DESIGNING A VIRTUAL REALITY HELMET
FOR RACING SIMULATORS

GRADUATION THESIS

Tom van de Water

cesys TUDelft

DESIGNING A VIRTUAL REALITY HELMET
FOR RACING SIMULATORS

Graduation thesis for Cesys

Graduate Student
Tom van de Water (4031059)

Master Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

Supervisory team
Chair: Ir. R.H.J.G van Heur (Ruud)
Mentor: Ir. S.A.J. van den Elshout (Sebastiaan)
Company mentor: R. Holtkamp (Reinder)

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PREFACE

In front of you lies my master thesis "Designing a VR Helmet for racing simulators", which covers a design project for Cesys. This report has been written in context of my graduation project for the master Integrated Product Design at Delft University of Technology.

I chose to do this graduation project for Cesys, because it was a great opportunity to design a new type of product for a new and upcoming technology (VR). Moreover, the hands-on approach that the company has, also appealed to me.

This project has been quite a challenge, design-wise as well as mentally. However, looking back on this project, I can proudly present to you this report. This report will guide you through my design process and ends with a final product proposal. Throughout my graduation project I've been lucky to have received guidance and support. I would like to thank my supervisory team, colleagues at Cruden, my friends, my girlfriend and family. Your support has really helped me throughout the the project.

Tom van de Water
Delft, October 2017

Figure 1 Final design proposal

EXECUTIVE SUMMARY

Design Brief

This project is executed for Cesys, a company which develops and produces high-end, innovative racing simulators for the entertainment industry. Recently, the company started using Virtual Reality headsets on their racing simulators. Currently, a consumer grade VR headset (Oculus Rift) is used in these type of racing simulators. However, it should preferably be a customised VR headset that is fitting for the simulators and is suitable to be used in an entertainment context. In short, the assignment is to integrate two products together: A racing helmet and a VR headset. Main requirements were that the VR Helmet should re-use components of a current VR Headset and should be one-size-fits-all.

Analysis

The project started with an analysis phase. A contextual analysis showed that hygiene and durability are important aspects to take into account during the development of the VR Helmet. A technological analysis provided insights which components of a chosen VR headset were necessary to be reintegrated. In an ergonomic analysis, various aspects such as anthropometrics, thermal comfort, pressure sensitivity and maximum weight was researched. In a business analysis, a batch size and first cost price estimation for the VR Helmet was set. Finally, a product experience analysis led to the questions regarding the desired look, feel and use of the VR Helmet. Basically, the question was whether the VR Helmet should be a Racing helmet with VR or a VR headset with racing helmet characteristics.

Concept

This above mentioned question was answered during the conceptualisation phase. Two concepts were constructed in order to answer this question. The first concept stayed close to the look, feel and use of a racing helmet. The second concept was almost the opposite of the first concept regarding the look, feel and use. This concept was designed as a VR headset with racing helmet characteristics. Both concepts were detailed to such extent that it could be user tested. The user test showed that the first concept was preferred on various aspects, such as intended emotional response, matching the current simulators, (surprisingly) comfort and practicality. Therefore, concept 1 (Racing helmet with VR approach) was taken as a basis for the final design proposal.

Final design proposal

Figure 1 shows the final design proposal. This VR Helmet is designed to match and enhance the current experience of the VR simulators by mimicking the look, feel and use of a racing helmet. Like a real racing helmet, it has a visor which can be opened and closed. In this visor the VR components are situated which provide the VR experience. Besides displaying VR, it also has speakers integrated in the helmet for audio display. Moreover, this is one of the first VR Helmets which has a one-size-fits-all feature. By turning the knobs located at the back and top of the helmet, the VR Helmet can be adjusted and fixed on various head sizes. In order to guarantee a hygienic experience, the helmet has to be worn in combination with a balaclava.

Evaluation

The final design proposal was prototyped and user evaluated. In this user evaluation, the VR Helmet was compared to the current solution: the Oculus Rift. Combined with a review on the product requirements, a full evaluation on the final concept was conducted. The final design proposal meets the requirements regarding comfort (one-size-fits-all), experience, hygiene and cost-price. However, aspects such as durability, the weight of the product, integration of the Oculus Rift (electronics) need to be researched further or improved.

In all, the final design proposal is a promising concept, but will need another full iteration before it will meet all the product requirements.

CONTENT

0 INTRODUCTION

In this paragraph an introduction to the company, problem definition, assignment and initial requirements will be given.

Company

This project is executed for Cesys. Cesys is a subsidiary company of Cruden, which is one of the world's leading companies in developing driving/racing simulators for international motorsport teams (including Formula 1), automotive manufacturers and research institutions (see Figure 2). The company originates from Fokker Aircraft Company and used their flight simulation know-how for developing a racing simulator that combined a motion base with a dynamic vehicle model, motion-cueing software and image generation. As Cruden focuses on developing simulators for professional use, the Cesys subsidiary focuses on developing simulators for the entertainment and attractions industry. The company headquarters are in Amsterdam.

Figure 2 Racing simulator for professional industry

Problem definition

The company has recently developed software that enables to run a Virtual Reality headset on their motion-based simulators for the entertainment/attractions industry. There are currently two motion-based simulators in the company's portfolio which use Virtual Reality as a visualisation medium: a F1 simulator and motorbike simulator (see Figure 3 and Figure 4). A consumer grade VR headset is currently used, but this should preferably be a VR headset which is customised for racing simulators and that is suitable to be used in the entertainment/attractions industry.
An important aspect of customising the VR headset for the racing simulator is that the simulator driver, besides wearing the VR headset, should also ideally wear a racing helmet-like product. Adding this aspect to the VR headset will probably increase the overall experience of the simulator attraction. The problem is therefore that the driver needs to wear two items on one head: a racing helmet-like product and a HMD (Head Mounted Display). Wearing these two products separately is not possible, due to interference.

Figure 3 VR Formula 1 simulator for entertainment industry

Figure 4 VR motorbike simulator for entertainment industry

Figure 5 Assignment: VR Headset and Helmet that need to be integrated

Assignment

Figure 5 shows the two products that need to be integrated: a VR headset and helmet. The solution that is displayed in the artist impressions (see Figure 4) is unrealistic and unholistic. Therefore the objective is to analyse, design and engineer a solution that integrates a helmet-like product and a Virtual Reality headset.
Aspects such as Virtual Reality experience, functionality, comfort, ease of use, durability, cost, hygiene and aesthetics should be taken into account.

Initial requirements

Apart from the above mentioned aspects that need to be taken into account, the company also provided some initial requirements:

The product needs to be one-size-fits all
From a business perspective it's interesting to design and manufacture one product that fits different types and sizes of heads. Current VR headsets also have this feature, but helmets don't: they are sold in various sizes.

The product should re-use functional parts of an existing VR headset
The development of custom-made functional parts of a VR headset (e.g. lenses, display, tracking hardware) is deemed to be too expensive for a first small batch size. Therefore the functional parts of a current VR headset will be re-used.

Minimum age that will be wearing the product is 15 years old
This is the result of the minimum age limit of the simulators. The minimum age is important to take into account when doing ergonomic research.

During the upcoming phases these requirements will be taken into account, but also reviewed to see whether they are feasible.


oculus

1 ANALYSIS

In the analysis phase various aspects related to the design of a Virtual Reality helmet will be researched. The results of these analyses will provide a clear overview of product requirements and/or challenges that need to be solved in the next two phases of the project. The analysis phase is build up as following:

1.1 CONTEXT

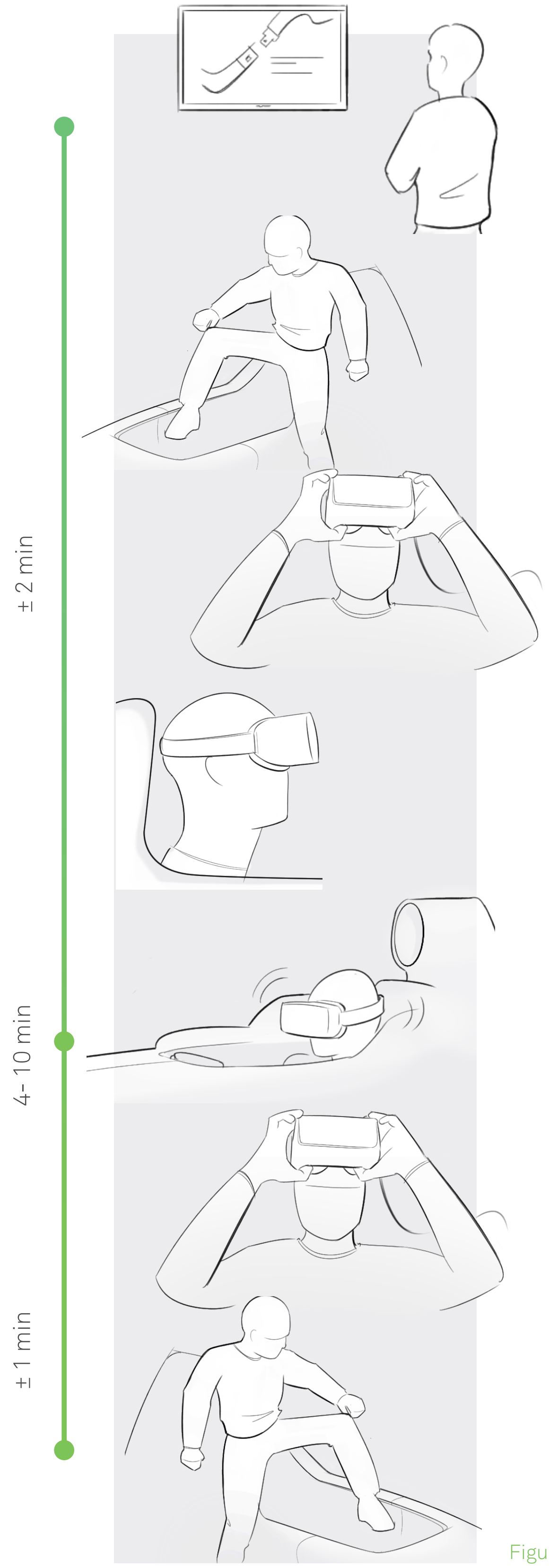
This paragraph reviews the current context of a Virtual Reality racing simulator attraction.

The goal of this paragraph is to create an overview of the current context by answering the following questions: what, who, where, when and why. This overview will offer insights that can eventually influence the design of the Virtual Reality helmet. The following findings are predominantly based on observations at an entertainment venue (Kartbaan Winterswijk) who recently purchased a VR racing simulator and an interview with the owner (R. Rensink, personal communication, 4-1-2017).

What

The first aspect that will be reviewed is the process of attending a VR racing simulator attraction. First aspect to review is the current process of attending a VR racing simulator attraction. As mentioned earlier in the introduction, Cesys sells two types of VR racing simulators: A Formula 1 and motorbike simulator. The process of attending both simulators is very similar, therefore the process of attending the Formula 1 simulator is taken as example. Figure 6 shows an impression how such a simulator can be set up. During the entire process there are two stakeholders involved: the driver and operator. The operator is present throughout the whole process. Figure 7 describes a step-by-step process of racing in a F1 simulator.

Figure 6 F1 Simulator at Kartbaan Winterswijk



Race instructions
The driver watches race instructions on a screen outside the simulator. In practice, these instructions are not often watched. After these instructions, the operator notes the contact information for sending information regarding the lap times afterwards.

Stepping into simulator
The driver steps into the simulator. The operator explains how to adjust the position of the pedals for the optimal race position. After adjusting this, the operator attaches the steering wheel to the car.

Putting on VR headset
Then, the operator hands over the VR headset to the driver and explains how to put the headset on and how to adjust the fit for the optimal comfort and VR experience. In practice, adjusting the fit of the VR headset doesn't happen that often. The VR headset is already wired and connected to the computer of the operator.

Calibrating VR Headset
In order to calibrate the view of the VR headset the driver has to look straightforward, while the operator hits a button on the computer to calibrate the view.

Racing
After calibration, the driver is ready to race a couple of laps on a virtual race track. It's an intense activity that involves considerable sweating. When crashing, the simulator will vigorously move in various directions. Sometimes, the fit of the VR headset needs to be tightened due to these motions. Moreover, some people (2/10) experience motion sickness.

Taking off VR Headset
After racing the driver takes off the headset and waits for the operator to hand the headset over. The operator also removes the steering wheel and after this the driver is free to step out of the car.

Stepping out of simulator
The driver steps out of the car and the operator shows him the lap times of his virtual race.

Figure 7 Process of attending VR Racing simulator

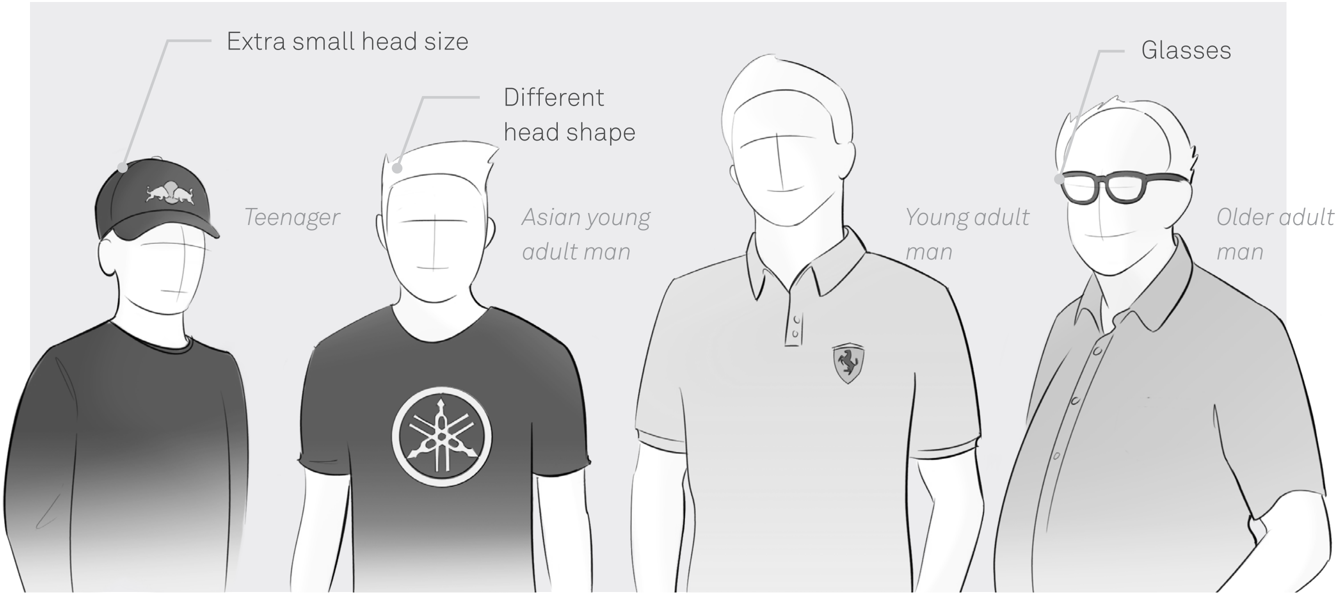


Figure 8 Visual summary of target group

Who

Next aspect to review is the target group of these VR racing simulators. To start, these people are (quite obviously) racing enthusiasts and predominantly male. However, there's a large variety within this group of male racing enthusiasts. These varieties can affect the design of the VR helmet, which will be explained shortly.
First of all, the age difference between these males can vary between 15 – 60 years old. 15 years old is the minimum age when you can participate in a racing simulator. Within the adult age group (21 – 60 years old) the size of the head can already vary quite a lot (Zhuang et al., 2010). But having also a young adult age group (15-21) will add some extra size variations, because the head is not full grown in this stage (TNO, 2010). Also something to take into account is the number of people wearing glasses, which can sometimes be a problem in current VR headsets. On average for this age group, 6 out of 10 people are wearing glasses (CBS, 2013).

Furthermore, because Cesys sells their simulators worldwide, people with different ethnic backgrounds (e.g. Western/ Asian) can use the simulators. This will not only add some extra variation in size, but also variation in shape of the head (Ball et al., 2010).
Figure 8 gives a visual summary of the above mentioned differences to give an idea of the diversity of people that the product has to be designed for. The differences in dimension and shape will be researched further in chapter 1.3 'Ergonomics'.

Dedicated simulator centre (I-way, Lyon)

Racing related theme park (Ferrari World, Abu Dhabi)

Arcade hall (HubZero, Dubai)

Figure 9 Possible locations for a VR simulator

Where

The third aspect to analyse is the environment where these VR racing simulators can be found. A distinction can be made in three types of places (see Figure 9):

- Racing related theme park - e.g. Ferrari World in Abu Dhabi
- Racing venue – e.g. karting centre, a visitors centre of a racing track or a dedicated simulator centre
- Arcade hall– e.g. a venue that combines multiple (group) activities, where a VR racing simulator can be a part of

When

Next aspect to take into account is the time-relatedness of the activity of racing in a VR simulator. As described in Figure 7, the whole activity of preparing for racing, racing and after racing can take around 7-13 minutes per person (depending on race time, which can vary from 4-10 minutes. The preparation time before racing is significant when comparing it to the actual race time, but it is considered as a part of the entire experience, as the preparation steps are showing resemblance with the preparation steps a professional driver goes through before he starts racing.

Depending on the type of venue, throughput time can be considered to be an important aspect (e.g. theme park). The average throughput currently is around 8 persons/hour when the actual race time is around 4 minutes. So, when a simulator is fully occupied throughout the day, around 50-60 (different) persons can make use of a VR simulator and the VR helmet. This aspect could have some design implications for the VR helmet, for example when thinking of hygiene and durability/ruggedness.

Why

The last aspect to review is the reason why the target group wants to participate in the activity of racing in a VR simulator. First of all, the real activity of racing in a professional race car or on a motorbike is only given for a few people. It’s costly and you have to be skilled and fit enough to practice it in real life. Racing in a VR simulator is an accessible and (almost) risk-free alternative that will give racing enthusiasts the opportunity to experience in a ‘romanticized’ manner of what it’s like to race in a professional race vehicle. By calling it a ‘romanticized’ experience it is meant with that during racing, the forces and difficulty of driving are less than in real-life. Paragraph 1.6 will focus on the possible and desirable experience of the VR helmet.

Figure 10 People racing on motorbike simulator

Summary

The contextual analysis provides the following aspects that need to be taken into account when designing the VR helmet or need to be analysed more:

- The experience of the simulator ride, from preparation to end, is a key aspect. This experience doesn’t have to be exactly the same like in real racing contexts, but can be romanticized.
- The male target group shows large variations in shape and size of the head. Moreover, people wearing glasses will also need to be taken into account.
- A simulator can be used by 50-60 different persons on one day. This has implications for the hygiene, durability and ease of use of the VR Helmet.

1.2 TECHNOLOGY

This paragraph will focus on the various aspects of Virtual Reality. First, the concept of Virtual Reality will be explained. Then, the focus will shift to the more tangible aspect of Virtual Reality: the technology that enables it.

1.2.1 Virtual Reality

In the last 5 years the technology of Virtual Reality has seriously evolved. It's not a new technology, the roots of this technology can be traced back to the 1960's and during the 1990's it already emerged as an interesting technology, but at that time it couldn't live up to its potential due to the limited computing power, poor display technology and tracking hardware that was available at that time (Schnipper,n.d.). In the next two decades, advancements in other areas were made (e.g. smartphones) and that resulted in available hardware that was affordable and could provide a better virtual reality experience. Since the arrival of the Oculus Rift in 2012, the technology has been put back on the map and has been evolving ever since. However, the technology still has to reach its full potential in the upcoming years.

Figure 11 Inside of VR Headset

Figure 12 Virtual World

Definition

During this project the following definition of VR (Sherman & Craig, 2003) will be used: "A medium composed of interactive computer simulations that sense the participant's position and actions and replace/augment the feedback to one or more senses, giving the feeling of being immersed in the simulation"

Key elements that define Virtual Reality

In order to create a Virtual Reality there are key elements that define this state: a virtual world, immersion, sensory feedback and interactivity (Sherman & Craig, 2003).

Virtual World

In this case, a computer based simulated environment. How well the real world is represented in this simulated environment affects the level of immersion of the user, which will be explained on the next page.

Sensory Feedback

Essential for virtual reality. Users are getting direct sensory feedback based on their physical position. Sensory feedback can be displayed through visuals, smell, touch or sound. In case of the racing simulator, visual, haptic (simulator movements) and aural (sound) feedback is given during the simulator ride. In order to give sensory feedback a tracking technology is necessary. Figure 13 shows an example of an Oculus Rift, which has a tracker to track the movements of the head and hands of the user. In case of the racing simulators, the movement of the head and body (only for motorbike simulator) are tracked.

Interactivity

In order to have an authentic experience, the virtual reality system should respond to user actions (interactive). The computer simulation model scripts these interactions. In case of the racing simulator, the interactivity is related how the vehicle responds to the user's actions.

Immersion

Immersion is an important term used in most media and generally refers to a mental state of being involved in the VR experience. Reaching a high level of immersion is the ultimate goal of a VR experience. Multiple aspects can affect the level of immersion of the user. It starts with the emotional state and personal characteristics of the user. For example, when the user is a motorsport enthusiast and able to drive a car, he or she will be more likely to be immersed in the VR experience of a racing simulator. The quality of the virtual world, sensory feedback and interactivity are also very important in defining the ultimate level of immersion.

The next question is how the VR helmet can have an impact on one or multiple aspects. This will be discussed in chapter 1.6 'Experience'.

Figure 13 Man wearing Oculus Rift VR headset

1.2.2 VR Headset

This subparagraph will focus on how a VR headset works and which components are necessary in order to create VR. There are various classes of VR headsets on the market, but this subparagraph will focus on tethered high-end consumer VR headsets (connected to computer, opposed to stand-alone smartphone VR headsets).

Operation principle of a VR headset

The goal of VR headsets is to have the feeling of being immersed in a life size, 3D virtual environment without any boundaries. VR headsets are often referred as a head mounted display (HMD), so the virtual world is displayed through one or two (one-per-eye) displays in front of your eyes. As the displays are placed right in front of your eyes, you need lenses to focus and magnify the picture for each eye in order to create a stereoscopic image with a wide field-of-view. A stereoscopic image is important to give a perception of 3D depth. Moreover, a wide field-of-view is important for having the feeling of being in a 3D virtual environment without no boundaries. Therefore, it's important to match the human field-of-view as much as possible.
As the user moves or tilts his head, the virtual world displayed should shift accordingly. In order to track these head movements at a certain time interval a tracking technology is necessary.

Components of a VR headset

As the basic operation principle of a VR headset is described, a more detailed review of the functional components of a VR headset will be given (as seen in Figure 15).

Display

The function of the display is to present the virtual world. The VR headset can contain one large display or two smaller separate displays. The resolution of the display is an important aspect, since this aspect is an important factor for determining the realism of perceiving the virtual world. Moreover, as the picture of the display is magnified by the lenses, the perceived pixel density is even lower than the pixel density of the actual display. Currently, perceived pixel density of a

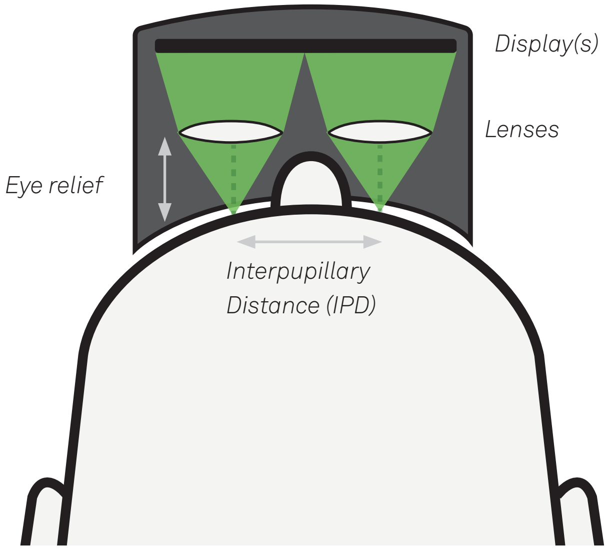


Figure 14 Schematic Visualisation of how VR lenses work

VR headset is around 12 pixels/degree (Boger, 2016a). However, the human eye can perceive a multiplication of this pixel density, which is around 60 pixels/degree. This shows that the development of VR technology is still at an early stage.

Lenses

The function of the lenses is to focus and magnify the picture for each eye and create a stereoscopic image. Most VR headsets use a single lens (opposed to two lenses) made of acrylic or polycarbonate instead of traditional glass lenses, in order to save weight. A common type of lens that is used is the Fresnel lens, which is thin and light compared to standard convex lenses, but can have lesser focus (image and colour) (Waters, 2016). As the lenses magnify the picture, a wide field-of-view is created. As mentioned earlier, it is desirable to create a field-of-view which approaches the field-of-view of the human eye as much as possible. In current VR headsets the field-of-view is around 80-100 degrees horizontally and 90-110 degrees vertically (Hunt, 2016). The field-of-view of the human eye is almost 180 degrees horizontally and 135 degrees vertically (Marieb & Hoehn, 2013).
In order to see the clearest and widest picture, a lot of VR headsets offer the possibility of adjusting

Figure 15 Parts of VR Headset

the position of the lenses. There are two types of adjustments, interpupillary distance and eye relief (see Figure 14) The first one, interpupillary distance (IPD), is adjusting the distance between the lenses. The interpupillary distance for humans can vary between 55 – 95 mm (5th percentile – 95th percentile) (NASA, 1978).

The second adjustment, eye relief, is adjusting the distance between the lenses and the eyes. If the distance is smaller, the field of view becomes bigger. The ideal distance is around 12 mm (Boger, 2016b), but for people who wear glasses a larger eye relief (>20 mm) is preferable. However, a large eye relief can seriously reduce the field-of-view and in the case of an eye relief of >20mm, the field-of-view can be reduced by 40% (Kreylos, 2016).

Motherboard

The function of the motherboard is to process various signals & sensing relative motion. It contains an Inertial Measurement Unit (IMU) combined with an accelerometer and gyroscope in order to track motion in six dimensions.

Infrared LEDs

The Infrared LEDs are part of the tracking system that tracks absolute motion for correcting drift motion of the IMU. There are various types of tracking systems, but in this case constellation tracking is used. In short, a camera with an infrared filter tracks the infrared LEDs on the VR headset at a high time interval.

Selecting donor VR headset

Oculus Rift CV1 *HTC Vive* *OSVR HDK 2*

Figure 17 Possible donor VR headsets

As mentioned in the introduction, the VR helmet will use components of an existing VR headset. Currently there are a couple of high-performance VR headsets available on the market. A comparison is made between the following VR Headsets:

- Oculus Rift CV1, which is used in the company's current VR simulators
- HTC Vive, which is one of Oculus Rift's main competitors
- OSVR HDK2, a promising open-source VR headset

In Appendix A a full comparison between these VR Headsets can be found. The comparison is done on several aspects such as price, image quality, ability to open the VR headset, tracking technology and software development (each VR headsets comes with its own software developers kit).

Based on this comparison, the Oculus Rift is chosen as the designated donor VR headset for the VR helmet. First of all, the tracking technology of the HTC Vive is not compatible with the motion platform of the simulators and is therefore not a contestant to be a donor VR headset. The OSVR HDK2 is an open-source VR headset, which seems to be ideal, hardware-wise, as a donor VR headset. However, the software team of the company spend some time working with the software developers kit and concluded that it's hard to achieve the same fluid VR experience that they already achieved with the Oculus Rift.

This means that in the upcoming design process of the VR helmet, the size and dimensions of the components of the Oculus Rift will be taken into account. In the third chapter of this report, more attention will be given to the integration of the components of the Oculus Rift in the VR helmet (see paragraph 3.1.1).

Audio

The previous sections focused more on the visual aspects of the VR headset. However, as described in section 1.2.1, audio is also an important sensory aspect to take into account as it directly affects the VR experience.

Most VR headsets don't provide an audio solution and separate headphones have to be worn on top of wearing the VR headset. The Oculus Rift is one of the few VR headsets that provide optional headphones that can be attached to the headset (see Figure 16). However, these on ear headphones are currently not experienced as high quality as they're small and hard to place correctly on the ears (R. Rensink (Personal communication, 4-1-2017)).

Therefore, a better alternative component has to be

Figure 16 Man wearing Oculus headset with headphones

found that will be integrated in the VR helmet.

Donor Audio components

In appendix A a small analysis can be found regarding the sourcing of better audio components. The main strategies are as following:

- Use donor headphone
- Use spare parts of headphone
- Use OEM speakers (original equipment manufacturer)

Based on this analysis, the best strategy is to use OEM speakers. These speakers are the most suitable to integrate in the new VR Helmet, are good value and a lot of choice is available. This will be elaborated in the final chapter, in section 3.1.2 'Audio'.

Figure 18 OEM speakers

3D audio

Besides choosing the right hardware, the software can also have an important role in enhancing audio display. An interesting technique is using 3D audio (The Verge, 2015). 3D audio is the simulation of the natural positioning of sounds (see Figure 19). The anatomy of the human head dictates how people hear: with ears on left and right side of the head. When, for example a race car drives past the user on the right side, the sound enters our right ear earlier than our left ear. This is also simulated in 3D audio and this is giving the user a sense of space and can direct attention of the user to elements outside the user's field-of-view in order to create a more immersive experience.

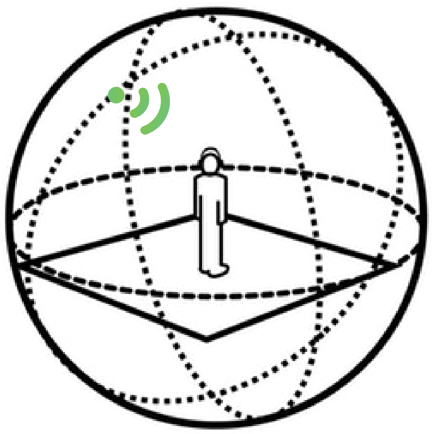


Figure 19 3D audio

Summary

The technological analysis provides the following aspects that need to be taken into account when designing the VR helmet or need to be analysed more:

- The Oculus Rift CV1 will be used as the donor VR headset for the VR Helmet. The following parts are essential to reintegrate: Lenses, display(s), motherboard, tracking infrared LEDs.
- In order to fully optimise the VR experience, the lenses need to be adjustable. There are two types of lens adjustments: Interpupillary Distance (distance between the two lenses) and Eye relief (distance between lens and eye).
- OEM speakers will be used for integrating audio in the VR Helmet.

1.3 ERGONOMICS

This paragraph will focus on various ergonomic aspects that are important when designing a helmet-related product. First, the varying dimensions of the human head are reviewed. Then, the thermal comfort and pressure sensitivity of the human head will be discussed. Last, attention will be given to head mounted loads.

The goal of this paragraph is to gather information that will provide insights how to design a safe and comfortable product that can be worn by the various types of persons that are defined as the target group (see paragraph 1.1).
Comfort is an important aspect when designing a VR related product. Comfort has a direct relationship with the level of immersion (Oculus, 2015). For example, when something doesn't feel right on the user's head (e.g. fit is too tight, too hot), the attention will be pulled away from the virtual world and directed at the experienced discomfort. Therefore, the ergonomics are key for the development of the VR helmet.

Figure 20 Standard headforms

1.3.1 Dimensions

As mentioned in the introduction, one of the initial requirements is that the VR helmet should be a one-size-fits-all product, if possible. Therefore, the variations of different dimensions of the human head will be gathered and analysed in order to see whether this initial requirement is feasible.

Headforms

Most helmets are currently designed by using standard mannequin headforms in various sizes (See Figure 20). These sizes are based on national or international standards (Skals et al., 2016). However, these standard headforms are hard to obtain and abstracted in such manner, that facial information regarding the eyes, ears, nose and mouth are omitted. When designing a VR product that is mounted on the head, this facial information is as important as the global dimensions of the human head. Therefore, standardized headforms including facial information are preferred.

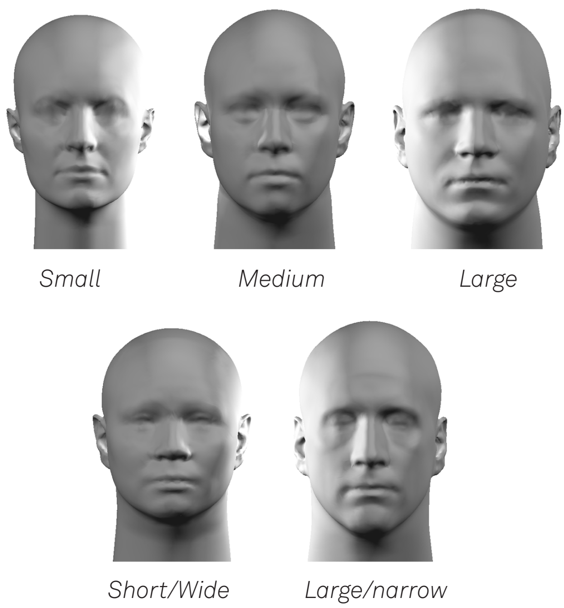


Figure 21 Caucasian 3D headforms with facial features

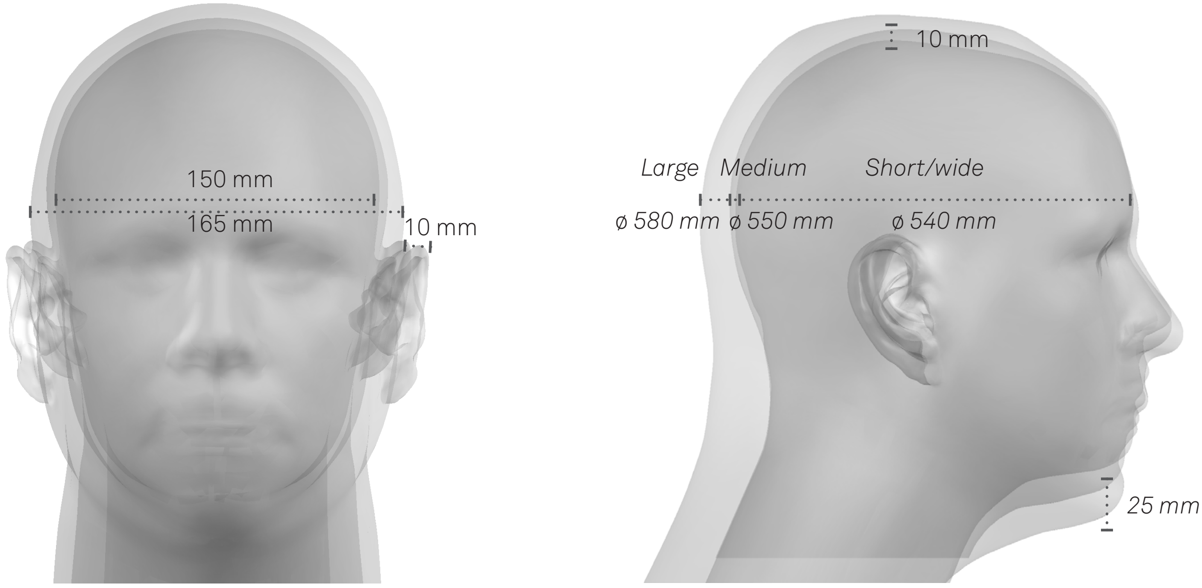


Figure 22 Differences in dimensions between Short/Wide, Medium and Large headforms

Caucasian 3D Headforms

Zhuang et al. (2010) presents this type of standardised headforms of the current US workforce, which are based on ± 4000 3D scans of human heads. The headforms are categorized in 5 types: small, small-wide, medium, large and large-narrow (See Figure 21). In total, these 5 types represent ± 95% of the various facial sizes and shapes of the population (men and women). For men, the short/wide (17.9%), medium (49.9%) and large (20.8%) are the most predominant head types. When comparing the measurements of these various 3D headforms to other anthropometric data (NASA, 1978), the measurements are similar.

Figure 22 shows the differences in dimensions when comparing the most predominant head types (short/wide, medium and large) for men to each other. The biggest differences in dimensions can be found in the overall circumference (40 mm) and the distance between nose to chin (25 mm). The differences in head breadth (15 mm) and distance from top of the head to the eyes (10 mm) are less big.

When reviewing the target group, young adults (minimum age 15 years old) can also make use of the VR helmet. The head size of these people at this age are at around 96% (±20 mm difference in head circumference) of the full grown head size (TNO, 2010). As the head size difference is small when compared to adults, the young adults can be represented by the small size category of the headforms described above and don't need a separate category.

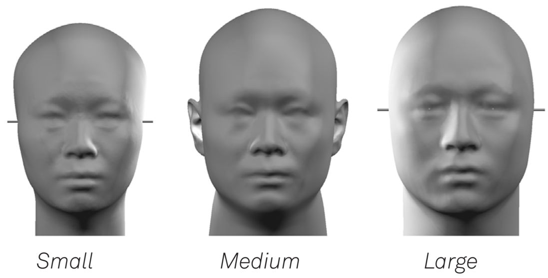


Figure 23 Chinese standard headforms with facial features

Chinese 3D Headforms

Cesys sells simulators world-wide, of which China is a large potential market. Therefore, it is likely that a Chinese person could also make use of the VR helmet. Ball et al. (2010) describes that, when comparing Caucasian headforms with Chinese headforms, there are significant differences between the two head shapes and size. Yu et al. (2011) presents standardised headforms of the Chinese workforce in the same manner as mentioned above (see Figure 23).

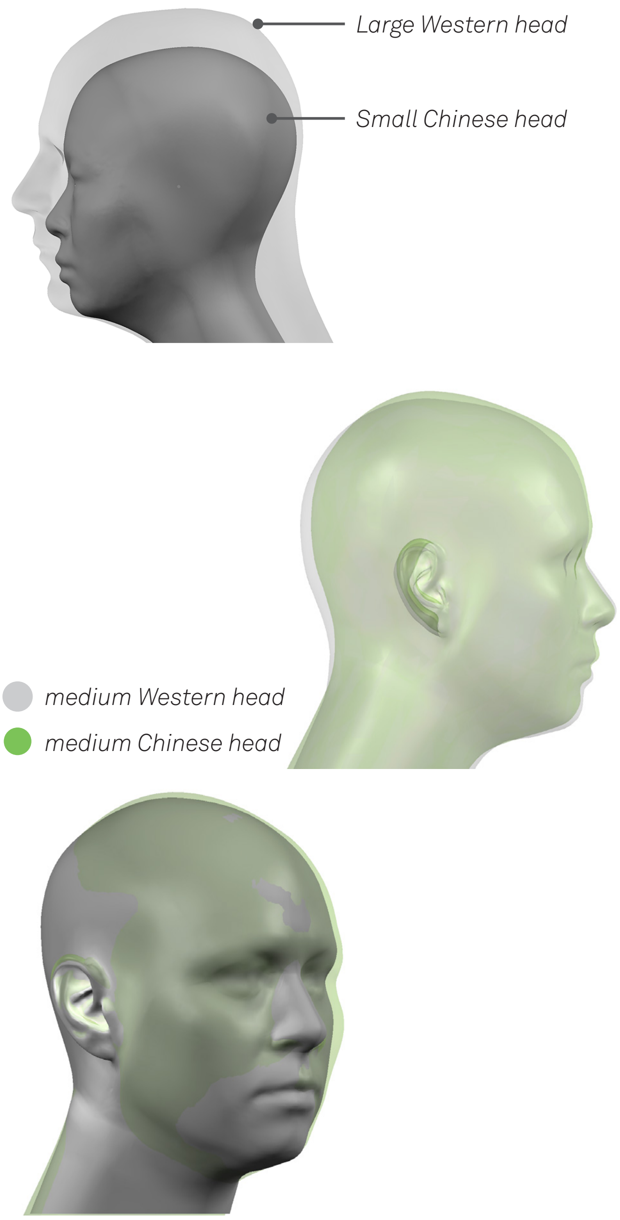


Figure 24 Comparing Caucasian and Chinese headforms

Differences

When comparing the available headforms to each other in order to see the differences that the VR helmet has to take into account, the following can be concluded (see also Figure 24).

First, when comparing Caucasian to Chinese headforms, it is clear that Chinese headforms are rounder and have flatter forehead and back than Caucasian counterparts. Moreover, the nose bridge of Chinese headforms is flatter than Caucasian headforms. This could be important to take into account, since a lot of VR headsets are resting on the nose bridge.

When looking dimension-wise at a medium sized Chinese and a Caucasian headforms, it can be derived that the Chinese headform has a wider face width, a shorter face length and a bit smaller head circumference.

Finally, when selecting a small Chinese headform and a large Caucasian headform as a minimum and a maximum, the difference in head circumference can amount to 70 mm.

When considering these differences, a provisional conclusion can be made regarding the initial requirement that the VR helmet needs to be one-size-fits-all. The differences in size are quite big, but not insurmountable. Current VR headsets also maintain the requirement of one-size-fits-all and are sold world-wide. The differences in shape between a Caucasian and Chinese headform could possibly impose some difficulties. One could think of the face mask, the foam interface between the face and housing of the VR headset, could be different for both types of headforms.

1.3.2 Thermal comfort

As described in chapter 1.1 'Context', the activity of racing in a VR simulator is intense and comes with considerable heat generation and possibly sweating. As the VR helmet will most likely cover more area of the head than the current VR headset, the thermal comfort of the head can be compromised.

Thermal discomfort

The human head is sensitive to temperature changes. It has been observed that thermal comfort of the head region is maintained in a narrow temperature range of 34 – 35 °C (Fanger, 1973). When the temperature rises above this narrow range, for example due to wearing a helmet, the helmet wearer can experience thermal discomfort (Bogerd et al.,2015). Next to skin temperature, there are other closely related factors such as sweating and skin wetness that affect thermal comfort (Bogerd et al., 2015).

Even more important is the fact that locally perceived thermal discomfort at a part of the body is sufficient to cause the whole body thermal discomfort (Bogerd et al., 2015).

Helmet hotspots

Next aspect to review, how much the skin temperature rises when the head is covered by a helmet. This will give an indication whether thermal comfort will be an important element to take into account when designing the VR helmet.

Thermal research regarding motorcycle helmets (Bogerd et al., 2010) and cricket helmets (Pang et al., 2011) shows that the temperature of the skin of the head increases by 1-2 °C after wearing these helmets for 10 - 20 minutes, which can cause serious thermal discomfort. Figure 25 shows the results of the motorcycle temperature tests (Bogerd et al., 2010) and the positioning of temperature hotspots (> 2°C temperature difference) are mostly around the temple region. The cricket helmet study (Pang et al., 2011) showed that temperature hotspots were also found around the temple region, but also around the forehead.

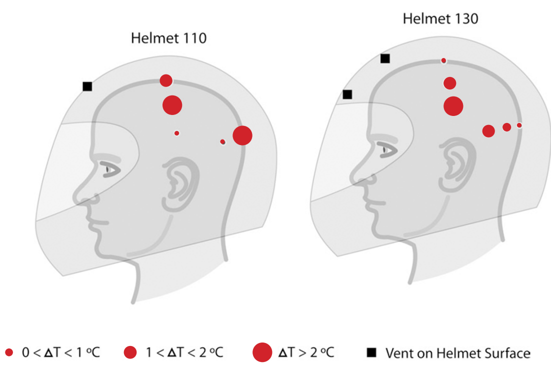


Figure 25 Temperature tests motorcycle helmet

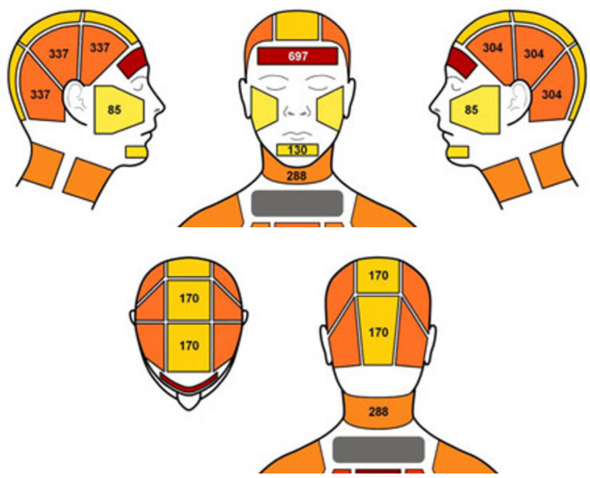


Figure 26 Anatomy of human head

Heat dissipation

Figure 26 shows a sweat rate map of the human head in mild exercise (Smith & Havenith, 2011). The map shows that the forehead and sides are important places for the human head to exchange heat. This finding corresponds with the above mentioned findings of the helmet temperature tests.

Taking these findings into account, it can be concluded that thermal comfort can be of importance when designing a VR helmet, especially when the product will be worn 10 minutes or more.

1.3.3 Pressure sensitivity

As mentioned earlier in this paragraph, comfort is an important aspect when designing a head mounted VR product. When designing for this aspect, it's important to know which areas on the head are pressure sensitive.

First of all, when looking from anatomical perspective, blood vessels and nerves running through the head are considered to be sensitive areas (J. Molenbroek (Personal Communication, 5-12-2016)). These sensitive areas are mostly around the temple region, forehead and lower back region of the head.

Some research regarding this aspect has been done. Figure 27 shows a 3D map of the sensitivity of the human head based on perceived discomfort (Snoek & van Dijk, 2014). The areas that are considered to be sensitive areas from an anatomical perspective are matching areas that are perceived to be highly sensitive.
Taking this into account, it can be concluded that the top and back area of the human head are less sensitive, thus more suitable areas to put weight/exert force on.

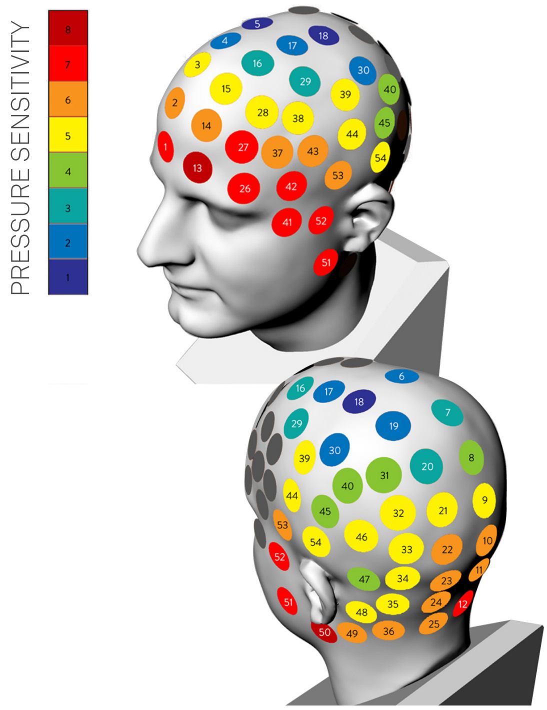


Figure 27 3D map of perceived discomfort

1.3.4 Head mounted load

This last subparagraph reviews the topic of weight mounted on the head. Before starting to design the VR helmet it is key to know what the maximum weight of the product may be. Next to defining the actual weight, weight perception is also important aspect and will also be researched.

Design parameters

First, Figure 28 shows a framework (van den Oord, 2012) which describes how various design parameters regarding helmet design are related to each other. When zooming in on the factors weight and weight distribution, they have an effect on the stability of the helmet and the perceived neck tension. This last factor is important, since this tension will be felt during and after the activity of racing and should be avoided as much as possible as this will negatively affect the overall experience.

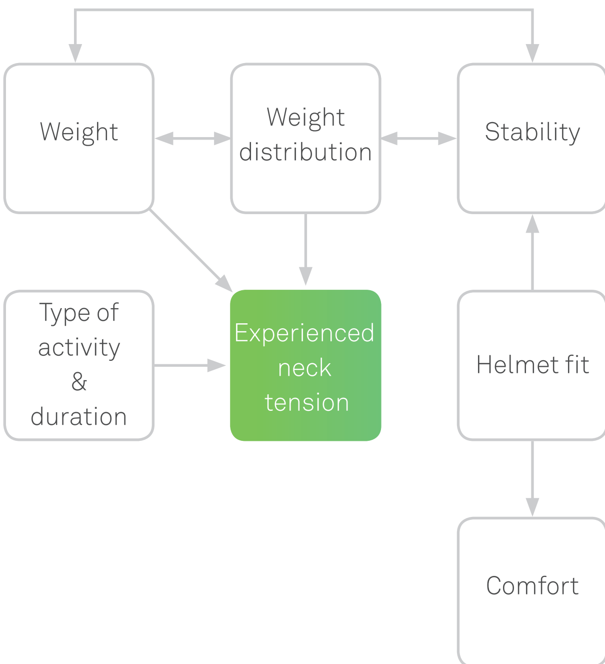


Figure 28 Framework design parameters helmet

When designing a helmet with the aspect of weight in mind, it's important to keep the overall moment of inertia as low as possible (Ivancevic & Beagley, 2004). The following parameters are important in order to achieve this:

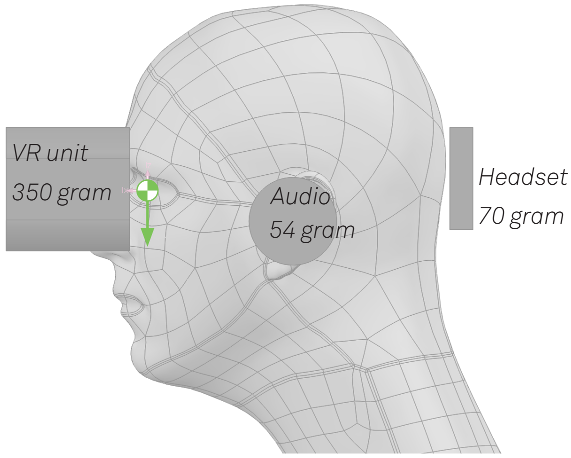
- Small mass
- Centre of mass symmetrically balanced and aligned to the natural head's centre of mass
- Smallest diameter (closest to the head)

Weight distribution VR Headset

With respect to weight perception is the position of the centre of mass of the product an important parameter. This distribution of weight can affect the perception of weight considerably. The weight of a common VR headset is not evenly distributed, since most of the hardware is positioned at the front (see Figure 29). Therefore, some VR headsets currently use counterweights in order to distribute the weight more evenly (see Appendix C). This adds to the overall weight, but is considered to be more comfortable than VR headsets that don't have this feature (Kuchera, 2016).

Maximum weight

In order to guarantee a neck-pain free experience in a VR simulator, a maximum weight has to be set for the VR helmet. Within the target group, young adults of the age of 15 years have the most underdeveloped neck muscles (Lavallee et al., 2013) and therefore set the limit of maximum weight that can be carried



Weights separate parts are weighed after a teardown of Oculus Rift CV1

Figure 29 Weight distribution of Oculus Rift CV1

on the head. For adults the limit of maximum weight is set on 2 kg (Arbogast et al., 2003). Carrying this amount of weight on the head will not cause injuries and will not induce neck fatigue over time. Around the age of 15, the neck muscles are developed for about 60 to 70 percent compared to adults (Arbogast et al.,2003) (Lavallee et al., 2013). When multiplying this percentage with the maximum comfortable weight limit for adults, a maximum weight for young adults can be derived. Therefore, the maximum weight limit is set around 1200 grams.

This weight limit also matches with current motorcycle helmets specifically sold for this age group, which are varying from 900 -1250 grams (MT helmets, 2016).

Summary

The ergonomical analysis provides the following aspects that need to be taken into account when designing the VR helmet or need to be analysed more:

- Comfort is directly related to the level of immersion and thus very important for the development of the VR Helmet.
- The difference in dimensions between various types of Caucasian heads are biggest at the circumference (± 40 mm) and nose-to-chin (± 25 mm). Other differences, such as head breadth (15 mm) and top of the head-to-eyes (10 mm) are less significant.
- The difference between Caucasian and Asian headforms are bigger, both size wise (e.g. 70 mm, circumference) and shape wise. These differences could impose some difficulties, when considering that the VR helmet should be one-size-fits all.
- Thermal discomfort can happen quickly, as 1 or 2 degrees raised skin temperature is noticeable. The most important heat exchange areas are the forehead and side of the head.
- The top and back area of the head are less sensitive to pressure and more suitable to put weight/exert force on.
- The maximum weight of the VR helmet is calculated at 1200 grams. Moreover, weight distribution is an important factor of the perceived weight.

1.4 BUSINESS

This paragraph will focus on the business aspects related to the development of the VR helmet. First, the batch size for this product will be discussed. Second, an analysis will be done to see how much the VR Helmet may and can cost.

The goal of this paragraph is to gain insights that can affect the development of the VR helmet. For example, batch size can have an effect on the choice of production methods. The available production methods can have an influence on the material selection and design freedom. Knowing this in advance can be of help during the design phase.

1.4.1 Batch size

First, it's important to come up with a batch size in an order of magnitude. This will be done qualitatively and will be approached from two angles: the company and the market.

Company

First, is to get clear what the company's current and expected sales of simulators are. The company's sales figures are varying per year, ranging from 3-10 simulators a year (R. Holtkamp (Personal Communication, 15-12-2016)). An average figure is hard to predict, since a large order for a car related theme park can instantly double their sales figures.

Market

Second, apart from providing the VR helmet along with their simulators, the intention is to sell the VR helmet also as a stand-alone product to other companies who are interested in using the product in a VR simulator/attraction. Figure 30 show examples of other types of simulators where the use of a VR helmet could be interesting. Especially the low-end racing simulators could be a very interesting market for the VR helmet.

Based on the insights mentioned above, a first batch size can be derived of 1 – 20 (max) products. This batch size is mainly based on the company's sales figures, since it's hard to predict how many VR helmets will be sold for other types of VR simulators/attractions. Therefore, the estimated batch size will be on the safe side.

Figure 30 Other interesting types of simulator applications for VR helmet

1.4.2 Price

With the batch size set, the price for the VR helmet can be discussed. This aspect will be reviewed from various perspectives.

Alternative display option

Next to VR, there are alternative display options available, such as a combination of beamers and a projection screen and a set of LCD displays. The most comparable alternative for VR is the set of three LCD displays. Each display costs around €2000 each (M. de Mooij (Personal Communication, 19-1-2017)), which in total amounts to €6000. As this is a comparable alternative, this will give an indication of how much the VR helmet may cost.

Competition

Second, it's important to know if there are competing products on the market. Currently there are a few competing products on the market, two are highlighted in this section. First, is Helmet VR, a simple combination of a helmet with a VR headset (Oculus Rift). The set is available at a price of around €3000 per size (S, M, L and XL) (HelmetVR, n.d.). This means that an owner of a VR simulator will need several (2 or 3) of these products in various sizes in order to provide proper fitting VR helmets to their guests. The second competing product is the VR helmet of Vizuality studio. This product is currently still in development, but will be available at a price of €9500 (F. Meyer (Personal Communication 21-12-2016)).

Costumer

Furthermore, it's important to know how much the customer is willing to pay for the VR helmet. Based on an interview with a current owner of a VR simulator, initial indications are that €2000 - €4000 is the amount of money that a costumer is willing to pay (R. Rensink (Personal Communication, 4-1-2017)).

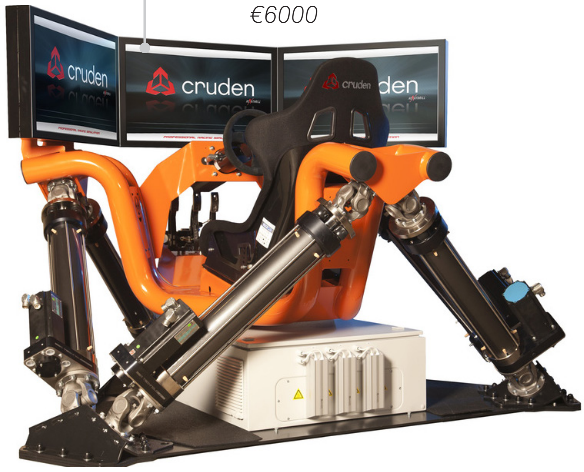


Figure 31 Alternative display option

Figure 32 Competing products

Product

Last of all, it's good to get a first idea of the cost price of the VR helmet. This approximation will help to come up with better substantiated price indication. Obviously, there's no design for the VR helmet yet, but some expenses like the donor parts can already be approximated quite accurately. Costs for the material and production of parts are estimated as following. First, an analysis based on various teardowns of current VR headsets is executed. This will give insights in the number and size of various parts & materials that are involved. Next, specialized low-volume/prototype companies are interviewed and based on these interviews a price for these various components can be derived. Table 1 shows a summary of this cost approximation, Appendix B will give a detailed cost breakdown structure. One of the most important expenses could be the development costs. At this stage it is hard to predict what these costs could be, but they could start from €10,000 (in total) up to a multiplication of this. This could seriously impact the overall cost price, since the first batch size is so low (less than 20 VR Helmets).

Donor parts	
Donor VR headset	€ 400 - 800
Donor Audio headset	€ 100 - 200
Donor Microphone	€ 10 - 50
Material & Production parts	
Housing parts	€1100
Other parts	€100 - 500
Purchase Parts	€10 - 100
Assembly	€ 100 - €200
Development costs	€ 500 - €2500
(avg.) Cost price	€3885 /unit
Safety factor (20 %)	€ 4660/unit
Sales margin (50%)	± € 7000/unit

Table 1 Summarising initial cost price breakdown

Selling price

Based on the various aspects mentioned above, an initial selling price indication can be made. An initial selling price is estimated at around € 7000. Comparing this price to competing products, this VR helmet will be in the upper half of the price range (€ 3000 - € 9500). However, it must be taken into account that multiple competing products in various sizes needs to be bought in order to provide proper fitting helmets, while the VR helmet will have a one-size-fits all feature. When comparing this price to the cost of alternative display options it stays within the same price category. However, this price indication is at the top end and over what costumers are willing to pay. Considering that a complete VR simulator will cost up to €100k - €200k, this difference seems to be trivial. However, selling this helmet for costumers with low-end racing simulators, this can be more of a problem.

Summary

The business analysis provides the following aspects that need to be taken into account when designing the VR helmet or need to be analysed more:

- The first batch size is set on 1-20 products
- The VR Helmet will also be sold separately. Especially the market of low-end racing simulators could be an interesting market.
- There are a few competitors on the market, ranging from €3000-€9500. This VR Helmet would be one of the first products to be a real integration between a helmet and VR headset.
- An initial selling price is estimated around €7000.

1.5 EXPLORATION STUDY

This paragraph will show interesting findings that were found during an exploration study. This exploration study consists of three separate studies: current solutions, interesting materials and production techniques.

One of the goals of this exploration is to get an idea how other products solve similar problems that the VR helmet will face. Also, before starting to design it's good to know with which materials can be worked with and what type of production techniques can be used.

1.5.1 Current solutions

This section highlights interesting solutions that are currently used in VR headsets or other types of products that solve similar problems that the VR Helmet will also face. The full study can be found in Appendix C 'Current solutions'.

Comfort

Changing size

In various helmets and VR headsets different solutions can be found that enable the product to change its size. A typical solution that can be found in VR headsets as well as in building helmets or bicycle helmets is the rack and pinion principle (see Figure 33). By turning a knob at the back of the product, the fit of the helmet can be loosened or tightened.

Opposed to manual adjustments, there are also automatic size adjusting principles. One can think of using elastic materials or mechanisms who use springs (see Figure 34).

Weight distribution

Most VR headsets are designed to fixate the headset on the head by straps and letting most of the weight rest on the bridge of the nose. The Playstation VR Headset does this differently (see Figure 35). First of all, it lets the weight of the headset rest on the top of the head, while at the back it's fixated at the lower end of the back of the head. Moreover, adding counterweights (±100 gram) at the back of the VR headset adds to a more

Figure 33 Manual size adjustment

Figure 34 Automatic size adjustment

Figure 35 Comfortable VR headset

optimised weight distribution. This makes it currently one of the most comfortable VR headsets (Kuchera, 2016).

Ease of use

Figure 36 shows a VR headset specially developed for public use. The VR unit is removable from the rest of the headset, which is interesting for multiple reasons. First, it's an advantage to have multiple 'cheap' headsets per VR unit. In between use there's more for cleaning and the user can already put on and adjust the headset before the VR unit is attached which results in quicker throughput times.
Figure 37 shows another interesting feature: being able to flip up the VR unit. This comes in handy if you want to switch quickly to see your surroundings before, after or in-between a VR experience.

Hygiene

Few helmets and VR headsets have features that are related to hygiene. One of the most common solutions is to have removable and washable pads that are in contact with the skin. Another solution that is used often in helmets to ensure hygiene, is using a balaclava (see Figure 39. Finally, the use of rubber as material for facemask is also interesting from a hygienic point of view.

Figure 36 Detachable VR Unit

Figure 37 Rotatable VR unit

Figure 38 Rubber facemask

Figure 39 Balaclava

1.5.2 Materials

This initial material study focused on 5 aspects that are important for the design of the VR helmet: Comfort, hygiene, lightweight, temperature and robustness. During this material study, a lot of attention is given to current material use of helmets and VR headsets. These products also have to deal with similar above mentioned aspects. The entire material study can be found in Appendix D 'Material study'. Below the most important and interesting materials are shortly explained.

Foam

Polyurethane foam is often used in VR headsets and helmets as comfort padding (see Figure 40). There are a lot of variations available (open/closed cell type, density and resilience). An open cell type of foam is preferable, because this is less insulating and allows water and air to flow through. This is important for the thermal comfort. In most products, the foam is lined with a fabric.

Fabric

As mentioned above, most foam padding is covered by a fabric. Because the fabric is in contact with the human skin, hygiene is an important aspect. There are fabrics that are easy to clean (water and dirt resistant) and are coated with for example Teflon. However, this is a trade-off with thermal comfort, because these coated fabrics are insulating. If thermal comfort is important, a fabric such as a Polyester mesh is an interesting option (high air permeability).

Rubber

Rubbers are also an interesting type of material when thinking of features that need to adapt to a different shape. Moreover, this material is easy to clean. Features such as the facemask that need to adapt to the shape of head, but also need to stay hygienic are ideal for this type of material. Finally, rubbers are also interesting material when thinking of robustness: rubbers are shock absorbent and provide a good feel and grip.

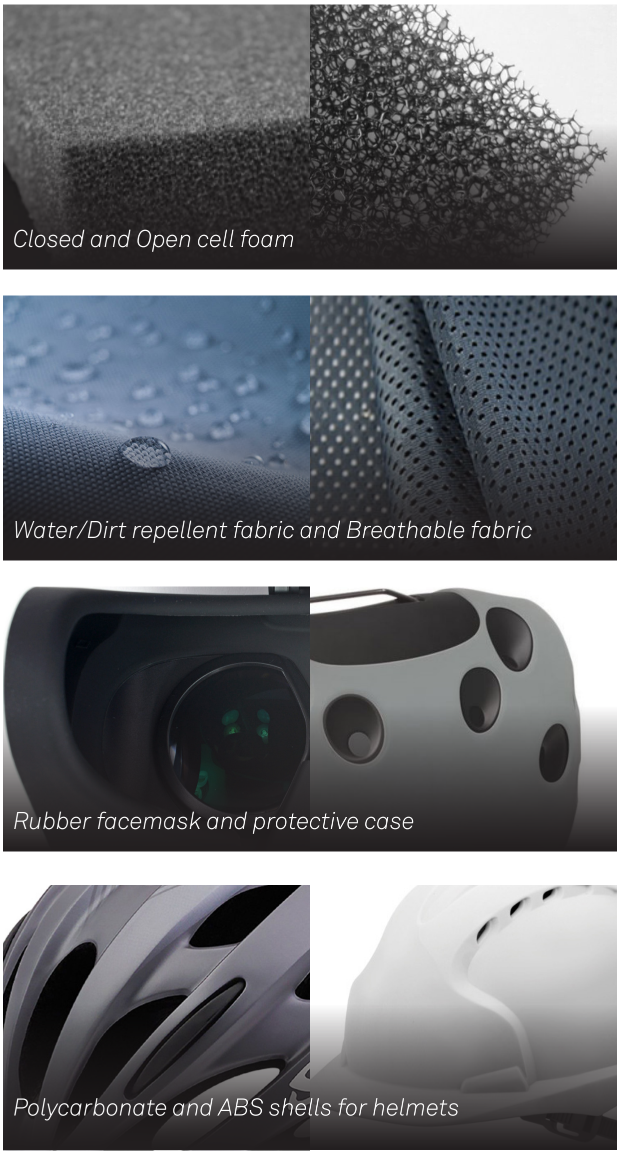


Figure 40 Selection of material study

Plastic

In almost any helmet or VR headsets plastic is used as the material for the housing/outer shell. There are various plastics available that are able to resist high impacts during an occasional dropping. Hard plastics such as ABS and PC are tough materials and impact resistant.

1.5.3 Production techniques

The initial production study focused on finding production processes which are suitable for low batch sizes (1-20 units). Moreover, attention mainly went to finding suitable production processes for (most likely plastic) housing parts. Below are the three most promising options highlighted (see Figure 41). The entire study can be found in Appendix E 'Production study'.

One-off Part

When thinking of producing plastic housing parts in a small batch size, 3D printing would be a considerable option. This technique provides a very high degree of design freedom and is accurate. There are various materials available for this production technique, but there's the freedom of choice is not big. More importantly, the 3D printed parts need considerable finishing time (sanding and painting) if the parts need to look like injection moulded parts. This will add to the cost per part.

1-20 Parts

An interesting alternative to 3D printing is vacuum casting. In this process, a two-component Polyurethane is injected in a silicone mould, in a vacuum condition. This process is used for prototypes and products with batch sizes up to 20 products. After this, a new silicone mould has to be made. There are various sorts of Polyurethanes that can mimic various sorts of plastic, ranging from hard plastic to rubber-like materials. The end result can be compared to the result of an injection moulded part, accuracy-wise and aesthetically. Finally, the costs per part are comparable to 3D printing and in some cases even cheaper.

1-100 parts

Another interesting production process, especially if a batch size is becoming higher than 20 parts, is injection moulding with an 3D printed mould (Javelin, 2015). Normally an injection mould is a CNC milled part of aluminium or steel and therefore very expensive. A 3D printed mould is compared to aluminium/steel moulds quite cheap. The final result is comparable to an injection moulded part and therefore don't need any post processing.

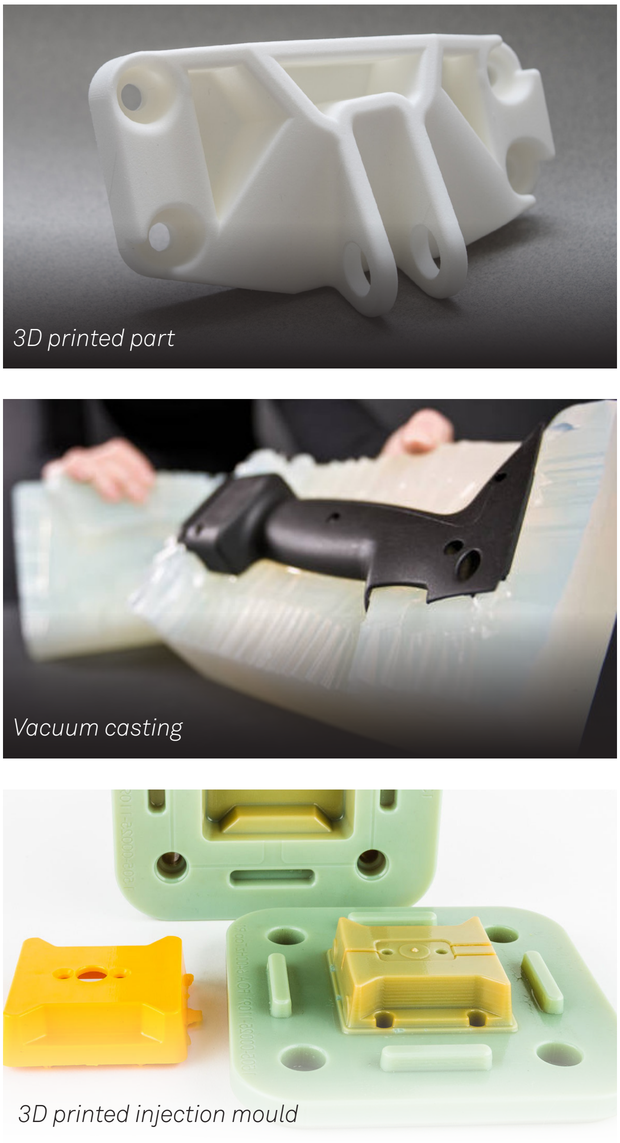


Figure 41 Selection of production study

1.6 PRODUCT EXPERIENCE

This paragraph will focus on the current experience of a VR headset and a racing helmet. Next, research questions are formulated in order to investigate what the desired experience of the VR helmet is.

1.6.1 Current experience

The VR helmet will be an integration of a VR headset and a racing helmet. First, the current experience of the VR headset and a racing helmet will be reviewed separately. Both analyses provide insights that can help to construct a research concerning the desired experience of the VR helmet in the next chapter.

The product experience is explained with the help of the product experience framework by Hekkert & Desmet (2007), which distinguishes three components that define the product experience:

- Attribution of meaning: symbolic association
- Aesthetic pleasure: gratifying the senses / look & feel
- Emotional response: feeling & emotions elicited

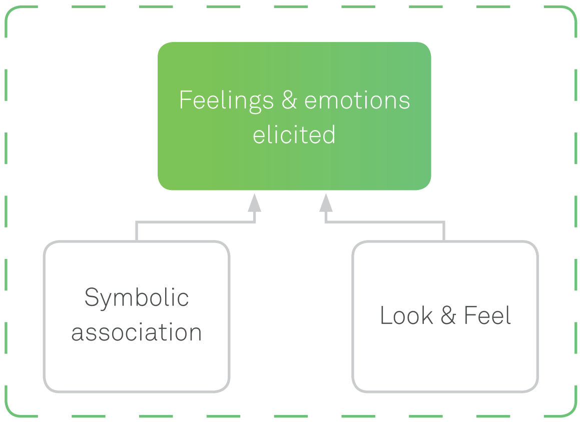


Figure 42 Product Experience Framework

Experience of VR headset

First, the product experience of a VR headset is analysed. Figure 43 and Figure 44 show an example of a VR headset and how it's used.

Symbolic association

First of all, a VR headset is a (relatively) new product containing a new type of display technology. This product can be associated with terms such as innovative, new and futuristic.
Also, the terms personal, individual come to mind. Wearing this product, you're cut off from the real world. Furthermore, the product itself can be tailored to the user: the size, position of the lenses can be adjusted in order to provide the best VR experience.

Look & Feel

A VR headset is designed to be as unnoticeable as possible. This unobtrusiveness is crucial to the level of immersion (Oculus, 2015) and can be traced back to various product characteristics. First, the

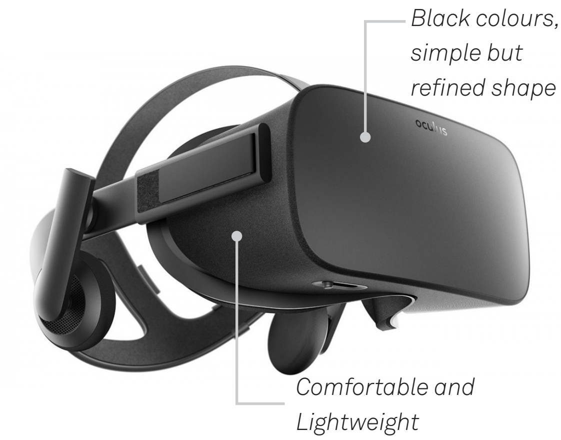


Figure 43 Look & Feel VR Headset

Figure 44 Using a VR Headset

product is lightweight and very comfortable to wear (soft materials). Aesthetically, this unobtrusiveness is also applied: (often) black coloured and simple, but refined shapes.

Emotional response

First, because this is a new and immersive technology, people are often excited during the use of a VR headset. Also, in order to be fully immersed, the user need to fully trust that the VR headset stays securely on his/her head.

Racing helmet

After the product experience of the VR headset is analysed, the product experience of a racing helmet will be analysed. Figure 45 and Figure 46 (next page) show a racing helmet and how it's used in a motorsport context.

Symbolic association

The first symbolic association with a racing helmet is that it is a symbol of safety. However, this also implicates that the activity is fast and dangerous.

Look & Feel

In contrary to the VR headset, wearing a racing helmet is quite noticeable (Revzilla, 2015). The helmet provides some uncomfortable pressure on the head and is considerable times heavier than a VR headset (3x). During a race, various forces are exerted on the helmet (Wind, g-force). All helmets have a ventilation system, which provide cooling to the head. The force of the wind flow entering the ventilation system is not noticeable on the skin of the person wearing the helmet (Overkamp motors (Personal Communication 23-1-2017).
Aesthetically, a VR headset and racing helmet are contradicting: A racing helmet has a dynamic shape and makes use of one or multiple flashy colours.

Figure 45 Look & Feel Racing helmet

Figure 46 Process of putting on racing helmet before racing

Emotional response

Figure 46 shows how a helmet is used in a motorsport context. The action of putting on a helmet and rotating the visor down is one of the last actions that race drivers are doing before starting to race. You could therefore argue that these actions are linked to an emotional state of readiness. Also during a race, the covering and providing pressure on the driver's head will give a safe and secure feeling.

1.6.2 Desired experience

The individual product experiences of both products (VR headset and racing helmet) are compared in order to get an overview which aspects have things in common or are contradicting. This overview is a first step in defining the desired experience of the VR Helmet.

Symbolic association

Both products have a very different symbolic association (safe vs innovative/futuristic product). However, both can be applicable to the VR helmet. On the one hand, it can still have the traditional safety association with a helmet, but on the other hand also have a futuristic element which justifies the VR aspect of the product. The question is how traditional or futuristic the VR helmet should be. That will be researched in the next phase.

Look & Feel

First of all, the aesthetic approaches of both products are different. A VR headset has a basic and unnoticeable design, while a racing helmet has a dynamic and noticeable design. A choice has to be made between these two aesthetic approaches. The VR helmet won't be a universal headset for various gaming contexts, but a dedicated headset for VR racing related simulators. Therefore, the aesthetic approach of a racing helmet will be taken into account in the upcoming phase. First, with this aesthetic approach, the VR headset will match the aesthetic approach of the simulator, which creates a better first impression. This first impression can affect the initial emotional state of the user (e.g. excitement), because it's looks more like it's in real life.

Also, the two product experiences of the VR headset and helmet regarding the feel of the product are different. First, the VR headset feels comfortable and lightweight when wearing it. In contrast, the helmet is quite heavy and has to fit quite snug onto the users face. The question is, which approach to choose. For both approaches, something can be said. For the level of immersion it's important that you feel the VR helmet as less as possible. On the other hand, if the VR helmet feels like a real racing helmet it can increase the perception of realism. Considering both arguments, there's no obvious approach to go for. Therefore, this will be user researched with prototypes in the next design phase. The results of that user research will be decisive.

Emotional response

The intended emotional responses for both products have overlap and can be complementary to each other. First of all, both products experiences are aiming to let the user trust that their product will stay securely on their head. Next to this, the process of putting on and wearing the VR Helmet can be designed to be exciting. The question is whether this can only be achieved by mimicking the race helmet ritual (see Figure 46) or that this can be taken more freely by using different product interactions. This also will be researched in the next design phase.

Product experience of VR Helmet

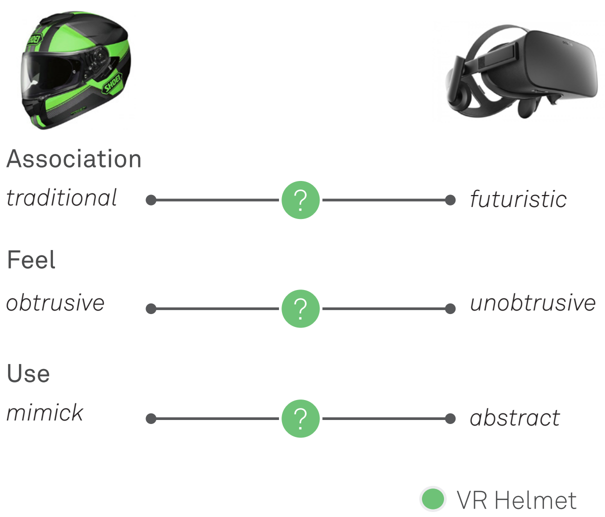


Figure 47 Visual summary of product experience characteristics of the VR Helmet that will be researched

Summary

The product experience analysis provides the following aspects need to be researched more:

- The question whether the VR Helmet should stay close to the traditional helmet association or that it can be more futuristic.
- The question whether the VR Helmet should feel as a VR headset (unobtrusive) or should stay close to the feeling of a racing helmet (obtrusive).
- The question whether the use of the VR Helmet should mimick the ritual of using a racing helmet or that the product interactions could be designed more freely.

1.7 CONCLUSION

This paragraph will list the most important conclusions for future development of the VR helmet. These conclusions are based on the analyses described in the previous paragraphs.

The conclusions will be presented in the form of product requirements. In appendix F the full list of product requirements can be found. Moreover, appendix F is a summary of the analysis phase, describing behind every product requirement the reasoning and showing possible solutions in order to fulfil the requirement. The reasoning and possible solutions are also based on findings derived in the analysis phase.

1.7.1 Product requirements

The most important product requirements will be presented per paragraph. The requirements are based on findings derived throughout the analysis phase (see Appendix F). These product requirements will be taken into account in the next design phase.

Context

- The product needs to withstand intense use and occasional dropping.
- The product needs to feel, look and be hygienic during use.

Technology

- The product will integrate the functional parts & sensors of an Oculus Rift CV1
- The product will integrate high-quality audio OEM drivers.

Ergonomics

- The product needs to feel comfortable on the users head.
- The fit of product needs to be adapted to users head.
- The product needs to provide proper ventilation and cooling to the head of the user.
- The product should have a maximum weight of 1200 grams.

Business

- The product will be designed for a batch size of 1- 20 (max.) products.
- The product has to have a maximum sales price of around €7000

1.7.2 Further research in next phase

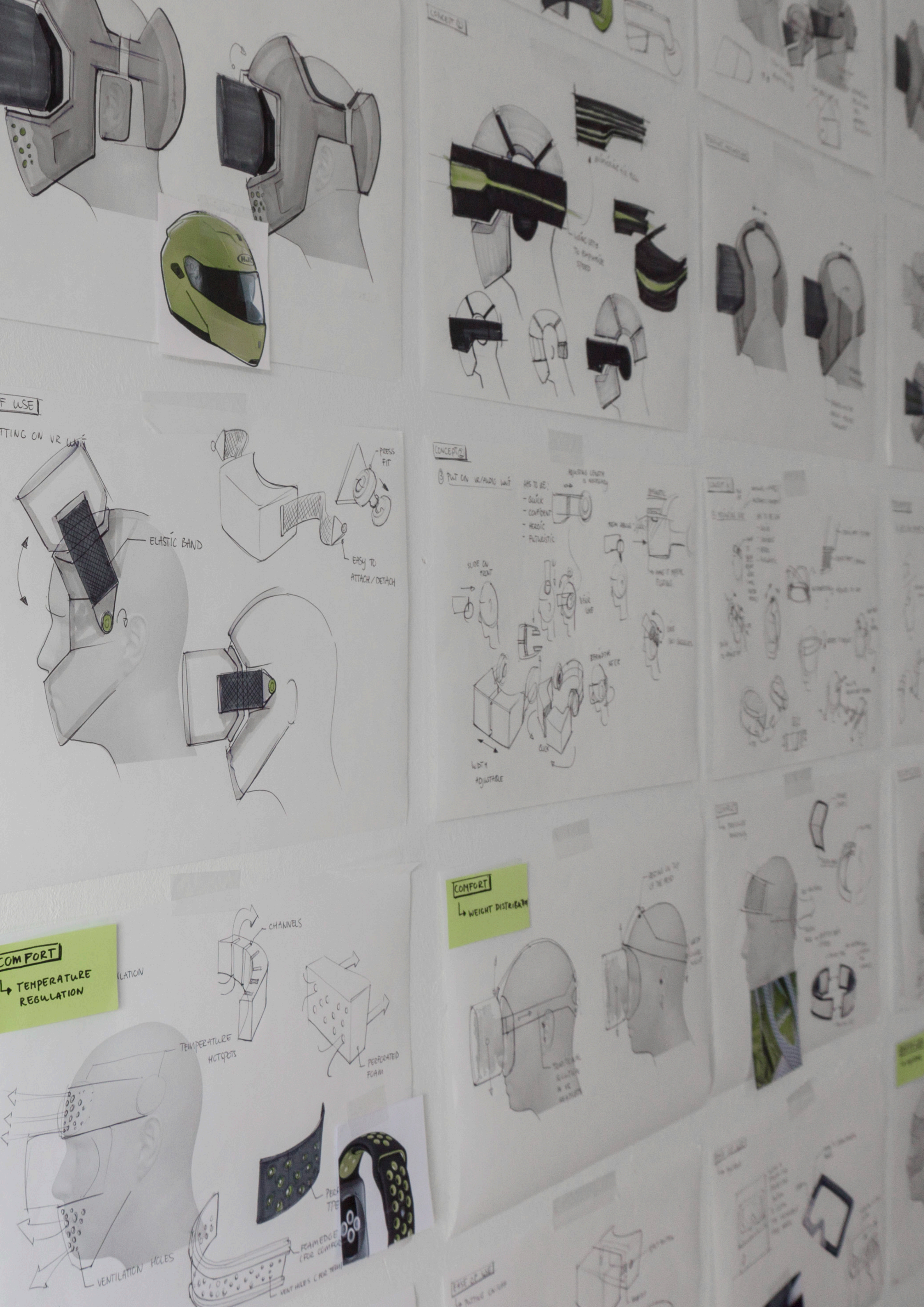
A lot of findings of the analysis phase are already translated in the form of product requirements. However, there are also a couple of findings which need extra research in order to come up with a substantiated product requirement. Researching these findings will be done in the next design phase. Researching these findings during the design phase is done with a reason. Most of these questions left open need to be answered with feedback from the user. The most motivated feedback can be given when the user can hold and test a physical product (e.g. prototype)

Product experience

The research in the next phase will focus on the product experience of the VR Helmet. As discussed earlier, the experience of the VR simulator is one of the most important aspects of the attraction. Therefore, it's key to get the product experience of the VR Helmet right.

The following questions will be answered in the next phase:

- The question whether the VR Helmet should stay close to the traditional helmet association or that it can be more futuristic.
- The question whether the VR Helmet should feel as a VR headset (unobtrusive) or should stay close to the feeling of a racing helmet (obtrusive).
- The question whether the use of the VR Helmet should mimick the ritual of using a racing helmet or that the product interactions could be designed more freely.



ELASTIC BAND
PRESS FIT
EASY TO ATTACH / DETACH
CONCEPT 3
PUT ON VR/AUDIO UNIT
HAS TO BE:
- QUICK
- CONFIDENT
- HEROIC
- FUTURISTIC
SLIDE ON FRONT
CLICK
WIDTH ADJUSTABLE
COMFORT
↳ TEMPERATURE REGULATION
CHANNELS
TEMPERATURE HOTSPOTS
PERFORATED FOAM
VENTILATION HOLES
COMFORT
↳ WEIGHT DISTRIBUTION

2 CONCEPTUALISATION

The actual product development starts at the conceptualisation phase. The goal of this phase is to go through a first loop of generating ideas, refining them into concepts, building and testing them. Based on test results and additional evaluation, a concept will be chosen which will act as a basis for the next phase.

2.1 IDEATION

This paragraph will focus on the idea generation part of the conceptualisation phase. First, the set-up of the ideation phase will be discussed. Then, this paragraph ends with a pair of concept directions, which will form the basis of the concepts that are presented in the paragraph 2.2.

2.1.1 Idea generation

In this phase, ideas are generated for various aspects that are related with the development of the VR helmet. These aspects can be clustered in four ideation studies. Appendix G shows a selection of ideas that were generated in those four studies. The studies will be shortly discussed below.

Archetypes

The idea generation phase started with a first study how a VR unit and a helmet could be integrated. The fact that the VR helmet needs to be one-size fits all, was also taken into account in this study. Sketches were made on underlayers that included a medium sized human head and the most important components of the VR unit (lenses, display, PCB of OSVR HDK 2). This was done in order to ensure realistic solutions/proportions from an early stage in the design process.

Product experience

As discussed in paragraph 1.6 'Product experience', the product experience of the VR helmet is a very important and will have the main focus during this design phase. In section 1.6.2 'Desired product experience', the two product experiences of a VR headset and helmet were compared. This led to research questions that need to be user tested, but also to an initial vision:

- **Secure** The VR helmet should be recognised as a secure product throughout the use.
- **Complementary to simulator** The VR Helmet should complement the aesthetics of the simulator.
- **Exciting** The VR helmet should be a product that excites the user from the moment that he sees the product till the moment that he has used it.
- **Confident** The VR helmet should give the user a state of feeling confident and is ready to race.

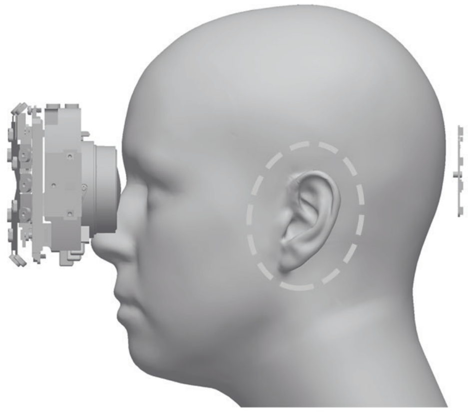


Figure 48 Underlayer of ideation phase

With a first vision on the product experience set, it is also important to know for which possible product-user interaction moments can be designed for. These are as following:

- Putting VR helmet on
- Adjusting size
- Connecting to simulator (visual/aural display)
- Putting VR unit/Audio on
- During racing
- Taking VR unit /Audio off
- Taking VR helmet off

Comfort

As mentioned earlier in paragraph 1.3, comfort is also an important aspect of the VR helmet. Thus, an ideation study concerning the comfort of the product was conducted. Aspects such as fixating the VR headset on the head of the user, distributing the weight and regulating the temperature were explored in this study.

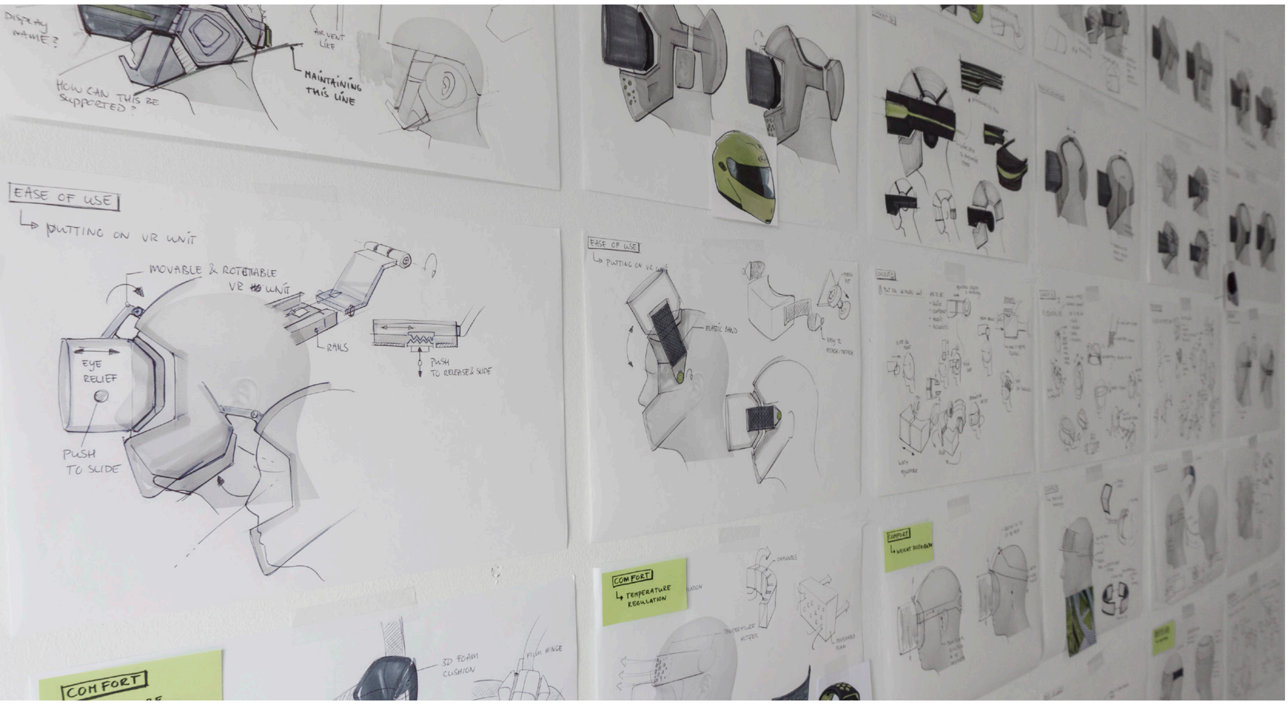


Figure 49 Impression of ideation phase

Practical

The final ideation study that was conducted related to the practical side of the VR helmet. Aspects such as cleaning/hygiene, maintenance, sensitivity for damage and changeover time of the product were investigated in this study.

2.1.2 Concept directions

The idea generation phase provided a lot of ideas for a wide spectrum of aspects that are related to the development of the VR Helmet. The next question is how concepts are derived from this great variety of ideas. Therefore, one focus point has been chosen upon which concept directions are determined. The aspect of product experience is chosen as a focus point, since there are questions regarding this aspect that need to be answered (see 1.6.2). The questions can be answered by designing and testing two VR helmets with two different product experience approaches as can be seen in Figure 50. With the two approaches selected, the ideas generated in the ideation phase were reviewed and selected if they could fit within one of the two approaches. The next page shows the concept directions with ideas that formed the basis for the concepts that are presented in the next paragraph.

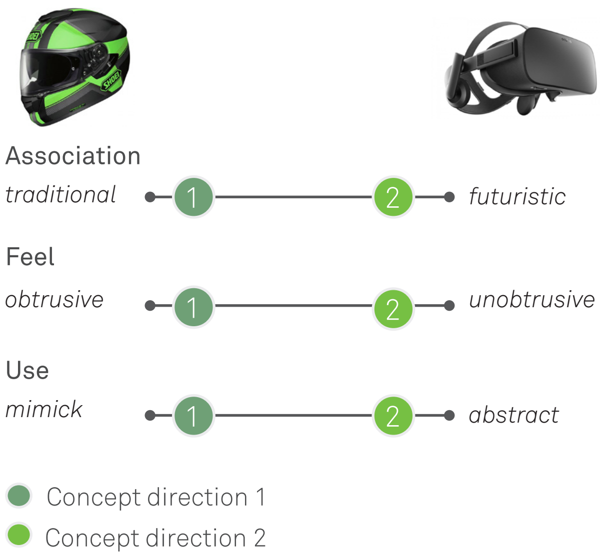


Figure 50 Strategy for concept directions

Concept direction 1: Realistic racing helmet experience

In this concept direction the design stays close to experience of a racing helmet. This means that the look, feel and use of VR helmet is similar as a racing helmet. The possible advantage of this direction is that the realism and familiarity of the experience appeals to the user.

Figure 51 shows an impression of sketches/images that relate to the look, feel and use of the first concept direction.

Concept direction 1

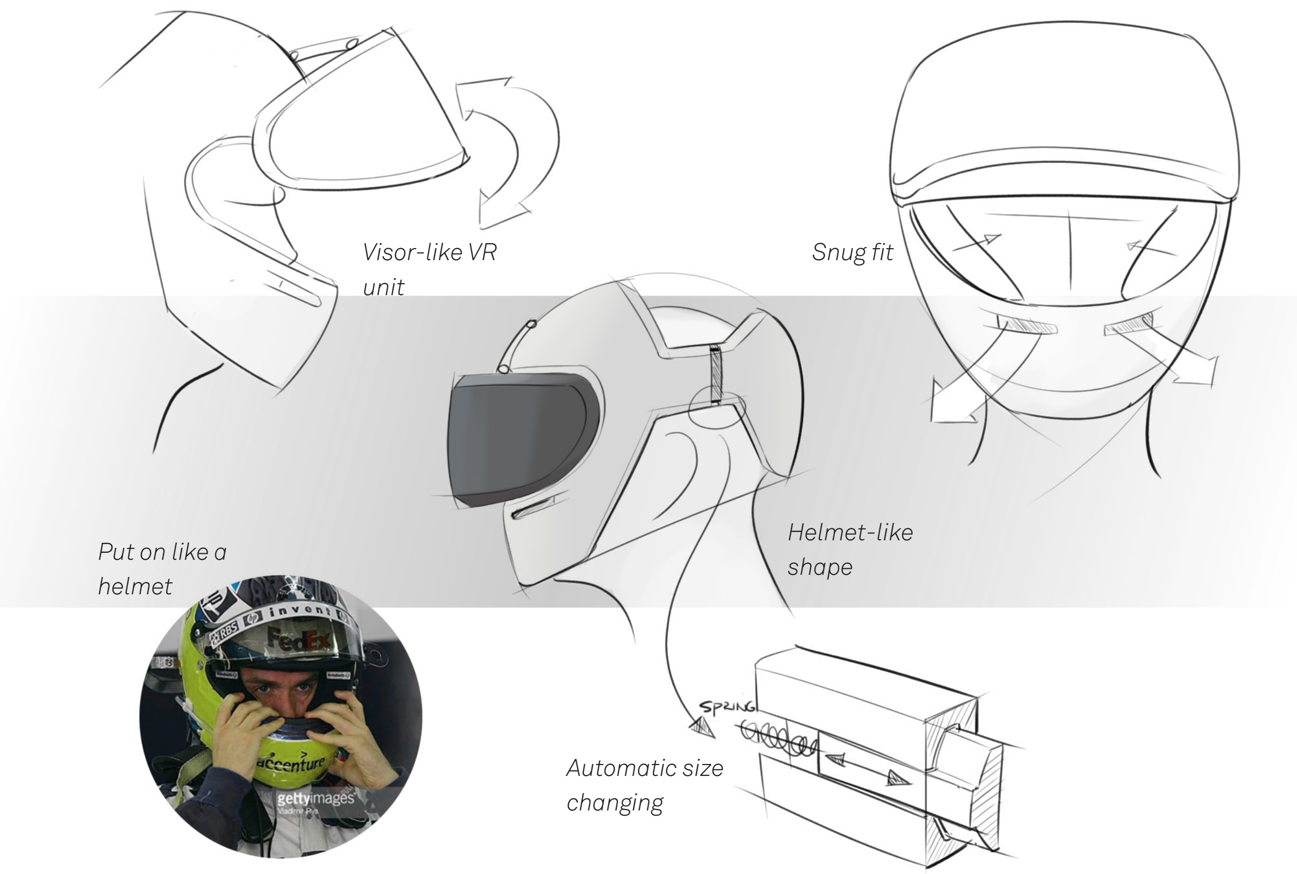


Figure 51 Impression concept direction 1

Concept direction 2: Abstract racing helmet experience

In this concept direction the racing helmet experience will be abstracted. The possible advantage of this direction is that there's more design freedom to design a tailored experience for the context in which the VR helmet will be used. Moreover, the abstraction also provides more design freedom regarding other aspects. One could think of a more comfortable and practical VR helmet in contrast to when staying close to the experience of a racing helmet.

Figure 52 shows an impression of sketches/images that relate to the look, feel and use of the second concept direction.

The two concept directions are detailed into concepts that will be presented in the next paragraph (2.2). It's important to mention that these concepts are mostly detailed on the look, feel and use that are relevant experience-wise (e.g. putting on VR helmet, adjusting size & putting on VR glasses). Other aspects, related to comfort and practicality are less detailed, but are not forgotten. It is assumed that these aspects are more related to optimising the final concept and will be again taken into account in the detailing phase.

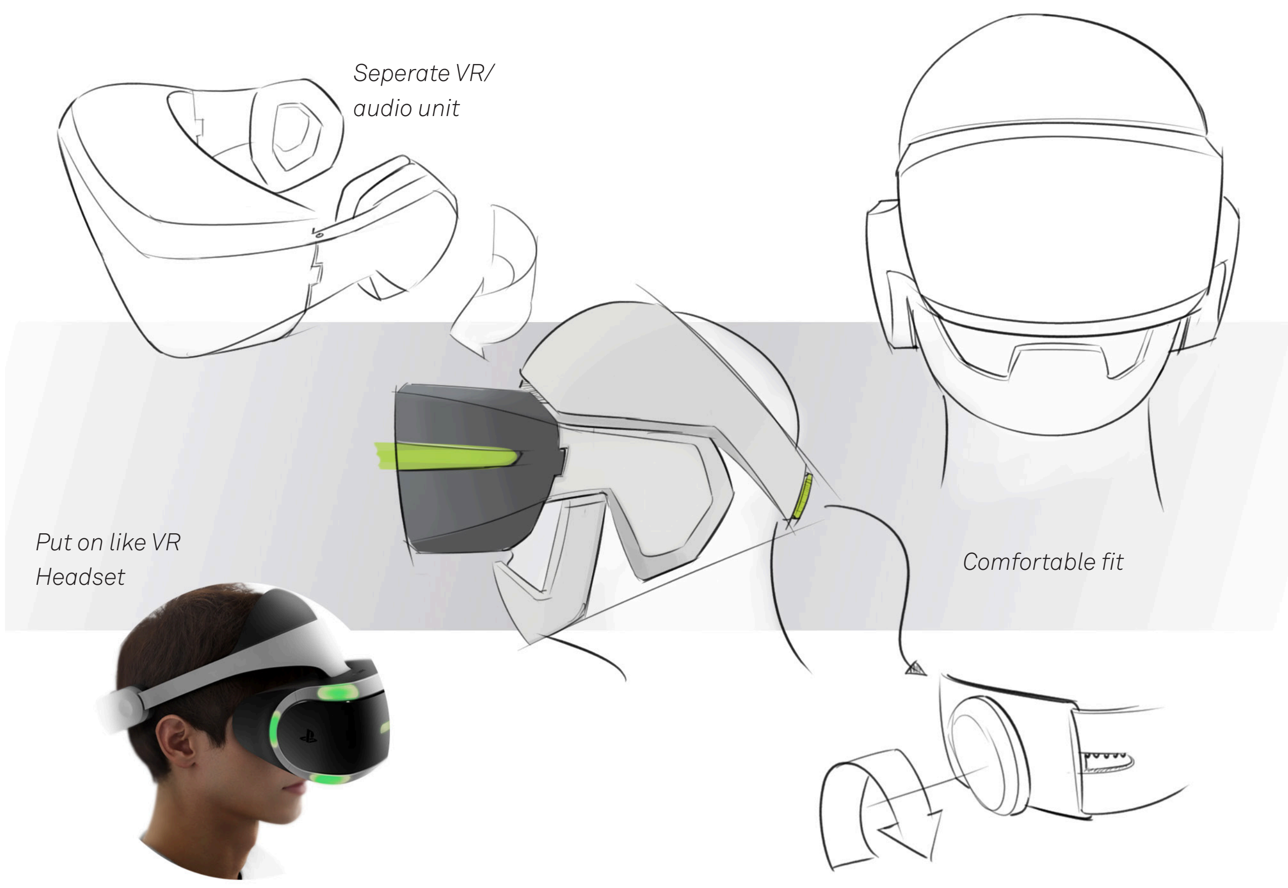


Figure 52 Impression concept direction 2

2.2 CONCEPTS

This paragraph will focus on the concepts designed during the conceptualisation phase. First, the concepts will each be presented and described. Then, the set-up and results of the user research will be discussed. Finally, by looking at the results of the user research and taking other relevant aspects into account a conclusion is made regarding which concept will be detailed further in the detailing phase.

2.2.1 Concept 1

Figure 53 (prototype) and Figure 54 (artist impressions) show the first concept of which its product experience is based on product experience of a real racing helmet.

Look & Feel

The overall shape of this concept is based on the idea of a front and back part that can shift to- and away from each other, in order to change size. While this is different from a racing helmet, which covers the entire head, this is necessary and may also provide some cooling. The concept is designed to provide pressure on the cheeks, forehead and back of the head. These areas on the head are sensitive for pressure (see 1.3.2) and the idea is that by providing pressure on these areas the feel of a racing helmet can be mimicked. Last of all, the padding in this concept is 35 mm to make sure that every head can fit in nicely and gives the same voluminous feeling of a real racing helmet.
To give an indication of the overall weight of this concept, it is estimated at ± 1000 grams (predominantly based on weight of prototype).

Use

This VR helmet concept is designed to be used like a racing helmet. It starts with grabbing the helmet at both sides, placing the helmet above the head and pulling the VR helmet down. The fit of the VR helmet adjusts automatically (spring mechanism) when placed. This feature of automatic fitting is used in this concept, because it's fast and feels secure (snug fit). When the VR helmet is on (and the visor up), the user can step into/onto the simulator. When seated, the operator connects the audio/video cable at the back of the VR helmet. When the user feels ready to race, he/she can put the visor down him/herself.

Figure 53 Prototype of concept 1

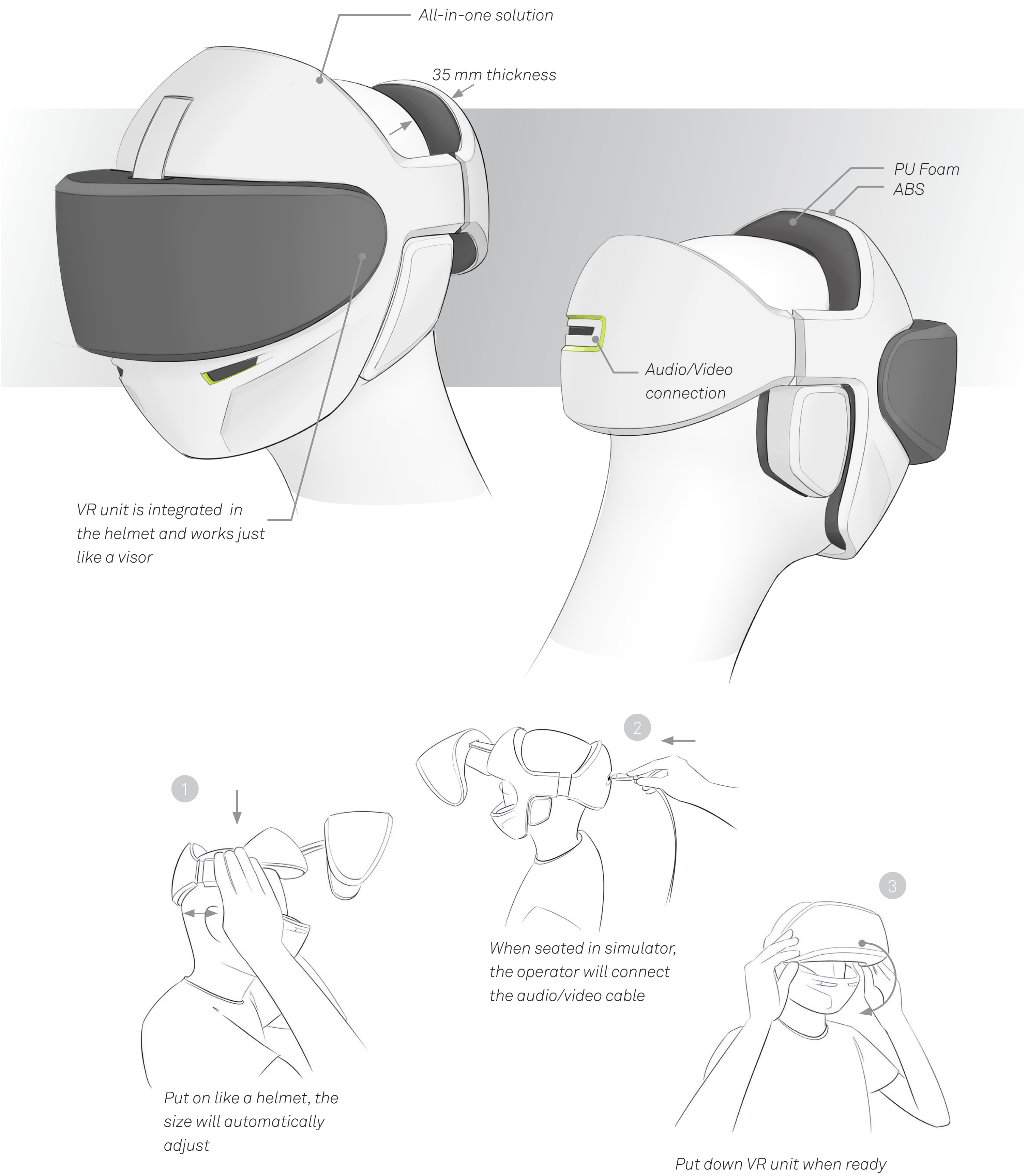


Figure 54 Artist impressions of concept 1

2.2.2 Concept 2

Figure 55 (prototype) and Figure 56 (artist impressions) show the second concept of which its product experience is based on an abstracted helmet experience.

Look & feel

The second concept is designed as a VR headset with helmet-like features. This starting point is applied on the look, feel and use of the concept. First of all, the overall shape of the concept is based on ergonomic principle of fixating the VR headset on the top and lower back of the head. This principle can be seen in various current VR headsets (See Appendix C). In order to make the concept feel more like a helmet, a jaw-like feature that covers the front of the face is added. This concept is designed with comfort in mind, just like other VR headsets (in order to enhance the level of immersion, see 1.3). This means that the overall weight and applied pressure on the head is lower with respect to concept 1.

Use

Concept 2 consists of 2 separate parts; A helmet part and VR/Audio part. This is opposed to concept 1 that is an all-in-one solution. The concept is used as following. First, when the user is waiting in line for the simulator, he/she can already put on the helmet part. This is done for various reasons: a faster throughput time, the user has more time to adjust the helmet to his/her liking and the experience of the simulator starts already when waiting in the queue. The helmet part is put on like a baseball cap. Then, the size can be adjusted by manually rotating the knob at the back of the head. The ability to control the size could give the participant more confidence. Next step is to rotate the jaw-like feature onto the face. This feature is designed with the aim to reproduce the feeling of rotating down a visor of racing helmet just before the race (feeling ready to race). When seated in the simulator, the VR/Audio unit is pushed on the helmet part by the operator. Separating the VR/audio unit from the helmet part is most of all practical: it reduces the chance of damage because the operator only handles the VR/Audio unit. When placed, the VR/audio unit can be shifted font and back to optimise the eye relief. When the user is ready to race, he/she can put on the headphones by rotating them towards the ears.

Figure 55 Prototype of concept 2

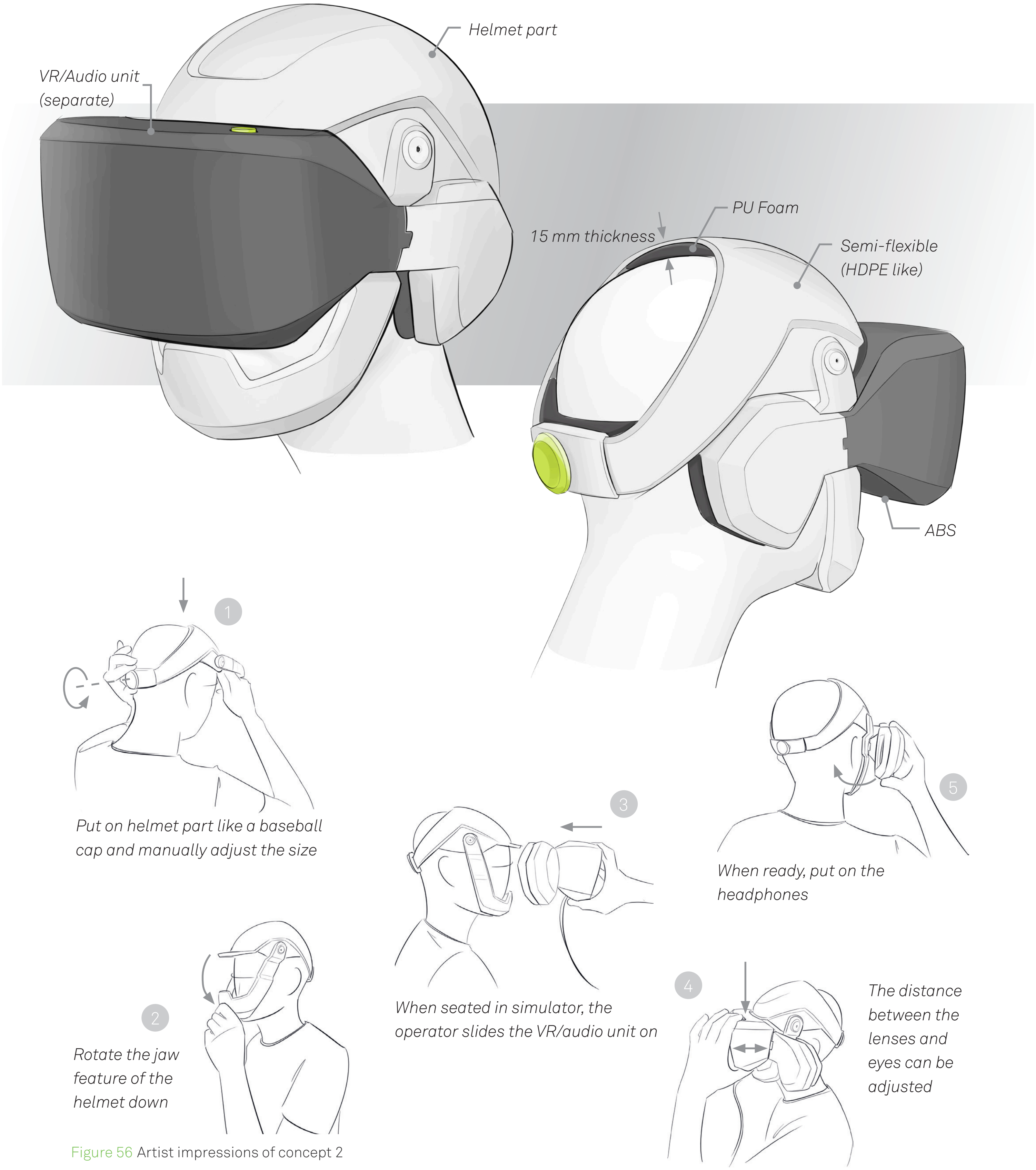


Figure 56 Artist impressions of concept 2

2.2.3 Research

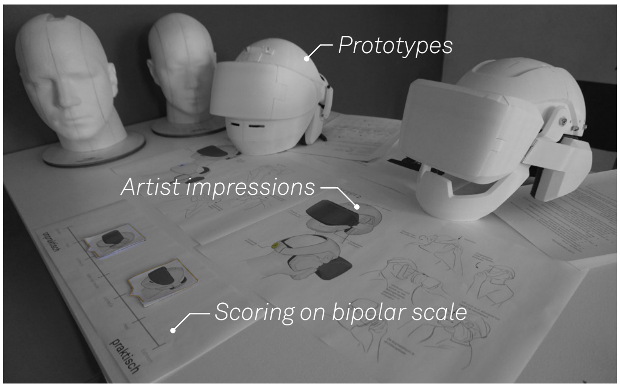


Figure 57 Impression of research

Both concepts are detailed to such an extent that the product experience can now be researched. Both concepts are designed with a different look, feel and use in order to achieve the initial vision on product experience discussed in 2.1. A user research will provide insights which features of both concepts are beneficial for achieving the optimal envisioned product experience.

Set-up research

Research questions

The research consists of three main research questions, the first one regarding the product experience of the VR helmet is as following:
Q1: What is the desired product experience of a VR Helmet for racing simulators for racing enthusiasts in an entertainment context?

This main research question can be divided in the following subquestions:
Q1.1 Which concept elicits the intended emotional response (feeling confident and excited) the most? And due to which aesthetic/ interaction aspects?
Q1.2 Which concept is associated the most with a racing helmet? And due to which aesthetic/interaction aspects? Moreover, is this association relevant?

Since there are prototypes that will be used for the research, something can be also said about the comfort and practicality (from perspective of user) of the concepts.
This leads to the remaining research questions:
Q2: How comfortable are both concepts experienced? And is discomfort in order to experience the real racing experience justifyable?
Q3: How practical are both concepts experienced?

Participants

The research was conducted with 10 participants. A prerequisite was that the participant had affinity with motorsport. This prerequisite was made to match the target group as good as possible. The participants consisted of 5 TU Delft students and 5 Cruden employees.

Set-up

The research consisted of 2 parts. First, in part 1 the ideally intended product experience of both concepts was researched by presenting the concepts with sketches and storyboards. After both concepts were clearly presented to the participant, the participant had to score both concepts on some aspects. Then, in part 2 the prototypes of both concepts were handed over to the participant and they could try on each prototype and use them as intended in a simplified simulator context. During the simplified simulator ride, the participant could watch a 360° VR racing related movie. After using both concepts they had to score each concept again on some aspects. The reason

why the research is divided in two parts (intended and actual product experience) is due to the fact that the prototypes are still imperfect and could affect the intended experience.

The scoring was done on bipolar adjective scales. Figure 58 shows an example of how this was done during the research. The bipolar scales used in the research are based on the research questions and the concepts are scored on the following scales:

- Boring – Exciting to use
- Insecure – Confident to use
- Non-matching – Matching for the VR simulators
- Uncomfortable – Comfortable to use
- Unpractical – Practical to use

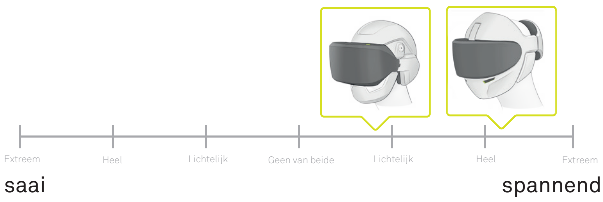


Figure 58 Example of bipolar adjective scale used in research

After every scoring, the participant was asked to substantiate his/her scoring. Figure 57 shows an impression of the research that was conducted. In appendix H a more detailed set-up of this research can be found.

Results

This section will discuss the results of the research. Figure 59 shows the average scores for each concept on the various bipolar adjectives. The main findings will be discussed per bipolar adjective below.

Boring – exciting to use

Concept 1 scored higher on the scale of feeling bored – excited to use (in part 1 and 2 of the research).

- The look, feel and use of concept 1 stayed close to the association of a racing helmet, which elicited more excitement at first sight and during use.
- The action and autonomy of putting down the VR unit as a visor by the participant him/herself was a frequently mentioned aspect that elicited the excitement.
- During the race the feeling of seclusion of concept 1 also elicited more excitement during the race.

Insecure – Confident to use

Concept 1 scored higher on the scale of feeling insecure – confident to use (in part 1 and 2 of the research).

> Concept 1 feels more sturdy and makes the participants more confident to use it, because it's not consisting of multiple parts (as is the case for concept 2).

> The action of putting down the VR unit in concept 1 gives the participant more confidence before going to race. In contrast to this, the action of pushing the VR unit onto the helmet part in concept 2 is being experienced as unpleasant.

> Concept 1 had a snug fit on the heads of the participants, which elicited more confidence before and during the race.

> Opinions regarding automatic (concept 1) or manual size changing (concept 2) were divided. Some thought that the automatic fitting gave less room for personal error as some thought that manual size changing gave them more control, thus more confidence.

Non-matching – matching for the VR simulators

Concept 1 scored higher on the scale of non-matching – matching to existing VR simulators.

> Participants thought that the look and use of concept 1 matched the existing VR simulators better.

> Moreover, participants thought that the VR helmet should resemble a racing helmet as well as possible, as it would increase the level immersion.

Uncomfortable – comfortable to use

Concept 1 scored higher on the scale of uncomfortable – comfortable to use.

> Concept 1 was perceived as the most comfortable concept, due to a better weight distribution. The weight distribution of concept 2 was imbalanced and therefore perceived as uncomfortable.

> The snug fit of concept 1 was also often perceived as a comfortable aspect.

> A slight discomfort in favour of a more realistic racing experience is permitted according to the participants.

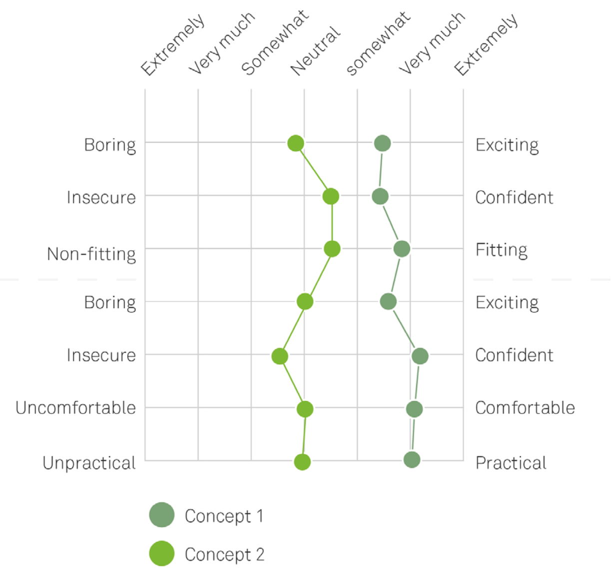


Figure 59 Average scores research concept phase

Unpractical – practical to use

Concept 1 scored higher on the scale of unpractical – practical to use (from perspective of user).

> The multiple actions involved with concept 2 are perceived as complicated. The straightforward use of concept 1 is perceived as logical and quick to use.

> The dependency on the operator related with pushing on/taking off the VR unit of concept 2 is perceived as impractical.

It can be concluded that concept 1 scored higher on every aspect that was taken into account in this research. However, analysing the average scores displayed in Figure 59, it can be seen that concept 1 scores around 'somewhat' on 'exciting to use' (in both parts of the research). This could be an area of attention in designing the final concept. The results of this research will be included in concept choice section on the next page.

2.3 CONCLUSION

This paragraph will focus on the choice of concept and identifies focus points for the final concept that will be detailed in the next chapter. The concept choice will be based on the results of the user test and on a review on other criteria.

2.3.1 Concept review

The concept review of both concepts will be done in a qualitative manner on various criteria. The following criteria are taken into account:

Criteria

- **Product experience** Since experience is a key aspect the simulator attraction, it's important to review how is each concept experienced and if it matches the simulator attraction.
- **Comfort** When wearing the VR headset, comfort is an important aspect that affects the VR experience.
- **Practicality** The entertainment context brings some practical aspects along, such as is the VR helmet quick and understandable to use (affecting throughput time,, the ease of cleaning in-between shifts and the ease of servicing the VR helmets.
- **Durability** The VR helmet will be used dozens of times a day, so it's important that the VR helmet needs withstand heavy use.
- **Cost**

Review

Figure 60 shows a general review of the concepts on the five aspects that are mentioned above. The substantiation for this review is done in the upcoming sections. This substantiation is done by reviewing both concepts on the main principles behind every concept. The details of both concepts are not fully worked out and still could be improved in the next design phase. Taking this details into account would obscure the concept choice. There are three main principles on which the concepts differ: The product experience, the integration/separation of VR unit and the type of size adjusting. These three main principles will be reviewed separately and a choice for each principle will be made.

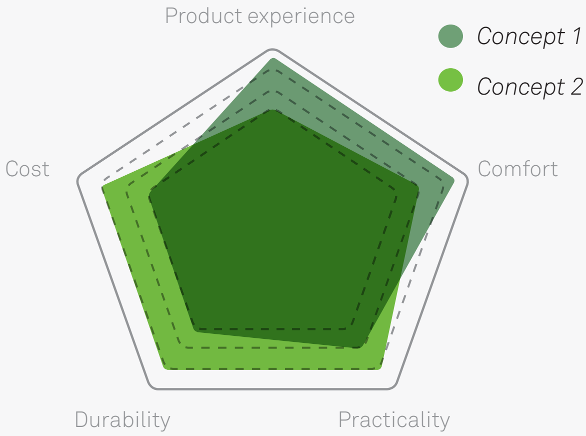


Figure 60 General concept review

Real vs Abstract racing helmet experience

First of all, the two concepts were both designed with a different approach. Concept 1 was designed as a racing helmet with VR (real racing helmet experience), while concept 2 was designed as a VR headset with helmet-like features (abstract racing helmet experience). The following review regarding this aspect can be made:

Real helmet exp.	Abstract helmet exp.
+ Experience Higher feeling of excitement and confidence + matched current VR simulators better	- Experience Lower feeling of excitement and confidence + matched current VR simulators less
+ Comfort The snug fit and heavier VR helmet was (surprisingly) experienced more comfortable	- Comfort Poor weight distribution

Table 2 Review of real vs abstract racing helmet experience

Therefore, the product experience of the final concept will be based on concept 1.

Integration / Separation VR & Audio

Secondly, the concepts differ on product architecture level. Concept 1 is all-in-one solution: Helmet, VR and Audio are integrated in one solution. Concept 2 has separated the helmet part and VR/audio part. This leads to the following review:

Integration	Separation
+ Experience Letting the user to put down the VR unit gives more excitement and confidence	- Experience Letting the operator attaching the VR unit is perceived as really unpleasant
± Practical There are less actions before racing (throughput time), but it is harder to service	+ Practical Easier to clean + it's easier to service (seperation of parts)
- Durability More moving parts and will be handled more by user (higher chance of dropping)	+ Durability Operator handles the expensive part (VR unit) which reduces the chance of dropping
- Cost Most likely two full VR helmets necessary per simulator	+ Cost Only one expensive VR unit necessary + multiple cheap helmet parts

Table 3 Review of 1 part vs 2 parts

When looking at the review above, it's clear that the separation of the helmet and VR/audio part has a couple of advantages over an all-in-one solution. However, in consultation with the company there's chosen to detail an all-in-one solution for the final concept. Main reason is the higher product experience that comes with this principle. The company sees this as a premium option over an Oculus VR headset, so therefore the extra costs that are implicated with this principle are justified in this manner. The negative aspects that are related with the all-in-one solution need to be minimised in the final design of the concept.

Automatic vs Manual size adjustment

The last principle that will be reviewed is regarding adjusting the size. Concept 1 had an automatic size adjustment mechanism, while Concept 2 had a familiar manual size adjustment mechanism. The two size adjustment principles are reviewed as following:

Automatic size adj.	Manual size adj.
+ Experience Cool feeling that it adjusts automatically	+ Experience Having more control on the size adjustment is also appreciated
- Comfort It's more difficult to adjust size for large variations (in case of spring mechanism)	+ Comfort It's easier to adjust size for large variations
- Durability Chance of fatigue of mechanism is higher (in case of spring mechanism)	+ Durability Less chance of fatigue/wear

Table 4 Review of automatic vs manual size adjustment

As already discussed, the user research showed that there was no clear favourite size adjustment principle from a product experience point of view. The review above shows that the manual adjustment principle has more advantages from a comfort and durability standpoint. Therefore, a manual size adjustment mechanism will be implemented in the design of the final concept.

2.3.2 Summary final concept

Based on the review in the previous section, it can be concluded that concept 1 will form the basis for the final concept that will be detailed in the next chapter. This final section will discuss points for improvement that will be taken into account in the detailing phase of the design process.

1. VR Unit

The first feature that needs to be detailed more is the VR unit. Below are important aspects related to the optimisation of this VR unit discussed.

Positioning of VR unit with respect to eyes

To start, during the testing of both concepts, it was observed that the positioning of the VR unit with respect to the eyes was inadequate for various people (too high or too low). The positioning of the VR unit with respect to the eyes is key for an optimal VR experience. Therefore, this will be taken into account in the design process of the last phase.
The second aspect of the VR unit that will be optimised and is related to the positioning

Opening/closing the VR unit

Second aspect that needs to be optimised is the mechanism that enables the VR unit to be opened and closed like a visor. The mechanism needs to be more durable (able to withstand occasional dropping) and the movement of the mechanism needs to be more defined.

Components Oculus Rift

Finally, the components of an existing VR unit, in this case the Oculus Rift, will be incorporated into the final design of the VR unit.

2. Audio headset

The second feature that will be optimised is the audio headset. In the current concept adjustable ear cups are used to display the audio. However, this feature is not very durable, since a lot of moving parts are involved. Instead of using ear cups, research will be done to use fixed speakers placed near the ear.

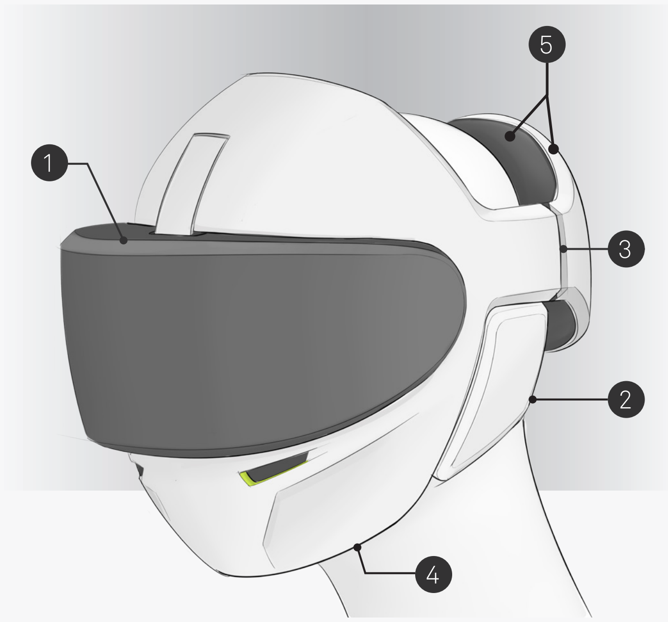


Figure 61 Final concept with attention points

3. Comfort

The aspects related to comfort need to be improved a bit more. Aspects such as the fit, adjustability and weight distribution need to optimised.

Fit

The fit of the concept has to be a bit better. The main thing that was observed during the user test, was that people could pull the VR helmet too far down over their head. Therefore, the final concept has to rest more on the top of the head to prevent this.

Adjustability of size

The adjustability of size was already in the good direction, but the final concept needs be more adjustable to a larger variety of sizes. Moreover, the manual size adjustment mechanism used in concept 2 will be implemented in concept 1.

Weight distribution

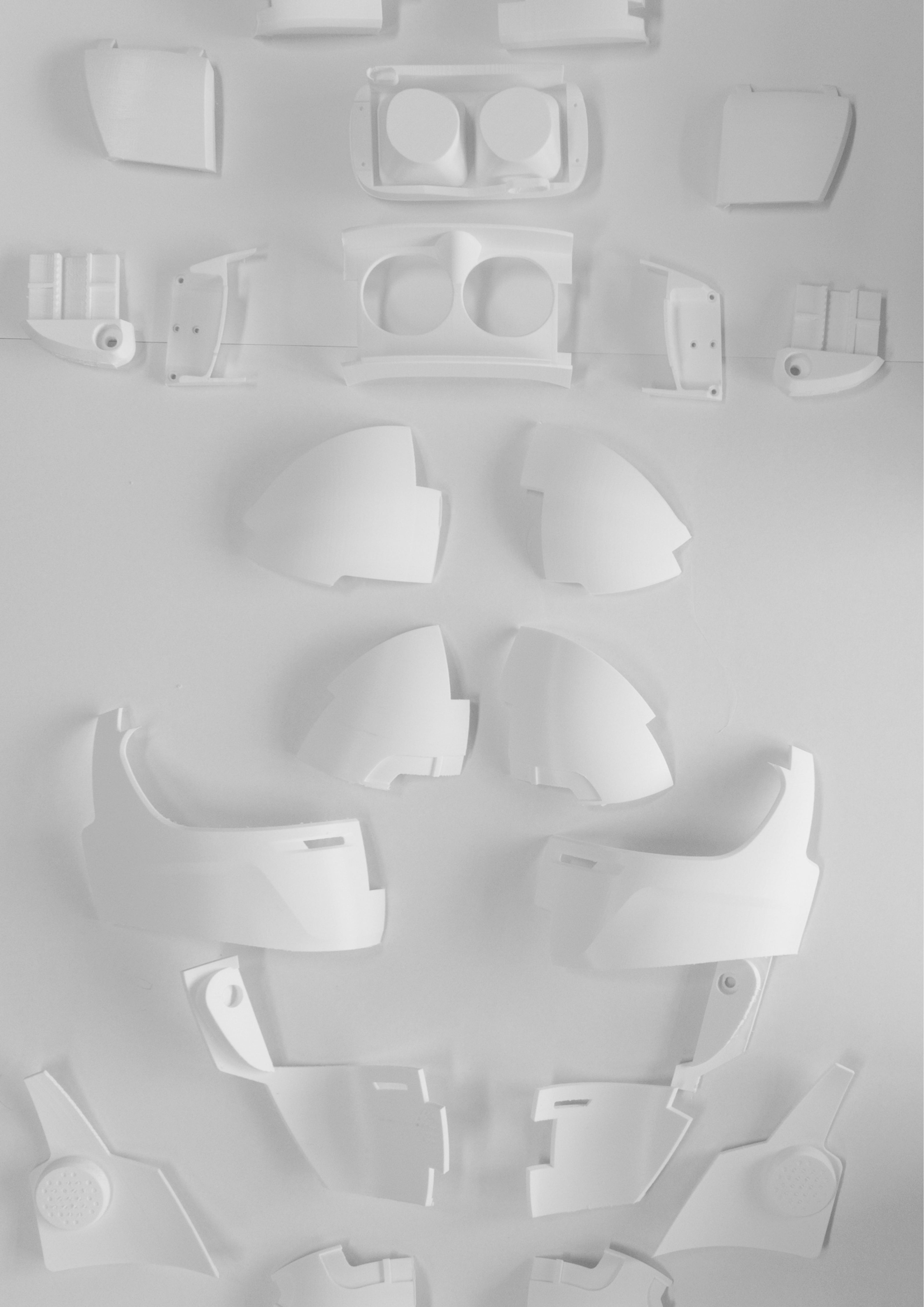
The weight distribution was already quite good, but can be optimised a little bit more.

4.Aesthetics

The aesthetics of the concept are roughly explored. Therefore, in the next phase a more elaborate design study for especially the details will be conducted

5. Material use

The final aspect that will be researched is the material use. In the concept phase, not a lot of attention went to material selection of the body and cushions. In the next phase, attention will be given to selecting materials that are durable and hygienic (and/or easy to clean). Moreover, as discussed above, the fit/adjustability of the VR helmet needs to be improved and this can also be improved by selecting the right materials.



3 DETAILING

In this phase, the chosen concept will go through a final design cycle of improving, detailing, building, testing and evaluating. All these aspects will be covered in this chapter.

3.1 REDESIGNING FINAL CONCEPT

This paragraph explains the improvements made on the chosen concept (concept 1). Improvements were made with respect to the VR Unit, audio, comfort and aesthetics.

3.1.1 VR Unit

The VR unit of the VR Helmet is an important part that needs to be redesigned on several aspects. The main alterations for this part are discussed below.

VR donor components

The concepts presented in the previous chapter didn't use actual components of an existing VR headset. Therefore, a teardown of an existing VR headset was conducted. The VR headset that was chosen to be taken apart, is the Oculus Rift. Paragraph 1.2.2 explains the choice of this VR headset. Taking the Oculus Rift apart is doable, but not easy due to the use of e.g. hard-to-reach snap fits. The components that are necessary in order to provide the VR experience (Display, lenses, motherboard and front-faced IR LEDs) are conveniently packed together. Figure 62 shows the package that can be re-used in the final concept. However, there are arrays of IR LEDs in the housing of the Oculus Rift that cannot be re-used, because these components are glued to the housing (see Figure 63). These IR LED arrays are important for tracking the user when he/she turns his head to the back. In appendix I a more elaborate analysis can be found concerning the importance of these IR LED arrays for the two different VR simulators (motorbike and F1 car). Main conclusion of this analysis is that the front facing IR LED arrays are sufficient when in a F1 simulator context and somewhat for the motorbike simulator. Furthermore, the difficulties observed during this teardown has led to the conclusion that getting the parts of the Oculus Rift to work optimally can cost a lot of time and most likely extensive knowledge about electronics is also required. Therefore, focus during the remaining of the design project will lie on the other remaining design challenges. The final concept will take the dimensions of the package into account, making sure that in future development that the parts will fit. Figure 64 shows the simplified CAD model of the package.

Figure 62 VR components package

Figure 63 Glued IR LEDS

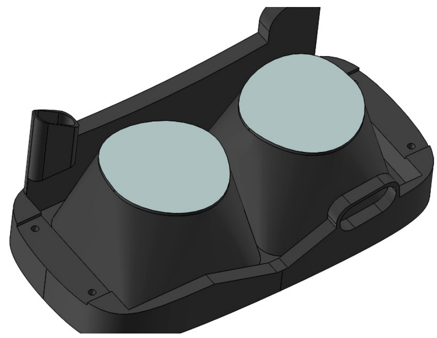


Figure 64 Simplified 3D model of VR components package

Mechanism

The mechanism to open and close the VR unit also needs to be redesigned. As mentioned before, the final concept is based on concept 1. The mechanism used in that concept is not sufficient when considering various aspects, such as durability, adjustability and experience of the movement. Therefore, Figure 65 shows the new principle of the mechanism that will be detailed in the final concept. The way of using is almost similar to the open and closing of a visor in a racing helmet. This has several advantages, but one important advantage is that it stays close to the experience of a racing helmet, which is beneficial for the overall experience of the VR helmet. An additional horizontal movement before rotating is necessary, because the lenses are otherwise interfering with the helmet. This horizontal movement provides the opportunity to adjust the eye relief (horizontal distance between lens and eye). This enables that people wearing glasses, which have a bigger eye relief, also have a good VR experience. Next to being more exciting and better adjustable, this principle is also more durable since it is connected at both sides of the VR helmet.

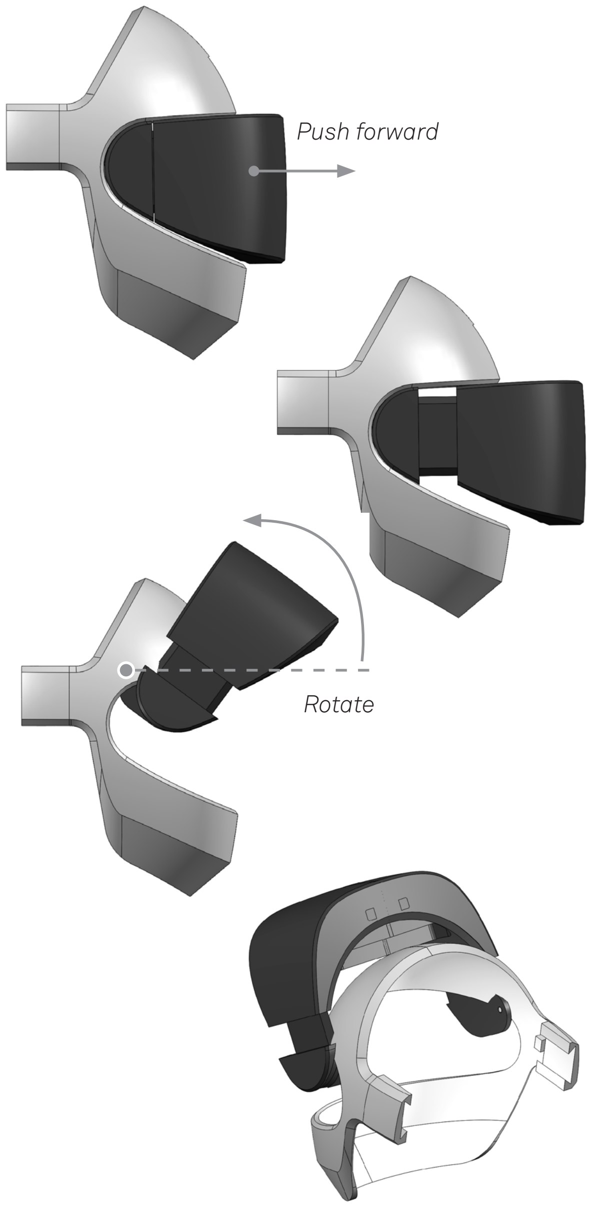


Figure 65 Mechanism principle of open and closing

Positioning VR unit with respect to the eyes

The last aspect concerning the VR unit that needs to be solved is the positioning of the VR unit with respect to the eyes. During the research presented in paragraph 2.2.3, it became apparent that the lenses sometimes couldn't be fully placed in front of the eyes on the vertical axis. This makes sense, because the vertical distance from the top of the head to the centre of the eyes can vary up to 20 mm (NASA,1978) (diameter of lens is ± 50 mm), while the vertical distance in the prototypes in this research was fixed. Therefore, this has to be resolved in the final concept. This can be either solved by moving the package with the lenses up or down through some kind of mechanism or by fixating the helmet also on the top of the head. This latter solution is often used in current VR Headsets (see Appendix C)). This solution will also be used in the final concept, since it also solves the problem that the user can pull the helmet too far over his/her head, which occurred during the use of the prototype of concept 1. Figure 67 shows a first impression of this fixation strap at the top of the head.

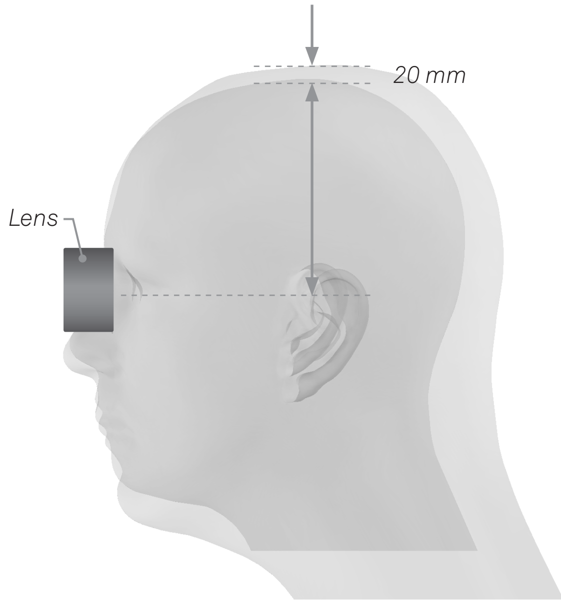


Figure 66 Difference distance top head to middle of the lens

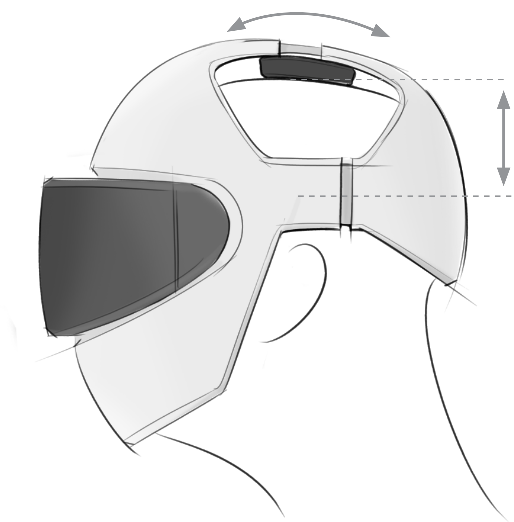


Figure 67 Top strap fixation

3.1.2 Audio

As discussed earlier in section 2.3.2, the starting point for the audio feature in the final concept was to place speakers near the ears at a fixed position. Figure 68 illustrates the principle of this starting point. Integrating the speakers at a fixed position in the helmet, opposed to moveable headphone earcups (in the case of concept 1), has multiple advantages. First, the solution is more durable since there are no fragile and moveable parts in involved. Next, since the speakers don't make contact with the head of the user it's also a lot more hygienic. Finally, because there are less parts involved, it's also likely to reduce the costs. However, there is one potential drawback and that's related to the sound quality. An advantage of using earcups, is isolating the user from ambient noise and letting the user optimally experience the audio. The new audio feature will be somewhat closed off by the helmet, but will not have the same isolation as earcups. To compensate this loss of isolation, slightly bigger speakers can be chosen to display the audio better.

Next step is to select the right audio driver. As discussed in section 1.2.3, the best way to fully integrate a good quality speaker, which comes at a reasonable price, is to use an OEM headphone driver. There are numerous speakers with varying specifications available in this category, making it hard to select the best speaker straight away for a non-expert. However, based on a short research, a full-range dynamic mylar headphone driver of 40/50 mm diameter are commonly used in quality headphones (GerrardSt, n.d.). Therefore, this part will be taken into account in the final concept.

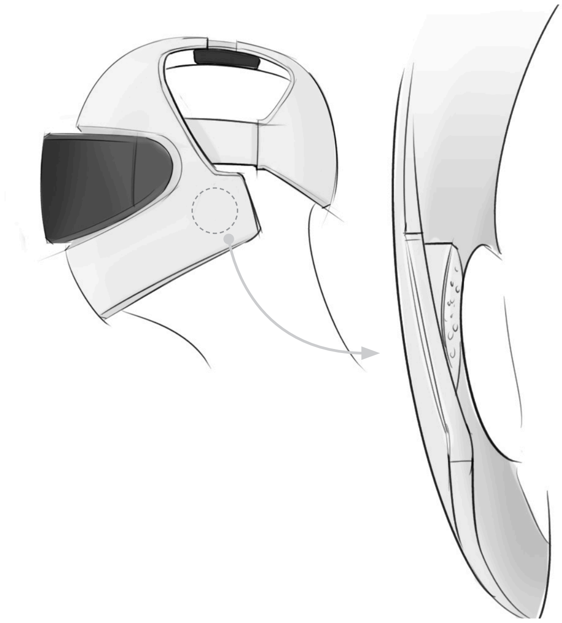


Figure 68 Fixed positioned audio

Figure 69 Mylar speakers

3.1.3 Comfort

The third aspect of the final concept that needs to be further developed is the overall comfort of the VR helmet. This general term can be broken down into three specific aspects: size adjustment, fit and weight distribution.

Size Adjustment

Headforms

To start, the various sizes that the final concept has to accommodate have to be better than concept 1. During the research in the conceptualisation phase, it became obvious that the prototype was slightly too small for the majority of the participants (see Figure 70). The prototypes were based on a medium sized western 3D headform (presented in section 1.3.1), but based on further research it became clear that the circumference of this specific headform (550 mm) is quite small when comparing this to the average circumference of a Dutch male (570 mm). This led to the conclusion that the final concept has to fit a larger range of head sizes, especially larger heads. Therefore, a set of altered 3D headforms (as can been seen in Figure 71) were devised for design and validation for the final concept. These set of altered 3D headforms will cover around 90% of all male Caucasian headform sizes (P5 – P95) (NASA, 1978). Next to that, the male Chinese headform sizes are covered around 50 % (P50-P100) (NASA, 1978).

Manual Size adjustment

As mentioned in paragraph 2.3, the final concept will make use of a manually adjustable size adjustment system. The system used in concept 2, a rack-pinion system with rotation knob, will also be used in the final concept (see Figure 72). Adjusting the size with this system is simple and familiar to the user, because it is widely used in various types of helmets.

Figure 70 Example of too small prototype

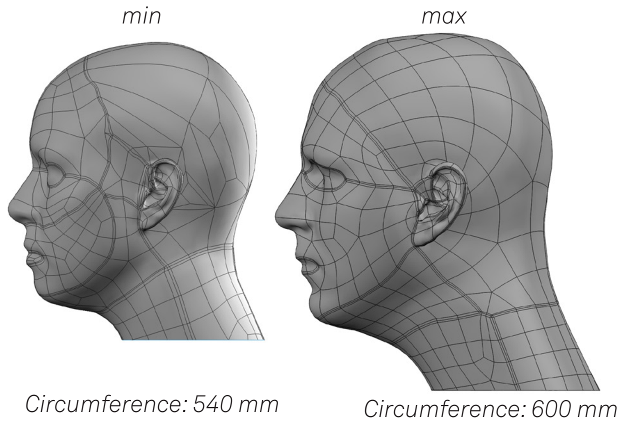


Figure 71 New range of headforms

Figure 72 Manual size adjustment system

Flex zones

In order to successfully integrate the rack-pinion manual size adjustment system, the back of the helmet needs to have some flexibility. This has to do with the way the system works: when tightening the fit, the adjustment straps will come closer to the head of the user and vice versa (see Figure 75). Therefore, the idea is to use flexibility zones in the final concept (see also Figure 75). These flexibility zones are made of a semi-flexible material (e.g. PU) and will provide the flexibility and guidance for the adjustment straps.

Prototype

In order to validate the proposed redesigns (upper strap, manual size adjustment system and flexibility zones), a prototype was made. Figure 74 shows a picture of the prototype. The 3D model of concept 1 was taken as basis and modified for this prototype. The prototype proved that the suggested redesigns are improving the comfort and level of adjustability. This means that these redesigns will be taken into account in final design of the concept.

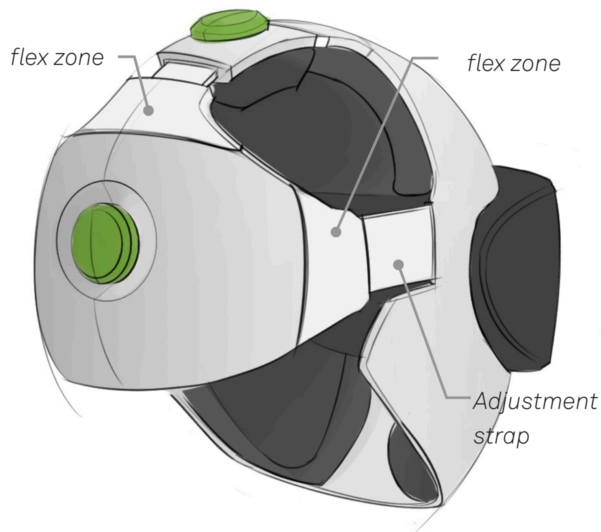


Figure 73 New size adjustment system + flex zones

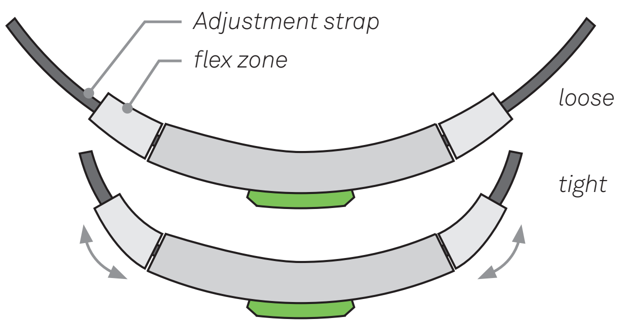


Figure 75 Flex zone principle

Figure 74 Comfort redesign prototype

Weight Distribution

The final aspect related to the optimisation of the comfort of the final concept is optimising the weight distribution. As discussed in section 1.3.4, weight distribution is an important factor of perceived comfort. First, the current weight distribution without any improvements is analysed with the use of the 3D model of the previously mentioned prototype. In this 3D model, materials are assigned to the various parts and weights of the VR donor/audio parts are included. Figure 76 shows the location of the centre of gravity of the unimproved VR helmet for situations when the visor is open or closed. This shows that the VR helmet has a slight tendency to rotate downwards. A secure fit will prevent this from happening, but it shows that the natural balance of the VR helmet can be improved. Adding a counterweight at the back of the VR helmet would be a logical next step. Figure 77 shows the improved results of the location of centre of gravity when adding a counterweight of ±100 gr in the form of a small steel plate in CAD. In order to validate whether the shift of the centre of gravity is noticeable for the user a counterweight of 100 grams was added to the prototype of concept 1. This small validation test showed that the addition of the counterweight is noticeable and beneficial and therefore will be taken into account in the design of the final concept.

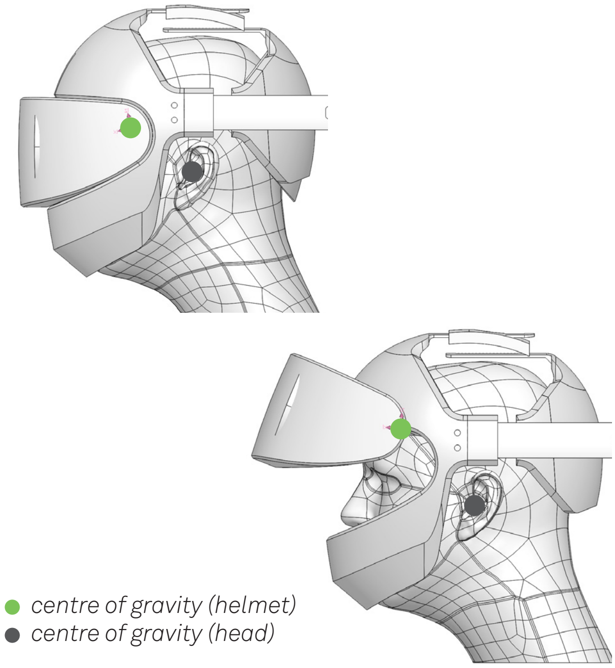


Figure 76 Current weight distribution

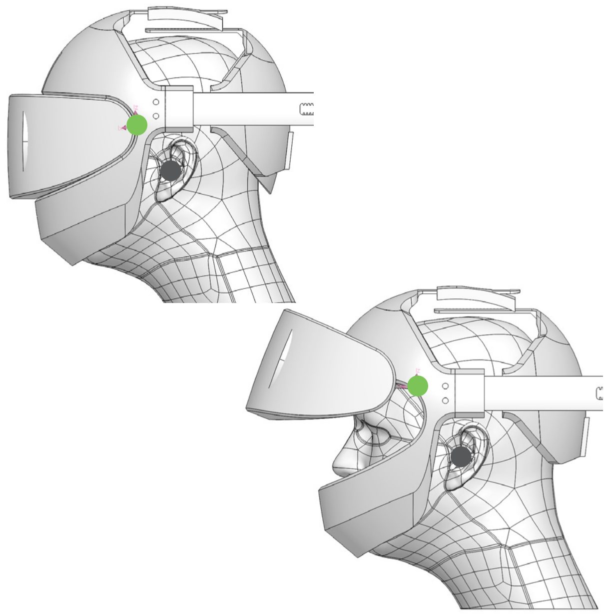


Figure 77 Improved weight distrbution (Counterweight)

3.1.4 Aesthetics

The look and feel of concept 1 was only roughly designed. Therefore, a more thorough design exploration is done for the overall shape and details for the final concept.

Figure 78 shows inspiration images which reflect the vision regarding the overall shape and details of the final concept. First, the overall form has to be dynamic/ aerodynamic to match the aerodynamic exterior of the F1/Motorbike simulator. This can be achieved by using dynamic lines and dynamic cutouts in the helmet.

Figure 78 Inspiration images look & feel

Furthermore, an important aspect that needs to be taken into account is customisation/branding of the VR helmet for the operator of the simulator. This can be achieved by designing the VR helmet in two/three tones that reflect/support the logo on the helmet. This will create a harmonious entirety.

Figure 78 shows also inspiration images regarding the details of the product. One of the important aspects in this selection is to style the parts with chamfered-like details. These type of details will support and add to the aerodynamic styling. Another important detail is to use matte and glossy materials in the VR helmet. The matte materials will be used on places where a lot of contact is with the user. In this way, dirty fingerprints are less noticeable.

Figure 79 shows a selection of sketches that show how design vision is reflected in the final design.

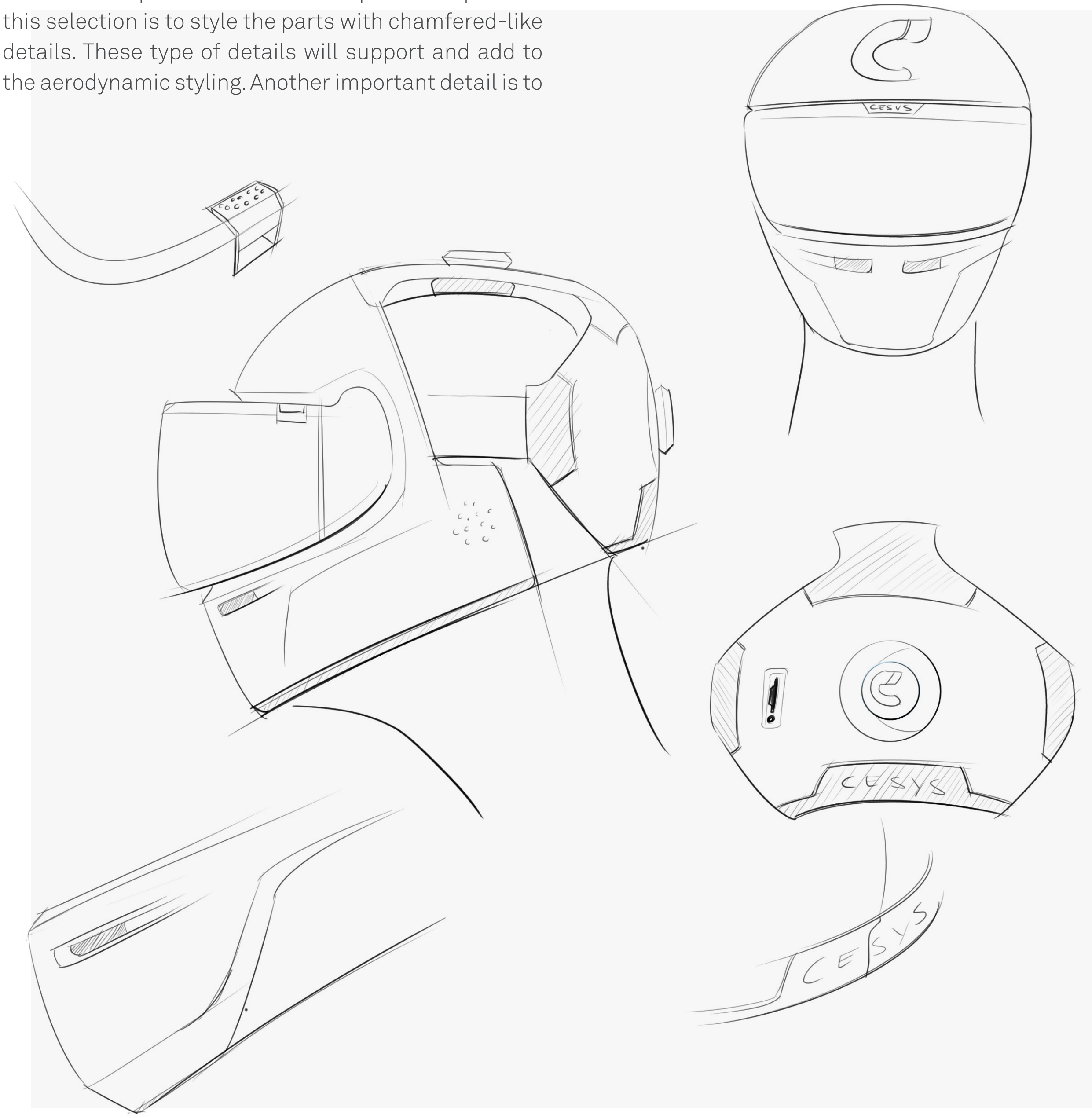


Figure 79 Styling sketches

3.2 FINAL DESIGN

This paragraph will present the final concept of the VR helmet. First, an overview of the final concept will be presented. Then, the use and features of the product will be covered in-depth. Third, the customisation of the VR helmet will be shortly explained. Next, the product architecture of the final concept will be explained. The paragraph will be concluded with a cost calculation of the product.

3.2.1 Overview

Figure 81 shows the final proposal for the VR helmet. This VR helmet is designed to fit and enhance the current experience of race simulators (F1 and motorbike) Cesys currently sells. The look, feel and use of the VR helmet are aimed to reproduce the experience of wearing a real race helmet. Next to this, the VR helmet is designed to provide a comfortable and secure fit for a wide range of head sizes. Apart from displaying Virtual Reality, the helmet also houses audio components and microphone that enhance the Virtual Reality experience. Finally, the VR helmet is optimised for heavy use in entertainment context. This means that aspects like hygiene and durability are also taken into account. The design will be further explained in the upcoming sections.

Figure 80 Final design proposition

Figure 81 Final design proposition

3.2.2 Features & use

In this section the process of using the VR helmet through various stages will be presented and explained.

Preparing for race

1. Putting on a balaclava
In order to guarantee good hygiene, wearing a balaclava in combination with the VR helmet is recommended. Moreover, the balaclava can enhance the experience, since it is also part of the pre-racing ritual of a racing driver. The balaclava also provides some extra surface roughness (when compared to smooth, long hair) which prevents the VR helmet to accidentally slide during use. The use of a balaclava will add to the overall price per ride, ranging from €0,1 (disposable) to €1 (semi-disposable) (Helmetliners.co.uk, n.d.).

2. Putting on VR helmet
When the user has put on the balaclava, he/she can put on the VR helmet. By grabbing the two outer edges of the helmet the user can slide down the helmet on his/her head.

3. Adjusting size
When the helmet is on, the size can be adjusted to the user's preference. This is done by holding the helmet in one hand at the optimal position, while the other hand can adjust the circumference and top height by rotating the two knobs.

4. Stepping into/onto race simulator
After the helmet is comfortably fixed on the user's head, he/she can step into/onto the race simulator. When seated, the operator will attach the video/audio cable to the system. The audio/video cable starts at the VR Unit and is guided over the back of the helmet. In this way, the cable will cause the least possible distraction to the user in various head positions. When the cable is plugged in, the operator and driver can already communicate between each other. The VR helmet has built-in speakers and microphone.

5. Closing down visor and adjust eye relief
After everything is set, the user can rotate down the visor. Then, the distance between the eyes and lenses can adjusted by simply sliding the visor towards or away from the user. A ratchet mechanism ensures that the visor stays in its place.

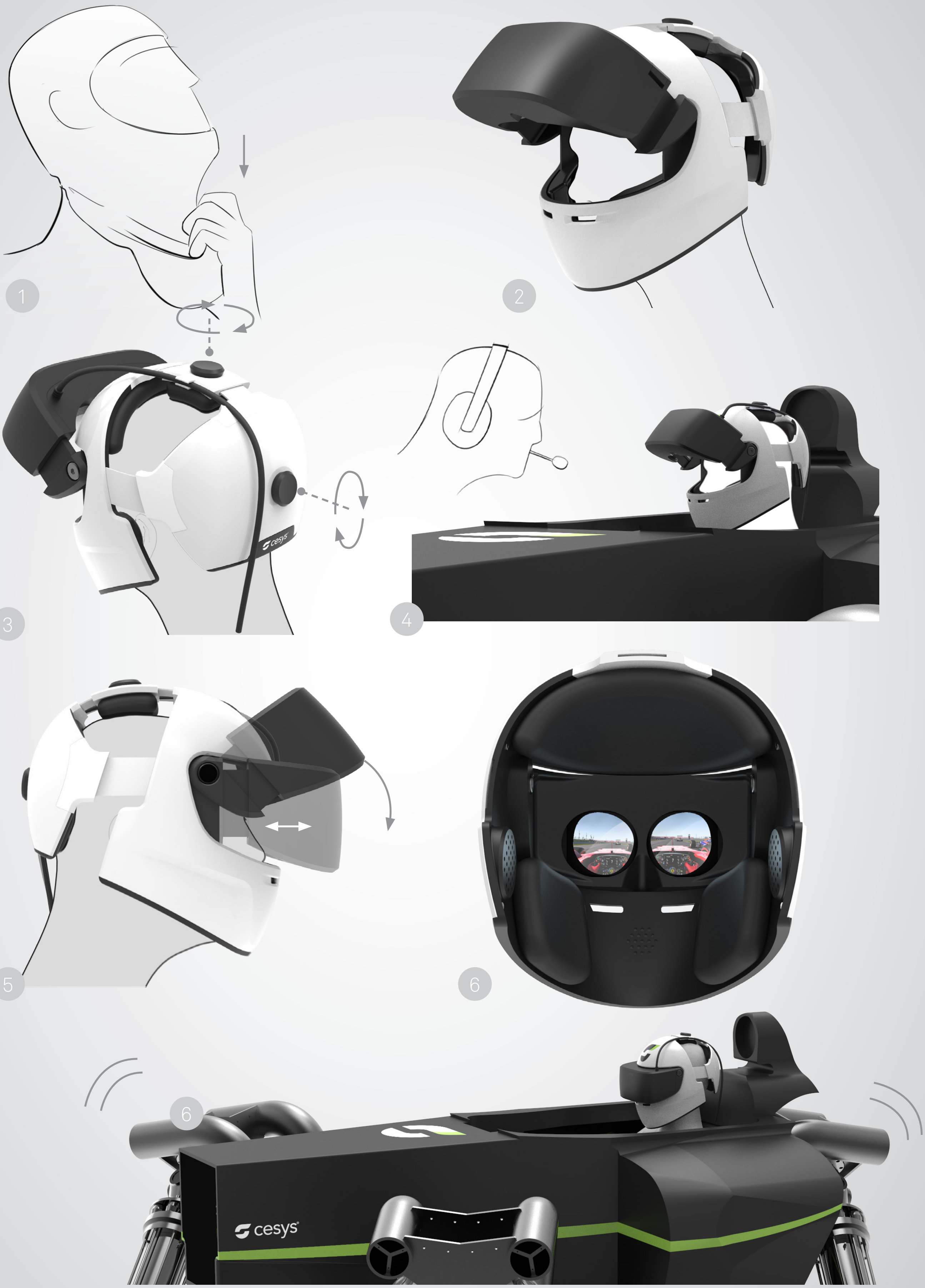
Racing

6. Visual/Audio display and communication
During the race, the helmet provides visual and audio display, but also means to communicate with other contestants or the operator by providing a microphone in the helmet.

After racing

7. All steps prior racing, but then in reverse order.
After the race, the user can put up the visor by sliding the visor forwards and then rotate the visor upwards. After the operator has removed the video/audio cable, the user can step out the simulator and take off the helmet. The balaclava can be taken home as a souvenir.

8. Cleaning the VR helmet
Before the next user is going to use the helmet, the padding will be first cleaned. While this may not be always necessary hygienically (because a balaclava is worn), it's a visual action that ensures the user that the VR helmet is clean.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3.2.3 Customisation

Figure 84 Final design

The design of the VR Helmet has been kept modest (see Figure 84), because it has been taken into account that racing related graphics will be applied on the helmet. The customisation of the VR Helmet will be discussed in this section.

Branding

The Cesys brand will always be applied on the front of the VR unit and back of the product. The branding is done subtle, but will be always visible. This is done for brand awareness.

Colour

First of all, as will be explained in the next section, the production process of making this VR helmet allows each helmet to be produced in any desired colour.

Graphics

Graphics can be applied with the use of stickers (cheap) or letting a helmet painter custom paint the VR Helmet (expensive).

Case study: Red Bull Racing

In order to give an idea how a customised helmet would look like in a specific theme, a case study is made. In this case study a helmet in a Red Bull Racing theme is created. This could be for example for a F1 Simulator located at visitors centre of the Red Bull racing track in Austria. Figure 86 shows the customised helmet. The balaclava that will be used in combination with the helmet can also be customised. A logo of the racing track and the number of a F1 driver could for example be printed on these balaclavas. Because the VR Helmet has open areas, therefore the print (e.g. driver number) of the balaclava can add to the visual overall appearance (see Figure 85).

Figure 85 Customised Balaclava

Figure 86 Customised VR Helmet (Red Bull Racing)

3.2.4 Product Architecture

This section will focus on the product architecture of the VR helmet. First, an overview of various components of the VR helmet are presented. Then, a selection of parts and mechanisms will be explained further on detail level.

Overview

Figure 87 shows an exploded view of the main parts that the VR helmet consists of. In the next subsections these parts will be explained further on how they are constructed. The overall weight of this final concept is calculated at 1400 grams (incl. Oculus Rift package + Counterweight)

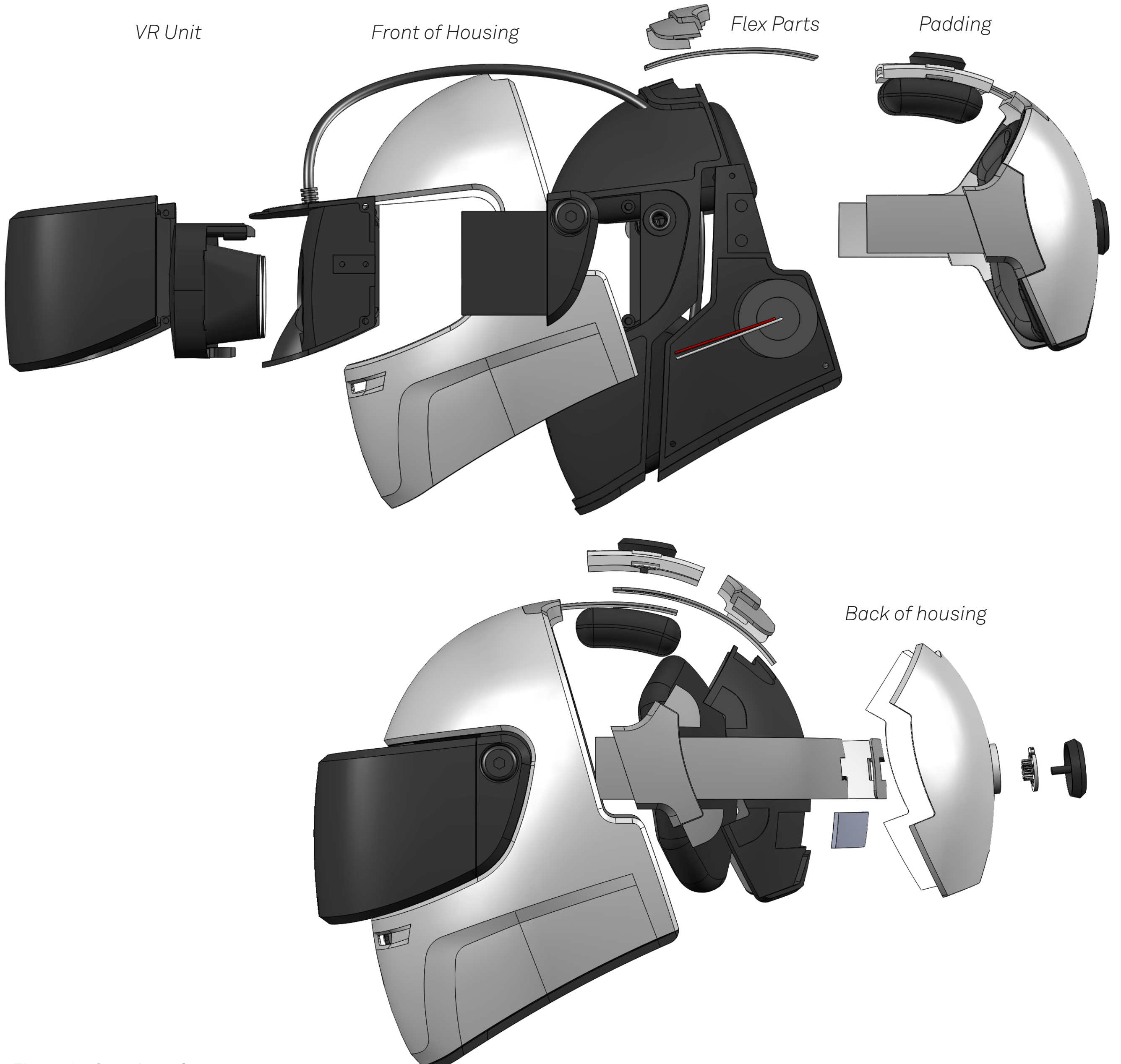


Figure 87 Overview of parts

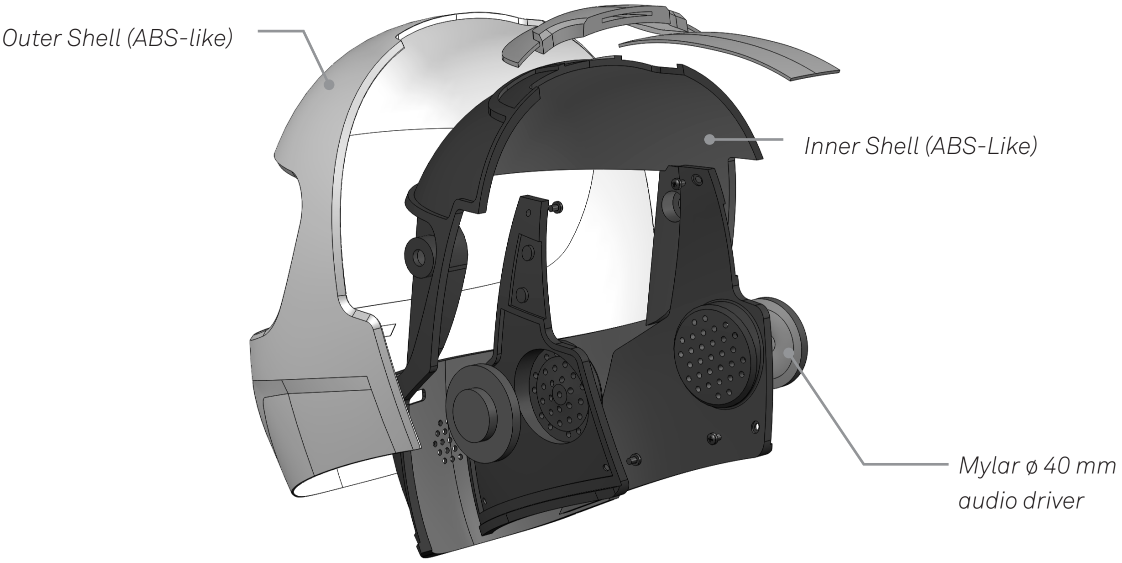


Figure 88 Parts front of housing

Front of housing

The front of the housing of the VR helmet is split in two parts: an inner and outer shell (see Figure 88). This split has multiple reasons. First of all, the housing has to accommodate the two audio drivers and microphone. Having an inner and outer shell, these parts + corresponding cables can be nicely concealed between the shells. Furthermore, the two shells also give the helmet some visual 'body', Last of all, the two shells give the housing a lot more structural rigidity, by adding fortifying ribs in between the layers, while keeping the wall thickness (and thus weight) low.

As explained earlier in paragraph 1.5, vacuum casting is an ideal production process for this product. The two shells of the front of the housing will therefore be vacuum casted. Vacuum casting can be done with a range of different Polyurethanes (PU). For these two parts, an ABS-like PU is chosen. It offers great structural properties, especially impact strength (Materialise, 2017) which is necessary when considering that the helmet has to resist an occasional drop.

The two shells are connected to each other by making use of threaded bosses and screws. Instead of threaded bosses, making use of metal thread inserts could also be a option (more durable). This allows the front housing to be opened/closed for several times, which could be important for servicing the VR helmet.

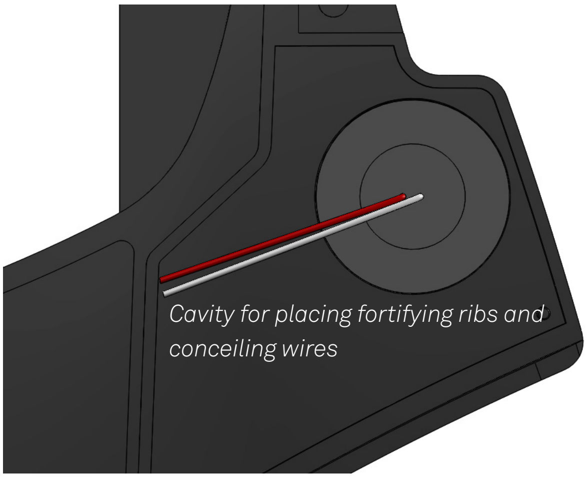


Figure 89 Fortifying ribs and conceiling parts/wires

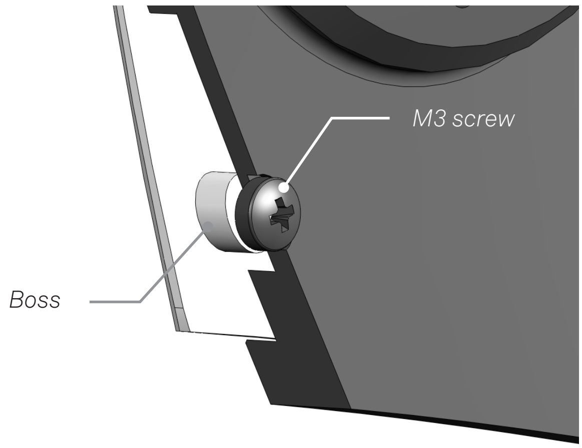
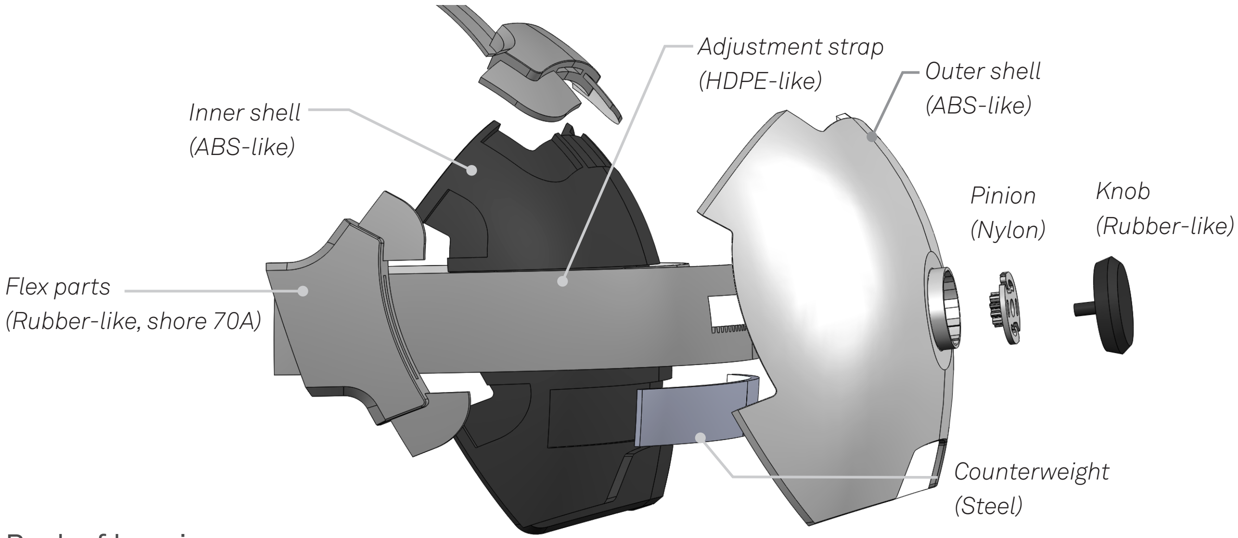


Figure 90 Fixation of plastic parts



Back of housing

Like the front of the housing, the back of the housing is also split in an inner and outer shell. The back of the housing accommodates the size adjustment system that regulates the circumference size. Also, a 3mm steel plate, weighing ± 100 grams is situated in the back, functioning as a counterweight (see also 3.1.3 'Comfort').

Both shells at the back will be produced of the same material mentioned for the front of the housing parts. The same applies for fixating both parts together.

Size adjustment system

This subsection will focus on the mechanics of the size adjustment system. This system has a rack and pinion and when rotating the pinion right or left, the two racks are sliding towards or away from each other. In order to fix the preferred position, the pinion is attached to a ratchet system, which gives the system the distinctive clicking sound when rotating the knob. Figure 91 shows how this adjustment system is integrated at the back of the housing.

The straps with the rack feature are made of a semi-flexible material. This flexibility is necessary, because the straps are guided through a curved slot. The straps will be made of a HDPE-like PU material: a tough, smooth and slightly flexible (Shore D60) material.

The ratchet-pinion part is made of nylon, a strong, durable and low friction material (Lefteri, 2014).

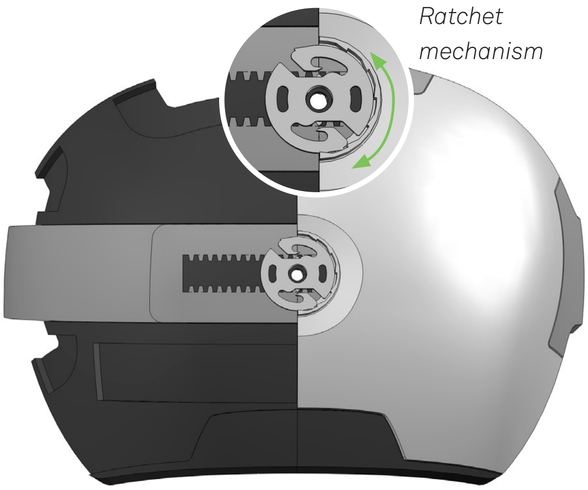


Figure 91 Rack-pinion mechanism

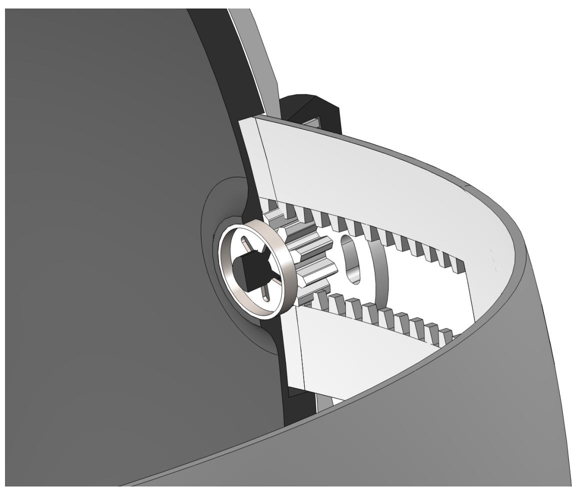


Figure 92 Close-up rack-pinion mechanism

Flex parts

The flexible parts that are attached to the sides and top of the back of the housing are designed to guide the straps to the front of the housing, while still be able to flex along with the straps when size is changed. These flexible parts are made of a rubber-like material (± shore A70). The flex parts will be fixed between the two shells by using an interlocking shape (see Figure 93).

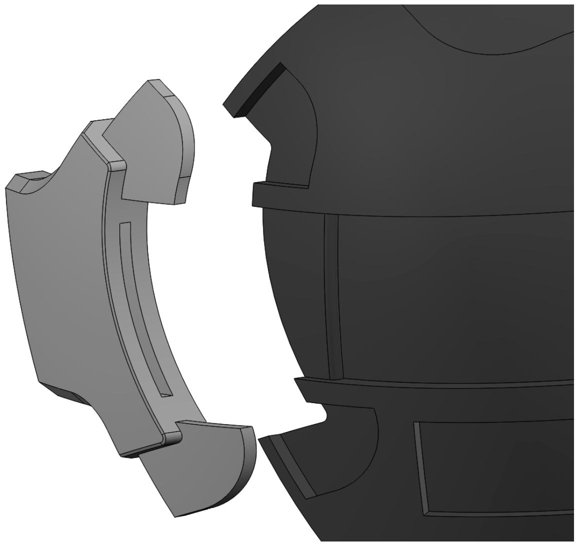


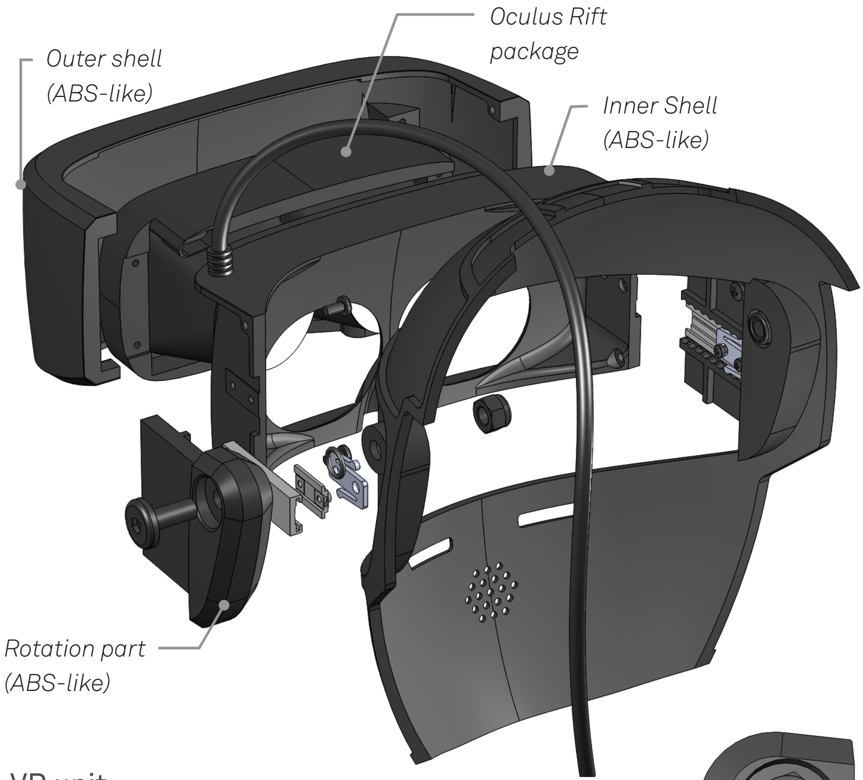
Figure 93 Fixating the flex parts

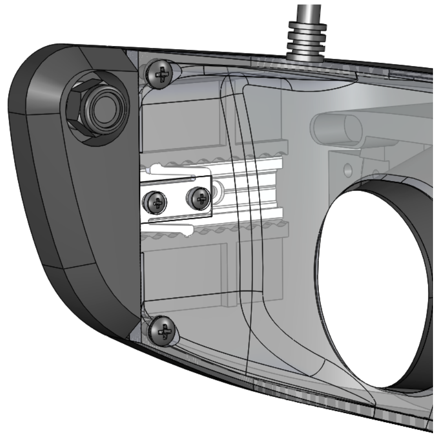
Padding

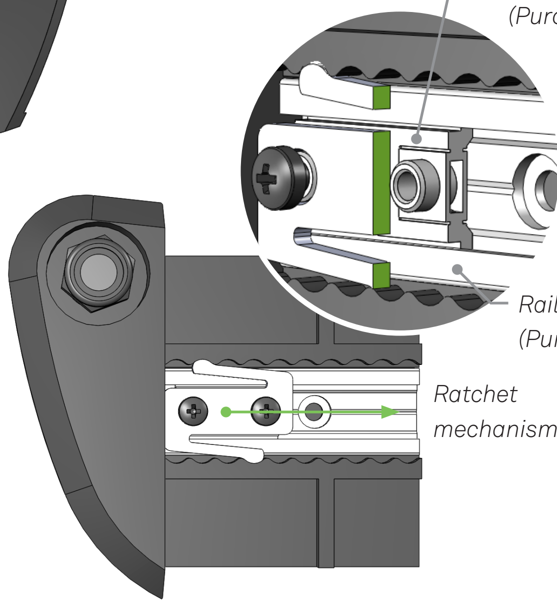
The padding inside the VR helmet ensures a stable and comfortable fit for various head sizes. Therefore, a thick and flexible PU foam is used. This foam will be upholstered by fabric to make the padding easy to clean. The suggested fabric for this padding is a PU coated Polyester fabric. This type of fabric is also used in outdoor clothing products. It is waterproof, durable, somewhat breathable and lightweight (5 times lighter than fake leather for example).

The padding is attached to the inner shells of the housing by making use of press studs (see Figure 94). This makes it easy to attach/detach the padding (in case of washing), but when placed it stays nicely in place (opposed to Velcro).

Figure 94 Padding details







VR unit

The last group of components that will be detailed are the parts related to the VR unit. The VR package is enclosed by two housing parts (see Figure 95). The outer housing part holds the VR package into place. The two housing parts are connected to the two rotation parts with rails at the side of the helmet which enables the VR unit to rotate and slide.

Slide mechanism

The slide mechanism operates as following. The inner housing of the VR unit is fixed to a ratchet part and a carriage. This carriage is slotted in an aluminium rail that ensures a smooth and tilt-free movement. Both the carriage and the rail are purchase parts. The Nylon ratchet part ensures that the VR Unit can be set in different positions and doesn't slide during a simulator ride.

Rotate mechanism

The rotate mechanism works like a swivel torsion hinge. The rotation part is firmly pressed to the inner housing with the use of a bolt and locknut. A rubber O-ring in between the parts provides the necessary friction that allows the VR Unit to be rotated and staying in place after rotating. A swivel torsion hinge purchase part (e.g. used in desk lamps) can also be used as a rotate mechanism.

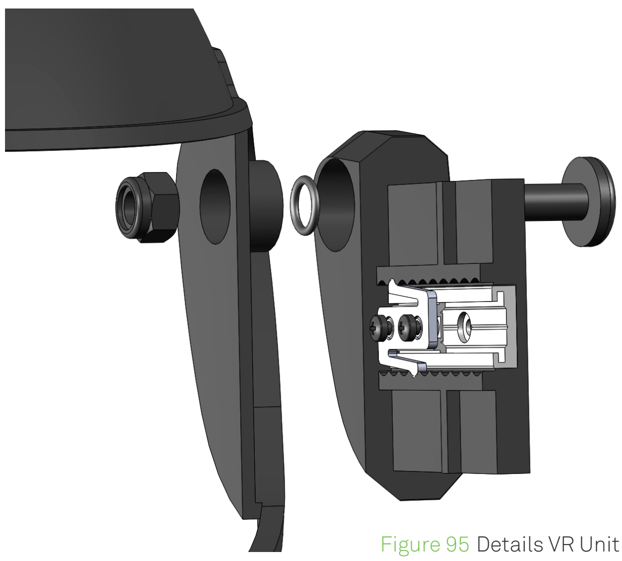


Figure 95 Details VR Unit

3.2.5 Cost

Cost price

This section covers an overview of the cost price (see Table 5) for the final detailed concept of the VR Helmet. A first batch size of 20 products has been taken into account. In appendix J a more detailed cost price calculation can be found. In the estimation of cost price, the following aspects are taken into account:

Material/Production cost

The costs related to the production of the various parts of the VR Helmet. The biggest part of this expense will go to the plastic/rubber-like parts that will be vacuum casted. The cost price for these parts is calculated in consultation with a pair of vacuum casting production companies. Next to these plastic parts, the material/ production of the padding of the VR Helmet is also taken into account.

Purchase parts cost

The cost of various parts that are off the shelve or already exist in current products is also taken into account. Notable purchase parts are the Oculus Rift CV1, Audio drivers and microphone.

Stickering/ Painting cost

This type of cost is related to finishing the helmet in a desired custom appearance. During the vacuum casting process, the VR Helmet can already be finished in the desired colour and texture. However, adding stickers to the helmet has to be calculated additionally. Stickering is the cheapest option (€±100), while a custom paint job in F1 style can be quite costly (€895). Therefore, the stickering option will be seen as standard and a custom paint job will be seen as an extra option.

Assembly cost

The disassembly of the Oculus Rift, modifying the Oculus Rift package for reintegration, assembling the VR Helmet and testing the final product is taken into account in the assembly cost.

Type of cost	Cost / VR Helmet*
Material/Production	€ 1492,00
Purchase Parts	€ 667,93
Stickering / Painting	€ 100,00 / € 895,00
Assembly	€ 176,00
(Development)	(€ 1500,00)
Total cost price (Without development cost)	€ 2435,95
Safety factor (1.2)	€ 2923,12
Sales factor (2)	from ± € 5850 (ex VAT)

** Based on batch size of 20 pieces*

Table 5 Overview cost price calculation

(Development cost)

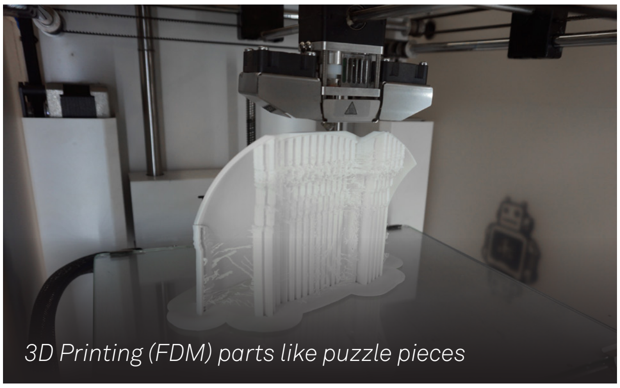
This may be an indirect cost that doesn't need to be directly calculated with the overall cost price of the first batch of 20 VR Helmets. However, it is good to take the estimated development cost (at least €30k) of the future VR Helmet into account, especially when it is expected that these will be sold in a low volume. This type of cost can be a large portion of the total cost price.

Selling price

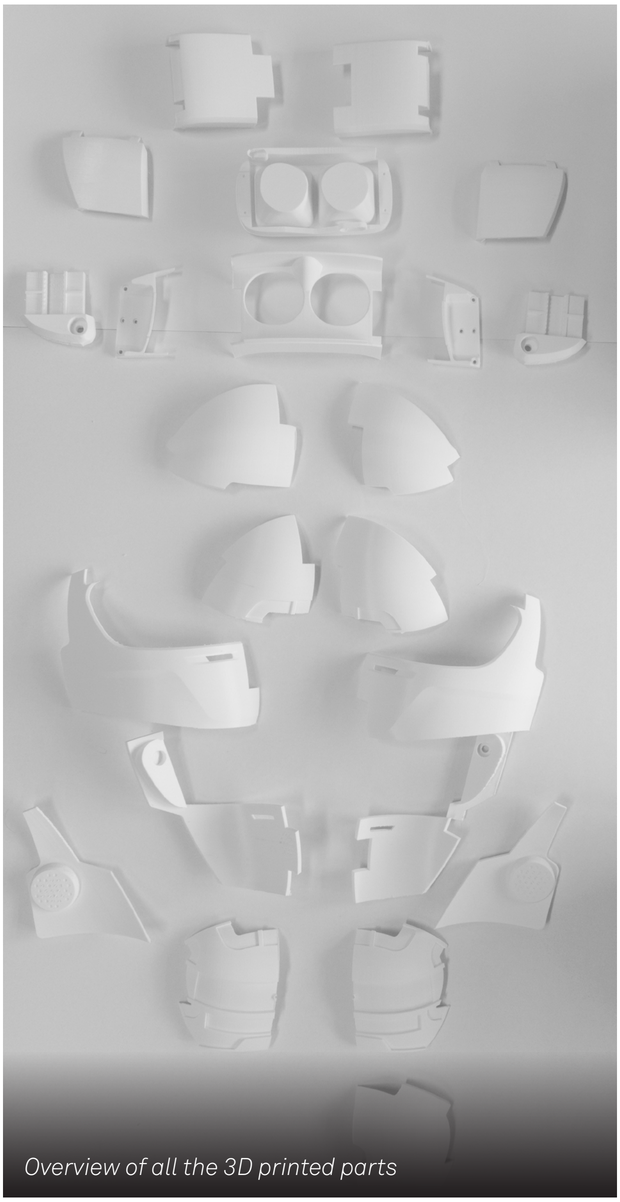
The overall cost price is calculated at € 2435. Because this is an estimation, a safety factor of 1.2 is multiplied with this number. In order to calculate the selling price, a sales factor of 2 is used. This means that the selling price is around €6000 (ex VAT). Comparing this to competitor products (see paragraph 1.4.2), this makes the VR Helmet a worthy alternative to other VR Helmets on the market. The cheapest option on the market is €3000 at a specific size (and therefore multiple needs to be bought in order to provide proper fitting helmets), while the most expensive on the market is priced at €9500.

3.2.6 Prototype

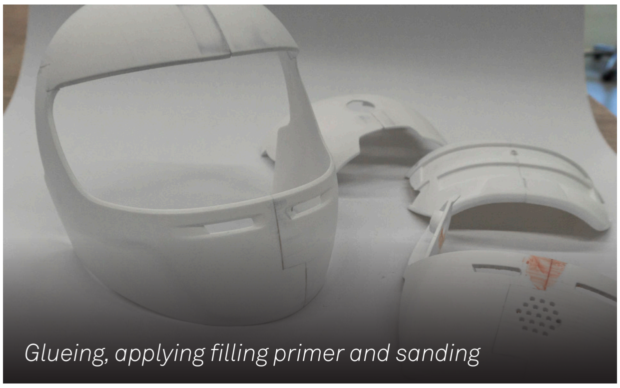
An alpha prototype is made of the final detailed concept. This type of prototype brings together the key elements of the appearance and functionality. Figure 96 shows the process of making the prototype. This prototyping process led to the final result that is showed in Figure 97. This prototype will be used in the final user evaluation that will be covered in the next paragraph.



3D Printing (FDM) parts like puzzle pieces

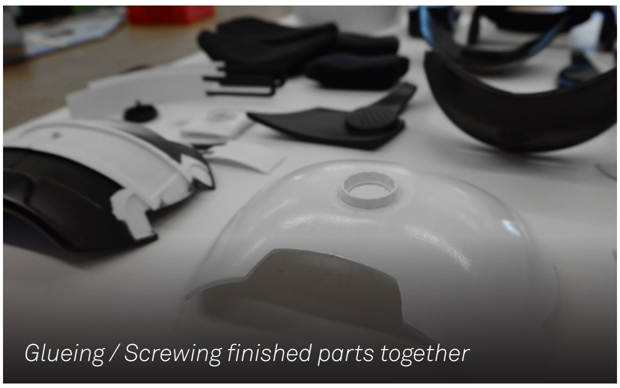


Overview of all the 3D printed parts



Glueing, applying filling primer and sanding

Spray Painting



Glueing / Screwing finished parts together

Figure 96 Prototype Process

VR Helmet in action on motorbike VR simulator

Figure 97 Final VR Helmet Model

3.3 USER EVALUATION

This paragraph will discuss the final user evaluation test that was conducted with the final prototype that was made. Appendix K contains the full set-up and results.

The goal of this final evaluation user test was to evaluate the final detailed concept of the VR Helmet. The final detailed concept is deemed to be detailed on such a level that it can be compared to the current solution that is used in the VR simulators: the Oculus Rift CV1. The comparison between these two products will show whether the proposed concept has the potential to replace the current solution. Second, the comparison will show on which aspects the final concept is better or needs to be improved. It's important to mention that the VR experience will not (and cannot) be tested, the research will focus on the look, feel and use of both products.

Set-up

The set-up of this final user test doesn't differ much from the user test conducted in the concept phase. The user test of the concept phase focused mainly on the product experience, this test also takes comfort and intuitiveness into account. The research
questions are as following:

- How is the process of using the final detailed concept experienced, compared to the benchmark product?
- How comfortable is final detailed concept perceived, compared to the benchmark product?
- How easy to use is the final detailed concept perceived by the user and operator, compared to the benchmark product?

Participants

6 Participants, 3 fellow students with a high affinity with motorsport and 3 Cruden employees.

Method

2 Parts:

- Part 1: Following the two processes of intended use of the Oculus Rift and VR Helmet. By experiencing both products, the participant can substantiate their opinion on questions in the second part of the research.

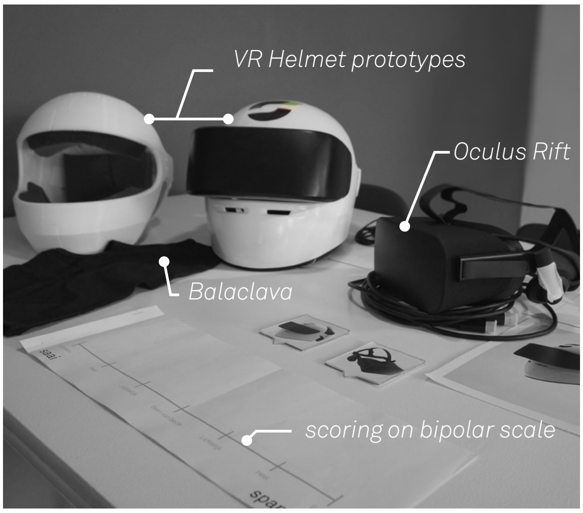


Figure 98 Stimuli Evaluation User test

- Part 2: Participants scores both products on bipolar adjective scale for various aspects. After scoring, the participant is asked to explain their scores.

Results

Figure 99 shows the average scores on 5 bipolar scales that were used to answer the aforementioned research questions. In the next sections these scores will be supported with recurring arguments throughout the research.

Boring – Exciting

The VR Helmet scored higher than the Oculus Rift on the scale of boring – exciting.

- Many participants already thought of the Oculus Rift as something special
- The design and race related use steps of the VR Helmet excites the user more before starting to race.

Insecure – Confident

The Oculus Rift scored somewhat higher than the VR Helmet on the scale of Insecure – Confident.

- The tight fit and smaller weight of the Oculus Rift were often called reasons for the high score.

Figure 100 Impression of part 1 of research

> The weight of the VR helmet and the fact that it could still move a little were one the main reasons of the lower score. (Note: the size adjustment system of the prototype was not working as it should be, which could have affected the score).

Unhygienic - Hygienic
The VR Helmet scored higher than the Oculus Rift on the scale of unhygienic – hygienic.

> Hygiene is considered as a very important part of the product experience.

> The use of a new balaclava was the main reason that the VR Helmet was perceived as very much hygienic. Especially in the case of a helmet, with a lot more contact area, the use of a balaclava is deemed necessary.

Uncomfortable - Comfortable
The VR Helmet scored somewhat higher than the Oculus Rift on the scale of uncomfortable – comfortable.

> The top heavy weight distribution of the Oculus Rift was often mentioned as uncomfortable.

> Even though the VR Helmet was thought of too heavy, the better weight distribution and pressure provided on the entire head were often mentioned as comfortable.

Unintuitive – Intuitive
The VR Helmet scored higher than the Oculus Rift on the scale of Unintuitive – Intuive.

> The size adjustment knobs of VR Helmet were

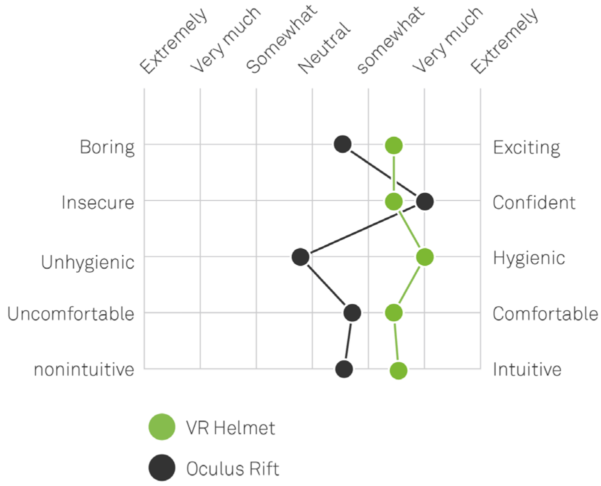


Figure 99 Results Validation Test

thought of easy to find by touch. Moreover, the system is familiar and didn't give many problems for many.

> The use of the VR Unit as a visor was also found to be very intuitive.

In the end, the participant was asked which product they would choose if they would make a ride in a VR Simulator. The choice for the VR Helmet was unanimous. The experience of the product was decisive in this choice.

These findings and results of this research will be taken into account for the next paragraph 'Recommendations'.

3.4 DESIGN EVALUATION & RECOMMENDATIONS

The goal of this paragraph is to evaluate the final detailed concept on product requirements that were set at the beginning and during the project. Furthermore, based on this evaluation, recommendations are made for further research/ development.

First of all, the final detailed concept will be evaluated on the most important product requirements that were set at the end of the analysis phase (see 1.7.1 and Appendix F).

3.4.1 Evaluation on product requirements

Comfort

One size fits all

The requirement that the VR Helmet had to be adaptable for various sizes and types of heads was set at the start of the project. In the end, the final concept fits for people with a head circumference ranging from 540 mm – 600 mm. This accounts for 90% of the Caucasian headforms (NASA, 1978). For Chinese headforms, this percentage lies around 50% (NASA, 1978). Taking this into account, it can be concluded that the VR Helmet fits a great variety of head sizes, but predominantly the smaller head sizes (<540 mm circumference) will not fit perfectly.

Weight

The overall weight of the final VR Helmet concept is calculated at ± 1400 grams (including Oculus Rift components, Audio and Counterweight). This means that the current concept is too heavy and does not meet the requirement of maximum weight of 1200 grams.

Heat

During the analysis phase, thermal (dis)comfort was taken into account in the ergonomics research. The design of the final concept of the VR Helmet has not given much attention to this aspect. Aspects such as hygiene (use of balaclava and waterproof padding material) and product experience (enclosed helmet feeling) were deemed to be more important.

Technology

Re-use functional parts of VR Headset

An initial requirement at the start of the project was to re-use functional parts of an existing VR Headset in the VR Helmet. During the project a complication was found (see 3.1.1 'VR Unit') related to re-using parts of the chosen VR Headset. This complication was not solved during this project and therefore it cannot be concluded if it's possible to successfully re-integrate functional parts of a VR Headset in the VR Helmet. However, the design of the VR Helmet does has taken into account how these parts can be fully integrated.

Integrate speakers and microphone

The design of the final VR Helmet concept provides space for placing quality speakers and a microphone.

Durability

Considering the context in which the VR Helmet will be used in (heavy-use, occasional dropping), the VR Helmet needs to be a durable solution. The design of the final VR Helmet concept has given some thought at this aspect (e.g. material use, structure of product), but was not tested/simulated and improved this during the project. Therefore, it cannot be concluded whether the final concept is durable enough.

Business

At the end of the analysis phase a batch size and a maximum cost price of around €4000 (including development costs) was defined. The cost price of the final VR Helmet concept is calculated at around € 2500 (without development costs). If the developing costs stay within the estimated €30k (€1500 per VR Helmet) then this requirement is met.

Experience

The experience of a VR racing simulator attraction is very important. This means that the VR Helmet had to add to this experience. The look, feel and use of the final VR Helmet concept is optimised, which makes the user feel more excited when compared to using an Oculus Rift (see 3.3).

Hygiene

Last of all, the VR Helmet was required to look, feel and be hygienic. The final VR Helmet concept has given attention to this aspect through material use (e.g. padding) and adding a product (balaclava) to the use of the VR Helmet.

3.4.2 Recommendations

The final VR Helmet concept presented in this report is promising, but still needs to be considered as an in-between version for an eventual final VR Helmet product. There are still a lot of attention points that need to be addressed in further development. Below are the most important attention points explained.

Comfort

Fixation

The first recommendation is for optimising the fixation of the VR Helmet at the back of the user's head. The current concept fixates on the curved part of the back of the head, which is a difficult place to fully fixate the product on the head. Lowering the fixation point to the base of the head would most likely solve this issue. Figure 101 shows this principle.

Adjustability for Chinese headforms

As mentioned before, the current VR headset can be adjusted to almost every Caucasian headform, but smaller head sizes, predominantly smaller Chinese headforms, cannot be covered by the current design. It's recommended to provide the VR Helmet with different/ thicker padding cushions when selling VR Simulators and Helmets in this region. This is the most cost-efficient solution, since the rest of the VR Helmet stays unaltered.

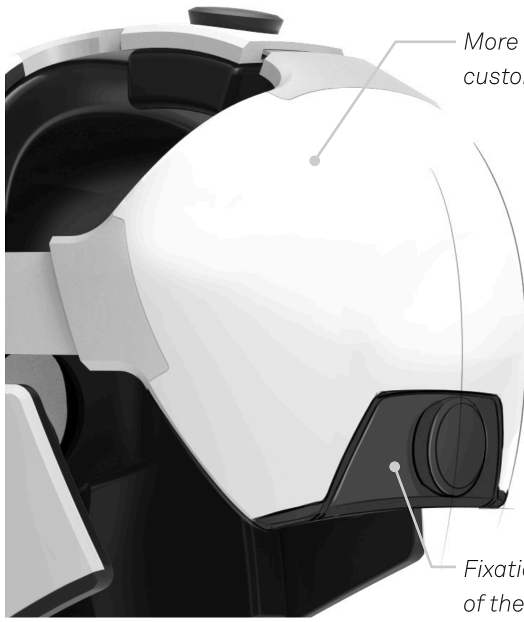


Figure 101 Fixation recommendation

Heat generation

As mentioned earlier, the aspect of thermal comfort is not addressed in the current concept. It is recommended to research first if a possible thermal discomfort is negligible for a simulator race of 5-10 min. Also, it is important to research if the generated heat during a race can for example fog the lenses.

Weight

The weight of the final VR Concept is still too high (200 grams too heavy) and was also experienced as too heavy. In order to reach the maximum weight requirement, it is advised to reduce the wall thickness of various parts from 3 to 2mm. This will give an approximate weight reduction of ± 250 grams. Hence, this wall thickness reduction can only be done if the durability analysis of the product allows this. Also, it is also advised to re-evaluate the necessity of a counterweight. This could yield another 100 grams.

Technology

VR donor headset

First of all, it's recommended to research whether it is possible to get a good VR Experience after re-integrating components of the Oculus Rift in the VR Helmet.
If this is not possible, it is advised to take a better look at the open source VR Headset (OSVR HDK2). From a hardware perspective, this headset would be preferable, since there are spare parts and detailed technical documentation is available.
If the Oculus Rift still has the preference and if re-integrating the components in the VR Helmet doesn't work, an in-between solution can be devised. Figure 102 shows an impression of an adjustable helmet part and the original Oculus Rift housing. This could be a solution that keeps all the original Oculus Rift component intact and still has the adjustability of the current VR Helmet. This could be an interesting solution (e.g. cost-wise), but needs to be researched further on other aspect (durability, experience-wise).

Figure 102 In-between solution: Oculus Rift & Adjustable VR Helmet

Audio

The current VR Helmet concept provides space for large speakers at a fixed distance. This solution was primarily designed with durability in mind. However, it's recommended to research whether this solution is good enough when considering the VR Experience. Due to current solution, the user is less closed off from environment noise and this could have an impact on the audio display. This in turn could affect the level of immersion.
Also, a type of speaker is recommended for the VR Helmet, but not a specific speaker. Because there is a lot of choice within this category of speakers, it's recommended to let an audio engineer choose a specific speaker that's optimal for the VR Helmet.

Cost

As analysed earlier, the cost price will most likely not exceed the set requirement. However, there are a pair of options that could make the VR Helmet cheaper. First of all, if the in-between solution of the Oculus Rift housing and VR Helmet is carried through, this could save around €150 per VR Helmet. The inner and outer housing of the VR Helmet doesn't need to be produced anymore. Moreover, this will save development costs, because the Oculus Rift will stay more intact. Second cost optimisation is related to the adjustment straps. Currently the adjustment straps (side and top) are vacuum casted. If it's possible to laser cut them out of a semi-flexible material, this could save around €240 per VR Helmet.

Durability

As mentioned before, the final VR Helmet is designed to be durable (e.g. structure and material use). However, this is only the first step. It's recommended to conduct stress analyses (e.g. FEM) for various scenarios and improve the design accordingly.

Experience

Use

The final VR Helmet concept is designed to be put on before stepping in the simulator. With the visor open, the user can walk up to the simulator and step on/into the simulator. After the user is seated, the operator plugs in the audio/video cable at the back. In hindsight, this actions could be dangerous and/or irritating for the user. First, with the helmet on, the user has more limited sight. This visual limitation could lead to a higher chance of missteps or potentially falling when entering the simulator. Moreover, when connecting audio cable, there's always a cracking/popping sound. This cannot be prevented and could be experienced as something negative. It's recommended to research if the experience is still good when the helmet is put on when seated in/on the simulator.

Facial interface

Most VR headsets have a facial interface which closes the eyes of the user off from any light. This darkness is important for an optimal VR experience. The final user evaluation test showed that some people noticed that some light was visible inside the helmet. This showed that some kind of facial interface is necessary in the VR Helmet. It's recommended to search for a solution that is hygienic, closes the eyes off from any light and that the VR Unit can still be used as a visor.

Sliding the visor open

The prototype used in the final user evaluation test showed that sliding the visor open is still not as fluent as envisioned: it tilts a little bit. It's recommended to further detail or revise this mechanism.

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