Appendix

1. Project brief

Wrist guard for goalkeepers — project title

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

start date 21 - 09 - 2020 — 18 - 02 - 2021 end date

INTRODUCTION **

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

Soccer is the most popular sport in the world with around 3.5 billion fans from all over the world. Not only is it popular for professional play, there is also a vast group of amateur soccer players. It is one of the most accessible sports in the world as the only things you need are a ball and something that resembles two goal posts [1].

Professional soccer is becoming more and more intense. The shots fired on goals today are getting increasingly faster with top speeds going up to 200 km/h [2]. Not only are the balls going faster, they are also starting to wobble resulting in unpredictable behaviour [3]. For the goalkeeper to catch these fast and unpredictable balls, he must be agile and his timing has to be precise.

Upper extremity injuries, such as of the wrists, hands and shoulders, are uncommon in elite soccer players. However, they have a 5 times higher occurrence in goalkeepers [4]. When the ball is kicked directly at the goalkeeper, the ball can knock his fingers and hands. Therefore, sprains, dislocations and fractures of the fingers, hands and wrist bones are not uncommon in goalkeepers [5]. To prevent injuries goalkeepers tend to tape their wrists. Taping is used to provide support, limit excessive range of motion, and protect against forces that cause injury. The supplies that are used to tape include cloth athletic tape, neoprene, and sometimes a thermoplastic material [6].

As a professional soccer goalkeeper Norbert Alblas has to deal with taping his wrists every day. He has noticed that goalkeeping gloves nowadays are developed based on the look and grip with less and less attention for protection. They are becoming lighter and weaker. From his own experience with taping and wrist injuries he developed the idea to create a wrist guard that can be worn under the current goalkeeping gloves.

In collaboration with a top athlete and the TU Delft this project will aim to create a wrist guard to prevent wrist injury in goalkeepers. Expertise from goalkeepers and a former hand therapist and facilities of the KNVB can be used to substantiate the project. During the project, the possibility of joining the Fieldlab UPPS will be explored.

[1] Sourav. (2020, June 3). Top 10 Most Popular Sports in The World. Retrieved August 25, 2020, from https://sportsshow.net/top-10-most-popular-sports-in-the-world/
[2] Agarwal, U. (2016, July 19). Sportskeeda. Retrieved August 25, 2020, from https://www.sportskeeda.com/football/5-fastest-shots-ever-recorded-football-history/5
[3] Chandler, H. (2010, June 3). Controversy over new World Cup ball. Retrieved August 25, 2020, from http://edition.cnn.com/2010/SPORT/football/06/02/football.jabulani.ball.world.cup/index.html
[4] Ekstrand, J., Hägglund, M., Törnqvist, H., Kristenson, K., Bengtsson, H., Magnusson, H., & Waldén, M. (2012). Upper extremity injuries in male elite football players. Knee Surgery, Sports Traumatology, Arthroscopy, 21(7), 1626–1632. https://doi.org/10.1007/s00167-012-2164-6
[5] FIFA.com. (2010, April 1). Goalkeepers and the constant risk of injury. Retrieved August 24, 2020, from https://www.fifa.com/who-we-are/news/goalkeepers-and-the-constant-risk-injury-77592#:%7E:text=When%20the%20ball%20is%20kicked,face%20and%20cause%20eye%20injuries
[6] Singletary, S., & Geissler, W. B. (2009). Bracing and Rehabilitation for Wrist and Hand Injuries in Collegiate Athletes. Hand Clinics, 25(3), 443–448. https://doi.org/10.1016/j.hcl.2009.05.012

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1. Project brief

introduction (continued): space for images

image / figure 1: Tottenham Hotspur goalkeeper Hugo Lloris with his wrists taped

TO PLACE YOUR IMAGE IN THIS AREA:
- **SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER**
- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:
- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
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- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 2:

1. Project brief

PROBLEM DEFINITION **

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

As was mentioned in the introduction, goalkeepers have to be highly mobile in order for them to perform well. Therefore, creating a product that limits their movement seems contradictory. One of the challenges of this project will be finding a balance between allowing the right kind of movement, in order for the goalkeeper to accurately and effectively stop the ball, while restraining the wrong kind of movement, that will result in injury of the wrist.

In this project it will be important to look at what factors can cause injury, i.e. overextension of the joints, high forces or high acceleration of the joints, and lowering the impact these factors have.

I will be looking at creating a wrist guard for professional play. Goalkeepers in professional play prioritise performance. Costs will therefore have a less significant role if the product performs well. However, the product should still be able to compete in some way with the costs of taping over a period of time. Furthermore, the wirst guard could be a more sustainable alternative to taping.

Since performance is priority, I will investigate the possibility of creating a personalised product. Everyone's hands are different and goalkeepers might have existing underlying injuries. A personalised product could provide better support and movability. Whether a personalised product is necessary will have to be investigated.

As taping takes a considered amount of time to be applied properly, creating an easy to use and wear product is a must. In addition, the wrist guard should be able to fit underneath most goalkeeping gloves.

ASSIGNMENT **

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

Design a strong, comfortable and reliable wrist guard for the professional goalkeeper, that they can wear under their goalkeeper gloves, as an alternative to taping. The wrist guard should have minimal influence on the goalkeeper's performance. The wrist guard could possibly be made personalised to the goalkeeper.

For this project I will be working towards a product that will solve the before mentioned issues.
To do so an analysis of the cause, forces and movements that result in injury, injuries that occur and already existing solutions will be done. The analysis will be done by doing literature and web research as well as by interviewing experts.

Based on the analysis, a program of requirements will be drafted that will set the boundaries for the to be designed product. Through an ideation phase multiple design solutions will be explored which will be validated by small prototypes.

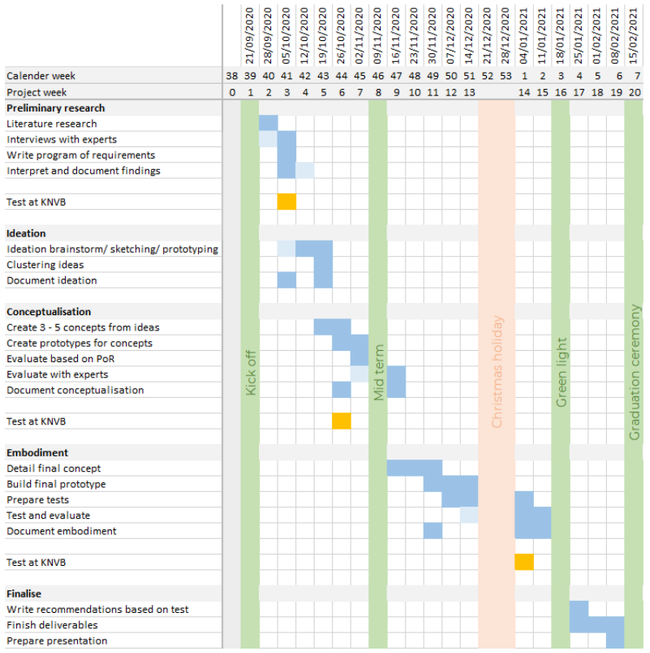
The result will be the design of a wrist guard for professional goalkeepers that has been tested in a motion lab to prove its working principle. Tests can be done using the measuring equipment and facilities provided by the KNVB.

1. Project brief

PLANNING AND APPROACH **

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

start date 21 - 9 - 2020 18 - 2 - 2021 end date



During my graduation project I will follow the design process of researching - ideating - conceptualising - embodying, also known as the double diamond method.

I will start by doing research on
- the forces that goalkeepers wrists have to withstand
- which injuries are most common
- which movements should and should not be restricted
- preferences goal keepers have regarding wrist protection
- current products and methods that prevent wrist injuries.

I will do this by performing literature research, interviews with goalkeepers and by consulting experts. During the research phase I will work on a program of requirements that I will use during the rest of the project.

Using the information found during the research phase, I will start ideating on possible solutions, turn the best ideas into concepts and choose the best concept based on the program of requirements. Throughout the process I will be evaluating the ideas and concepts with experts.

I will work towards a final prototype with which tests can be done to prove the principle of the wrist guard.

The project will span over 22 weeks due to the Christmas holidays.

1. Project brief

MOTIVATION AND PERSONAL AMBITIONS

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

During previous courses I have found that projects that involve looking closely at the interaction between user and product spark my interest the most. I find that a good design considers not only the bare function of a product but also the way the user will interact with the product on a physical and emotional level.
As I have had little experience in previous projects with heavily ergonomics-based products, I wanted to challenge myself with a graduation project in which I will have to explore this.

My motivation for this project mainly lies in the medical necessity that the product taps into. Furthermore, I will be able to use my already existing knowledge on prototyping and generative design in this project. Proving that the concept works will be a new challenge for my prototyping skills.

Within this project I will be able to explore comfort vs function, the medical necessities involving prevention of wrist injuries and the ease of use. All these topics have a strong relation to the human body. During my graduation I will have the ability to learn more about the human body and how to design for prevention of injury.

FINAL COMMENTS

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

2. Interview hand therapist

Dr. Annemieke Videler is trained as a physical therapist. She has 28 years of experience as a hand therapist, a specialization of physical therapy. She has had her own practice, worked at the AMC hospital for 18 years and the medical rehabilitation center of the AMC hospital. She has a PHD in hand therapy and teaches physical therapists who want to specialist in hand therapy. She is currently learning for physician assistant in the hand surgery department.

What injuries can be seen in goalkeepers?
In soccer you can see several contact sports injuries due to contact with each other or with the ball. In goalkeepers' injuries occur with contact with the ball but also with contact with the ground when they dive to catch a ball. When you fall onto the ground with an outstretched hand it is called a FOOSH (fall on the outstretched hand). There are several injuries that occur during a FOOSH. You can break a carpal bone or one of the bones in the under arm. You can also tear ligaments or sustain injury to the TFCC such as torn or stretched ligaments. Tendon irritations are also not uncommon. Repetitive impact to the hand, such as catching a ball, can also cause these injuries.

What kind of mechanisms cause injury?
When you fall there is a force transmitted through the wrist. Often a fall takes place more towards the thumb side of the hand. It depends on what is the weakest part of the wrist at that moment. When the scaphoid is the weakest it can fracture. If the scaphoid holds the scapholunate ligament could be the part that tears. If this ligament holds, the radius could also break. Most of the time it is one of these three things that injures. On the ulnar side of the wrist most injuries occur in the TFCC. An injury at one of these parts seems small but it disrupts the whole biomechanics of the wrist. The distal carpal row and the metacarpals can be seen as one rigid part. The proximal carpal row bones have a lot of freedom of movement between them. They need to be able to make certain movements in order for the wrist to move. The part on the radial side wants to tilt forwards while the part on the ulnar side wants to tilt backwards. It can be seen as a loaded spring. When one part malfunctions, for example the scaphoid, the spring will fall apart. This creates a biomechanical instability that could need surgery or splinting to fix.

How long is the rehabilitation time for a keeper?
A scaphoid fracture can take up to 3 – 4 months to heal. Professional goalkeepers are pushed to start playing again very soon. Full rehabilitation can take up to a year. This shows that we need to work more at preventing injury rather than curing.
The question is whether you can prevent a fracture with a brace of some sorts. Ligament and TFCC injuries can definitely be prevent by using a brace. This could be done by preventing the wrist from moving to their maximum range of movement.

Would you want to limit all ranges of movement?
Mostly the movement backwards, extension. Most of the time you will fall or catch a ball with your wrist moving backwards. The movement towards the front, flexion, goalkeepers might need to use when throwing a ball.

Could you explain the benefits of taping the wrist?
The non elastic tape is a thin tape, resulting in a thin brace. It can be made personalized; an extra layer of tape can be added to an area where the wearer wants more support. It can be tight during a game and can be taken off afterwards. You can limit certain movements well while leaving others open.
It also as a negative side. The tape has a think glue layer that has to be pulled from the skin. The skin can become irritated from repeated taping. It also doesn't breath and can pull on your skin when moving. It can also take about 10 minutes to apply.

In what way would you tape a wrist with a previous scaphoid fracture?
The scaphoid has to tilt when moving the wrist. I would provide support to prevent the wrist from moving too far backwards and also limit the sideways movement especially towards the radial side.

Do you have any tips on designing a wrist guard?
It can be quiet a puzzle. The challenge will be finding the right material, not too heavy, not too light, not too warm and a material that breaths. What kind of system will you use, a sort of wrap? A hard part on the front of the wrist will not work because it will limit moving the wrist forwards.

Wrist injuries and wrist injury prevention in goalkeepers

You are being invited to participate in a research study titled “Wrist injuries and wrist injury prevention in goalkeepers”. This study is being done by Noor Aberle from the TU Delft.

The purpose of this research study is to gather background information about goalkeeper's history with wrist injuries and preferences regarding wrist protection. This survey will take you approximately 10 - 20 minutes to complete. The data will be used for a graduation thesis of the master Integrated Product Design.
Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any question.

We believe there are no known risks associated with this research study; however, as with any online related activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by storing the data locally and by keeping the survey completely anonymous.

For any questions regarding the survey you can contact Noor Aberle:

1. Have you sustained a wrist injury due to goalkeeping in your professional soccer career? *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 5*

2. How many times have you injured your wrist(s) in your professional soccer career?

Mark only one oval.

- ◯ Only once
- ◯ 2 - 4 times
- ◯ 5 - 10 times
- ◯ More than 10 times

3. What type(s) of wrist injury did you sustain?

_____

_____

_____

_____

_____

4. What was the cause of the last wrist injury you sustained?

_____

_____

_____

_____

_____

Taping

This section consists of questions regarding wrist taping.

5. Do you tape your wrists? *

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to question 15*

6. When do you play with taped wrists?

Mark only one oval.

- ◯ During practice
- ◯ During competition
- ◯ During both practice and competition
- ◯ Other: _____

3. Survey goalkeepers

7. Why do you tape your wrists?

Tick all that apply.

- [ ] To prevent injury
- [ ] To provide stability
- [ ] To prevent injury aggravation
- [ ] To aid in healing existing wrist injury

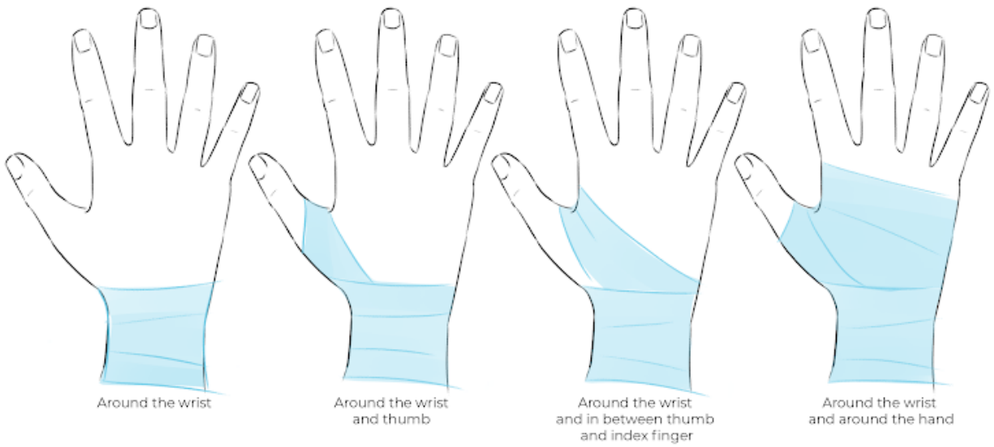
Other: [ ] _____

8. Who tapes your wrists?

Mark only one oval.

- ◯ I tape my wrists myself
- ◯ A physical therapist tapes my wrists
- ◯ Other: _____

9. In what way do you tape the back of your wrist?



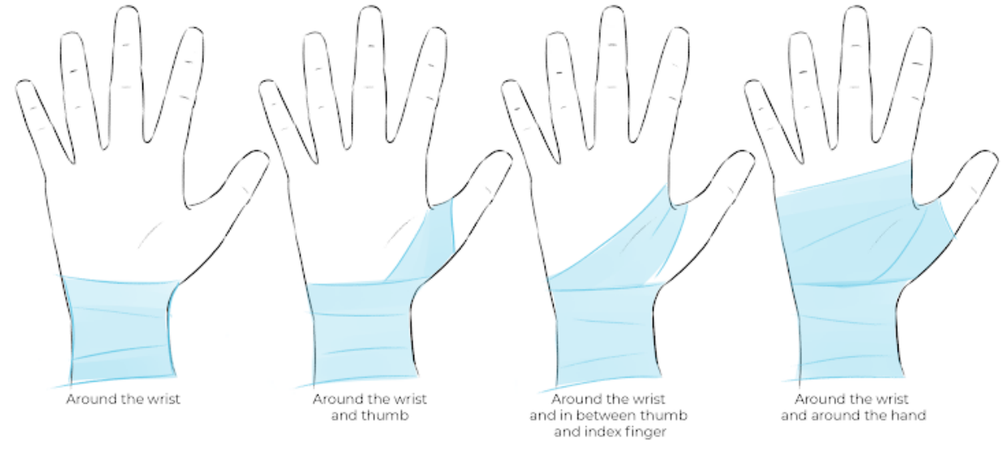
Tick all that apply.

- [ ] Around the wrist
- [ ] Around the wrist and thumb
- [ ] Around the wrist and in between thumb and index finger
- [ ] Around the wrist and the whole hand

Other: [ ] _____

3. Survey goalkeepers

10. In what way do you tape the palm of your wrist?

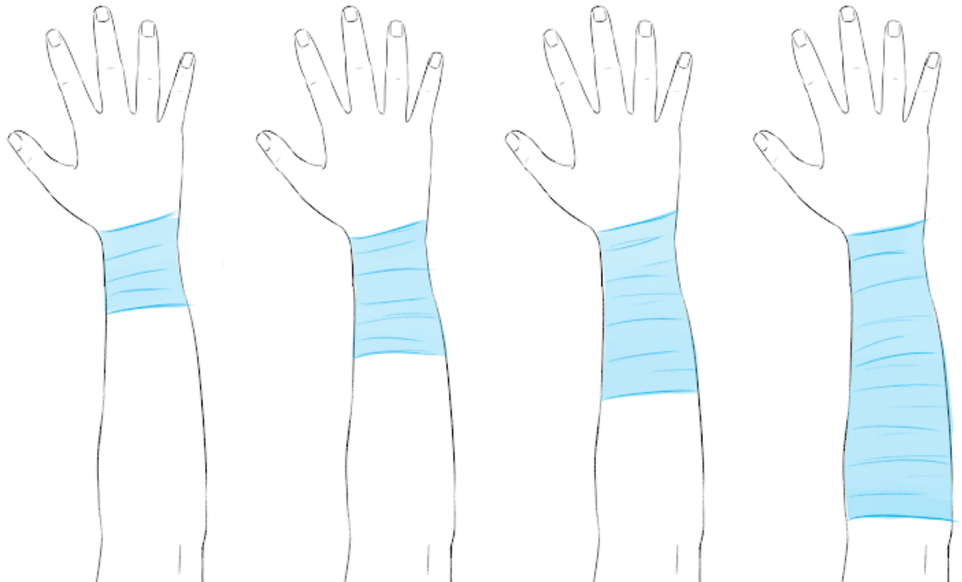


Tick all that apply.

- [ ] Around the wrist
- [ ] Around the wrist and thumb
- [ ] Around the wrist and in between thumb and index finger
- [ ] Around the wrist and the whole hand

Other: [ ] _____

11. How far up your arm do you extend your tape?



Mark only one oval.

- ◯ Only around the wrist
- ◯ Around the wrist and part of the under arm
- ◯ Half way up the arm
- ◯ Up to the elbow
- ◯ Other: _____

12. Why do you use this way of taping?

_____

_____

_____

_____

_____

13. Is there anything that bothers you about having your wrists taped? Please explain your answer

_____

_____

_____

_____

_____

14. Approximately how many rolls of tape do you think you use in a week?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Skip to question 16

15. Why do you not tape your wrists?

_____

_____

_____

_____

_____

Preferences

This section consists of questions about your preferences for goalkeeping equipment.

3. Survey goalkeepers

16. What type of goalkeeping glove do you use? *

Tick all that apply.

- [ ] Flat cut
- [ ] Rolled cut
- [ ] Negative cut
- [ ] Hybrid cut
- [ ] Other: _____

17. Why do you use this type of glove? *

_____

_____

_____

_____

_____

18. At what part of your wrist do you need extra support? *

Tick all that apply.

- [ ] Back of the wrist
- [ ] Front of the wrist
- [ ] Around the thumb
- [ ] Around the hand
- [ ] Other: _____

General

To round up the survey we will need some general information.

3. Survey goalkeepers

19. Is there anything we forgot to ask regarding wrist injuries and taping that is important for us to know?

_____

_____

_____

_____

_____

20. How many years have you been playing in the professional soccer league? *

Mark only one oval.

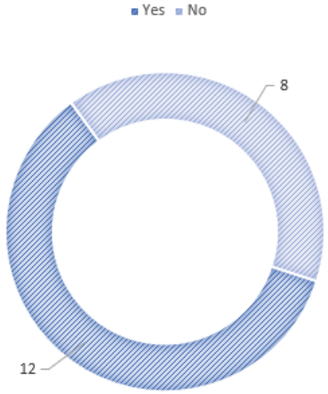
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10
- ◯ 11
- ◯ 12
- ◯ 13
- ◯ 14
- ◯ 15

21. What is your age? *

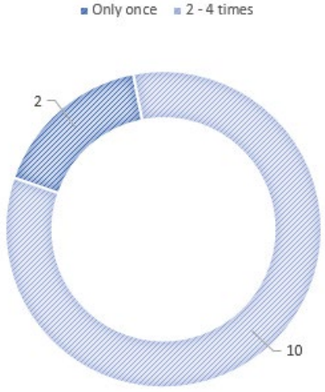
_____

4. Results survey goalkeepers

Have you sustained a wrist injury due to goal-keeping in your professional soccer career?



How many times have you injured your wrist(s) in your professional soccer career?

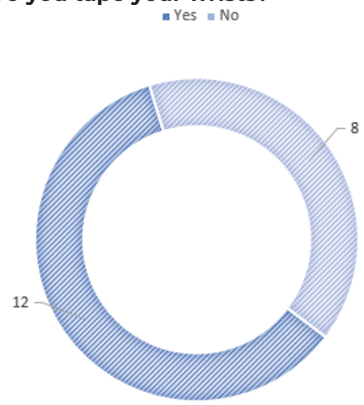


What type(s) of wrist injury did you sustain?
Sprained wrist
Sprain
Fractured wrist
Broken wrist
Overload and a sprained wrist
Swelling around the bone
Bruised wrist
Crack in the ulna and broken radius
Scaphoid fracture. 2x fractured, 2x surgery
2x scaphoid fracture
Ligament tear at the scaphoid
Bruise (contusion)

What was the cause of the last wrist injury you sustained?
Fast ball from a short distance that made my wrist fold double
Collision
Soccer ball contact
My wrist got caught between the ball and one of the strikers and folded double
Overload
Caught the ball awkwardly
Goalkeeping
A hard shot from up close. I had my wrist in an awkward position in front of my body which the ball had fully. This made my hand fold backwards
A really hard shot of an attacker, my wrist wasn't strong enough and flipped backwards
I broke my scaphoid 8 years ago and they said that 7 out of 10 times then the ligament will tore off
Over-extension of hand by powershot

4. Results survey goalkeepers

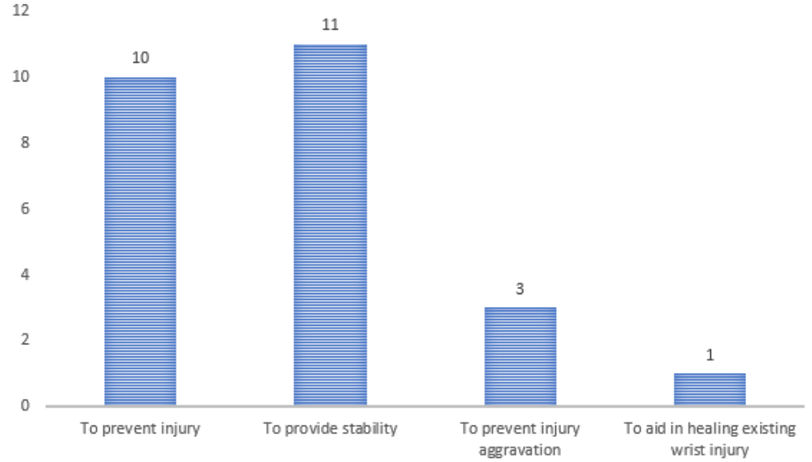
Do you tape your wrists?



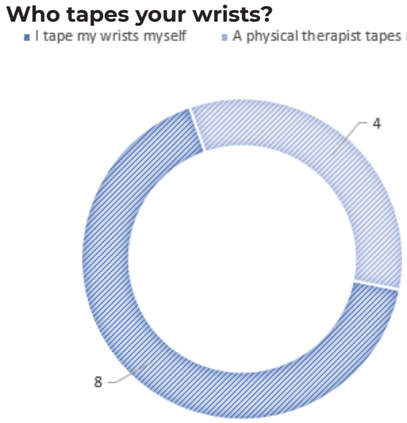
2 participants who did not sustain a wrist injury previously, do tape their wrists
3 participants who have had a previous injury, do not tape their wrists

When do you play with taped wrists?
100% Of the goalkeepers who tape their wrists do this during both practice and competition

Why do you tape your wrists?

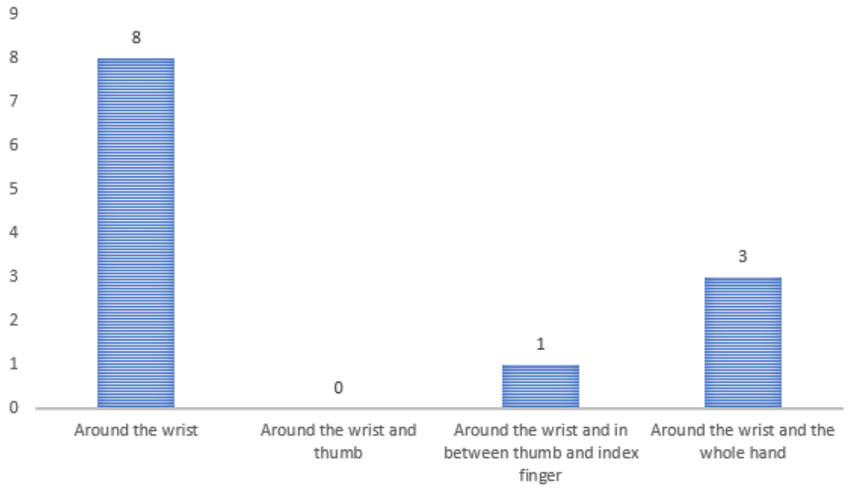


Who tapes your wrists?



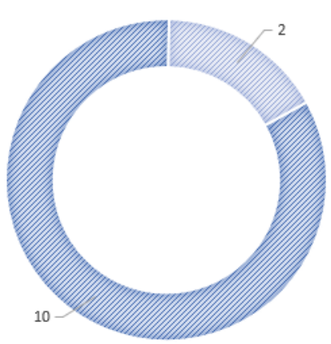
4. Results survey goalkeepers

In what way do you tape the back of your wrist?



One participant mentioned that they needed to limit extension with the tape. Therefore, he tapes his wrist and a strip above his thumb. On the inside of his hand he applies strips to prevent extension.
In what way do you tape the palm of your wrist?

How far up your arm do you extend your tape?



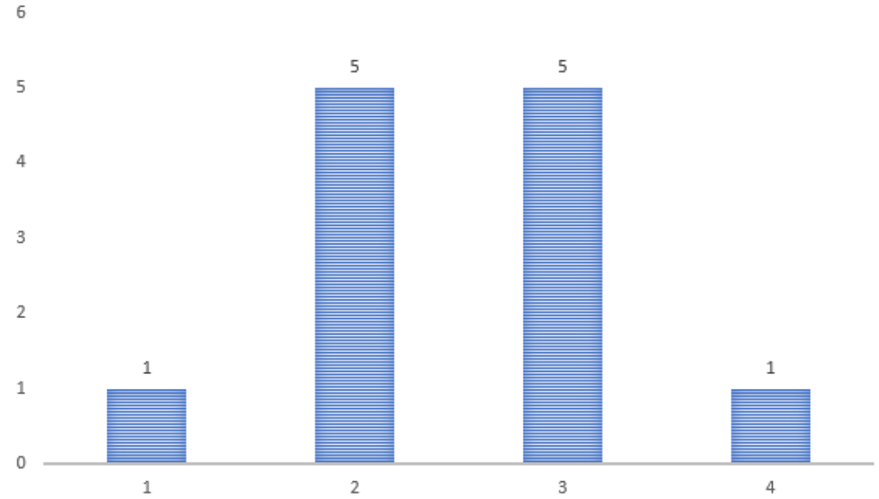
Why do you use this way of taping?
Feels good
Provides stability and certainty
Feels nice
Its' comfortable and safe
Most comfortable
I like it when the tape is located a bit higher. If I place the tape lower I get the feeling that I am pinching off my wrist
It feels more comfortable, I feel naked without
This feels secure to me. When I tape more I start losing that feeling a bit
I started with this after the surgeries. It feels familiar and nice
It provides stability and prevention
The therapist taught me so
He can't come in the end position

Is there anything that bothers you about having your wrists taped?
Sometimes getting into new gloves
Gloves are sometimes to tight

4. Results survey goalkeepers

Not really, it is part of my system and does not annoy me. I like the way it feels
When the tape is too tight, I get cold hands in the winter
It is uncomfortable under my gloves, especially at my hand palm
Sometimes when I save a hard ball the tape can cut into my skin by the thumb

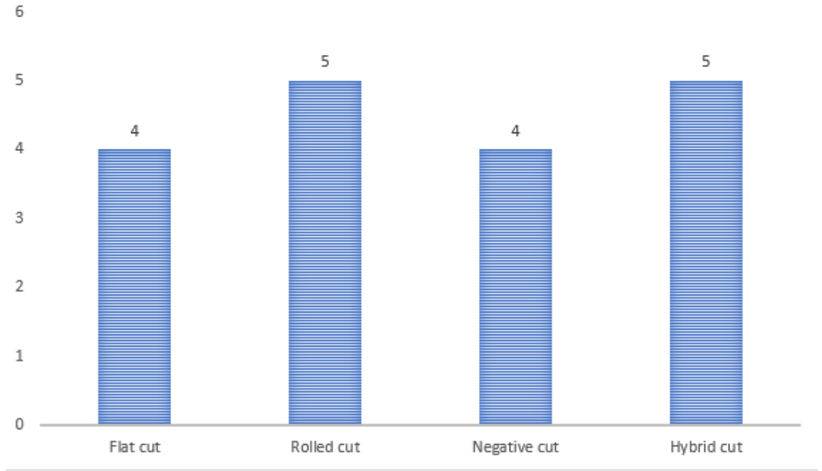
Approximately how many rolls of tape do you think you use in a week?



Why do you not tape your wrists?
Don't like the feeling
It doesn't feel necessary
Lack of tape
No actual reason
I DON'T like tape in my glove, and I don't feel pain
Don't feel the need

4. Results survey goalkeepers

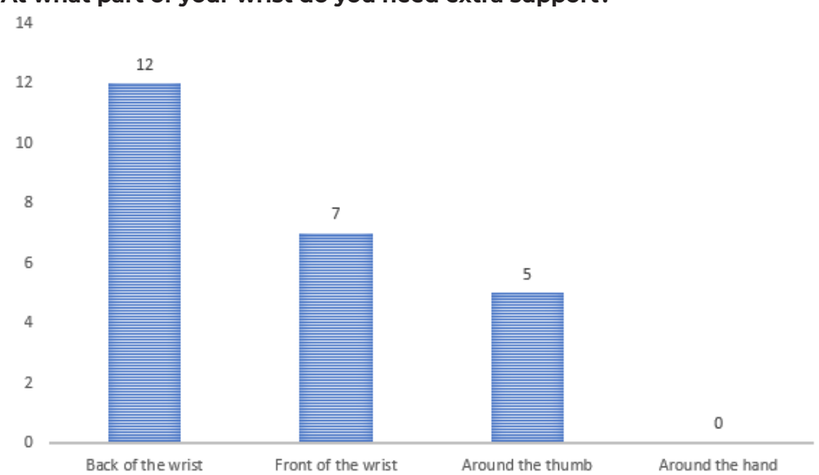
What type of goalkeeping glove do you use?



Why do you use this type of glove?

Most comfortable
Feels nice
More comfortable
Feels nice
It feels comfortable! I like a glove that has no space by the fingers
Good grip. Robust glove but flexible fingers
It's the best fit for me
Most comfortable and soft
Feels comfortable
Control of fingers, best when holding balls
Good feeling about it
This one fits most comfortably
Because the fingers are slightly thinner the ball feeling with the hand is more noticeable
Tight around hand which I like best
It feels good and the brand doesn't have roll finger anymore
Best feeling
It feels right to me
All round grip of the ball

At what part of your wrist do you need extra support?

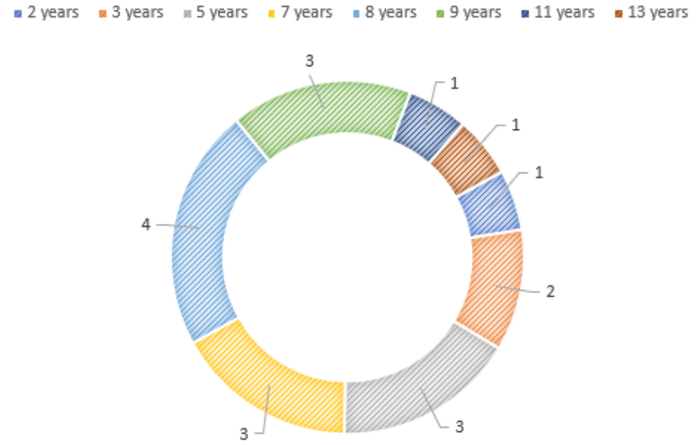


4. Results survey goalkeepers

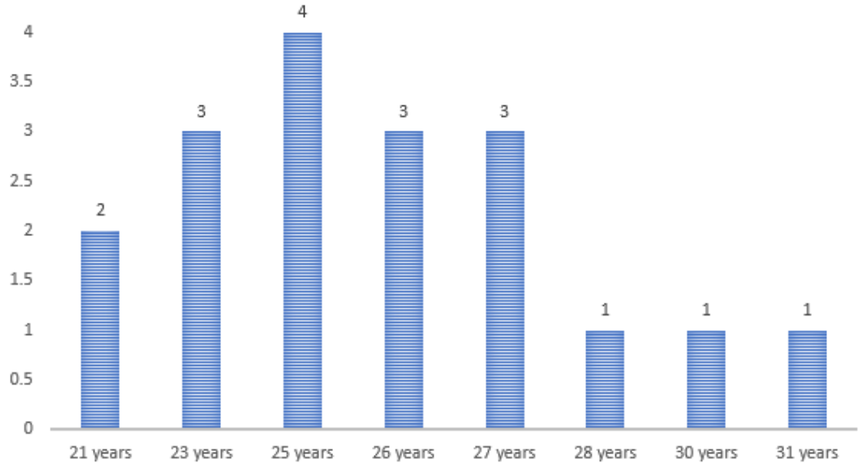
Is there anything we forgot to ask regarding wrist injuries and taping that is important for us to know?

I tape my right wrist as mentioned in the survey, while I tape my left hand only around the wrist.
I only tape my right wrist

How many years have you been playing in the professional soccer league?



What is your age?



5. Wrist joint excursion

Introduction

During the various goalkeeping techniques, explained in chapter “Goalkeeping”, the goalkeeper moves their arms and hands in specific motions in order to perform the techniques correctly. A wrist protector for goalkeepers should allow these movements as not to obstruct their performance. To find out which movements of the wrist the goalkeeper has to be able to make, a test was performed. The results found with this test can be used as guidelines for designing a wrist protector.

Materials and method

The goal of this research was to find the joint excursions of the wrist goalkeepers make during their goalkeeping tasks.

Three male, professional goalkeepers participated in this study. The goalkeepers were all right handed. They were asked to perform five goalkeeping tasks three times. During these tasks, the different movements, extension, flexion, ulnar deviation and radial deviation, are measured in real time using digital goniometers from Biometrics Ltd.

The goalkeeper had to perform the tasks without their goalkeeping gloves. The goalkeeping gloves would obstruct the visibility of the movements as well as influence the results from the goniometers. For the rest the goalkeepers wore their regular apparel: soccer shorts, shirt with either long or short sleeves and gym shoes.

The goniometers were attached to the wrist with skin safe double sided tape on the bottom and a few layers of under-wrap overtop to secure them in place. The wires from the goniometers were guided along the arm, over the shoulders, to the back of the goalkeeper where the blue-tooth module was located. The whole system was attached to a harness to make it easier to put on and take off. The fully equiped system can be seen in Image 72.

Image 72: Equiped system

5. Wrist joint excursion

Image 73: Goalkeeper positioning

Once the goniometers were attached, the goalkeeper was positioned on a fixed spot, 5 meters away from the person shooting the ball, see Image 73. They were asked to perform the following exercises:

- 3x Scooping a low shot ball
- 3x Cupping a torso height ball
- 3x Catching a high ball with the W technique
- 3x Rolling the ball
- 3x Throwing the ball

Each individual task was recorded with the goniometers, which show the angels the wrists make in two directions, ulnar / radial deviation and flexion / extension. A video camera, positioned to film the right side view of the goalkeeper, also recorded the different tasks. From the goniometers the most extreme values were gathered. Together with the videos this was used to qualitatively analyze the movements the goalkeepers make during the various tasks.

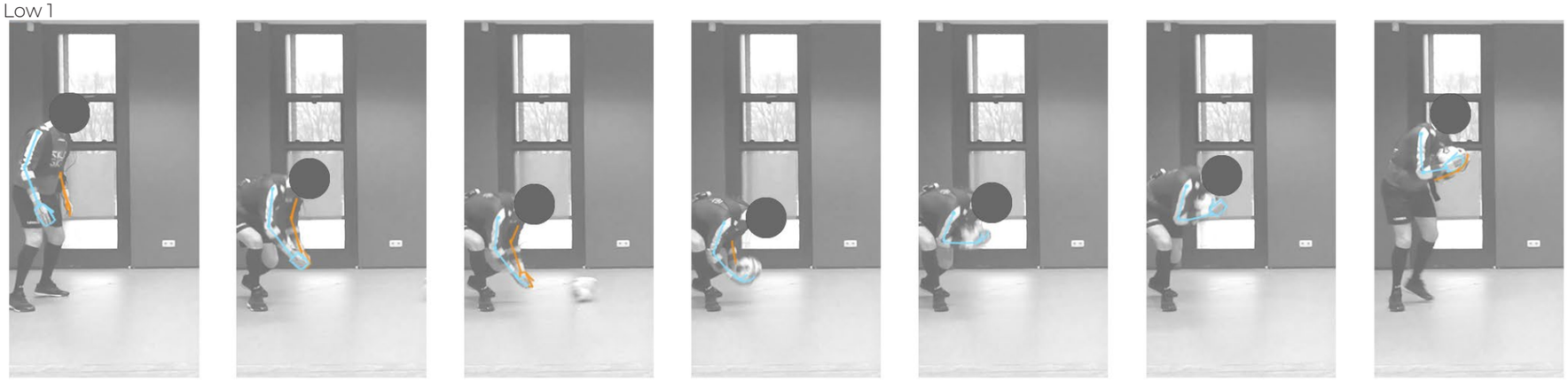
Two of the three goalkeepers had their wrists photographed from all sides in order to create a 3D model using photogrammetry for further development.

5. Wrist joint excursion

Results

Participant 1 video analysis

Low 1



Low 2

Low 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 1 video analysis

Cup 1

Cup 2

Cup 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 1 video analysis

High 1

High 2

High 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 1 video analysis

Roll 1

Roll 2

Roll 3

5. Wrist joint excursion

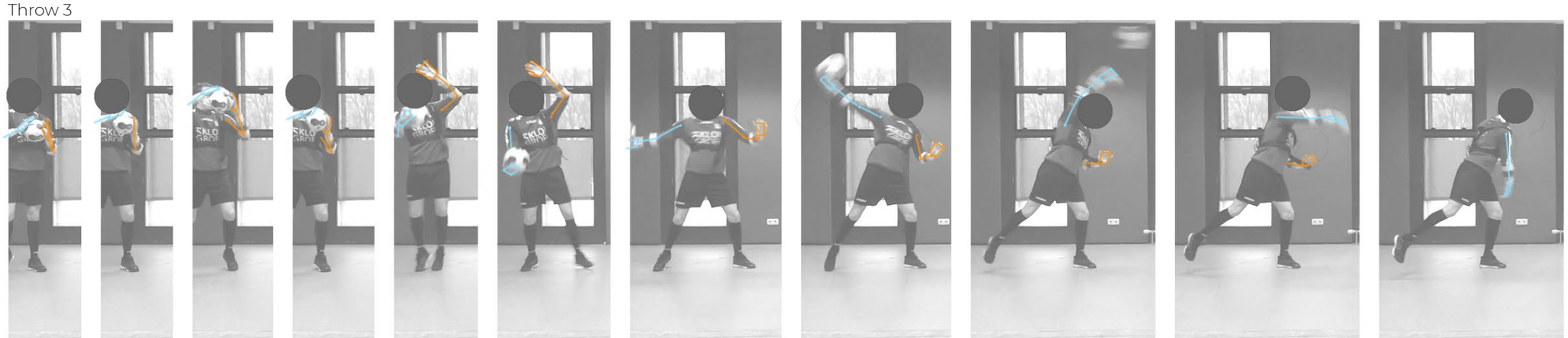
5. Wrist joint excursion

Participant 1 video analysis

Throw 1

Throw 2

Throw 3



5. Wrist joint excursion

5. Wrist joint excursion

Participant 1 goniometer results

Goniometer results for participant 1 during the different goalkeeping tasks and the maximum joint excursion of each task.

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Low 1	20 degrees	54.2 degrees	2.8 degrees	30.3 degrees	-	24.7 degrees	20.8 degrees	33.3 degrees
Low 2	19.4 degrees	1.2	1.9 degrees	31.2 degrees	-	25.4 degrees	17.4 degrees	37.4 degrees
Low 3	18.7 degrees	10 degrees	4.8 degrees	27.3 degrees	4	24.7 degrees	28.6 degrees	47 degrees
Max	20 degrees	54.2 degrees	4.8 degrees	31.2 degrees	4 degrees	25.4 degrees	28.6 degrees	47 degrees

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Cup 1	17.1 degrees	9.9 degrees	-	28.6 degrees	3.9 degrees	23.1 degrees	12.4 degrees	60.6 degrees
Cup 2	5.9 degrees	55.4 degrees	-	32.8 degrees	-	24.2 degrees	11.9 degrees	49.4 degrees
Cup 3	12 degrees	60.7 degrees	3.7 degrees	29.2 degrees	-	25.2 degrees	18 degrees	54.7 degrees
Max	17.1 degrees	60.7 degrees	3.7 degrees	32.8 degrees	3.9 degrees	25.2 degrees	18 degrees	60.6 degrees

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
High 1	41.8 degrees	35.6 degrees	7.8 degrees	21.9 degrees	1.6 degrees	21.5 degrees	47.8 degrees	29.6 degrees
High 2	43.5 degrees	29.9 degrees	12.5 degrees	17.4 degrees	4.5 degrees	21.2 degrees	49.5 degrees	23.9 degrees
High 3	41.5 degrees	34.5 degrees	-	25.8 degrees	0.4 degrees	22.8 degrees	47.5 degrees	28.5 degrees
Max	41.8 degrees	35.6 degrees	12.5 degrees	25.8 degrees	4.5 degrees	22.8 degrees	49.5 degrees	29.6 degrees

5. Wrist joint excursion

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Roll 1	26.1 degrees	53.2 degrees	3.2 degrees	21.9 degrees	-	25.7 degrees	32.1 degrees	47.2 degrees
Roll 2	22.7 degrees	49.3 degrees	2.3 degrees	17.4 degrees	-	25.7 degrees	28.7 degrees	43.3 degrees
Roll 3	31.8 degrees	51.7 degrees	8.2 degrees	25.8 degrees	-	22.8 degrees	37.8 degrees	45.7 degrees
Max	31.8 degrees	53.2 degrees	8.2 degrees	25.8 degrees	-	25.7 degrees	37.8 degrees	47.2 degrees

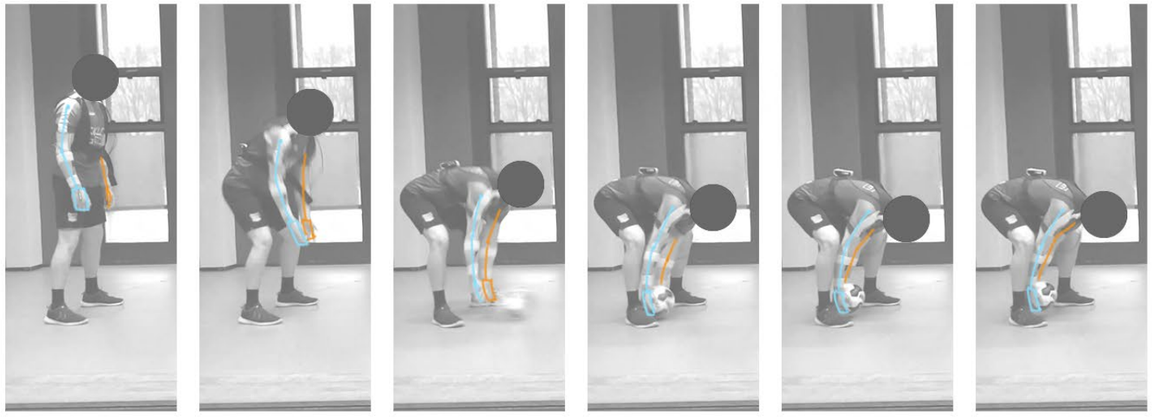
	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Throw 1	48.3 degrees	-	1.1 degrees	28.2 degrees	-	25.5 degrees	23.9 degrees	33 degrees
Throw 2	18.2 degrees	44.3 degrees	3.4 degrees	28.7 degrees	-	26.2 degrees	24.2 degrees	38.3 degrees
Throw 3	29.7 degrees	40.1 degrees	-	28.8 degrees	-	26.4 degrees	35.7 degrees	34.1 degrees
Max	48.3 degrees	44.3 degrees	3.4 degrees	28.8 degrees	-	26.4 degrees	35.7 degrees	38.3 degrees

5. Wrist joint excursion

Participant 2 video analysis

Low 1

Low 2



Low 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 2 video analysis

Cup 1

Cup 2

Cup 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 2 video analysis

High 1

High 2

High 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 2 video analysis

Roll 1

Roll 2

Roll 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 2 video analysis

Throw 1

Throw 2

Throw 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 2 goniometer results

Goniometer results for participant 2 during the different goalkeeping tasks and the maximum joint excursion of each task.

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Low 1	7.9 degrees	21.7 degrees	11.6 degrees	22.3 degrees	5 degrees	19.4 degrees	13.9 degrees	15.7 degrees
Low 2	-	18.3 degrees	6.3 degrees	23.8 degrees	-	15.6 degrees	6 degrees	12.3 degrees
Low 3	2.4 degrees	20.3 degrees	3.9 degrees	26.2 degrees	-	21.4 degrees	8.4 degrees	14.3 degrees
Max	7.9 degrees	21.7 degrees	11.6 degrees	26.2 degrees	5 degrees	21.4 degrees	13.9 degrees	15.7 degrees

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Cup 1	45 degrees	50.5 degrees	8.6 degrees	15 degrees	corrupt	corrupt	corrupt	corrupt
Cup 2	35.3 degrees	43.8 degrees	7.3 degrees	13 degrees	7 degrees	28 degrees	16 degrees	53.1 degrees
Cup 3	31.5 degrees	49.3 degrees	12.3 degrees	17.5 degrees	0.6 degrees	29.2 degrees	13 degrees	68.3 degrees
Max	45 degrees	50.5 degrees	12.3 degrees	32.8 degrees	7 degrees	29.2 degrees	16 degrees	68.3 degrees

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
High 1	61.8 degrees	-	6.4 degrees	20.8 degrees	5.2 degrees	13.1 degrees	67 degrees	1 degrees
High 2	62.6 degrees	12.7 degrees	14.7 degrees	21.7 degrees	5.5 degrees	11.1 degrees	65 degrees	-
High 3	58.5 degrees	-	9.8 degrees	18.8 degrees	3.3 degrees	12.6 degrees	61.8 degrees	-
Max	62.6 degrees	12.7 degrees	14.7 degrees	21.7 degrees	5.5 degrees	13.1 degrees	67 degrees	1 degrees

5. Wrist joint excursion

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Roll 1	40.3 degrees	-	20.2 degrees	-	0.4 degrees	29.1 degrees	17.4 degrees	51 degrees
Roll 2	42.9 degrees	7.1 degrees	24.6 degrees	-	-	29.6 degrees	16.1 degrees	55.3 degrees
Roll 3	41.2 degrees	-	27.1 degrees	-	-	28.9 degrees	12.9 degrees	54.7 degrees
Max	42.9 degrees	7.1 degrees	27.1 degrees	-	0.4 degrees	29.6 degrees	17.4 degrees	55.3 degrees

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Throw 1	43.9 degrees	24 degrees	15.6 degrees	6.8 degrees	10.7 degrees	27.7 degrees	21.9 degrees	52.7 degrees
Throw 2	25.8 degrees	23.5 degrees	5.2 degrees	5.5 degrees	9.8 degrees	26.3 degrees	23.7 degrees	51.6 degrees
Throw 3	11.6 degrees	37.4 degrees	32.5 degrees	-	-	27.1 degrees	5.3 degrees	54.1 degrees
Max	43.9 degrees	37.4 degrees	32.5 degrees	5.5 degrees	10.7 degrees	27.7 degrees	23.7 degrees	54.1 degrees

5. Wrist joint excursion

Participant 3 video analysis

Low 1

Low 2

Low 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 3 video analysis

Cup 1

Cup 2

Cup 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 3 video analysis

High 1

High 2

High 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 3 video analysis

Roll 1

Roll 2

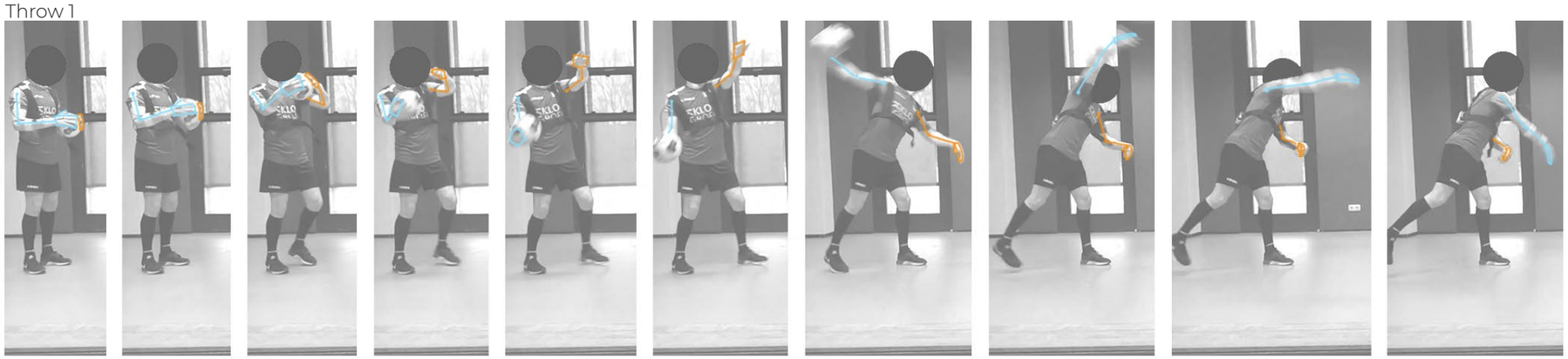
Roll 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 3 video analysis

Throw 1



Throw 2

Throw 3

5. Wrist joint excursion

5. Wrist joint excursion

Participant 3 goniometer results

Goniometer results for participant 3 during the different goalkeeping tasks and the maximum joint excursion of each task.

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Low 1	30.6 degrees	11.1 degrees	-	15.4 degrees	9.1 degrees	17.3 degrees	26.5 degrees	36.7 degrees
Low 2	38 degrees	-	2.9 degrees	15.5 degrees	9.7 degrees	9.7 degrees	38 degrees	1.6 degrees
Low 3	35 degrees	7.6 degrees	3.1 degrees	16.2 degrees	18.6 degrees	18.6 degrees	34.6 degrees	-
Max	38 degrees	11.1 degrees	3.1 degrees	16.2 degrees	18.6 degrees	18.6 degrees	38 degrees	36.7 degrees

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Cup 1	11.8 degrees	72.3 degrees	6.5 degrees	18.3 degrees	-	33.9 degrees	12.6 degrees	66.5 degrees
Cup 2	13.2 degrees	72.8 degrees	7.3 degrees	19 degrees	-	23.1 degrees	14.2 degrees	67 degrees
Cup 3	16.7 degrees	78.7 degrees	14.1 degrees	17.2 degrees	-	24.4 degrees	13.7 degrees	62.7 degrees
Max	16.7 degrees	78.7 degrees	14.1 degrees	19 degrees	-	33.9 degrees	14.2 degrees	66.5 degrees

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
High 1	33 degrees	17.6 degrees	18.9 degrees	17.9 degrees	1.8 degrees	21 degrees	62 degrees	5.4 degrees
High 2	31.5 degrees	19.5 degrees	19.1 degrees	17.3 degrees	1.9 degrees	17.5 degrees	56.9 degrees	16.1 degrees
High 3	34.7 degrees	6.6 degrees	9.1 degrees	20.7 degrees	1 degrees	17.4 degrees	55.7 degrees	40.7 degrees
Max	34.7 degrees	19.5 degrees	19.1 degrees	21.7 degrees	1.9 degrees	17.5 degrees	67 degrees	40.7 degrees

5. Wrist joint excursion

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Roll 1	9.6 degrees	16.5	-	20.8 degrees	-	23.4 degrees	5.3 degrees	45.2 degrees
Roll 2	8.9 degrees	9.3 degrees	-	16.2 degrees	-	26.5 degrees	9.8 degrees	37.2 degrees
Roll 3	8.7 degrees	14.9 degrees	-	21.3 degrees	-	26.6 degrees	13.3 degrees	32.4 degrees
Max	9.6 degrees	16.5 degrees	-	21.3 degrees	-	26.6 degrees	13.3 degrees	45.2 degrees

	L Ulnar	L Radial	L Extension	L Flexion	R Ulnar	R Radial	R Extension	R Flexion
Throw 1	15.7 degrees	49.3 degrees	8.6 degrees	15.5 degrees	-	21.1 degrees	16.5 degrees	43.2 degrees
Throw 2	17.5 degrees	42.2 degrees	5.8 degrees	14.6 degrees	-	19.8 degrees	19.2 degrees	36.8 degrees
Throw 3	8.4 degrees	45.7 degrees	8.9 degrees	19.1 degrees	-	20.2 degrees	6.1 degrees	34.1 degrees
Max	17.5 degrees	45.7 degrees	8.9 degrees	5.5 degrees	-	21.1 degrees	19.2 degrees	43.2 degrees

5. Wrist joint excursion

Discussion

Participant 1

The goalkeepers' non-dominant hand (left) almost never moves into extension.
His dominant hand only moves into ulnar deviation mildly.

Analysis Low:
When the goalkeeper has to catch a ball that is shot low to the ground, he first bends his knees hunching his body forwards. While doing this the goalkeeper turns his hands outwards to create a cup for the ball to roll into. To create this cup, the goalkeepers' hands move slightly into extension and ulnar deviation. The right hand moves more into these movements than the left.

Once the ball has rolled onto his hands, the goalkeeper first moves his hands towards his body by flexion of the wrist. Afterwards he folds his underarms towards his body as well. This locks the ball between his arms and his upper body. When hugging the ball towards their body, the goalkeepers' wrists are in flexion and radial deviation. His left hand is on top of his right hand, explaining the high radial deviation in this hand.

For easier balls, the goalkeeper does not roll his arms fully towards his body. Instead, he can step forward to redistribute the ball back into the field immediately.

Analysis cup:
When catching a ball at torso height with the cup technique the goalkeeper slightly bends through his knees and moves his underarms up, 90 degrees to the body. As he moves his arms up, his hands move closer together and outward to create a cup similar as in the previous technique. There is slight extension of the wrists moving into this position.

He then catches the ball between his arms and torso, locking it in place. As he catches the ball, his hands move into flexion at the wrist. Resulting in flexed, radially deviated wrists when the ball is caught, similar to the previous technique. As the ball is shot more to one side of the goalkeeper, the body of the goalkeeper has to face more towards it. This influences the deviation of the wrist.

Analysis high:
The goalkeeper moves his arms up, bringing his thumbs together. His hands are in slight extension and radial deviation. His right hand has a more extreme extension than his left. This can be explained by the goalkeeper placing his right hand almost directly behind the ball, to stop it, while his left hand is more towards the side of the ball, to guide it. This also explains the larger ulnar deviation of the left hand.

Analysis roll:
When rolling the ball, the goalkeeper positions the ball into his dominant hand (right). He moves his arm backwards, keeping his hand in flexion to keep the ball in his grip. When moving his arm backwards his hand also moves into radial deviation. As he swings his dominant arm forwards, he releases the ball and moves his hand back into a neutral position.

During this, his non-dominant hand is in front of his torso. His hand is relaxed, in a slight flexion position, left to move freely in ulnar and radial deviation.

Analysis throw:
When throwing the ball, the goalkeeper first positions the ball with both his hands. His dominant (right) hand is laying on top of the ball with an extended wrist. His left-hand lays loosely on the front of the ball with a slightly flexed wrist to keep the ball in between his hands.

The goalkeeper moves his right arm down and left arm up. His right hand moves into flexion, to keep the grip on the ball. As he rotates his right arm forwards to throw the ball his right hand moves into radial deviation.

The goalkeepers' left arm is used as a counterweight. As the right arm moves down, the left arm moves up and vice versa. When his left arm is up, his hand is bent backwards in radial deviation and flexion. As his arm moves down the hand stays in flexion but moves from radial deviation into ulnar deviation.

5. Wrist joint excursion

Participant 2

His dominant hand (right) almost never moves into ulnar deviation.

Analysis low:
To catch a ball that has been shot low to the ground, the goalkeeper slightly bends through his knees. He hunches forward, moving his hands towards the ground. He turns his hands outwards, bringing his little fingers towards each other. Moving towards the ground his hands are in slight extension and radial deviation.

As the ball gets closer, he angles his hands and underarms forwards to create a slight ramp for the ball to roll onto. As the ball hits his hands, he moves his underarms slightly towards himself, cupping the ball in his arms to catch it. From the moment the ball hits his hands, he moves into flexion of the wrist. If the ball is caught more to the right side of the body, the left hand has more flexion and vice versa.

Analysis cup:
For cupping a ball at torso height the goalkeeper hunches forward slightly. He moves his underarms up to create a 90 degrees angle with his body with his elbows slightly outwards. He moves his left arm up slower than his right. He turns his hands so that the back of his hands is facing the ground. His hands move from slight extension into slight flexion to create a cup for the ball to fall into.

As the ball hits his upper arms and torso, he moves his underarms towards his body and wraps his hands around the ball through flexion of the wrist. This locks the ball between his arms and torso. In As he holds the ball his hands are in slight radial deviation due to his elbows being outwards.

Analysis high:
To catch a high ball, the goalkeeper moves his arms up creating an almost 90 degrees angle between his body and his upper arms. His elbows are bent slightly. He moves his hands to be in line with the ball, thumbs touching. As he moves his arms up, his hands move from slight flexion into slight extension. To keep his thumbs and index finger close together his hands have slight radial deviation. His left hand catches the ball more to the side than to the back. This causes ulnar deviation as he brings the ball closer to his body.

Analysis roll:
When rolling the ball into the field, the goalkeeper moves the ball into his right hand. He turns the back of his right hand towards the ground to keep the ball in his hand. He moves his arm backwards while keeping his hand underneath the ball through flexing it at the wrist. As he moves his arm forwards again to roll the ball, his hand flexes less and less eventually releasing the ball. During this movement he has some slight radial deviation in his wrist.

His left hand is kept relaxed. As he moves his right arm backwards, his left arm moves down to rest his hand on his knee. This causes the hand to be slightly flexed. He steps his right foot backwards, bending through his left knee. Bending through this knee makes his elbow move outwards while his hand remains in line with his knee. This causes ulnar deviation of his left hand.

Analysis throw:
To throw the ball, the goalkeeper moves the ball into his right hand. He moves his right arm backwards while keeping his hand underneath the ball. To do this he has to flex his wrist to keep the ball in his hand. As he rotates his arm forwards again to throw the ball, his right hand must be radially deviated to keep the right trajectory of the ball.

His left hand is used to counterbalance the movement. He moves his left arm up with his under arm in front of his body. As he throws the ball, his left arm moves together with his body. This causes his arm to move down as he bends forwards to throw the ball. His left wrist is left relaxed, allowing it to move freely.

Participant 3

Analysis low:
For a ball that is shot low to the ground, the goalkeeper steps his right foot backwards, using it as an extra tool to block the ball. His left knee is bent. The goalkeeper hunches forwards, moving his hands towards the ground. He turns his hands outwards, little fingers touching. His hands are slightly flexed to create a ramp for the ball.

As the ball touches his hands, he moves his wrists into extension to stop the ball. He moves his wrists back into flexion to scoop the ball up from the ground.

Analysis cup:
When cupping torso height balls, the goalkeeper stretches his underarms forwards to create an almost 90 degrees angle with his body. His elbows are positioned slightly away from the body. He rotates the palms of his hands towards the ceiling. This creates a platform for the ball to fall onto. As the ball hits his arms, he moves his underarms towards his body, locking the ball between his arms and his torso. His wrists are flexed around the ball to securely keep it in place.

Analysis high:
To catch a high ball, the goalkeeper moves his arms up. He creates a 90 degrees angle with his upper arms and his body. His arms are bent at the elbow so that his hands are in line with his face. As he moves his arms up, his hands move from flexion into extension.

Analysis roll:
To roll the ball into the field, the goalkeeper moves the ball into his right hand. He moves his right arm backwards while keeping his hand underneath the ball. To do this his right wrist has to be flexed to create a cup for the ball. He steps his right foot backwards, bending through his left knee to get closer to the ground. As the goalkeeper moves has right arm forwards again to roll the ball, his wrist flexes less and less eventually releasing the ball.

His left arm is left to the side of his body. As the goalkeeper moves closer to the ground, he lifts his left arm by bending it at the elbow. His left hand is relaxed during these movements, in a slightly flexed position.

Analysis throw:
When throwing the ball, the goalkeeper moves the ball into his right hand. He moves his arm backwards while keeping his hand underneath the ball. This is done by slight flexion of the wrist which creates a cup for the ball. He rotates his arm forwards again, creating momentum for the ball. As he reaches the highest point of the arc, the ball is released by flexing the wrist less. When rotating his arm forwards his hand needs to radially deviate slightly to keep the trajectory of the ball.

His left arm is used as counterbalance for the movement. As his right arm moves down, his left arm moves up. As his right arm moves up again to throw the ball, his left arm moves down and in front of his torso. During this his wrist moves from slight extension when his arm is at the top and into flexion when his arm is in front of his torso. As he moves his left forearm towards his torso, his wrist moves into radial deviation.

Overall analysis

Looking at the different performances of one goalkeeper performing one of the tasks, it can be seen that there is some variety in the way the wrist moves in order to catch the ball. This is mostly influenced by the side to which the ball is shot, more to the left or right side of the body, and the difficulty to catch the ball. For example for the first participant there is a large difference in flexion of the right wrist between different tries of catching a low ball. This can be explained by the goalkeeper locking the ball between his arms and his torso to get a secure grip on it.

Between the goalkeepers there are also similarities and differences in the wrist excursion for similar tasks. These are mostly influences by the technique used. These similarities and differences as well as the insights found within one keeper will be explained for each task.

Wrist excursion low shot ball
For catching a low shot ball, the goalkeeper moves his arms and upper body towards the ground. Two of the three goalkeepers stepped one foot back and bent through the other. The third goalkeeper bent slightly through his knees and covered the rest of the distance towards the ground by hunching over.

All goalkeepers then turn their hands outwards to create a ramp or cup for the ball to roll into. When turning their hands the goalkeepers hand are mostly relaxed, they either have a very slight extension or very slight flexion in their wrists.

The third participant extended his wrists as he stopped the ball and moved them into flexion to pick the ball

5. Wrist joint excursion

up from the ground. The other two goalkeepers kept their wrists in flexion while stopping and scooping the ball from the ground.

After the ball has been stopped by the goalkeeper, they can either lock it between their torso and arms to create a firm grip such as participant number one or immediately distribute the ball back into the field. A faster ball or more difficult to catch shot might require the goalkeeper to lock the ball. This locking of the ball causes a more extreme flexion of the wrist.

Image 74: Cupping towards one side

Wrist excursion cupping ball
For cupping a ball, all three goalkeepers moved their forearms up and turn the palms of their hands towards the ceiling. During this movement the goalkeepers move their wrists into slight extension.

As the ball hits their arms and torso, they move their forearms inwards to lock the ball between their arms and their torso. To lock the ball in place, the goalkeepers wrap their hands around the ball, moving their wrists into flexion. Since the goalkeepers elbows are slightly outwards during this, their wrists are radially deviated. When the ball is shot more to one side the goalkeepers face their body towards it. This can influence the deviation of the wrist, see Image 74.

During this task, all goalkeepers had more radial and ulnar deviation in their non dominant hand than in their dominant hand. This can be explained by the goalkeepers first cupping the ball with their right hand around the ball and finishing the movement by placing their left hand slightly on top of their right.

Wrist excursion W technique
During the W technique, the goalkeepers move their arms up, bringing their thumbs together. Their upper arms are almost perpendicular to their body. Their elbows are bent so that their hands are in front of their face. Their hands are in slight extension and radial deviation. As the ball hits their hands their wrists stay in extension.

Image 75: Rolling the ball - Hand underneath the ball

Wrist excursion rolling the ball
To roll the ball, the goalkeepers move the ball into their right hand. They move their arm backwards while keeping their hand underneath the ball. This results in a flexed wrist, see Image 75. When they move their arm back, their wrist is radially deviated to create the correct trajectory for the ball.

They step their right foot backwards and bend through their left knee. They move their arm forwards again decreasing the flexion in their wrist to eventually release the ball.

Their left hand is not needed for this task. Two of the goalkeepers moved this hand in front of their torso in a relaxed, slightly flexed position. The third goalkeeper places his left hand on top of his left knee, extending it.

Wrist excursion throwing the ball
Similar to the previous task, the goalkeepers move the ball into their right hand in order to start throwing it. They move their right arm backwards while keeping their hand underneath the ball. This causes a flexed and slightly radially deviated wrist. They rotate their arm forwards and up releasing the ball at the highest point by decreasing the flex in their wrist.

The left hand is used to counter balance the movement. Two of the three goalkeepers move their left arm up and rotate it down as their right arm rotates up. The third goalkeeper does not move his arm all the way up, but only to shoulder height. As they finish the movement their hand moves towards their torso in a relaxed position.

5. Wrist joint excursion

Conclusion

From this test can be concluded that there are lot of factors that influence the joint excursion during the different tasks and between the goalkeepers. However, there are still similarities in the joint excursion of the wrist. These similarities can be used to evaluate the functionality of a to be designed wrist protector.

During all the tasks the most prominent joint excursion was in the flexion and extension direction. Deviation took place in several instances mostly in the non-dominant hand. The test also showed that the goalkeepers need free movement in the flexion direction in order for them to roll and throw the ball.

There are some limitations to the performed test that influenced the results gathered. First of all, the goniometer results show extreme joint excursion angles. In some instances these angles are bigger than would be possible according to the DINED measurements. Because of this variety in results the goniometer results cannot be evaluated separately but have to be evaluated together with the footage. On this footage the excursion in deviation direction is more difficult to see, increasing the difficulty of drawing conclusions from them. A way to increase the accuracy of the goniometers would be to perform a null measurement in which the goalkeeper moves their wrist into maximum excursion in each direction.

A second factor that influenced the results was the variety in the goalkeeping techniques used. The goalkeepers used their own preferred technique which result in a large variety in goniometer results. By comparing these results with the recorded footage the variety in goniometer results could be evaluated and explained. In order to gather more accurate results the goalkeepers should be asked to perform the task with a specific technique.

6. Persona

A persona created based on the questionnaire results shown in appendix “4. Results survey goalkeepers”. The persona is used as a guide for gathering insights and exploring ideas to create a wrist protector for professional goalkeepers.

Personalia

- 25 years old
- 7 years of experience
- 2 wrist injuries
- 6 days a week playing soccer
- 3 rolls of tape used a week

Bio

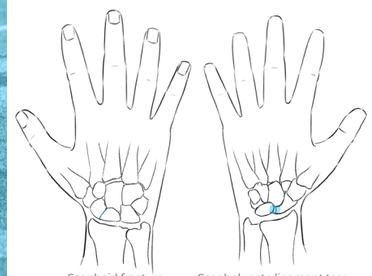
“Mark Hatting is a professional goalkeeper. He has been playing in the professional league for 7 years. During this period he has sustained two wrist injuries due to a hard shot against his hands. To prevent future injuries he tapes his wrists before each practice and competition.”

Wants & Needs

- Safely catch high impact balls
- Support the back of his wrists
- Perform at the top of his abilities
- Have freedom of movement of his hands
- Use comfortable equipment

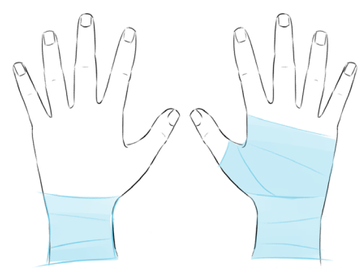
Frustrations

- Gloves can be too tight when taping
- Balls are shot with high speeds
- Balls can swerve, making them unpredictable



Scaphoid fracture | Scapholunate ligament tear

Wrist injuries



Around the wrist | Whole wrist and hand

Taping method

7. Prototyping process

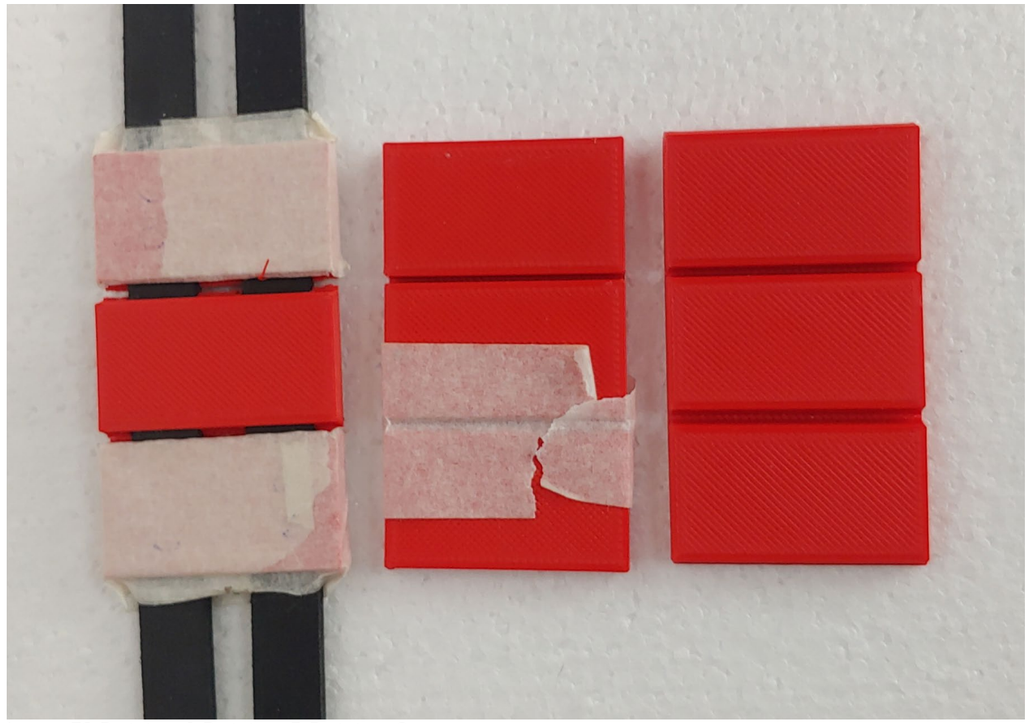


Image 76: Prototype 1, Prototype 3, Prototype 2

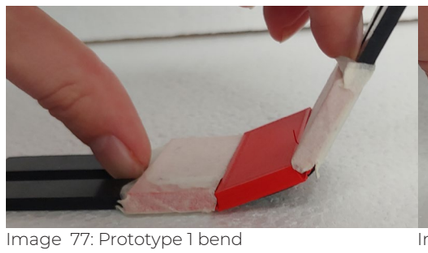


Image 77: Prototype 1 bend

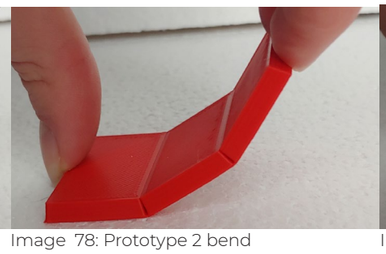


Image 78: Prototype 2 bend

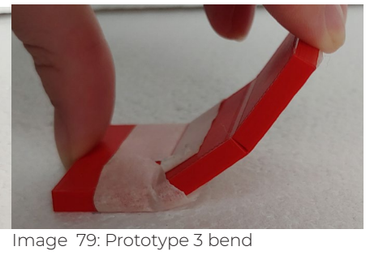


Image 79: Prototype 3 bend

Prototype 1
Flat piece with slits at 10 degrees. Viton rubber 3 mm thick inserted into the piece. Printed in PLA

- Rubber makes the piece spring back slightly towards its original position
- 10 degrees has to much freedom of movement, still able to move towards hyper extension
- A flexible piece such as rubber will not limit the movement

Prototype 2
Flat piece with slits at 10 degrees. No rubber, printed in PLA

- 10 degrees has to much freedom of movement, still able to move towards hyper extension
- No rubber prototype has less resistance than prototype with rubber

Prototype 3
Flat piece with slits at 5 degrees. No rubber, printed in PLA

- Movement is restricted more, no longer able to move to hyper extension
- Flat piece has a lot of gaps between pieces and wrist

7. Prototyping process

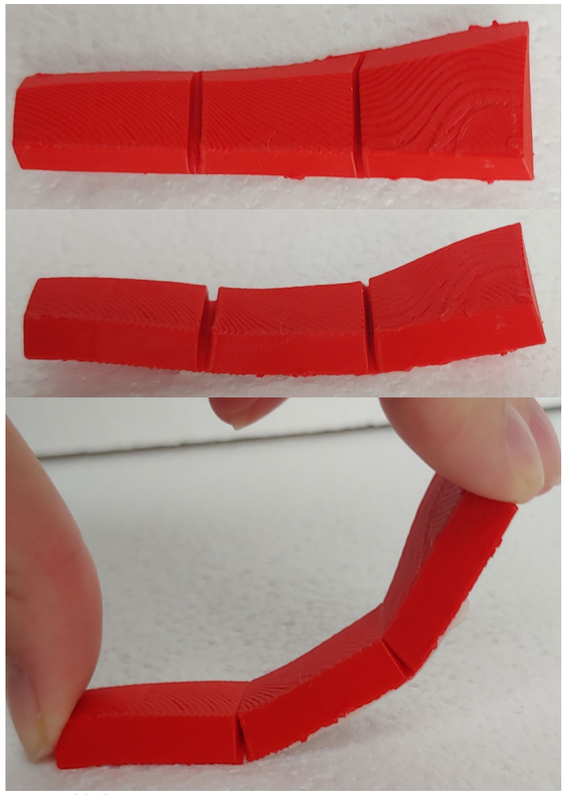


Image 80: Prototype 4

Image 81: Prototype 5

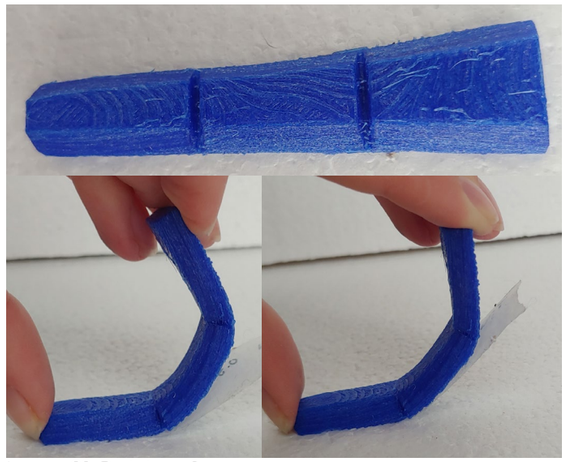


Image 82: Prototype 6

Prototype 4
1/3 of back of hand piece. Fit to the wrist and hand. 1 mm between the partitions, bottom layer 0.5 mm thick. No rubber. Printed in PLA

- Piece cuts into arm during extension
- 0.5 mm gives enough resistance
- 0.5 mm might break easily because of its low thickness
  Middle partition should be positioned on top of wrist joint

Prototype 5
1/3 of back of hand piece. Fit to the shape of the wrist and hand. 0.5 mm bottom layer. 0.5 mm between partitions. Middle partitions positioned over wrist joint. No rubber, printed in PLA

- Limits movement sufficiently
- Back of partition cuts into arm
  Piece can take up more space on back of hand to distribute the load more evenly
  Middle piece should stay in contact with the arm/ wrist to limit the movement, other parts can shift a little

Prototype 6
1/3 of back of hand piece. Fit to the shape of the wrist and hand. 0.5 mm bottom layer. 0.5 mm between partitions. Middle partitions positioned over wrist joint. Printed in TPU (Rubber)

- Less obtrusive into cutting into the hand and arm
- Too much freedom of movement due to extension of the material between the partitions

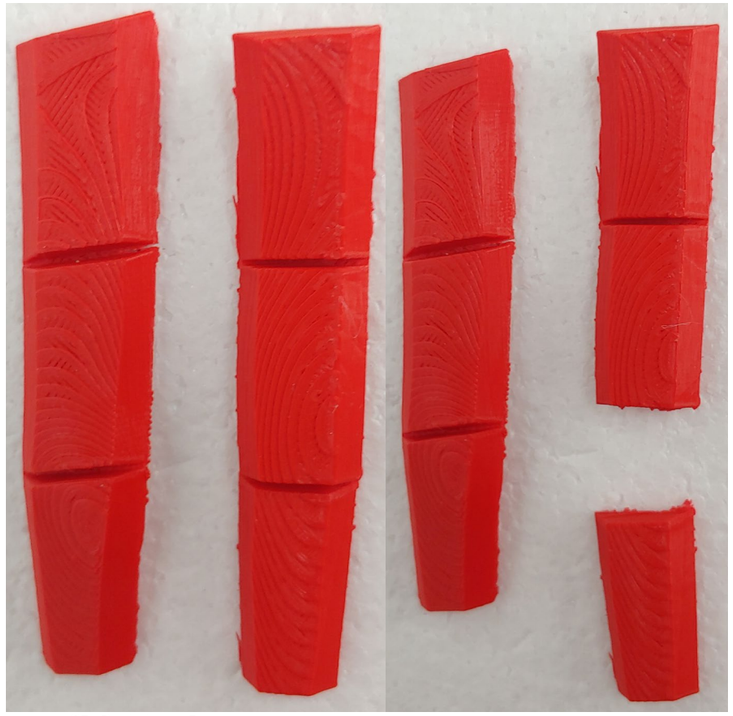


Image 83: Prototype 7

Image 84: Prototype 8

Prototype 7

2 pieces of the back of the wrist fit to the shape of the wrist and hand. 1mm bottom layer. 0.5 mm between the layers. Printed in PLA

- 1mm bottom layer makes the piece stiff, resulting in breaking of the PLA. Too stiff to comfortably move?
- Last partition does not move towards middle partition due to stiffness of the bottom layer
- Print is “messy”
- Shape fits nicely to the hand

Prototype 8

1/3 of the back of hand pieces. 1mm bottom layer. 0.5 mm between layers (PLA). Changed print orientation.

- Print looks and feels cleaner, smooth surfaces
- 1 mm bottom layer still too stiff, no movement in the bottom partition resulting in it instantly cutting into the arm

Image 85: Prototype 9 glove

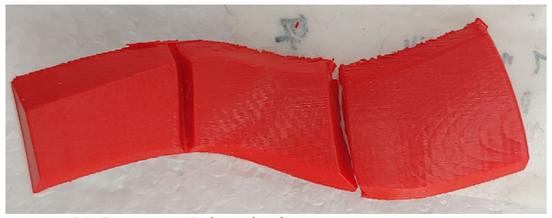


Image 86: Prototype 9 thumb piece

Prototype 9

Back of hand pieces scaled to fit smaller hand + thumb piece. 1mm bottom layer. 0.5 mm between layers. Taped onto thin piece of “celrubber”. Piece is taped to a glove made of a compression sleeve for the leg.

- Glove stays on the hand nicely due to it being tight
- Movement left to right is unobstructed
- Extension is limited to a certain degree but not fully
- Tape is not strong enough to hold the pieces together
- Glove is too tight
- Thumb piece has too much curvature, obstructing movement, resulting in the piece breaking
- Pieces do not bend during flexion, lifting the glove from the hand
- Pieces cut into arm during extension
- Distance between the pieces was guessed
- Middle piece moves away from wrist during flexion, leaving a space between piece and wrist and limiting extension less

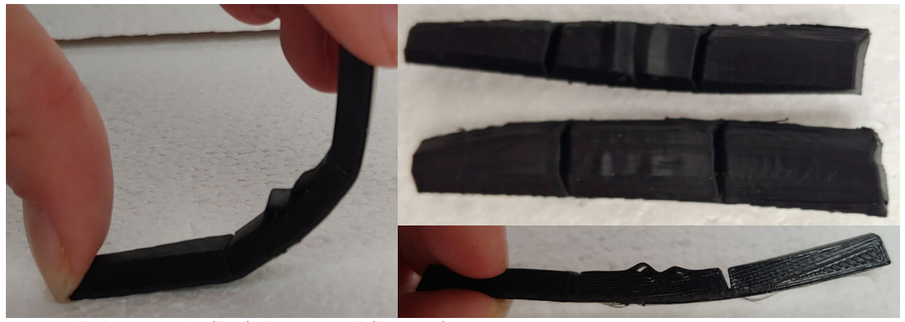


Image 87: Prototype 10 (Top) , Prototype 11 (Bottom)

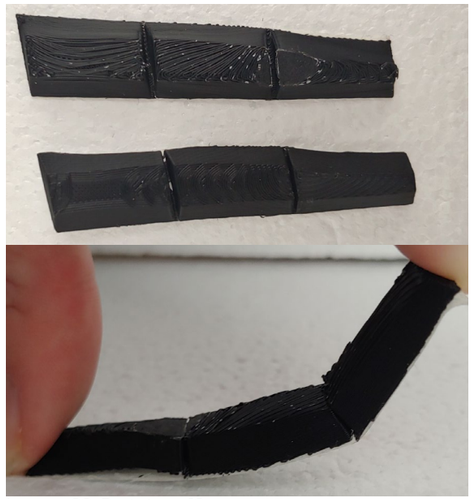


Image 88: Prototype 12

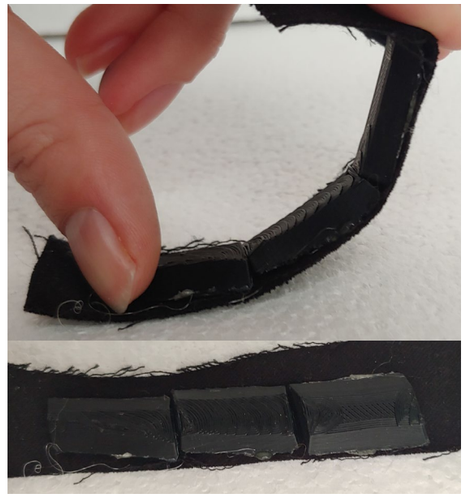


Image 89: Prototype 13

Prototype 10
1/3 of back of hand piece printed in PP. 1 mm bottom layer, 20% infill

- Layers did not fully merge, letting go of each other when bend
- Because of flexibility of printed material and possibly the infill percentage the piece does not restrict enough (too much bending, like TPU)

Prototype 11
1/3 back of hand piece printed in PP. 1 mm bottom layer, 80% infill

- Layers did not fully merge
- Even with higher infill percentage the material is still too flexible

Prototype 12
1/3 back of hand piece printed in ABS. 1 mm bottom layer

- Rough top or bottom surface due to print orientation that is needed for a successful print
- Hinge parts lose structural integrity after bending it only once

Prototype 13
1/3 back of hand piece not connected with bottom layer. Cotton non stretch fabric used to connect the pieces.

- Bending movement towards flexion is not restricted at all
- Extension is still limited sufficiently

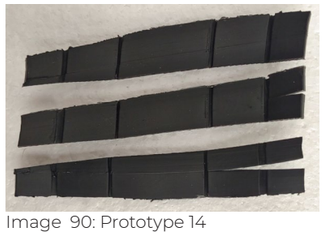


Image 90: Prototype 14

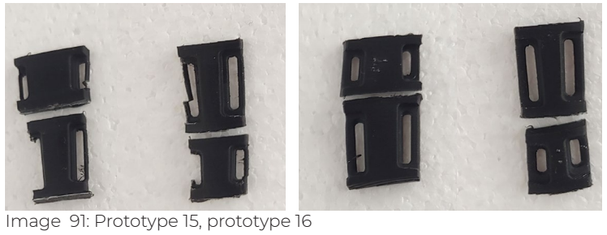


Image 91: Prototype 15, prototype 16

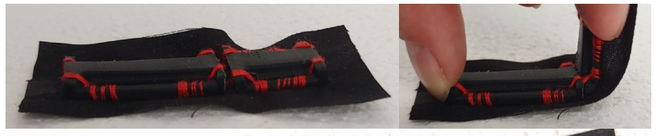


Image 92: Prototype 17, 18, 19

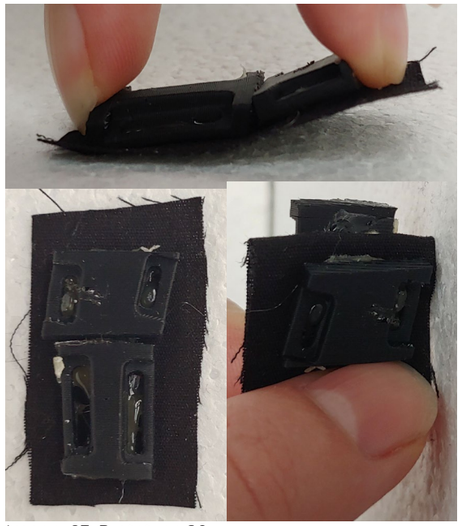


Image 93: Prototype 20

Prototype 14
All 3 back of hand pieces. More divisions in the pieces with varying widths. Middle piece widest. Printed in ABS. 0.5 mm bottom layer.

- More divisions allow for more gradual movement in line with the shape of the wrist
- ABS is splitting at the layers
- Hinges are fragile

Prototype 15, 16
Separated the divisions, created holes to attach pieces to fabric. Test to find right distance of hole outer wall. Printed in ABS.

- Hole outer wall should be 1 mm or more to create a strong enough wall

Prototype 17, 18, 19
Separate pieces connected to fabric, 1 mm between the pieces. Printed in ABS with cotton non stretch fabric underneath.

- Too much movement between the pieces, not limiting the extension movement, pieces can move on
- top of each other
- Shortest sides are not connected to the fabric, causing the pieces to be able to shift

Prototype 20
Separate pieces connected to fabric, pieces placed closer together during assembly, height of pieces increased to 4 mm.

- The pieces no longer move on top of each other
- The pieces have a set maximum extension
- Shortest sides are not connected to the fabric, causing the pieces to be able to shift

7. Prototyping process

Image 94: Prototype 21

Prototype 21

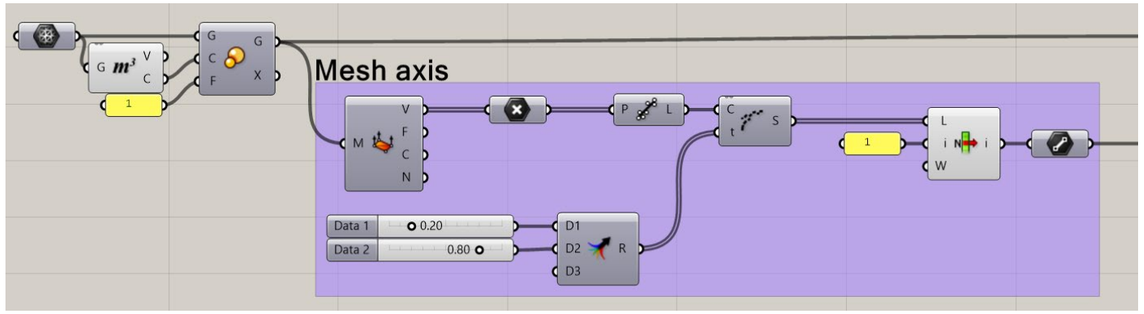
Full glove with protection pieces, sized for male goalkeeper, no rubber added to the glove. Glove made out of compression sleeve. (Evaluated with Norbert Alblas)

- The whole glove is nice and thin, would easily fit underneath a goalkeeping glove
- When glove is held to the hand the limiting effect can clearly be felt
- The wrist protection limits the extension movement sufficiently
- Flexion direction is completely free to move
- Glove needs to be held to the hand to keep the pieces from bulging up
- Glove is not tight enough around wrist
- Stretch fabric from the glove causes the pieces to bulge up, digging into the skin
- ABS prints break on the layer lines
- Protection pieces are not sewn on aligned to the wrist

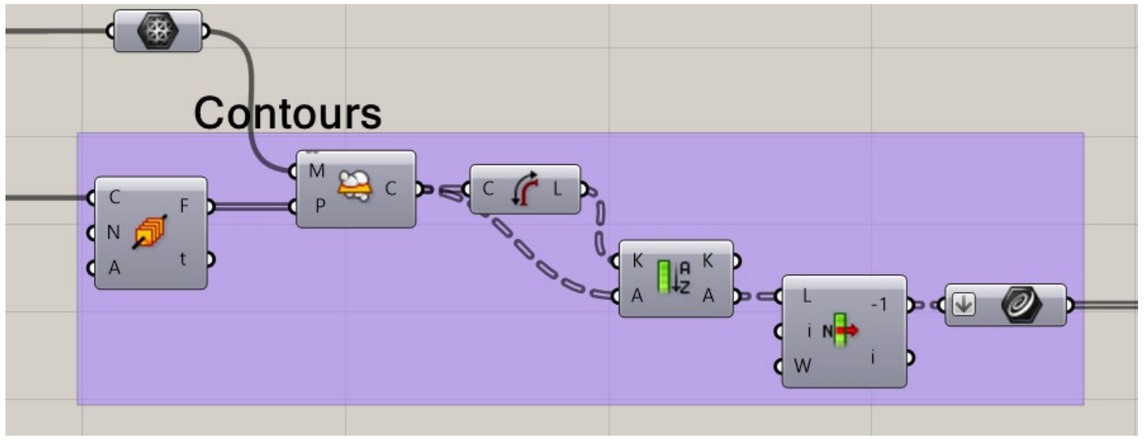
8. Grasshopper

Processing the 3D scan mesh

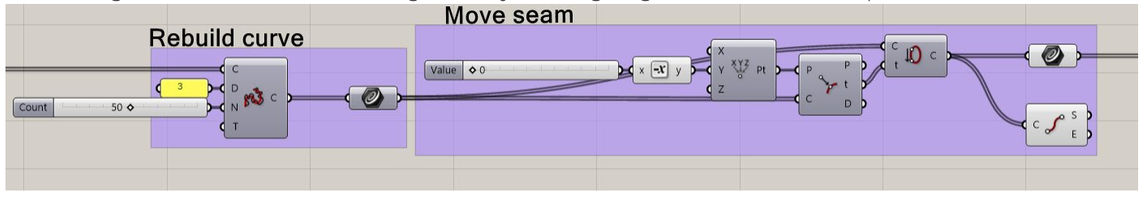
Finding the axis of the mesh and selecting the part of the mesh that should be used.



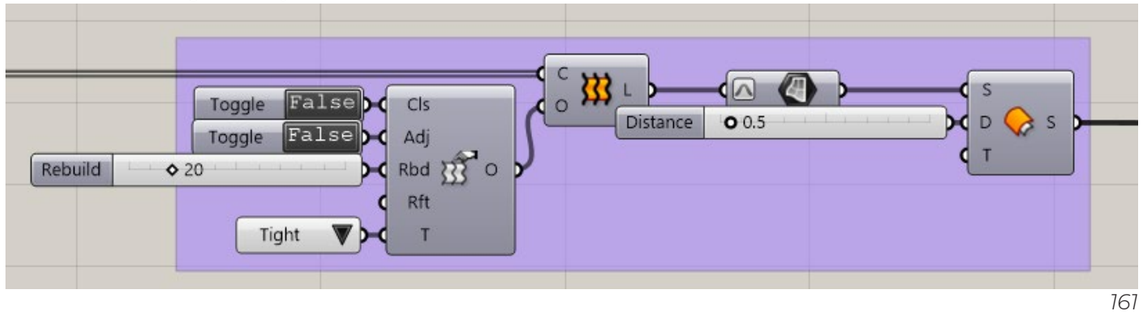
Creating contour curves of the selected part of the mesh



Rebuilding the curves to reduces the geometry and aligning the seams of the separate curves



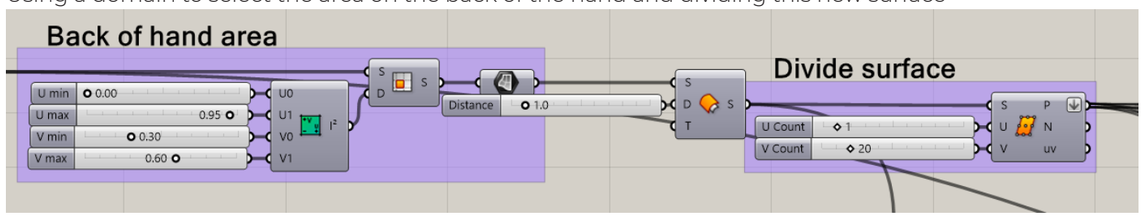
Creating a loft between the new curves and offsetting it slightly, creating a surface that closely approximates the mesh geometry



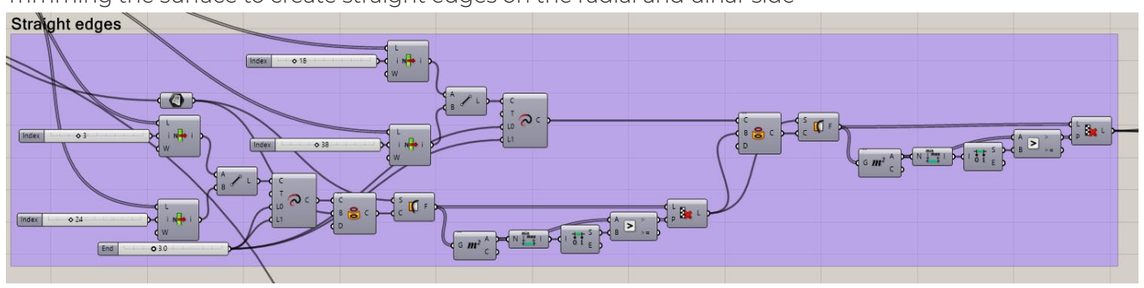
8. Grasshopper

Selecting protection area

Using a domain to select the area on the back of the hand and dividing this new surface

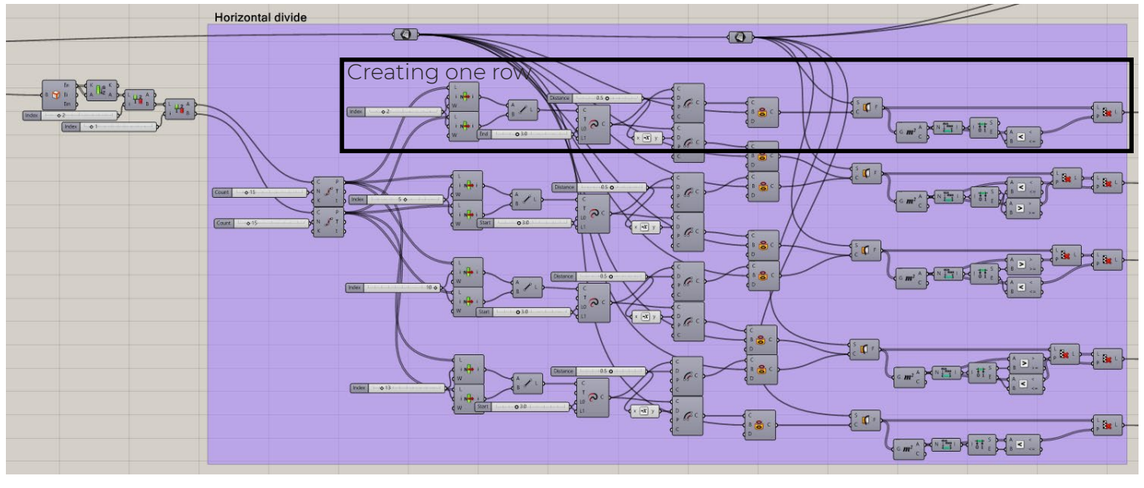


Trimming the surface to create straight edges on the radial and ulnar side



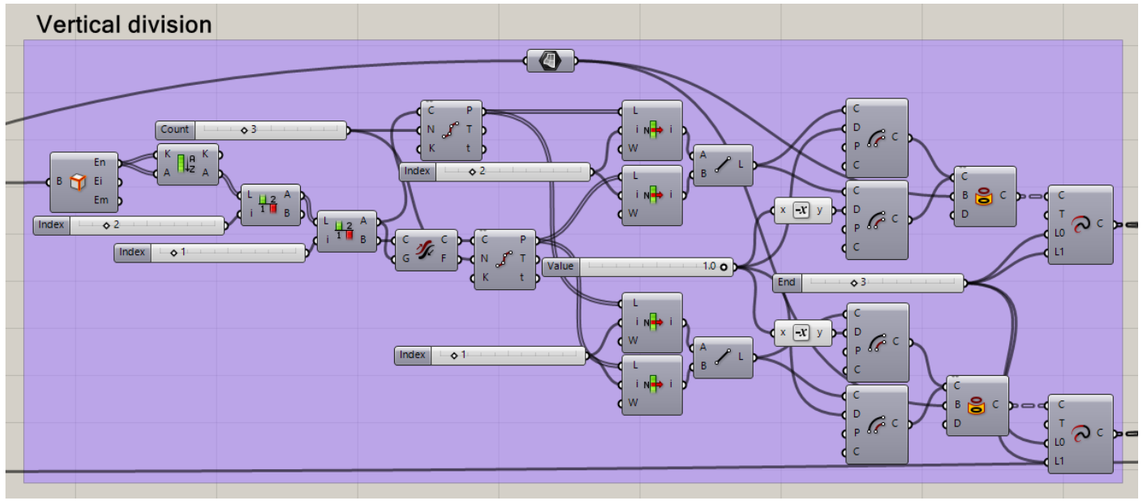
Dividing into protection pieces

Creating the horizontal divide to create the 5 rows of the protection pieces. This is done by selecting the vertical, long, edges of the previously made surface and dividing them into 15 parts. The larger pieces are made by combining multiple of these parts together. The rows are created to have a 1 mm distance between them.



8. Grasshopper

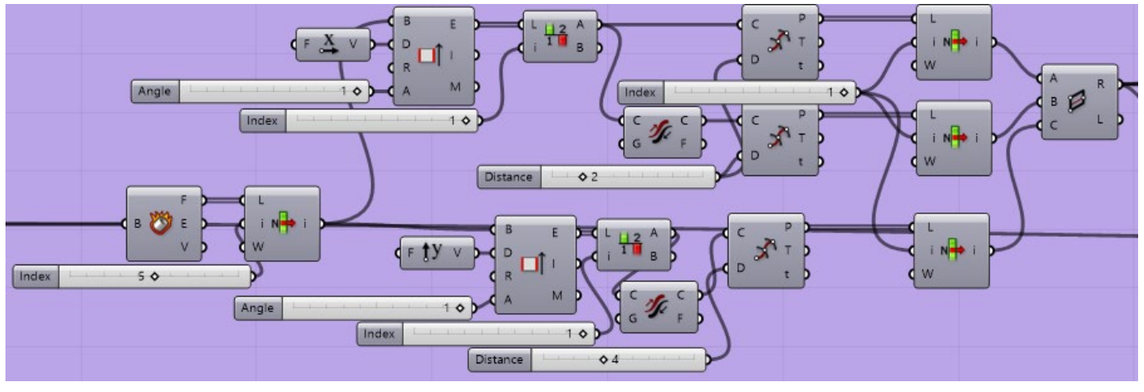
Creating the vertical division by selecting the horizontal, short, side of the surface, dividing it into three parts. The vertical divisions have 2 mm between them



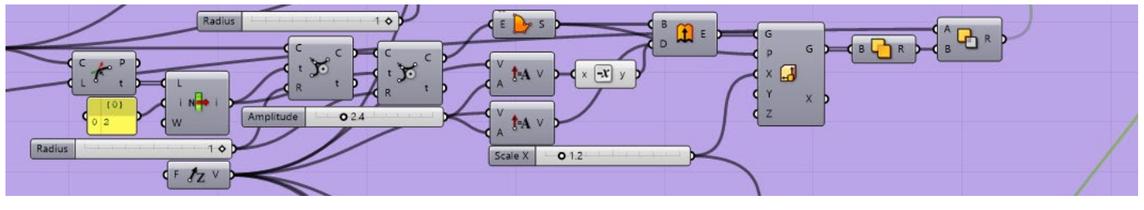
Creating attachment holes

To attach each individual protection piece to the non-stretch fabric layer, holes are created on either side with which they can be sewn onto the fabric. The following part of the script shows the hole on one side of one of the protection pieces. This script is repeated for the other side and for all pieces.

Creating a rectangle on the top surface of the protection piece with a set distance from the horizontal sides and a set width from the vertical side the hole will be located on.

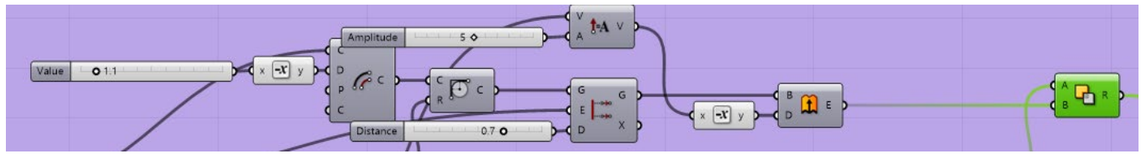


Adding a fillet to the corners inside of the protection piece, extruding the shape and subtracting it from the protection piece. This creates a recess in the protection piece.



8. Grasshopper

Creating a slit within the previously created rectangle and subtracting it from the protection piece shape with recess to create the attachment hole.



Thumb protection

The process for creating the protection for the thumb is mostly similar to the previously explained grasshopper script. The only differences are selecting a different protection area, around the thumb, not dividing the area vertically and only creating 3 rows instead of 5.

9. Cost estimation

Comparison price Nylon vs Aluminum SLS printing

	Description	Material	Details	Price p/part	Qty	Price
1	**RechtsMiddenZijde3.stl** 38.4 × 16.8 × 13.5 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€9.75	1	**€9.75** Change part specifications

Image 95: Price of laser sintering biggest protection piece in Polyamide plastic excluding VAT.

	Description	Material	Details	Price p/part	Qty	Price
1	**RechtsMiddenZijde3.stl** 38.4 × 16.8 × 13.5 mm Review manufacturability feedback	3D printing Aluminum AlSiMg10 (DMLS) Color: Default (Material color) 50µm	No description No attachments	€156.32	1	**€156.32** Change part specifications

Image 96: Price of laser sintering biggest protection piece in aluminum excluding VAT.

Protection pieces quote

	Description	Material	Details	Price p/part	Qty	Price
1	**RechtsMiddenZijde3.stl** 38.4 × 16.8 × 13.5 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€9.75	1	**€9.75** Change part specifications
2	**RechtsDuim2.stl** 15.1 × 16.7 × 21.7 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.96	1	**€8.96** Change part specifications
3	**RechtsDuim4.stl** 17.3 × 12.8 × 16.2 mm Printable with SLS	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.70	1	**€8.70** Change part specifications
4	**RechtsDuim1.stl** 18.1 × 14.1 × 21.8 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.83	1	**€8.83** Change part specifications
5	**RechtsDuim3.stl** 13.8 × 15.4 × 23.3 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€9.15	1	**€9.15** Change part specifications
6	**RechtsMiddenZijde5.stl** 16.4 × 11.9 × 6.9 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.77	1	**€8.77** Change part specifications
7	**RechtsMiddenZijde1.stl** 17.9 × 18.8 × 9.1 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.87	1	**€8.87** Change part specifications
8	**RechtsDuimZijde5.stl** 16.6 × 13.7 × 7.4 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.72	1	**€8.72** Change part specifications

10		**RechtsDuimZijde4.stl** 23.4 × 16.1 × 8.7 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.88	1	**€8.88** Change part specifications
11		**RechtsMiddenZijde2.stl** 24.5 × 17.9 × 8.7 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.92	1	**€8.92** Change part specifications
12		**RechtsDuimZijde2.stl** 24.3 × 20.6 × 7.3 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.74	1	**€8.74** Change part specifications
13		**RechtsPinkZijde2.stl** 24.8 × 17.0 × 13.5 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€9.06	1	**€9.06** Change part specifications
14		**RechtsPinkZijde4.stl** 23.3 × 13.2 × 13.9 mm Printable with SLS	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€9.15	1	**€9.15** Change part specifications
15		**RechtsDuimZijde1.stl** 17.7 × 20.9 × 7.6 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.82	1	**€8.82** Change part specifications
16		**RechtsPinkZijde3.stl** 38.9 × 15.6 × 19.1 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€10.01	1	**€10.01** Change part specifications
17		**RechtsDuimZijde3.stl** 38.1 × 20.4 × 13.7 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€9.78	1	**€9.78** Change part specifications
18		**RechtsMiddenZijde4.stl** 23.2 × 13.7 × 8.5 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.91	1	**€8.91** Change part specifications
19		**RechtsPinkZijde1.stl** 17.9 × 18.0 × 13.7 mm Review manufacturability feedback	3D printing PA 12 (SLS) Color: Dyed Black 100µm	Standard print orientation No description No attachments	€8.98	1	**€8.98** Change part specifications

Shipping	€0.00
Subtotal	€171.87
VAT 21%	€36.09
Total	**€207.96**

Image 97: 3D hubs price estimation

9. Cost estimation

Bulk pricing

Qty	Unit Price	Total Price
1	€8.85	**€8.85**
2	€5.68	**€11.36**
5	€3.58	**€17.90**
10	€2.69	**€26.90**
25	€1.91	**€47.75**
50	€1.55	**€77.50**
100	€1.30	**€130.00**
200	€1.14	**€228.00**
300	€1.08	**€324.00**
400	€1.03	**€412.00**
500	€1.00	**€500.00**

Image 98: 3D hubs bulk pricing

Viton rubber price calculation

The viton rubber can be bought on rolls from 5 meters onwards. The price of a roll of 5 meters with a thickness of 0.5 mm and width of 120 cm is €69,00 per meter. The average estimated size of the rubber layer required is 10 cm by 7 cm. This means that out of 1 meter by 1.20 meters of material approximately 170 wrist protectors can be made. This makes the price of the rubber layer for one wrist protector €0.40.

Polartec Delta price estimation

Since Polartec provides no information on their website on the prices of their materials, an estimation of the expected material price has been done based on another product made with the Polartec Delta fabric.

The Delta Pique Polo, see Image 99, is made of the Polartec Delta fabric. The retail price of this polo is €89,95. To get to the material price for the wrist protector this price should be divided a few times. In consultations with an expert on manufacturing and designing men's apparel an estimation of the fabric price was made.

Firstly, on average the price of such a product as this polo has been increased three times when going from the factory to the store, the margin of profit. (Stultiens, 2021) This means that this polo will most likely have a price of €30,- after production and shipping. For an in the USA produced material this would lead to a material cost of about €15,- per meter (Stultiens, 2021) on a roll of 90 cm wide.

Image 99: Polartec Delta Polo (Rhone, n.d.)

The wrist protector uses the Polartec Delta fabric in the fabric layer and in the under-glove. The fabric layer has similar dimension to the rubber layer, 7 x 10 cm. Which results in a price of €0.23. The under-glove will need approximately 50 x 50 cm. This results in a material price of approximately €10,- for the under-glove.

10. Prototype evaluation

Together with professional goalkeeper J. Schuurman the prototype was evaluated. During the test, the goalkeeper was asked about his first impressions, the comfort of the wrist protector, the usability with a goalkeeping glove and the usability during the different techniques. Several tasks were performed to evaluate the concept. Next to that, the goalkeeper wore the wrist protector for a whole training. The results are shown below in dutch.

Eerste visuele indruk van het prototype. Alleen kijken en vasthouden.

Wat is het eerste dat je op viel?
Het lijkt een beetje op wat je vroeger met vingersafe had

Wat denk je dat het product doet?
Het gebied bij je pols beschermen. Het verlengstuk van je pols naar je onderarm. Besschermen tegen polsblessures en stel dat je daar snel last van krijgt dat je er snel bescherming van hebt zonder dat je moet tapen.

Hoe denk je dat het product werkt?
Eigenlijk hetzelfde als fingersave denk ik. Zodra je hand naar achter gaat en dat de bescherming het tegenwerkt en tegenhoudt waardoor je stabielere pols heb als je een bal vangt of tikken erop krijgt.

Eerste indruk na het aantrekken van het prototype.

Wat is je eerste indruk bij het aantrekken van het prototype?
Hij zat bij de duim strak maar bij de pols zat die juist losser. Te los. Bovenaf strakker dan onderop. Voor de rest zat hij best prima!

Wat is het eerste dat je op viel?
Wat ik net vertelde over het te strak bij de duim en juist losser bij de pols.

Wat vind je fijn aan de manier waarop het prototype zit?
Hij zat goed strak bij de beschermingsplaatjes.

Wat vind je minder fijn aan de manier waarop het prototype zit?
Met het net naar achter bewegen van de hand voelde ik dat er een druk kwam op me hand. Hij moet meer bewegen met de hand.

Keepers handschoen aantrekken over het prototype

Wat is je eerste indruk bij de combinatie van keepers handschoen en protector?
Het begin ging moeizaam om aan te trekken vanwege de losse onderdelen. Toen die eenmaal zat zat hij prima. Verder vond ik het nog vervelend dat de beschermer korter was dan me handschoen waardoor de polsbandage van me keepershandschoen op het einde los zat omdat die polsbeschermer halverwege stopte. Ik zou het fijner vinden als die verder door liep onder me handschoen waardoor de band van de keepershandschoen gelijk is qua strakheid.

Hoe voelt de protector in combinatie met de keepers handschoen?
Voelde prima! In het begin even wennen maar zeker geen last van gehad tijdens het keepen. Het lijkt echt op fingersave. Alleen is die nog iets te kort. Na het vangen van een bal moest ik af en toe wel even over de handrug wrijven om de losse onderdelen weer goed te leggen.

Wat vind je fijn?
Fijn dat het een handschoentje onder de keepershandschoen. Het zit makkelijk. Heel fijn om onder je handschoen te hebben. Je voelt dat je een extra beschermlaagje hebt.

Wat vind je minder fijn?
Wat ik hiervoor genoemd heb: los bij de pols, te kort bij de pols, strak bij de duim en losse onderdelen die druk gaven op handrug of niet helemaal meer goed zaten.

10. Prototype evaluation

Training waarbij de volgende oefeningen uit gevoerd worden met prototype onder keepers handschoen. Linker hand heeft geen polsbescherming.

- 3x lage bal
- 3x cup
- 3x hoge bal
- 3x rollen
- 3x gooien
- 3x duiken links
- 3x duiken rechts

Bij de oefeningen merkte ik vrij weinig het was juist mooi om het in de training die daarop volgde gebruik te maken van het prototype. Tijdens deze training had ik mijn linker pols getaped en om de rechterpols het prototype. In beide gevallen voelde ik bescherming. Links daadwerkelijk gevoel van tape en rechts echt meer het gevoel van fingersave. Helemaal als die verder ontwikkeld wordt! Biedt absoluut veel perspectief als die verder ontwikkeld wordt!