight. In table 2 these values have been provided together with the measured data of Fs2.

A [mm]	0 [Kg]	1,25 [Kg]	2,5 [Kg]	5 [Kg]	7,5 [Kg]	alpha	B [mm]	E [mm]	Mass system at D [KG]
30	18,45	25,23	27,93	41,57	51,03	1,64	1050	770	0,62
50	5,16	8,76	15,11	25,54	34,75	2,73	1050	770	0,62
90	3,45	6,62	11,01	17,81	27,52	4,9	1050	770	0,62
130	2,65	6,01	10,72	14,85	19,08	7,06	1050	770	0,62
170	2,31	4,62	7,42	11,1	15,55	9,2	1050	770	0,62

Table 1; Data documented during the experiment.

As expected the load in the system will increase if A is kept very small or when weight is added. Especially if the weight is high, the load on the system reach high figures. However, a load of 214,29 kilograms in Fs1 seems highly unlikely to have been the case here, as this would require an ideal system without stretching or bending of materials. An important remark, as this applies to every value of Fs1. The fact that Fs1 is calculated leaves out the dynamic influences to which the system is subjected.
The coefficients between Fs1 and Fs2, provided in table 3, show that the ratio between the load on the two wires is dependent on the weight and length of A (or the value for alpha). Which is similar to what was expected upfront. If the weight and length of A increase the coefficient between the two loads was expected to get closer to 1.

Additional weights	Fs2-30 [KG]	Fs1-30 [KG]	Fs2-50 [KG]	Fs1-50 [KG]	Fs2-90 [KG]	Fs1-90 [KG]	Fs2-130 [KG]	Fs1-130 [KG]	Fs2-170 [KG]	Fs1-170 [KG]
0	18,45	21,71	5,16	13,03	3,45	7,26	2,65	5,05	2,31	3,88
1,25	25,23	53,81	8,76	32,31	6,62	17,99	6,01	12,51	4,62	9,61
2,5	27,93	85,9	15,11	51,58	11,01	28,73	10,72	19,97	7,42	15,35
5	41,57	150,09	25,54	90,12	17,81	50,19	14,85	34,89	11,1	26,82
7,5	51,03	214,29	34,75	128,67	27,52	71,66	19,08	49,81	15,55	38,29

Table 2; Overview of Fs1 and measuring results for Fs2 both in kilograms.

Figure A4-01; Experiment setup with the load sensor measuring Fs2

In table 3 Fs1 and Fs2 have been put side by side. For small values of α Fs1 is significantly bigger than Fs2. Fs1 was calculated assuming a perfect situation, in practice this is not possible as is proved by the large difference in measured load. By dividing Fs1 by Fs2, the ratio (friction coefficient) is calculated. Averaging 0,54, just under half of the load is converted into a friction force.

C: Since Fs1 was calculated and not measured similar to Fs2, there is a large difference when α gets smaller. When α is smaller Fs1 will quickly go up and eventually become infinite. In practice this situation can never occur, as the materials will have failed long before that. Unfortunately, in most cases the distance between hook and body (A) would be in a range from 50 to 100 mm. Therefore, to get a more accurate result the experiment would have to be redone.

B8 Shoulder coefficient - (2/2)

I: Simplifying the situation proved to generate insight in the situation at hand. However, important determinants for a friction coefficient could not be replicated. For instance, surface type and the force in Fs1 was calculated instead of measured. Leaving out any errors that might have influenced the system and comparing data from an ideal situation with data that might have measurement errors. In order to have that has the same measurement errors, both Fs1 and Fs2 were measured using a real body.

M: The measurements were conducted using two types of harnesses that were both modified enabling measurements of the force in the shoulder straps before and after wrapping around the shoulder. One harness was a seat windsurfing harness and the other a regular trapeze harness as showed in figure [xx]. To measure the load in the shoulders straps, a replacement shoulder strap system was constructed out straps with the load sensor in between. The shoulder strap construction was attached to the hook wrapping around the shoulders and groin to be attached to the hook again. Figure [xx] provides an overview how these straps were attached to the harnesses.

Windsurf harness **Regular harness**

Figure [xx]; Harnesses used for the experiment with the constructed shoulder straps, left the windsurf harness and right the regular harness.

Procedure
Anthropometric measurements were the first step of the experiment. In this case, body weight, stature and shoulder to hip length were measured and documented. Secondly, the participant was asked to wear the first trapeze harness and was helped to adjust the shoulder strap to fit. The preload of the shoulder strap was documented. Next the participant was asked to attach the trapeze line to the harness and start hiking for at least one minute. Meanwhile, the distance between hook and body was measured and the load sensor display was filmed to later document the load every three to four seconds (figure xx). Once a minute had passed, the participant could stop hiking and the system could be reversed so the other

part of the strap was measured. Using the documented preload, the strap was adjusted to match this figure and the process was repeated. Hereafter, the shoulder strap construction was attached to the next harness and the same process was conducted again in the same way as for the first harness.

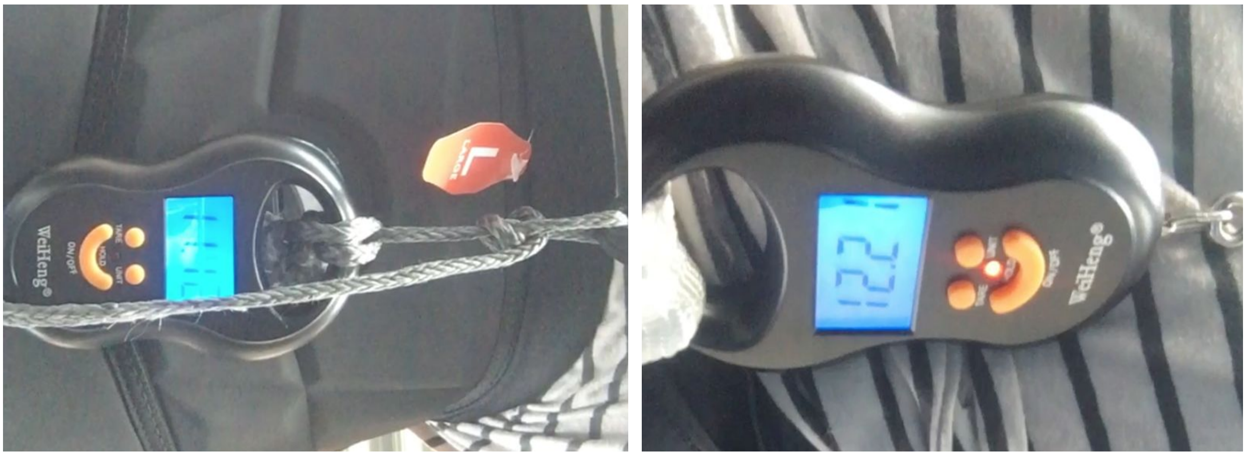


Figure [xx]; Printscreen of load sensor read offs during the experiment.

Figure [xx]; Experiment setup with constructed shoulder straps on the windsurf harness.

R: Figure [xx] provides an overview of the experiment setup used to collect the data as is documented in table [xx]. The participant used for the measurements had a body weight of

80 kilograms and a stature of 1850mm. The results show a large difference in load in the front part of the strap, a difference averaging +/- 17 kilograms. However, this same differences can not be identified in the part that has passed around the shoulder, which are not greater than 1 kilogram. The difference in the front part could be explained by the design of the harness. The windsurfing harness support reaches higher on the back than the regular harness. As a result the weight of the upper body is supported more by the harness and thus the front part of the strap will have a lower load. Even so, the load in the back part of the shoulder is about same, implying that a larger force will significantly influence the coefficient between the front and back part.

	Regular harness			Windsurfing harness		
Measurement	Front shoulder [KG]	Back shoulder [KG]	Total point load shoulder [N]	Front shoulder [KG]	Back shoulder [KG]	Total point load shoulder [N]
1	39,25	12,89	517,81	20,81	11,22	317,56
2	39,35	13,32	523,02	19,93	11,55	312,02
3	37,81	10,88	483,73	21,80	11,03	325,57
4	37,52	11,40	485,94	24,51	10,83	350,63
5	38,89	12,05	505,98	20,69	11,04	314,60
6	39,46	12,75	518,53	19,43	12,19	313,32
7	39,36	13,01	520,08	20,19	11,42	313,34
8	38,34	12,21	502,06	23,56	11,83	350,96
9	40,38	12,54	525,64	23,13	11,69	345,30
10	39,26	13,26	521,53	22,25	12,66	346,05
11	39,97	12,79	524,00	22,17	10,10	320,13
12	39,07	12,58	512,97	22,12	12,44	342,59
13	38,64	13,43	517,02	22,05	10,60	323,84
14	36,61	14,64	508,65	19,43	11,55	307,04
15	37,24	13,16	500,41	20,60	12,53	328,32
Average	38,74	12,73	511,16	21,51	11,51	327,42

Table [xx]; Measured data for both the regular and windsurfing harness.

For the regular harness the coefficient between the two loads are averaging 0,325 and for the windsurfing harness this is 0,535. Based on the fact that the regular harness is smaller and reaching less far on the back, it is acceptable to favour 0,325 as being a relevant coefficient. When comparing this coefficient to the previous experiment is almost similar to the average coefficient found for the measurements that were weighted down with 7,5 kilograms.

D: Since there was only load sensor the experiment had to be conducted twice, once for the front and once for the back. Between those measurements the initial conditions might have changed slightly, influencing the measurements. Also the positioning of the load sensor was not consistent. In one case it was just above the buttocks, whereas for the other situation it positioned in the upper middle region of the back. Last determinant was the design of the harnesses. The windsurfing harness is far stiffer than the regular sailing harness, which might have resulted in more support around the lower back region taking away some of the load from the shoulder straps.

C: In general it is possible to conclude that this experiment proved to generate interesting insights in the load in the shoulder strap. Especially the fact that there indeed is a significant difference between the loads before and after it has wrapped around the shoulder. This difference could possibly be attributed to the design of the harness in terms of support in the back. However the main influencer could be identified as being friction between the strap and the body. A friction coefficient is dependent on factors such as the weight and surface materials of an object and therefore is probably different for every sailor and harness. In further calculations the calculated coefficient between the loads in the front and back part of the strap will be used a friction coefficient to predict the total point load on the shoulder.

Appendix C: Models with Maple output

C1: Momentum on the boat based on trapeze wire length

Introduction

In races the mix of boat speed and tactics are the recipe for success. Keeping the boat speed high requires experience and stamina to keep the boat flat on the water. Figure [xx] provides an overview of the forces that act on the boat while sailing upwind. The force of the wind, Fwind, that gets caught by the sail pushes the boat sideways, but also generates a moment that tries to capsize the boat. Fwater is the force of the water pushing against the centreboard in the middle preventing the boat from going sideways through, but does not have enough weight to prevent the boat from excessively heeling. Once the boat starts to heel the centreboard will have less surface area to counter the pushing force of the sail and the boat will start to drift more, with that comes the loss of forward boat speed. By standing in the trapeze the sailor can apply a counter moment to the mast by using their body weight and reduce the tilting of the boat. The amount of countermoment is determined by the outward position of the sailor. The further away the centre of mass of the sailor's body gets from the pivot point of the boat, the more counter moment is generated. By bending the knees and altering the trapeze line length the sailor is able to determine the moment that is generated, continuously dosing to find the right balance.

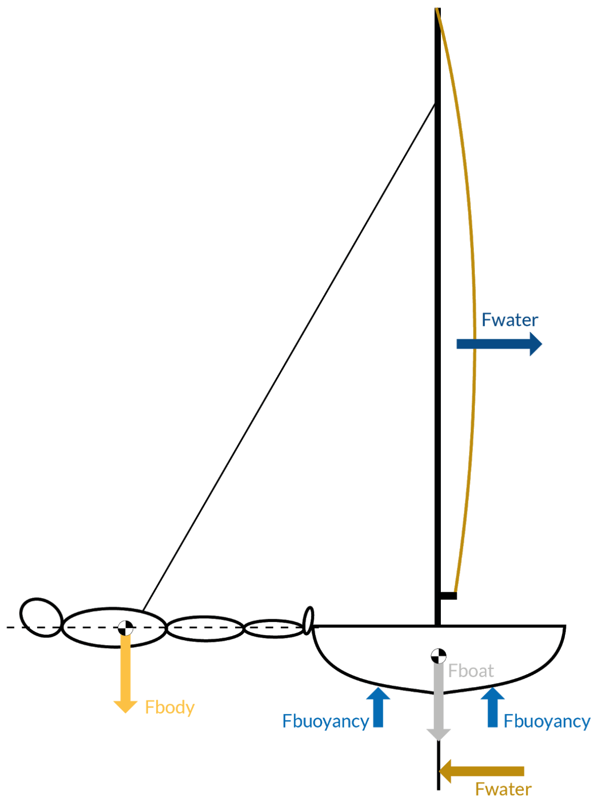


Figure xx; Overview of the forces working on the boat while sailing upwind.

Defining the model

The magnitude of the righting moment is determined by multiple factors. For example, the length and weight of the sailor. Assuming that the body proportions are similar to average people, the longer a sailor the further out the centre of mass and thus the applied moment on the mast. Furthermore there are the dimensions of the boat that influence the magnitude of the force the height of the trapeze line on the mast and width of the boat. Last there is the distance between the attachment point of the trapeze and the side of the boat, in general the trapeze hook on the harness is not directly above the centre of mass of a sailor.

In order to create a model that can determine the applied moment on the mast at any given position outside the boat and attached to the trapeze line, the system has to be simplified and scaled down (figure xx). By zooming in, a better overview can be produced, identifying relevant forces that work on the body and boat:

- The first simplification is the human body. Instead of analysing every body part, the body is simplified to a beam that is attached to the trapeze line at point B and is connected to the pivot point at A.
- The trapeze line 'L' has variable length and is attached to the mast at point C.
- The distance between point C and A is expressed in 'htrans'.
- The mast is considered to be infinitely stiff, angles τ and δ are therefore fixed
- Angles β, θ and ε in the triangle formed by connecting points A, B and C are determined L, h-trans and r2. r2 is the distance between the hook on the trapeze harness and the sailor's feet.
- α is the angle between the sailor and the perpendicular line from the mast through point A.
- Distance between the centre of mass and point A is expressed in r1.
- There is no space between the hook on the trapeze harness and the body of the sailor.
- r3 is the distance between the centre line of the body and the hook of the trapeze harness.
- r4 is the arm from the pivot point of the boat D to the the attachment of the trapeze line at point A.
- The system is considered to be static.

In order to determine the force that is generated on the mast, the force that gets exerted on the wire must be determined. The forces, Fs, Fwire and Ff, acting on point A must in balance. Creating the following equations:

$$\Sigma Fx = cos(\alpha) \cdot Ff - cos(\theta) \cdot Fwire \ = \ 0$$
$$\Sigma Fx = sin(\alpha \cdot Ff + sin(\theta) \cdot Fwire - Fs \ = \ 0$$
$$\Sigma M(A) = sin(\theta) \cdot Fwire \cdot r2 + cos(\theta) \cdot Fwire \cdot r3 - (\frac{Fs \cdot r1}{cos(\alpha)})$$

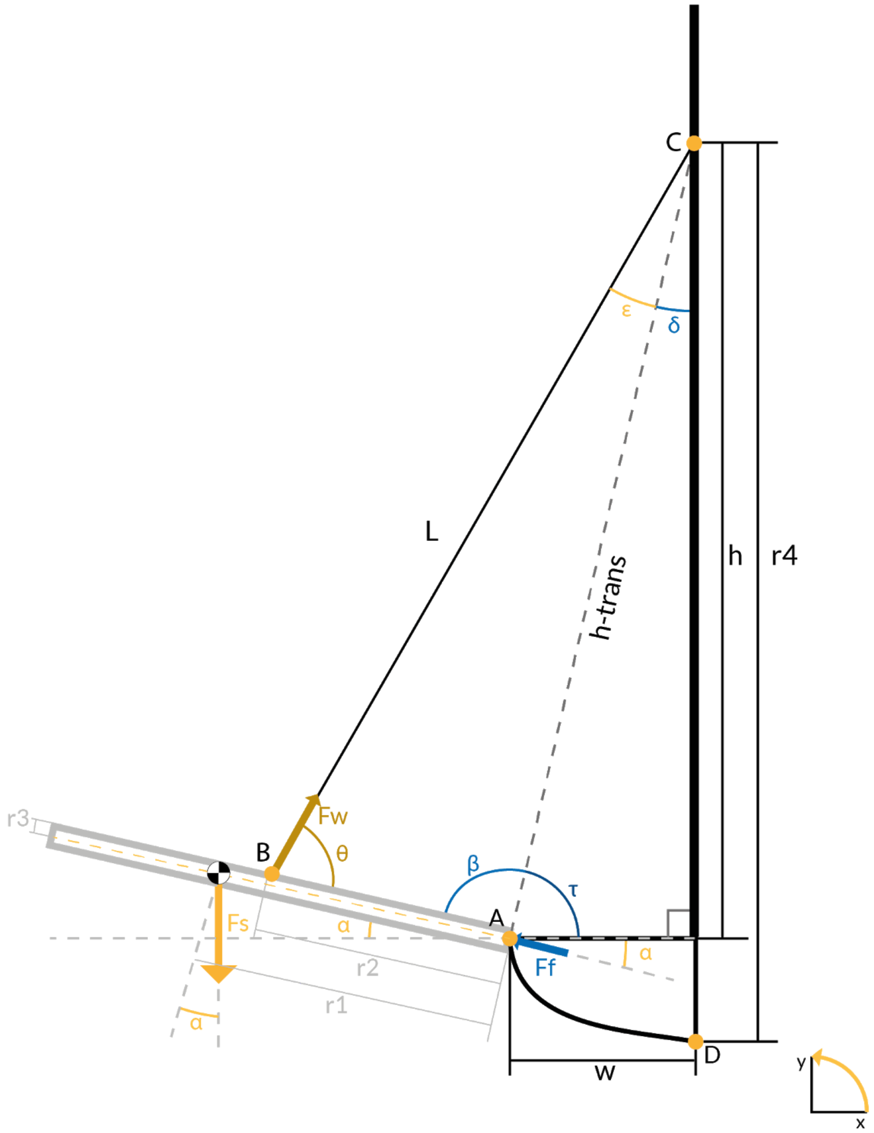


Figure xx; The system simplified with all relevant parameters and forces schematically presented.

Centre of mass

The centre of mass (COM) of a person is dependant on multiple factors such as body part volume, density and length (Clauser,, McConville and Young, 1969). Based on the stature and weight of person the average weight, length and position of the centre of mass of each individual body part can be determined. By creating a moment equation based on posture and using all these known parameters the COM can be calculated. In terms of posture, the situation is simplified by considering that the sailor is standing straight up with arms alongside the body and feet flat on the ground. To determine the r1 for the model described in 3.2.1, three conditions must determined. The weight, stature and gender. In this case a male sailor with a weight of the is 80 kilograms and a stature of 1850 millimetres. This results in a position of the COM at 1200 millimetres measured from the feet up.

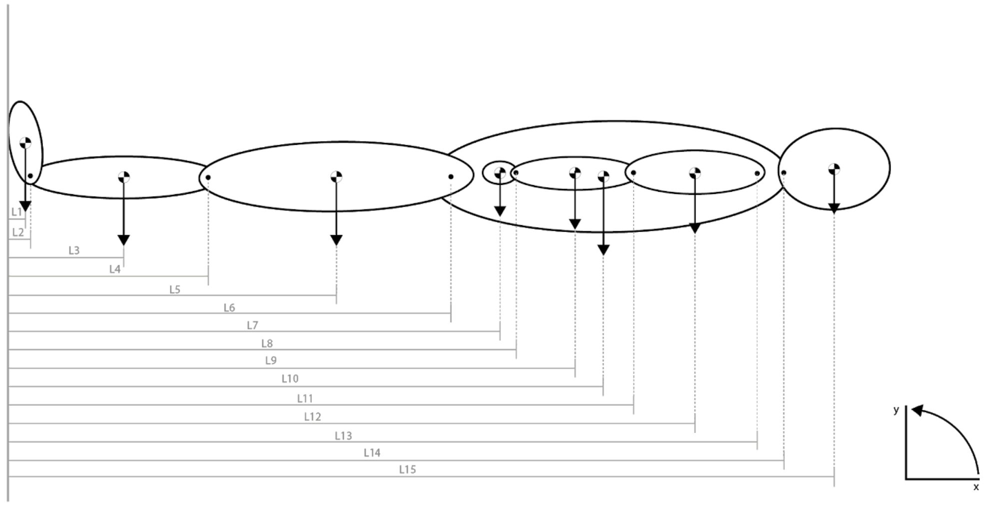


Figure xx; An illustration of the position of the body segments to determine the COM.

Righting moment

Using the known parameters of the 49er to determine the position of points A and C, the position of point B has to be determined. Using the same male person of 80 kilograms with a stature of 1850 millimetres, the r1 and r3 must be measured. By wearing a Magic Marine Ultimate II trapeze harness the perpendicular distance between the hook and the ground was measured. For this male person it was 1030 millimetres. The depth of the body at hook height was 180 millimetres. The last parameter that remains unknown is L, the trapeze line length. This parameter determines the magnitude of the angles β, θ and ε. Angle α can never be bigger than smaller than 0 degrees, as this would suggest that the sailor's body almost touching the water. Using L as a variable with a range between 5.00 and 7.00 (5000 and 7000 millimetres), the following graph is produced (figure xx). The yellow line represents α, if α =0, L=6.19 (6190 millimetres). At L = 6.19, Fwire = 998 Newton and the torque at point D = 2673 N/m. At his point the force on the feet is 442 Newton. If gets smaller the torque at point D gets smaller and thus less righting force.

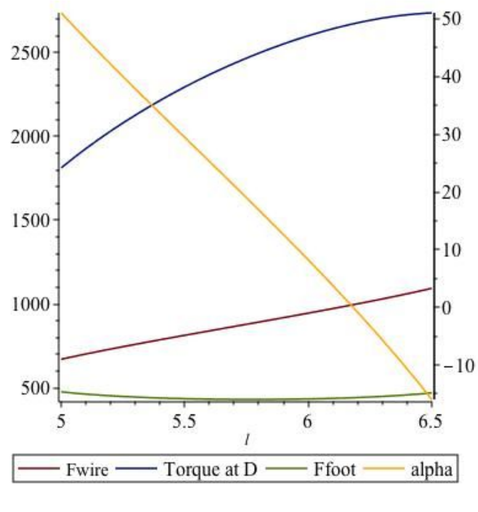


Figure xx; A graph showing the force on the wire (Fwire), torque at point D, force exerted by the foot and the angle α in the domain with L = 5 to L = 7.

Stretching out

In many cases it might occur that a crew member, of either the 470 or 49er, puts a hand behind the head to stretch out and move the centre of mass further out. Reaching the arm behind the head increases the pressure between the shoulder belt and the body, which might have disadvantageous consequences for on the long run. When a sailor moves a part of the body the COM slightly moves. If one arm gets put above the head, the position of the centre of mass should move upward and increase the torque at point D.

In order to identify this increase the first step would be find out if the centre of mass does move up. The moment equation for the COM has to be altered and modelled to an ideal situation where the arm is fully stretched above the head. Using the same male 80 kilogram sailor with a stature of 1850 millimetres, the COM moves from 1200 millimetres to 1246 millimetres. Since the other parameters remain the same the torque at point D would increase with a factor of x $3\frac{5}{6}$. Of course this is an ideal situation, but in sports at an Olympic level ~4% is not earned on a daily basis.

Maple output

C2: Force on the wire

Parameters and model

The sailor is hiking at an angle of 90 degrees relative to the mast. As a result the force in the wire is dependent the hook height, COM, body weight of the sailor and type of boat. In the model the vertical force on the feet and mass of the harness were neglected. The hook height is not a set parameter and dependents on the design of the harness and the stature of the sailor. For the COM weight and stature are the influencing parameters. Last, the type of boat. In all calculations the dimension of a 49er have been used, to be specific, these dimension were the width of the boat and perpendicular distance between hook and trapeze attachment. Once Fwire was determined the force could be decomposed over the two straps that support the body similar to the deconstructed version of the harness. With the equation provided underneath Fhip and Fshoulder (Fs1) could be calculated.

$$\Sigma M_A = F_{wire} \cdot cos(\beta) \cdot HookHeight + F_{wire} \cdot sin(\beta) * HookDepth - m \cdot g \cdot COM$$
$$\Sigma F_x = F_{wire} \cdot sin(\beta) - F_{shoulder} \cdot cos(\alpha)$$
$$\Sigma F_y = F_{wire} \cdot cos(\beta) - F_{hip} - F_{shoulder} \cdot sin(\beta)$$

The strap wrapping around the hip was considered to be vertically oriented. Whereas the strap supporting the shoulder is oriented at an angle, alpha, which is dependent on the distance hook to shoulder and hook to body. Indicating that every sailor and even harness could result in a different distribution of Fhip and Fshoulder. The next parts will zoom in on these areas and show what factors influence the system the most. The model was programmed in Maple, the worksheet is provided at the end of this chapter.

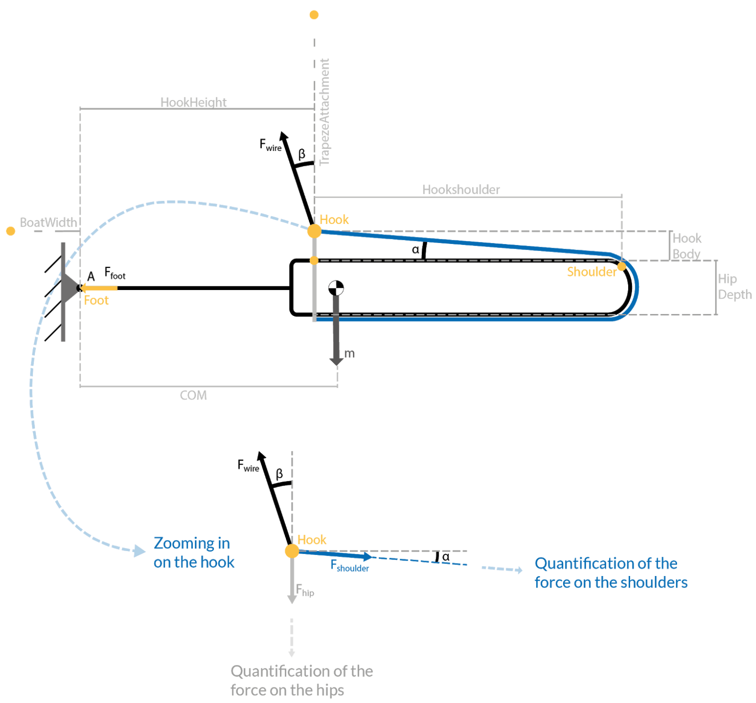


Figure xx; Illustration of the model overview with all parameters.

Sensitivity analysis
The model's outcome are based on multiple variables. To identify the importance of each variable the model is tested by means of a sensitivity analysis. By increasing and decreasing every variable by 10% the biggest influencers can be identified. For the calculations the model measured in Appendix Axx is used. The spreader bar width and hook - body distance were predetermined from previous test observations as described in Appendix A5. All variables and sensitivity results are shown in table [Bxx].

	Initial conditions	Force [N]	Force [N]
		10%-	10 % +
Weight [kg]	78	815,5	996,5
Stature [mm]	1850	815,5	996,5
Spreader bar width [mm]	250	906	906
Hip width [mm]	350	906	906
Hip depth [mm]	250	910,5	901,5
Distance hook - body [mm]	50	908	904,5
Distance hook shoulder [mm]	540	906	906
Hookheight [mm]	1030	995,5	832,5
Friction' coefficient	0,326	906	906

Table Bxx-01; Overview of all initial variables and the deviation of the outcomes.

From the analysis the main influencers could be identified. Weight and stature showed to have the biggest influence, followed by the hookheight. This might seem quite logical since the factors to determine the force on the wire are very limited.

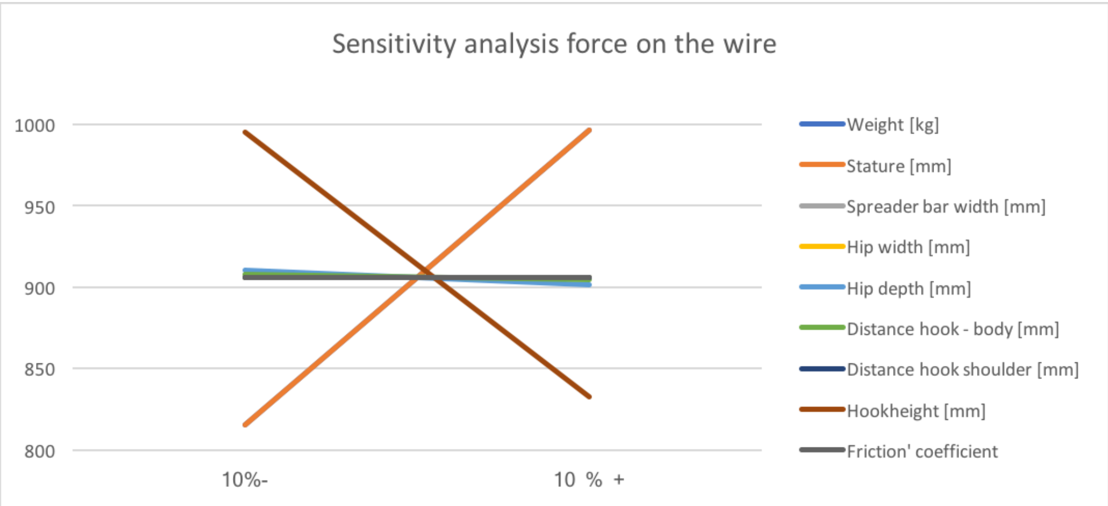


Figure xx; Results from the sensitivity analysis visualised in a graph, showing the main influencers.

C3: Normal force on the shoulders

Parameters and model

The distributed force on the shoulders is simplified to a horizontally oriented point force on the middle of the shoulder. The magnitude of the force in Fs1 is for a large part influenced by alpha. A more obtuse angle results in a lower force on the strap and directly in a lower reaction force of the shoulders. Since the strap wraps around an object, the strap is pulled from two sides. Therefore an extra force is defined, Fs2. The fact the strap wraps around an object means that friction is involved as well and acting on every point where the strap is in contact with the body. With the consequence that Fs2 < Fs1. Determining a friction coefficient is dependent on multiple factors, among one of them are material and weight. These factors differ for every sailor and harness, not to mention the effect of the water on the surface smoothness. However, to not completely ignore the effect of friction, two experiments were conducted to establish a conversion coefficient between Fs1 and Fs2. The results of these experiments are explained in detail in appendix A8 and A9. This conversion coefficient could at least help to demonstrate how the design of the harness effect the magnitude of the forces.

With Fwire known, Fshoulder could be calculated and run through the following equations. The magnitude of Fshoulder is largely dependent on alpha. Resulting in a one unknown, Fn. Due to the equilibrium of the system the forces have to be equal in the X-direction.

$$\Sigma F = F_{s1} \cdot cos(\alpha) \cdot CF - F_{s_2} = 0$$

$$\Sigma F_x = F_{s1} \cdot cos(\alpha) + F_{s_2} - F_N = 0$$

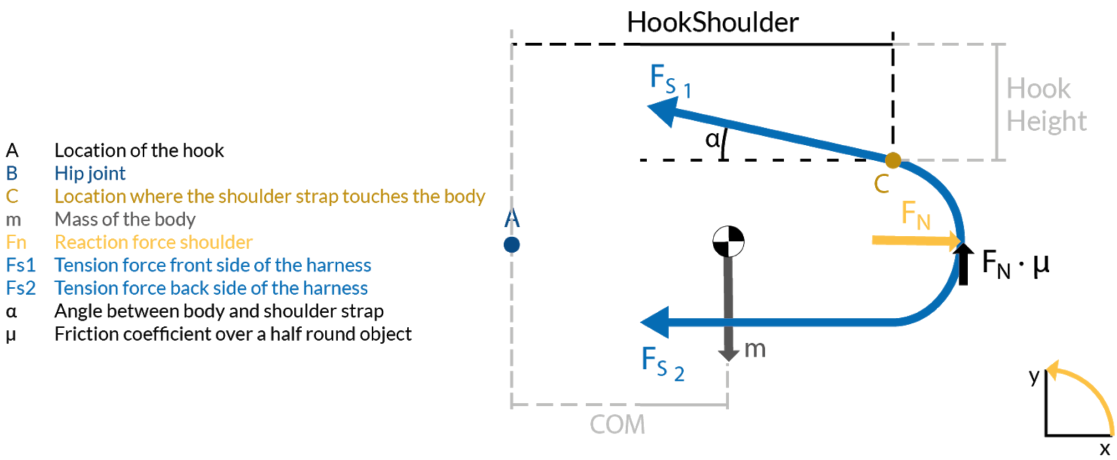


Figure xx; Illustration of the zoomed in system of the strap wrapping around the shoulder.

Sensitivity analysis
Table Bxx provides the an overview of the output data when decreasing and increasing the input parameters by 10%. Showing that weight and stature are dominant factors, but in this case the hook height is the most influential factor contributing to the force on the shoulders.

	Initial conditions	Force [N]	Force [N]
		10%-	10 % +
Weight [kg]	78	433	530
Stature [mm]	1850	433	530
Spreader bar width [mm]	250	482	482
Hip width [mm]	350	482	482
Hip depth [mm]	250	484,5	479,5
Distance hook - body [mm]	50	482,5	481,5
Distance hook shoulder [mm]	540	482	482
Hookheight [mm]	1030	510,5	458,5
Friction' coefficient	0,326	470	494

Table Bxx; *Overview of all initial variables and the outcomes by de- and increasing the input parameter by 10%.*

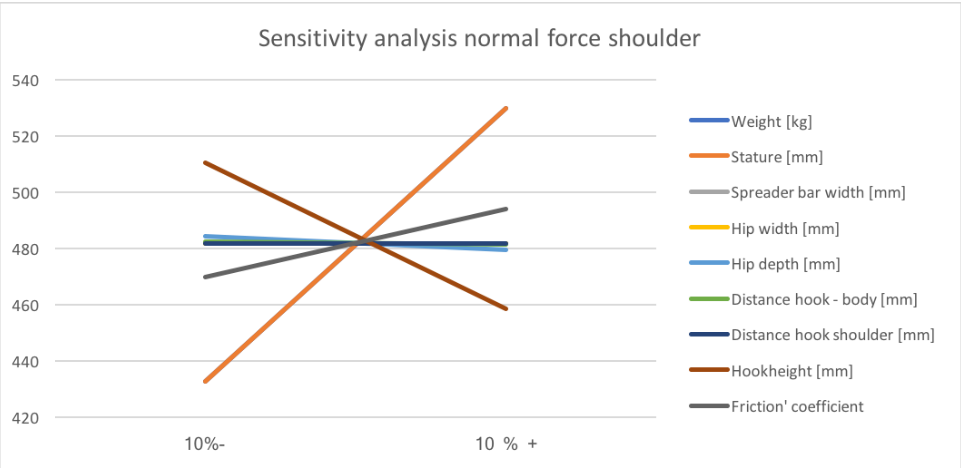


Figure xx; *Results from the sensitivity analysis visualised in a graph, showing the main influencers.*

C4: Normal force on the hips

Parameters and model
Deconstructing the harness simplified the hip part to a strap. Similar to a normal harness the strap is subjected to a distributed force (P(x)) from the point it touches the body. Which posed a problem as the exact distribution could not be determined and is different for every harness and body. To be able to quantify the reaction force of the body on the hips, the force was simplified to a point force (see figure [xx]). The point force (Fn) was horizontally oriented positioned at core height. A setup that allowed to calculate compressive force of the harness, an effect of the harness often pointed out by the sailors as being important. Since the harness wraps around an object, body, friction is involved. Both hip and shoulder are considered to be circular/oval shaped bodies, therefore the coefficient (CF) determined by the experiment in Appendix AXX was considered to be the same.

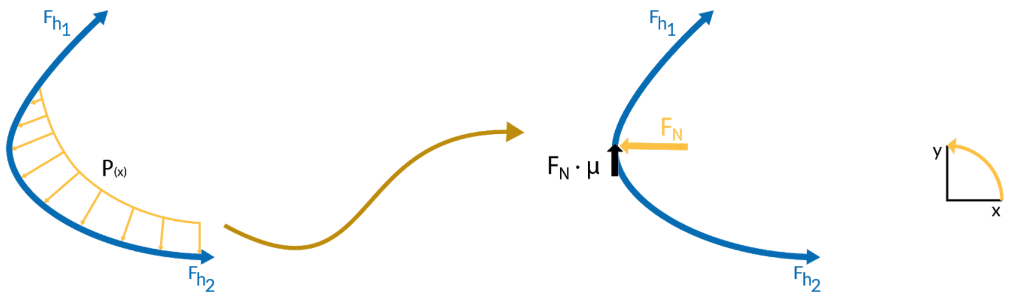


Figure [xx]; The distributed force around the hip simplified to a point force.

The normal force of the hips caused by the harness was determined by the angle between the strap and the horizontal drawn from the core. Depending on the spreader bar width, body width, body depth and hook height, this angle is varying for every body and harness. For further calculations the following assumptions were made:

1. The middle of the hook or spreader bar is exactly above the middle of the body
2. Point B is situated at the body contour at half body depth
3. The body is considered symmetric

With these assumptions in place, parameters such as location of the point force are pinned down, simplifying the system. As a result, variables for the model were being limited. In figure [xx] the created situation is visualised that served the base to define the equations needed to quantify the normal force. The total force directed to the hip, Fhip, was previously established by splitting the force on the wire over the hip and shoulder. Depending on the anthropometric measurements of the sailor and the harness' design, the resultant force, Fh1, could be calculated. Using CF to approximate Fh2 and subsequently Fn by finding the sum of all forces in the X-direction with the equations shown underneath. Resulting in an approximation of the normal force of the hip.

1. $F_{h1} = \frac{F_{hip}}{2} \cdot cos(\delta)$
1. $\Sigma F = F_{h1} \cdot cos\,(\delta) \cdot CF - F_{h2} = 0;$
2. $\Sigma F_x = F_{h1} \cdot cos\,(\delta) + F_{h2} - F_N = 0;$

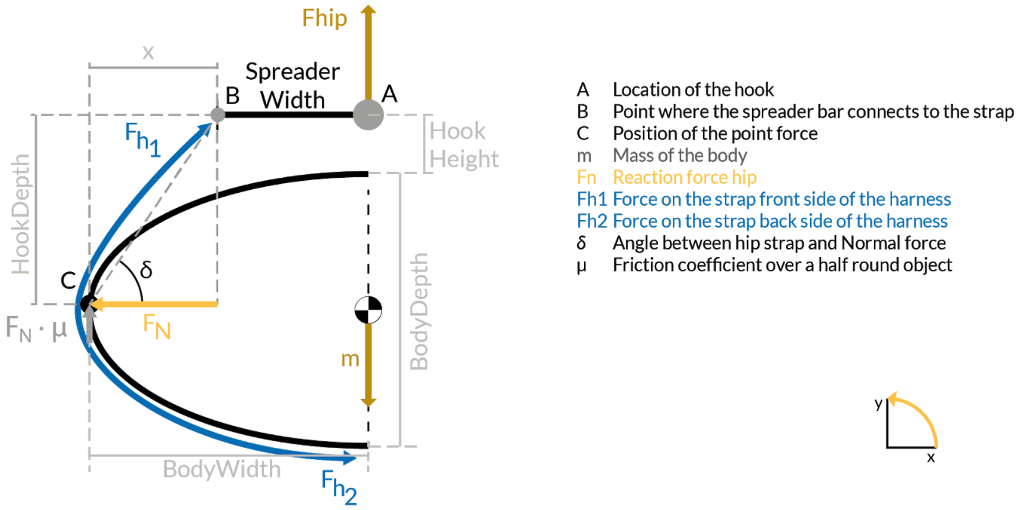


Figure [xx]; An illustration of the hip with the parameters needed to quantify the force.

Sensitivity analysis

The reaction force on the hips is dependent on multiple anthropometric dimensions, such as hip width and hip depth, see table Bxx. Of all parameters the spreader bar width and hip width are most influential, as is also clearly visualised in figure xx.

	Initial conditions	Force [N]	Force [N]
		10%-	10 % +
Weight [kg]	78	109	133
Stature [mm]	1850	109	133
Spreader bar width [mm]	250	145	93,5
Hip width [mm]	350	82	155
Hip depth [mm]	250	129,5	113
Distance hook - body [mm]	50	124,5	118
Distance hook shoulder [mm]	540	121	121
Hookheight [mm]	1030	136	108,5

Friction' coefficient	0,326	118	124

Table Bxx; Output results of sensitivity test for the hip force model.

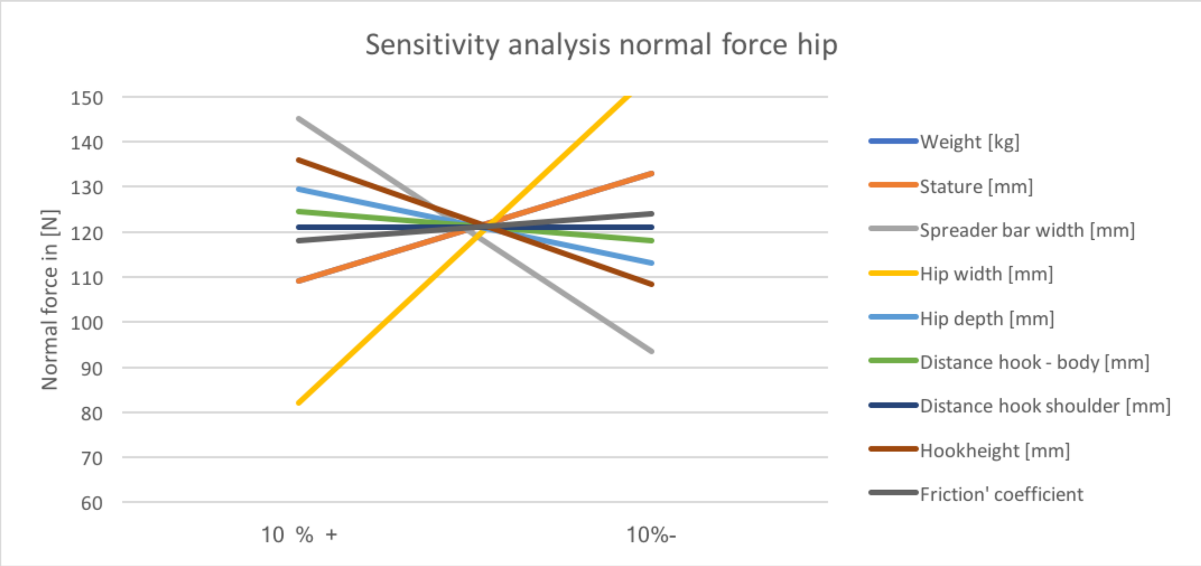


Figure xx; Visualised results of the sensitivity test for the hip force model, showing the influence of the input parameters.

C5: Normal force at the feet

Part of the system (see figure xx), however not directly relevant to the forces that are transferred on the body by the harness. An extra variable that generates insight in the amount of work is required from the sailor when hiking. The force on the feet is caused by the fact that the sailor is not hanging at 90 degrees, but at an angle beta. Since this is considered to be a static system the horizontal component of Fwire and the force on the feet have be in balance. Coming down to the following equation:

$\Sigma F_x = Fwire \cdot sin(beta) - Ffeet$

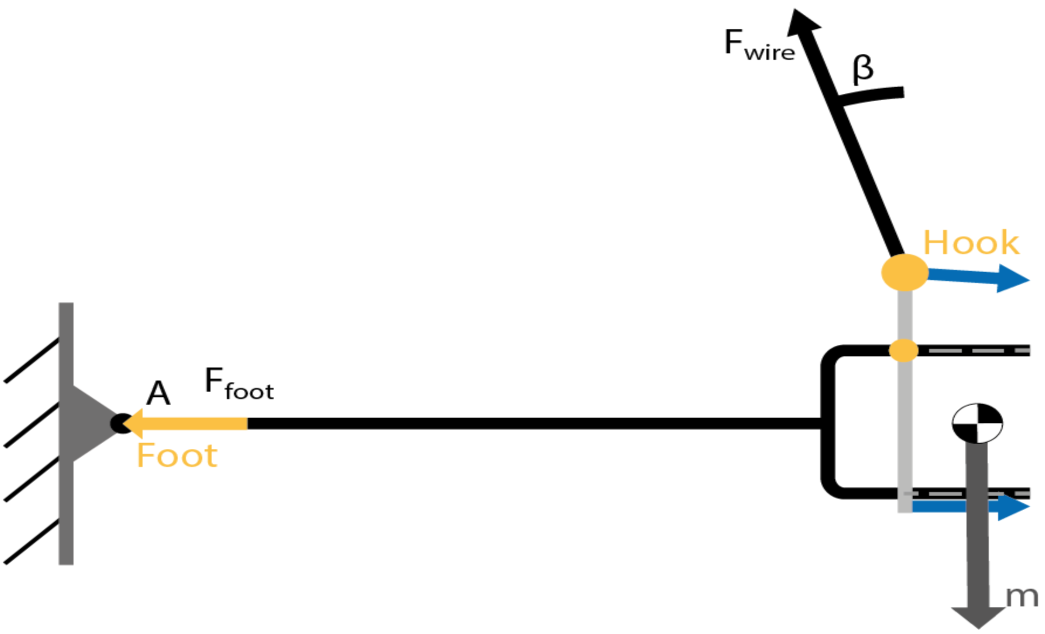


Figure xx; Partial system overview of the feet.

Sensitivity analysis

The force on the feet increases if the distance between the COM and the mast increases. Which can be the result of a taller sailor or a wider boat. The latter is not part of the sensitivity analysis since the 49er was chosen as main boat. Besides stature, weight and hook height are the dominant factors as the data shows in table Bxx and is visualised in figure xx.

	Initial conditions	Force [N]	Force [N]
		10%-	10 % +
Weight [kg]	78	327	399,5
Stature [mm]	1850	327	399,5

Spreader bar width [mm]	250	363	363
Hip width [mm]	350	363	363
Hip depth [mm]	250	365	361,5
Distance hook - body [mm]	50	363,5	362,5
Distance hook shoulder [mm]	540	363	363
Hookheight [mm]	1030	384,5	345,5
Friction' coefficient	0,326	363	363

Table Bxx; Output values from the sensitivity analysis for the force on the feet.

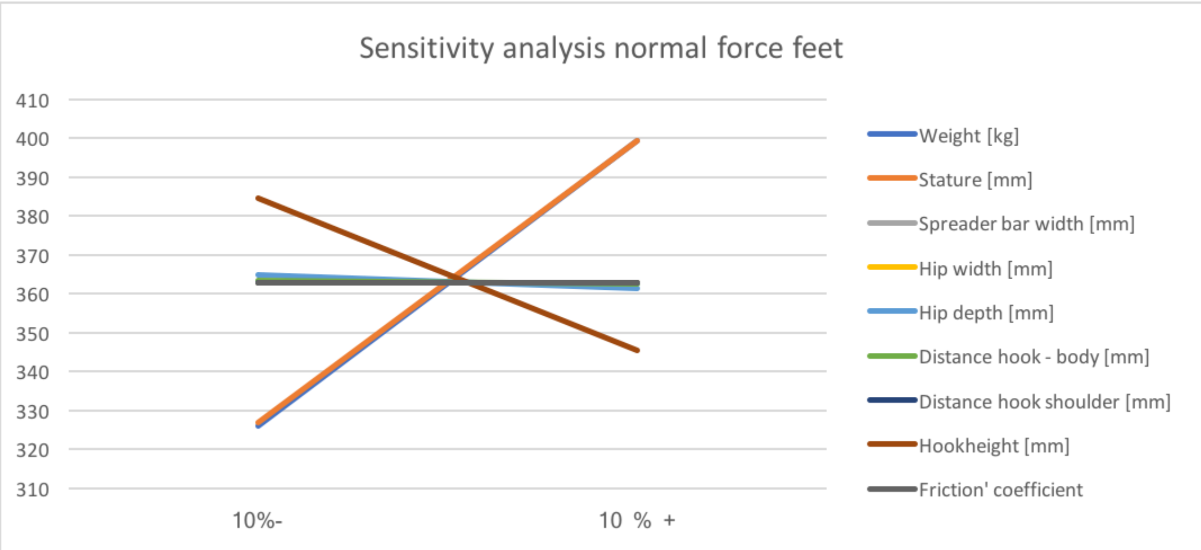


Figure xx; Data from the sensitivity analysis visualised in a graph, showing the main influencers

Appendix D Miscellaneous

D1: Market overview

In order to spot trends and analyse the features of harness, 34 harnesses currently on the market were examined. During the analysis the features, type of harness, intended use and other characteristics were documented. This allowed to quantify features and show what an average harness looks like and how this compares to the harnesses used by the athletes of the dutch sailing team.

The following abbreviations have been used:

Hook type

Spreader bar	-	SP
Hook	-	H

Design

Nappy	-	N
Leg strap	-	S

Weather conditions

Light	-	L
Medium	-	M
Heavy	-	H

Brand	Model	Weight (gr)	Features	Type of hook	Design	Price	Color	Adjustment	Conditions	Properties	Sizes	Link
Magic Marine	Aurelian	1400	Foaming in the back and on the lumbar spine and impact foam	SP	N	€ 230,00	Black	Two straps at spreader bar and a shoulder strap with buckel	M/H	Kevlar reinforced seat part Ripstop nylon polyester Neoprene crotch construction NIA Impact foam at hips Stainless steel spreader bar	S, M, L, XL	https://www.magicmarine.com/products/harnesses/aurelian-harness/#kleur_000000
Magic Marine	Wing	900	Support battens that can be taken out	H	N	€ 160,00	Black	Velcro hip / shoulder strap with buckle	L/M	Kevlar reinforced seat part Ripstop nylon polyester Fiberglass battens at back Stainless steel spreader bar	XS,S, M, L, XL	https://www.magicmarine.com/products/harnesses/wing-harness/#kleur_000000
Magic Marine	Pro racing	1375	Internal lower back support	SP	S	€ 180,00	Black/gray	One strap at the hips, one for the legs and one for the shoulder straps	M/H	Kevlar reinforced seat part Ripstop nylon polyester Neoprene leg straps Stainless steel spreader bar	XS, S, M, L, XL, XXL	https://www.magicmarine.com/products/harnesses/pro-racing-harness/#kleur_000000
Magic Marine	Smart	1175	Bare leg straps	Sp	S	€ 130,00	Black	One strap at the hips, one for the legs and one for the shoulder straps	M/H	Reinforced seat part Heavy-duty nylon Nylon webbing Neoprene padding	XXS, XS, S, M, L, XL, XXL	https://www.magicmarine.com/products/harnesses/smart-harness/#kleur_000000
Zhik	T2	2000	Adjustable lumbar support and integrated spreader bar	SP	N	€ 280,00	Black	Velcro hip adjustment and a shoulder strap with buckle	M/H	PADDED SHOULDER STRAPS ADJUSTABLE LUMBAR SUPPORT STRETCH CROTCH AREA KEVLAR REINFORCED SEAT	XS, S-M, L-XL, XL+	https://www.zhik.com/t2-harness.html
Gill	Trapeze harness	?	Removable and adjustable lumbar support	SP	N	€ 140,00	Black	Straps	M/H	Removable/adjustable stiffened lumbar support. Single handed tension lock at waist adjustment. Neoprene padding on shoulder strap	S, M, L, XL, XXL	https://www.gillmarine.com/gb/trapeze-harness.html
Gul	Evo 2	?	Air inflatable lumbar support + integrated spreader bar	SP	N	€ 170,00	Black	Velcro hip / shoulder straps	M/H	Kevlar seat Adjustable velcro waist Coloured marker fitting system Fully adjustable lumbar back pad 2 point adjustable strap system Neoprene crotch & shoulder straps	XS, S-M, L-XL, XL+	http://www.gul.com/sail/accessories/harness/evo2-trapeze-harness-25349
Neilpryde	Elite	?	Multiple support pads in the back. Looks like a surf seat harness with extra shoulder belts.	SP	S	€ 140,00	Black	Straps	M/H	Forward leaning ergonomic support Fully adjustable shoulder and waist strap Adjustable internal lumbar pad Stainless steel spreading bar	JNR / X/S / M/L / XL/XXL	https://www.neilprydesailing.com/assets/uploads/NeilPryde-brochure-2016-17.pdf

Crewsaver	Plasma	?	Adjustable back support pad. Straps can not be tucked away	SP	S	€ 180,00	Black	Straps	M/H	-	S-M, M-L, XL	https://www.wetsuitoutlet.co.uk/2018-crewsaver-plasma-trapeze-harness-with-quick-release-hook-3110-p-7461.html
Crewsaver	Phase 2	?	Nappy style with litte padding and cushening	H	N	€ 100,00	Light gray	Velcro and a strap for the shoulder	L/M	-	JNR, S-M, L-XL	https://www.watersportsoutlet.nl/2017-crewsaver-phase-trapeze-harness-6918-p-10672.html
Ronstan	Sailing harness	1150	Relatively simple design with no padding on the leg straps	SP	S	€ 155,00	Black	One strap on the shoulders without buckle, one strap at the spreader bar, one strap for each leg and a strap between the legs and the spreader bar	M/H	-	S, M, L, XL	https://www.ronstan.com/marine/range.asp?RnID=263
Ronstan	Sailing harness	1450	Bumpy padding on the back and more straps round the hips. However no protective padding on the legs	SP	S	€ 185,00	Gray/white	One strap on the shoulders without a buckle, two straps at the spreader bar, one strap for each leg and a strap between the legs and the spreader bar	M/H	Reinforced seat. Thermoformed battened back shell for maximum back support. Shoulder straps with 3D mesh padding Spreader bar with 8 point fixation	S, M, L, XL, XXL	https://www.ronstan.com/marine/range.asp?RnID=263
Banks	Skiff pro	?	The nappy with a back support pad. Only adjustable on the shoulders	H	N	€ 120,00	Blue	There is no waist adjustment and therefore it is clean of rope and webbing straps. The harness can only be adjusted at the shoulders	L/M	Banks trapeze harnesses are made from hard wearing polyester sailcloth with closed cell foam padding.	S, M, L, XL	http://banks.co.uk/accessories/harness.php
Banks	Lumbar	?	A nappy with a spreader bar that is adjustable using laces. There is also a back support pad that is adjustable	SP	N	€ 120,00	Blue	A lace-up spreader bar harness. Side stiffening around the lacing area spreads hip load. This harness also features non snag velcro leg strap adjusters. Extra adjustment for the legs and between legs and spreader bar. Shoulder adjustment with buckle	L/M	Banks trapeze harnesses are made from hard wearing polyester sailcloth with closed cell foam padding.	S, M, L	http://banks.co.uk/accessories/harness.php
Banks	Radial	?	A harness that is adjustable on the hips using laces that are attached to the spearder bar	SP	N	€ 150,00	Blue	Adjustable shoulder straps and lacing around the hips	L/M	Banks trapeze harnesses are made from hard wearing polyester sailcloth with closed cell foam padding.	S, M, L	http://banks.co.uk/accessories/harness.php
Banks	Nappy	?	Totally laced midsection which sits relatively high on the side of the body	H	N	€ 125,00	Blue	Adjustable buckle for the shoulders, the rest of the harness can be adjusted using laces around the hookplate	L/M	Banks trapeze harnesses are made from hard wearing polyester sailcloth with closed cell foam padding.	S, M, L	http://banks.co.uk/accessories/harness.php
Rooster	Classic trapeze harness	?	Has an extra strap that comes down from just underneath the arms to tag on to the spreader bar. Also a extra straps runs underneath the bottux to the spreader bar	SP	S	€ 70,00	Black	Adjustable using the straps at the shoulders, hips, legs, mid body straps	M/H	Soft neoprene crotch panel Kevlar reinforced seat panel Straps tidy away inside buckle covers Active load distribution for comfort	S, M, L, XL	https://www.roostersailing.com/pd/Classic-Trapeze-Harness_105331.htm
Burke	Webbing harness	?	Almost no padding very simple harness. Even shoulder bands are unprotected	H	S	€ 75,00	Black	Shoulder strap and straps around the hip to determine support and fitting of the harness	L/M	Stainless steel hook and plate Reinforced seat Adjustable shoulder strap	One size	https://www.burkemarine.com.au/collections/harnesses/products/adjustable-webbing-harness

Windesign	Mira	?	No buckle on the shoulder straps. Extra strap under the arm to the spreader bar. All straps are not covered to prevent loose strap ends	SP	S	€ 130,00	Black/blue	Straps to adjust shoulder, leg-spreader bar, legs, spreader bar around the hips and a straps between the midsection of the harness and spreader bar.	M/H	Full back support Eight points spreader bar fixation Comfortable and adjustable leg straps Adjustable shoulder strap release system Neoprene covered stainless steel buckles PVC coated 600D polyester shell Stainless steel spreader bar Heavy-duty rear	M, L, XL, XXL	http://www.optiparts.com/windesign-clothing/ex2560-mira-hiking-trapeze-harness-windesign-sailing
Hobie	Full auto	?	Back support pad relatively high on the back	SP	S	€ 175,00	Red/black	Shoulder straps, leg straps and spreader bar straps	M/H	Crotchless design for comfort Adjustable lumbar support Reinforced patch on seat Neoprene covered straps	One size	https://www.strictlysailinc.com/product/hobie-cat-full-auto-trapeze-harness-size-large-part-1376lg/
Aquata	Pro excellator XT	?	Partial see through mesh on the back. Special lumbar strap on the back to regulate tension. Suits looks like sear harness with shoulder straps	SP	S	€ 130,00	Blue/black	Straps to adjust shoulder, legs, hip and lumbar support	M/H	Adjustable lumbar Neoprene stretch leg straps Pre-formed Kevlar seat & lightweight mesh back Pre-curved shoulder straps	S-M, M-L, XL	https://www.aquatausa.com/harness.htm
Aquata	Equipe XT	?	Partial see through mesh on the back. Wide hips and looks like a surf seating harness. Special straps from under the arms towards the spreader bar.	SP	S	€ 130,00	Red/Black	Straps to adjust shoulder, legs, hip and tension of the midsection of the harness on the spreader bar.	M/H	Strapless Spreader. Advanced loading removes back compression and enhances freedom of motion. New:-SuperComfortNeo stretch leg strap with More Range of leg sizes! Protective rubberized shield isolates ALL metal on spreader bar Pre-formed Kevlar seat & lightweight mesh back Pre-curved anatomical shoulders.	XS, S-M, M-L, XL, XXL	https://www.aquatausa.com/harness.htm
Aquata	Class XT	?	Lumbar strap to alter tension.	SP	Leg straps	€ 120,00	Blue/black	Straps to adjust shoulder, legs, hip and lumbar support	M/H	Light weight X-cape tube spreader option Neoprene leg straps & Split leather pre-shaped seat Pre-curved shoulder straps with foam	S-M, M-L, XL	https://www.aquatausa.com/harness.htm
Aquata	Worrel XT	?	Big harness with leg pieces that should have no tension on the crotch. Harness offers a lot of support	SP	Leg straps	€ 210,00	Brown/black	Straps to adjust shoulder, two leg straps, hip and lumbar support	H	Totally Free Crotch Lightweight contoured Kevlar seat Adjustable Lumbar Back Support Lightweight Mesh Back Pre-curved anatomical shoulder straps	S-M, M-L, XL	https://www.aquatausa.com/harness.htm
Forward	Light harness	?	Bigger looking harness with limited strap tensioning options	SP	Diaper	€ 115,00	Black	One strap to adjust shoulder tension and one to adjust hip tension	L/M	Easy to put on and to adjust making this harness ideal for training and sailing school use Anti abrasion seat area with comfortable neoprene padded crotch support. Can be worn with the optional lumbar support.	S-M, L-XL	http://www.forward-wip.eu/en/6-sailing-harness.html
Forward	Pro harness	?	Harness with special lumbar belt that is strapped around the lowerbody. Spreader bar is covered. Strapping options seem quite limited for such a big harness	SP	Diaper	€ 180,00	Black	One strap to adjust shoulder tension and one to adjust hip tension	M/H	Adjustable Velcro waist straps and webbing shoulder straps with quick release catch. Comfortable neoprene padded crotch support and wear resistant seat areas	S-M, L-XL	http://www.forward-wip.eu/en/5-sailing-harness.html
Tribord	Harness	?	Buckle on the middle of the body. Extra padding on the back and leg straps	SP	Leg straps	€ 80,00	Black	One strap with buckle to adjust the shoulder strap, leg straps to adjust leg tension, straps between leg and spreader bar and hip strap on the spreader bar	M/H	One piece shoulder part Simple spreader bar without protection	S, M, L	https://www.decathlon.co.uk/sailing-trapeze-harness-id_8203869.html

Marinepool	Eco	?	Simple looking harness with limited padding and loose straps	SP	Leg straps	€ 95,00	Red	One strap to adjust shoulder tension, one to adjust hip tension, leg straps and extra on the back to adjust tension on the back	L/M	Simple spreader bar design No padding on the straps Strap on the back to adjust tension Straps are loose	XS, S, M, L, XL, XXL	http://www.adventuresafety.com.au/clothing/sailing-boating/marinepool-trapeze-harness-eco/
Blood red	Integra	1100	A harness with buoyancy vest integrated into the design. The leg straps seem quite heavily padded. Only drawback could be the limited support from the buoyancy vest on the back	SP	Leg straps	€ 260,00	Red	Shoulder strap, spreader bar straps are directly connected to leg straps and a strap around the hip	M/H	Shoulder strap in the buoyancy aid	XS-S, M-L, XL-XXL	https://www.bloodredclothing.com/trapeze-harness/
Shock	Trapeze	700 - 2000	A custom made harness, that looks very simple. Has little foam and no padding. Prefered by sailors due to its custom made abilities. If need to be the vest can have extra support battens or weight. Made from non breathable and water absorbent material	H	Diaper	€ 185,00	Black or white	Shoulder straps adjustable	L - H	Custom made, so anything is possible. This harness has a perfect cut out for the legs	Any size, S, M, M/L, L, XL	http://www.shocksailing.com/product-trapeze-harness.html
North Sails	Harness	?	Simple harness, but an Olympic winner. The harness has a spreader bar that can adjusted in many ways even in height. It has two stiff battens in the back that give it extra support. All straps seem quite loose and there is nothing to put them away.	SP	Leg straps	€ 175,00	Blue	Shoulders straps,	L - H	Designed with ergonomics in mind and maximum comfort as the goal, the stylish North Trapeze Harnesses have rigid back support combined with new Gel padding technology	Three sizes	https://www.northorder.com/securenew/harness.php
Bigfoot	Olympic	878	Simple harness made from light material partially a mesh on the sides and pvc on the seating area to prolong the life span	H	Diaper	€ 190,00	Black	Shoulder straps	L/M	The Olympic is constructed from Breathable Polyester Mesh.	Custom sizing	https://bigfootbags.com.au/product/olympic-trapeze-harness/
Bigfoot	Endurance	?	Relatively simple harness that is custom made according the users dimensions. Has more padding than the Olympic model and offers more support in the back using a pad	H	Diaper	€ 200,00	Custom color	Shoulders straps and pad in the back	L - H	They feature sturdy Semi ridged construction with padded comfort and adjustable lumbar support.	Custom sizing	https://bigfootbags.com.au/product/endurance-trapeze-harness/
Bigfoot	Slider hook harness	?	A harness that allows the user to twist his or her body forward due to the hook that can slide sideways. The harness has adjustable support in the back. Compared to the other bigfoot it has slightly more fabric on the sides which is beneficial when hanging slightly twisted.	H	Diaper	€ 250,00	Custom color	Shoulder straps and pad in the back	L- H	Asymmetric stance makes it easier to look to windward whilst trapezing, especially when hiking out hard.	Custom sizing	https://bigfootbags.com.au/product/slider-hook-harness/

D2: Video analysis notes

Movements in the boats could limit freedom of movement. To identify possible problem areas or movements were freedom of movement is essential, multiple racing videos were analysed to spot these aforementioned points. For the 470 and 49er the insights have been provided underneath.

Links to videos:

470:

- WorldSailingTV. (2017). Full 470 Men Medal Race from the World Cup Series Hyères 2017. https://www.youtube.com/watch?v=crI8i6z-cZc&t=1414s.
- WorldSailingTV. (2017). Full 470 Women Medal Race from the World Cup Series Gamagori 2017. https://www.youtube.com/watch?v=-6GvLL6xqro&t=1151s.
- WorldSailingTV. (2017). Full 470 Women Medal Race from the World Cup Series Final Santander 2017. https://www.youtube.com/watch?v=cXHhj1a4_PM.

49er:

- WorldSailingTV. (2017). Full 49er Medal Race Sailing's World Cup Series Gamagori Japan 2017. https://www.youtube.com/watch?v=Ilo8vQCsr3U&t=680s.
- WorldSailingTV. (2017). Full 49er Medal Race from the World Cup Series Hyères 2017. https://www.youtube.com/watch?v=zH63ASuMAT4.
- WorldSailingTV. (2017). Full 49er Medal Race Sailing's World Cup Series Santander 2017. https://www.youtube.com/watch?v=x8D516xNhZw&t=82s.

470 observations

- Deep bending to duck underneath the beam, more tension on the back of the trapeze harness during tacks and gybes
- Some go underneath the beam facing forward other facing backward during tacks
- The neck is flexed during the hiking position to look forward or to the side
- Thrusting of the hips to unhook and adjust trapeze line length
- To set the spinnaker pole the crew has to stretch fully in order to reach the ends of the pole
- Pumping hands on the handles and the hips are moving up and down in a rapid motion
- First stand on the gunwale and then hook in
- In the downwind leg, crew sits down on the luff side of the boat and controls the spinnaker

Light conditions	Heavy conditions

A lot of adjustment of the trapeze line length in the outward position	Steady hanging at 90 degrees or little less to avoid waves
Changing outward position by bending the knees	Hands above the head

Crew Tasks

- Boat trim
- Jib control
- Spinnaker control
- Spinnaker pole setting (reaching)
- Spinnaker drops (bending over)
- Body pumping

49’er observations

- Generally standing up sailing and walking from one side to the other, with bending over to go underneath the beam
- Main- and jibsheet are switched between helmsman and crew after a certain leg
- When approaching the top mark crew and helmsman step back a little on the gunwale
- During buoy rounding crew steps in the boat to hoist the gennaker, helmsman stays out to balance the boat
- Hoisting is done in a bend over posture with two hands quickly pulling one-by-one
- Fairly steady hiking, not a lot of movement or adjusting of the trapeze line length
- Crew and helmsman are standing closely together, largely depending on leg and conditions
- Downwind crew and helmsman are all the way back, with the crew tucked against the helmsman
- Both helmsman and crew swing in and outward to determine or compensate righting moment using their feet/legs
- Twisting of the upper body by both crew and helmsman
- Helmsman standing slightly higher to look over the crew

Light conditions	Heavy conditions
Crew pumps during tacks and helmsman stays in, standing on the inner ridge	Full hiking mostly not at 90 degrees to avoid was from smashing on the body
During tacks crew steps between jib and mast	Crew and helmsman stand approximately on the middle of the gunwale
Crew stands in front of the mast and wing, helmsman stands very forward on the wing	

Helmsman tasks

- Steering the boat
- Boat trim
- Jibsheet control
- Mainsheet in buoy roundings and downwind

Crew tasks

- Boat trim (primary)
- Mainsheet control upwind
- Hoisting gennaker
- Controlling gennaker
- Pumping on start and during tacks

In heavier conditions core muscles are important to absorb the constant battering of the waves.

D3: Building plan 49er simulator

Realistic experiment conditions required a boat and complete rig to be available. Due unavailability of either of these and the wish for a 49er simulator, a wooden model was built based on the exact measurements of the 49er hull (see figure xx). The simulator was set up inside with trapeze wires hanging down from the ceiling at the correct height and angle. In figure xx several images of the intermediate results are shown.

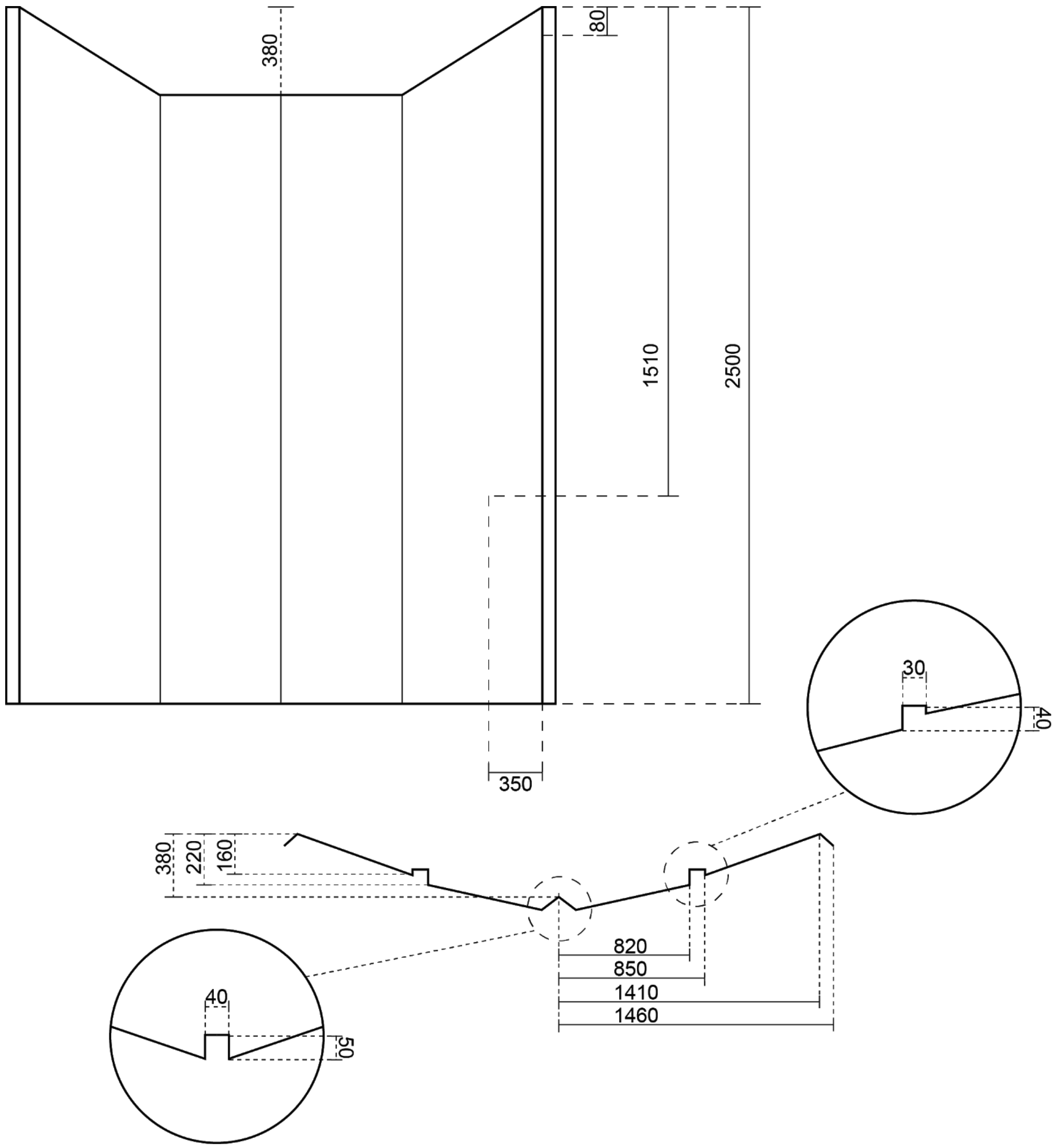


Figure Cxx; Building plan hull with all dimensions included in millimeters

Figure xx; Intermediate results of the woorden simulator.

D4: Prototype fabrication

Producing the prototype

The main goal for the prototype was to find out whether the shoulder strap design and open back would be able to carry a sailor and what the effect would be on freedom of movement. For this, the harness design was slightly altered into a less complicated version, that allowed to solely focus on the features of the harness. Initially, a first model of the harness was fabricated using straps and a spreader bar. However, the spreader bar is not part of the design, it served its purpose to find out whether the current strap setup was indeed capable of carrying a body. An image of this prototype is provided in figure [xx].

In order to have an basis that would work and fit, an existing harness nappy style harness was used. In figure [xx] on the top left and image of the initial harness is provided. To fabricate the prototype additional materials such as straps, double sided Velcro and buckles were used.
The harness was cut open in the back and foam was taken out of the harness to speed up and smoothen the sewing process. Subsequently, the shoulder straps were cut to size to fit a 1850 tall person, similar to the anthropometric model used in calculations. The straps were attached to the upper part of the harness and hook on the front. Next, the hip part was cut open to allow the region to be adjusted and four anchor points were sewn to the front part of the hip. Two to adjust the hip tension and two to adjust the lumbar support strap. The last step was to attach the Velcro layers to the back of the hip part and lumbar support strap. Resulting in the model as presented in figure [xx]. The prototype can not be regarded as a finished product as positioning of elements is not precise and finishing is limited.

Starting point

End result