DESIGNING A VIRTUAL REALITY HELMET
FOR RACING SIMULATORS

APPENDIX

cesys TU Delft

APPENDIX

These appendices contain additional information for various paragraphs of the graduation report.

Appendix

A DONOR COMPONENTS

This appendix consists of two analyses that compare various products or strategies that relate to the sourcing of components that enable VR and audio in the VR helmet.

Donor VR headset

Figure 103 shows the comparison chart between three high-performance computer tethered 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

They are compared on six categories:

- Price
- Image quality: The quality of the display and lenses (Tested, 2016) (VRbites, 2016)
- Teardown scores: The donor VR headset should also be easy to disassemble in order to obtain the necessary components (retrieved from ifixit.com)
- Tracking technology compatibility: Answering the question how well the tracking technology performs when the user is on a motion based platform (R. van Gaal (personal communication, 15-12-2016)

		Oculus Rift CV1	HTC Vive	OSVR HDK 2
				
Price		€ 600	€ 700	€ 240
Image quality	Display	2160 x 1200 pixels 90 Hz	2160 x 1200 pixels 90 Hz	2160 x 1200 pixels 90 HZ
	Lenses	Hybrid lenses 110˚ FoV IPD Adjustment	Fresnel lenses 110˚ FoV IPD + Eye relief Adjustment	Dual lenses 100˚ FoV Diopter adjustment
Teardownability		7/10	8/10	9/10
Tracking technology		IR Constellation tracking	Lighthouse tracking	IR Constellation tracking
Software development		Good	Bad	Bad
Additional features				Optional hand tracking feature Hardware & Software is open source

Figure 103 VRheadsetcomparisonchart

› Software development: Each VR headset comes with a different software developers kit, which is paired with the race simulation software. The quality and adjustability of this software development kit will determine whether a smooth VR experience can be achieved. (R. van Gaal (personal communication, 15-12-2016)

› Additional features: The VR headsets can offer additional features, which could make the VR experience better.

Strategy for sourcing audio driver

There are three different strategies to source an audio driver for (re)integrating this into the VR helmet.

Strategy 1: donor headphone

The first strategy is to buy a donor headphone and tear the product down in order to get to the audio drivers. This is a very expensive strategy, since you're paying for the whole product (€50 - €300), while the audio drivers are the only parts that are needed. The upside of this strategy is that good audio quality is ensured (if the right headphone is bought).

Strategy 2: spare parts / modular headphone parts

The second strategy is buying spare parts of separate parts of a modular headphone. This is a less costly option, however these parts are still costing easily €50 - €100 (AIAIAI, n.d.). Next to being less costly, there's still a guarantee that these audio drivers have good audio quality.

Strategy 3: OEM audio drivers

The third strategy is to select OEM (original equipment manufacturers) audio drivers. There's a very wide range of audio drivers available. Prices per driver are cheap and vary between €1 – 10 (Mouser, n.d.). Because there are so many audio drivers available with varying specifications (which aren't always trustworthy) it's hard to select straightaway a good quality audio driver. However, these parts are the best to integrate, because manufacturers supply technical drawings and other data.

Figure 104 Teardown existing headphone

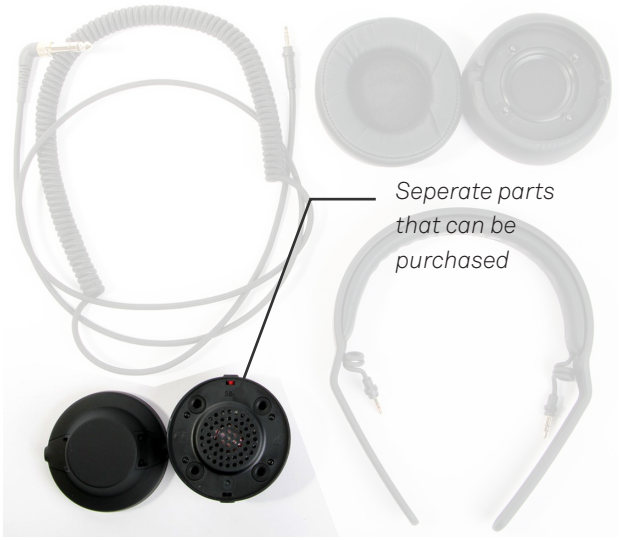


Figure 105 Modular headphone

Figure 106 OEM audio driver

B INITIAL COST PRICE ESTIMATION

In this appendix a detailed initial cost price breakdown structure can be found. This is additional information for Paragraph 1.4.2 'Price'.

Donor part cost

The first expense group are the costs of the donor parts. These costs can be estimated fairly well, since these parts are commercially available.

Donor VR headset	ranging from €400/unit (OSVR HDK2) - €800/unit (Oculus Rift)
Donor audio headset	ranging from €100/unit (separate audio parts) - € 200/unit (audio headset)
Donor microphone	ranging from € 10 - 50/unit
(Donor intercomheadset*)	ranging from €100/unit - €150/unit

* Would replace the audio headset and microphone

Material & production cost

The focus within this expense are on the production costs of housing parts, as these will likely be one of the main costs in this section.

As is discussed in paragraph 1.5 'Material & production study', the production technique of vacuum casting for plastic housing parts is an interesting option, from a product design perspective as well as an economic perspective. Therefore, the costs for housing parts will be based on using this technique.

First, based on analysis from teardowns of current VR headsets (iFixit.com), the number of plastic parts usually used in these headsets can be counted. Furthermore, a distinction between smaller and bigger parts will be made, because this will have an economic difference. Figure 107 shows the different plastic parts of a Playstation VR headset, in total 12, of which 8 bigger and 4 smaller parts. The Playstation VR is chosen as an example, because this headset contains more plastic parts than other VR headsets, but this will also be the case for the VR helmet.

Based on quotations of two prototype/low volume production companies, cost of a bigger and smaller part could be derived for a batch size of 20 (T. van de Boom/SKM Rapid, Personal Communication 10-1-2017) (B. Noordermeer/RP2, Personal Communication 11-1-2017).

This leads to the following costs:

Large sized plastic housing parts	8 parts *€115 = € 920/unit
Small sized plastic housing parts	4 parts * € 45 = €180/unit
Other parts*	ranging from € 100-€500/unit

* This expense is reserved other production for other types of parts (e.g. foam padding / metal mechanism parts).

Figure 107 Overview of parts of Playstation VR headset

Purchase part cost

Next to custom made parts, some parts can just be purchased (e.g. screws). An expense is also reserved for this.

Purchase parts	ranging from €10 - 100/unit

Margin

A margin of 40% is maintained for now, but that will be later on determined by the company.

Price indication

With the various sorts of expenses estimated, a final price indication can be made. When summing up every expense, in the most expensive scenario the VR helmet can cost € 2975/unit. When multiplying this with the margin of 40%, a selling price of ±€ 4000 is calculated. However, it has to be taken into account that this is still an rough estimate.

Assembly cost

One of the final expenses are assembly costs. The idea is that when the batch size is low (e.g. <20 units) that the VR helmets will be assembled in-house. Before assembling the product, the donor products have to disassembled which is also taken into account.

Disassembly donor products	1 hour * €22/hour =€22/unit
Assembly VR helmet	3 hours * €22/hour =€ 66/unit

C CURRENT SOLUTIONS

This Appendix contains a study, which focuses on current helmets and VR headsets, which already solve certain aspects that also need to be solved in the VR helmet. The results of this analysis will serve as inspiration for the ideation/ conceptualisation phase.

This analysis will focus on the following aspects:

- Comfort
- Adjusting the fit
- Ease of use
- Hygiene

Comfort

VR headsets

VR headsets (see Figure 108) make use of different materials, such as foam, wide elastic bands and soft/flexible rubber to make the product feel as comfortable as possible.

Moreover, weight support and distribution is also an important factor. A lot of traditional VR headsets are resting their weight (± 500 gr) on the nosebridge. However, a new approach by letting weight rest on the top of the head is quickly catching on in new VR headsets. The same applies for the use of counterweights.

Last of all, some VR headsets offer the possibility of changing the foam face mask. There are various types of face masks available (small, wide face) and changing these will improve the overall comfort.

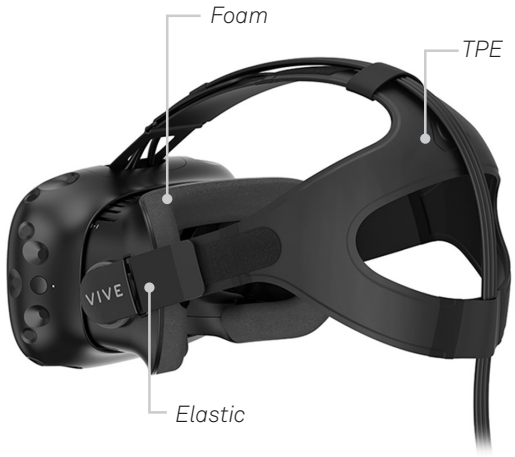


Figure 108 Comfort materials HTC Vive

Figure 109 Playstation VR headset

Figure 110 Face mask HTC Vive VR headset

Helmets

Figure 111 shows an exploded view of the inside of a motorcycle/racing helmet. As can be seen a lot of various foam parts are used to make the product comfortable

Figure 111 Foam padding motorcycle helmet

Adjusting the fit

VR headsets

The VR helmet has the requirement that the product has to be one-size-fits-all. VR headsets also maintain this principle. Figure 112 till Figure 114 show various solutions in order to make the product fit on various head sizes. The solutions can range from simple elastic bands and Velcro straps to more complex mechanisms, such as spring loaded tracks and a rack and pinion system. This last system is also often used in bicycle helmets, which will be reviewed in the next section.

Figure 112 Adjusting fit Oculus Rift DK2

Figure 113 Adjusting fit Playstation VR

Figure 114 Adjusting fit Oculus Rift CV1

Helmets

As mentioned in the previous section, a lot of (bicycle) helmets use the rack and pinion system in order to secure the fit on the head (see Figure 115). By rotating a pinion gear at the back of the helmet, the tracks are contracting or expanding, making the fit looser or tighter. Another similar system is the ratchet system (see Figure 116). A very different type of solution is making use of air cushions, tightening the fit by pumping them up with an air pump and loosening the fit by releasing air with a valve (see Figure 117).

Rack & Pinion system

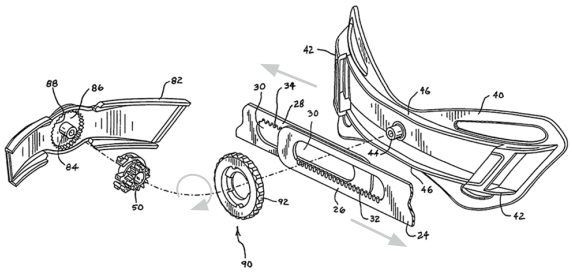


Figure 115 Adjusting fit bicycle helmet (1)

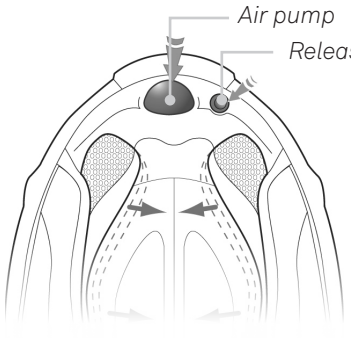


Figure 116 Adjusting fit using air cushions

Figure 117 Adjusting fit bicycle helmet (2)

Ease of use

VR headsets

This section focuses on the ease of use of VR headsets, because the adjusting the product (fit, optimal viewing experience) requires more action steps than a normal helmet, which are straightforward and easy to use. Figure 118 shows a VR headset (Sensics) optimised for public use, such as entertainment venues. In order to guarantee an optimal throughput, the VR housing is separated from the harness. Therefore, people waiting in line for the attraction can already put on the harness and optimise the fit. When it's their turn, the VR housing can be quickly joined on the harness and the person is ready for the VR experience.

Next, when a person wears a VR headset, it often happens that this person needs to see actual surroundings for a moment. Some VR headsets have the feature to rotate the VR housing easily (see Figure 119)

Last of all, when putting on a VR headset while at the same time wearing glasses, a lot of people experience difficulties. Figure 120 shows a VR headset which has a horizontally movable VR housing, which solves this aforementioned problem.

Figure 118 Detachable VR housing

Figure 119 Rotatable VR housing

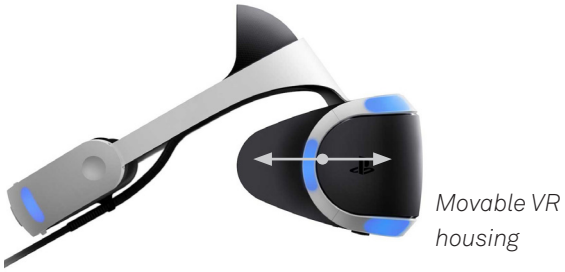


Figure 120 Movable VR housing

Hygiene

VR headsets

Hygiene is an underexposed feature of current VR headsets. Currently, there are a few solutions available to keep the VR headset hygienic. First solution is to have a removable and washable face mask (see Figure 121). Second solution is to have a VR headset which has easy to clean material/surfaces (see Figure 124). Third solution is to wear face covering headgear, which could be in the form of a washable/disposable balaclava. Less head covering options are also available (e.g. face mask).

Helmets

The same solutions as mentioned above are also used in current helmets.

Figure 121 Removable face mask VR headset

Figure 122 Removable foam pads motorcycle helmet

Figure 124 Rubber facemask

Figure 123 Types of balaclava's

D MATERIAL STUDY

In this appendix an initial material study can be found. This will provide additional information for chapter 1.5 ‘ Exploration study’

The goal of this initial material study is to search interesting materials on the following aspects: comfort, hygiene, robustness and temperature. Focus lies on material use of current helmets & VR headsets.

Foam

Foam is an interesting material type as a possible comfort padding for the VR helmet. The following aspects are important when choosing a type of foam:

- Firmness – measured in Indention Load Deflection, ranging from 5 – 75 units
- Density – measured in kg/m3, ranging from 45 – 800 units
- Air permeability
- Resilience

Figure 125 Comfort padding of a motorcycle helmet

Polyurethane (PU) foam

- Used often in motorcycle helmets as comfort padding
- Open-cell type is used often for this purpose – enables air flow (temperature), makes the foam softer and better shock absorbing
- Available in a lot of variations / qualities (e.g. high density foam, memory foam or dryfast foam)
- PU foam sheets can be (laser) cut, CNC milled, but it can also be casted

Fabric

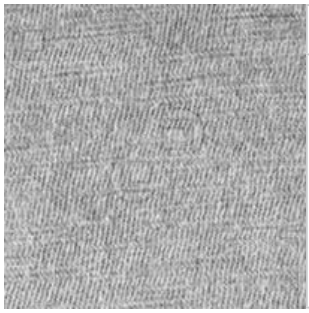
Fabric could be an interesting material for covering the comfort padding or even parts of the housing in order to make the product lightweight, as for example is done with the Oculus Rift CV1 or the Google Daydream VR (See Figure 126). The following aspects are important when choosing a type of fabric:

- Softness
- Temperature
  - Air permeability
  - Thermal insulation
- Hygiene
  - Anti Bacterial/Microbial

Figure 126 Use of fabric in VR products

Polyester (PE) mesh fabric

- Currently used often in motorcycle helmets as fabric liner of the PU foam.
- PE fabric is strong, durable, stretchable and does not wrinkle.
- It does not absorb moisture in hot temperatures, a mesh fabric can improve the temperature aspect of this material.



Cotton fabric

- Soft feeling
- Absorbs and releases moisture quickly, allowing the fabric to breathe.
- Wrinkles easily

Most fabrics can get a treatment with anti-Bacterial/Microbial coatings. For example silver nano coating.

Flat elastic

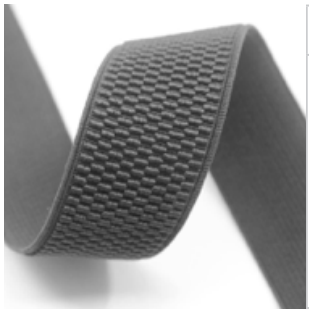
Elastics are interesting materials for strapping a product onto your head.
The following aspects are important when choosing a type of elastic:

- Elastic behaviour when stretched, X % of stretch
- Strength

Figure 127 Use of elastic in VR products

Knitted elastic band

- Elastic material is not going narrow when stretched
- Up to 200 % of stretch



Woven elastic band

- Better quality than knitted elastic band
- Strong and durable
- Is not narrowing when stretched
- Up to 115 % of stretch

Polymers

Polymers are interesting for parts of the housing. The following aspects are important when choosing a type of plastic for the VR helmet:

- Impact resistant
- Shock absorbing
- Hygiene, 'greasy fingers'

Figure 128 Housing material

Polypropylene (PP)

- Rigid
- Waxy feel
- Tough and flex resistant

ABS

- Rigid
- Extremely tough with good impact resistance
- Stable material for manufacturing

PC

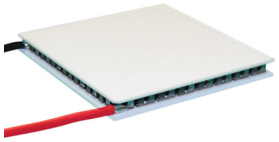
- Rigid
- Extremely tough with good impact resistance
- Excellent clarity, able to manufacture clear parts

TPE

- Flexible to Semi-rigid, available in varying grades of hardness
- Good feel and grip
- Shock absorbent
- Could even be inflatable (TPU)

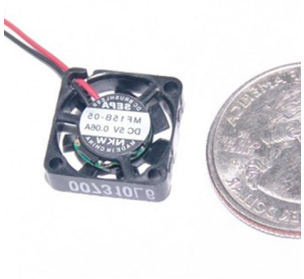
Smart materials

Especially for the aspect of temperature regulation are smart materials interesting to investigate. Below is a small selection of micro components that can be integrated with other materials, such as fabrics.



Micro Peltier element

- Active cooling
- Micro heat pump (without any moving elements) which induces a heat flow by having a cold bottom and hot top layer
- In various sizes available, power



Micro fan

- Active cooling
- Micro fans can move up to 1L/min of cool air

E PRODUCTION STUDY

In this appendix an initial production method exploration can be found. This is additional information for Paragraph 1.5 'Exploration study'.

The focus of this qualitative exploration lies on various production methods which are suitable for low batch sizes. Moreover, most attention will be given on finding suitable production methods for housing parts.

Per production technique information will be given on the following aspects:

- Design freedom
- Material choice
- Quality
- Costs (qualitatively)

3D printing

- Highest degree of design freedom
- Various techniques, SLA, SLS (Plastic) and DMLS (Metals) are providing high quality results
- Various types of resin/powders that can mimic different types of plastics. However when there are specific technical material requirements, this production method is inadequate
- High degree of accuracy (tolerances of ±0.15 mm), but requires finishing after manufacturing. Parts printed with SLA technique + additional finishing provide the best aesthetic result

Vacuum casting

- High degree of design freedom – slight undercuts are possible
- Various sorts of polyurethane that can mimic different types of plastics and rubber
- Silicone is used as mould material
- Tolerance is typically within 0.4%. A vacuum casted part is similar to mass-produced injection moulded part, so very high surface finish. Overmoulding is possible

Thermoforming

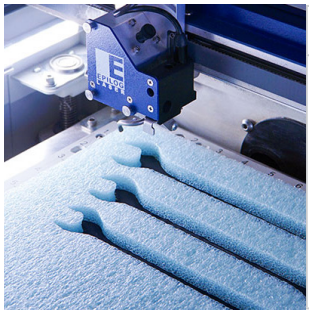
- Low degree of design freedom
- Various sorts of thermoplastics are applicable for this process
- Quality of result depends on the material and mold, but it can produce a fine surface finish and reproduction of detail. In-mold decoration is possible
- Moderate tooling costs, low part costs

Rotational moulding

- Medium degree of design freedom - hollow shapes
- Various sorts of thermoplastics are applicable for this process
- Shrinkage is ± 3%. Good surface finish. In-mold decoration is possible
- Moderate tooling costs, low-medium part costs

CNC milling

- High degree of design freedom
- Various sorts of material types, such as plastic, wood and metal are applicable for this process
- Produces high quality parts, with close tolerances (±0.02 mm)
- Low tooling costs, low to high part costs



Laser cutting

- Low degree of design freedom
- Various sorts of material types, such as plastic, foams, textiles and wood are applicable for this process
- Tolerance of ± 0.1mm. Quality depends on choice of material.
- Medium-high part costs

Costs 3D printing / Vacuum casting

These two production techniques are interesting for manufacturing plastic housing parts. So it's interesting to find out what the differences are cost-wise (roughly). Apart from costs, it's important to realise that the aesthetic result of a 3D print which is painted afterwards is still inferior to the result of a vacuum casted part. The costs are based on the personal communication with prototype/low volume production companies (T. van de Boom/SKM Rapid, Personal Communication 10-1-2017) (B. Noordermeer/RP2, Personal Communication 11-1-2017) and based on the following aspects:

- Small and Medium sized part
- Batch size of 20 parts

	Small part	Medium part
3D printing	€15/part	€45/part
Vacuum casting	€135/part	€110/part

F SUMMARY OF ANALYSIS PHASE

This appendix contains a summary of the analysis phase, containing the product requirements derived from the analysis phase. Next to that, questions that need to be researched further are also described. Every product requirement and open questions have a reason why they are formulated. Finally, some first solutions found during the analysis phase are also presented that can help to fulfil the requirements.

Ergonomics

Requirement

What?	**The product needs to feel comfortable on the users head**
Why?	• VR Experience: Comfort has a direct relation to the level of immersion, which is important in determining the overall VR experience. • Ergonomics: The comfort of the product affects indirectly the experienced neck load.
Research	• Ergonomics: Taking into account that especially the forehead and side head are pressure sensitve areas on the human head. • Current solutions: Using foams and/or elastic materials

Requirement

What?	**The fit of product needs to be adapted to users head**
Why?	• Ergonomics: The fitting of the product on the users head has a direct influence on the stability and comfort of the product. • Business: The adaptability of the product ensures that 1 product has to be manufactured and sold, instead of selling multiple sizes.
Research	• Ergonomics: Taking anthropometric information regarding the human head (western/asian) into account. • Current solutions: See examples of features of current types of helmets that can adapt their fitting to the users head.

Requirement

What?	**The product needs to provide proper ventilation and cooling to the head of the user**	
Why?	• Context: The activity of racing in a VR simulator comes with considerable heat generation and possibly sweating. • Ergonomics: Thermal comfort of the human head is important, since a slight increase of the temperature (1/2 °C) of the head can cause serious discomfort to the whole body. • Context: 2/10 people have motion sickness when driving. The amount of ventilation can enhance/reduce the feeling of motion sickness.	
Research	• Ergonomics: Taking into account that the human head has important arteries in exchanging heat.	
	• Materials: passive cooling by selecting materials with high air permeability	• Technology: active cooling by using e.g. fans or peltier devices

Requirement

What?	The product should have a maximum weight of 1200 grams
Why?	• Context: The target group is predominantly male, with an age range of 15-60 years old. • Ergonomics: 2000 grams is max allowable head mounted load that can be carried comfortably. Neck strength of 15 year old is at 60%, which makes 1200 grams.
Research	• Technology: Parts of donor HMD weigh at least ±*400* grams • Current solutions: Lightweight materials

Requirement

What?	The centre of mass of the product should be as closely aligned as possible to the centre of mass of the human head
Why?	• Ergonomics: The weight distribution of the product has an effect on the experienced neck load
Research	• Ergonomics: the centre of mass of the human head is located near the tragus of the ear • Current solutions: use of counterweights

Hygiene

Requirement

What?	The product needs to feel, look and be hygienic during use
Why?	• Context: The activity of racing in a VR simulator involves possibly sweating. Sweating is perceived as unhygienic. • Context: A considerable percentage of the target group (predominantly male) will have sticky/greasy hair products in their hair. A sticky/greasy feel is perceived as unhygienic.
Research	• Materials: Various anti-bacterial/microbial coatings on textiles • Materials: Low-gloss soft touch materials to see less greasy/sticky touch points. • Current solutions: Using an additional washable/disposable product could be an option (e.g. Balaclava)

Context

Requirement

What?	The product needs to provide a mean of communication between other simulator drivers and the operator
Why?	• Context: Communication between the simulator driver and operator is necessary for setting everything up before racing. The product could possibly impede natural communication. • VR Experience: Communicating while racing with multiple simulator drivers at the same time adds to the racing experience.
Research	• Technology: Professional racing communication headsets are available for integrating into products.

Requirement

What?	The product needs to withstand intense use and occasional dropping
Why?	• Context: The product is used by multiple people (up to *50* people) every day. This implies a realistic chance of dropping the product accidentally (± 1 meter).
Research	• Materials: Material characteristics such as good impact resistance (Polycarbonate, ABS) and shock absorbent (TPE, Rubber) are relevant.

Technology

Requirement

What?	The product will integrate the functional parts & sensors of a donor HMD (TBD)
Why?	• Business: Development of custom-made HMD parts (e.g. lenses, display) is expensive, especially for a low batch size. Therefore using donor parts of an existing, high-performance consumer HMD is a more viable alternative.
Research	• Technology: reviewing different HMDs on various aspects.

Requirement

What?	The product will integrate high-quality audio parts
Why?	• Context: Current audio solution is not sufficient • VR Experience: Audio is an important aspect that indirectly determines the total VR experience.
Research	• Technology: 3D audio • Technology: different strategies for integrating audio parts

Choice

What?	Does the product needs to incorporate the adjustability of the lenses for optimal viewing experience?	
Options	Fixed position of lenses	Adjusting InterPupillary Distance (IPD) and Eye Relief of the lenses
Why?	• Context: By fixing the position of the lenses, the time of adjusting the product before use is shortened. This directly shortens the throughput time. • Context: Currently, the lens adjustability feature of the consumer HMD is almost never used to optimize the view. • Product Architecture: By fixing the position of the lenses, the complexity and costs of the product will be reduced.	• VR Experience: getting the optimal viewing experience (widest field-of-view, which is already limited) • Context: People wearing glasses (average of 6/10 people) benefit from the adjusting the lenses.

Requirement

What?	**The product has to be designed with repairability in mind**
Why?	• Context: As the product is likely to be intensely used, it is possible that a part in the product could break. • Technology: The hardware enabling Virtual Reality is rapidly evolving. Therefore taking the possibility into account of upgrading hardware is reasonable.
Research	

Experience

Requirement

What?	**The product needs to have similar visual characteristics of a professional racing driver helmet**
Why?	• VR Experience: As a first impression, it can add to the initial emotional state of the user.
Research	• Helmet study: Visual characteristics of racing helmet

Choice

What?	**Does the product need to incorporate the professional racing driver ritual of putting on helmet, visor up, stepping in/onto simulator, visor down - before racing?**	
Options	No ritual – Not able to move HMD (unlike a visor) while wearing the product	Ritual –Able to move HMD (like a visor) when wearing the product
Why?	• Context: Not incorporating the ritual • Product Architecture: Not incorporating the ritual will result a less complex and costly product	• VR Experience: The above mentioned ritual relates to the memory of how professional racing drivers prepare for a race and therefore creates a better experience.

Choice

What?	**Does the product need to feel exactly as a professional racing helmet?**	
Options	Relaxed helmet experience	Professional helmet experience
Why?	• VR experience: higher level of comfort relates to higher level of immersion while racing.	• VR experience: Adds to the realism of the experience.

Business

Requirement

What?	**The product will be designed for a batch size of 1- 20 (max.) products**
Why?	• Business: Based on sales figures of simulators and possibility of selling to other simulation-based companies.
Research	• Business: other types of markets

Requirement

What?	**The product has to have a maximum sales price of €4000-6000**
Why?	• Business: competition • Business: compearable alternative • Business: willingness to pay
Research	• Business: initial cost price indication

Production

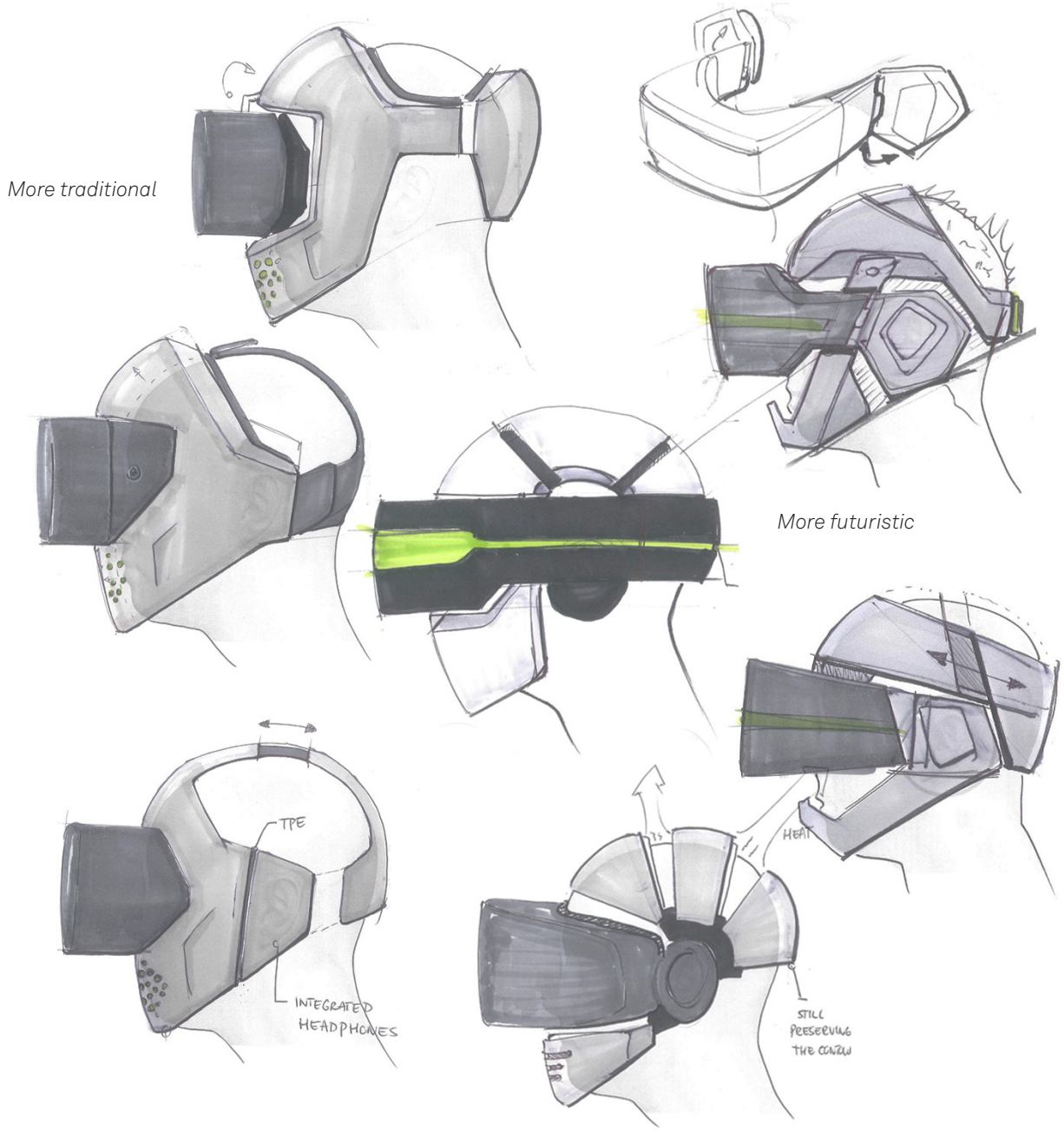
Requirement

What?	**The product has to be manufactured with production techniques that are applicable with low volume batch sizes.**
Why?	• Business: otherwise this will be too costly.
Research	• Production: Applicable production techniques

G IDEATION SKETCHES

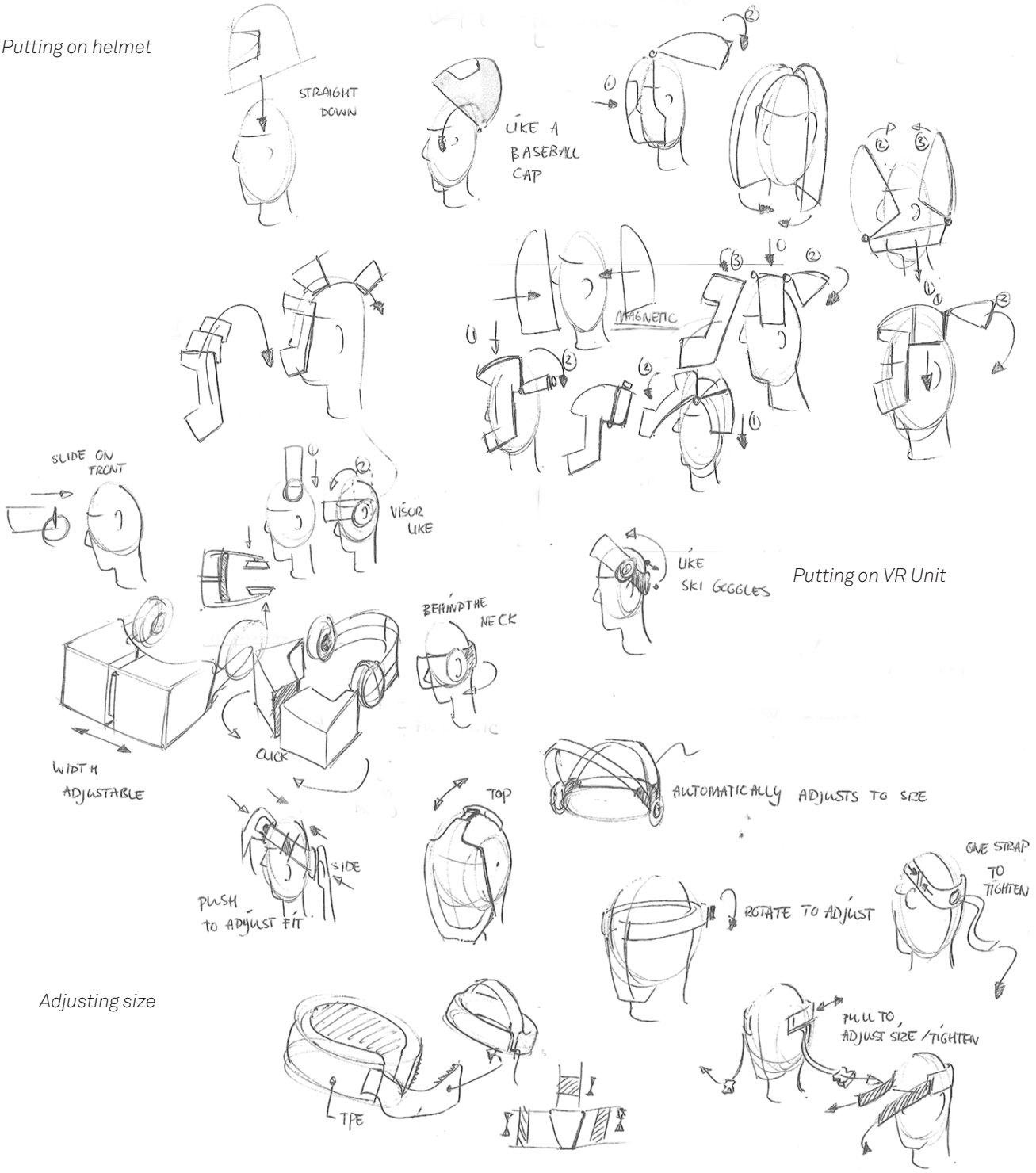
This appendix contains a selection of sketches that are categorised in four studies: archetype, experience, comfort and practical.

Archetype study



Experience study

Putting on helmet

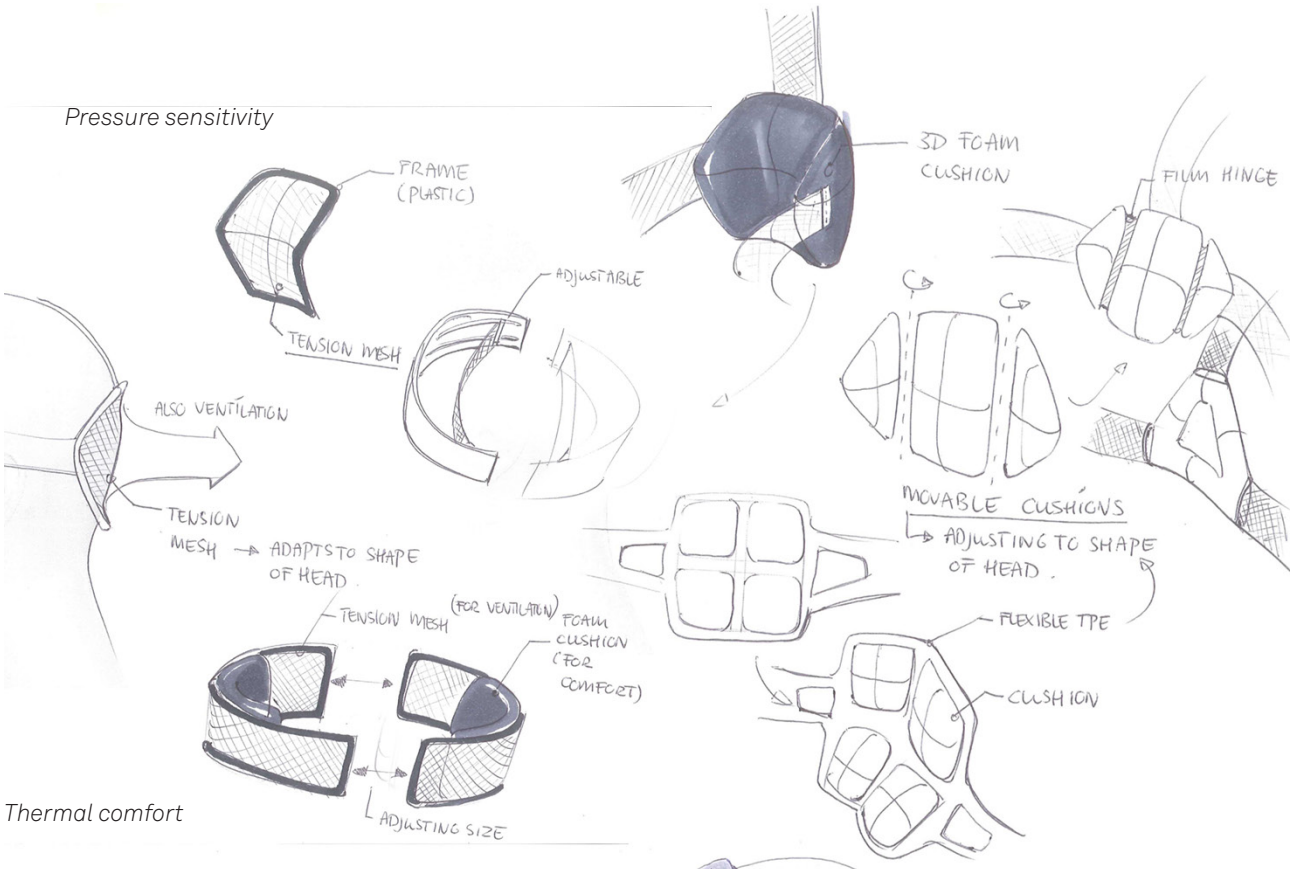


Putting on VR Unit

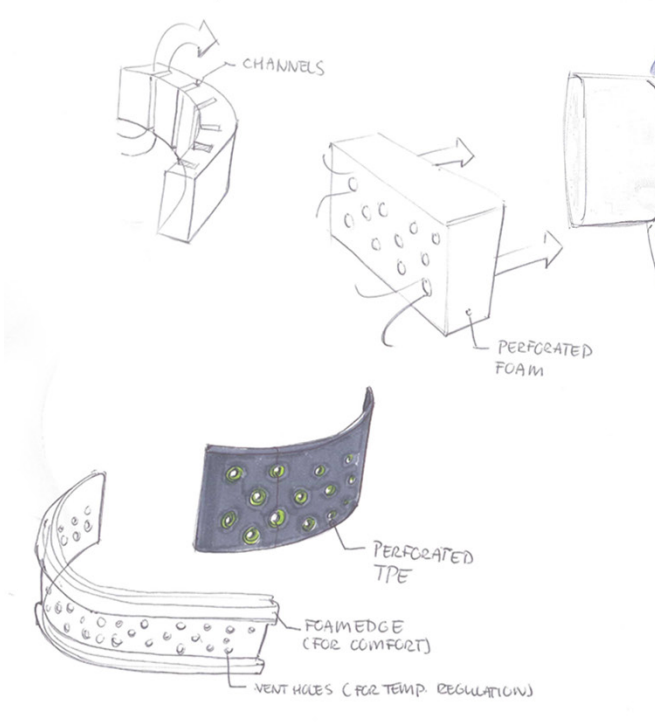
Adjusting size

Comfort study

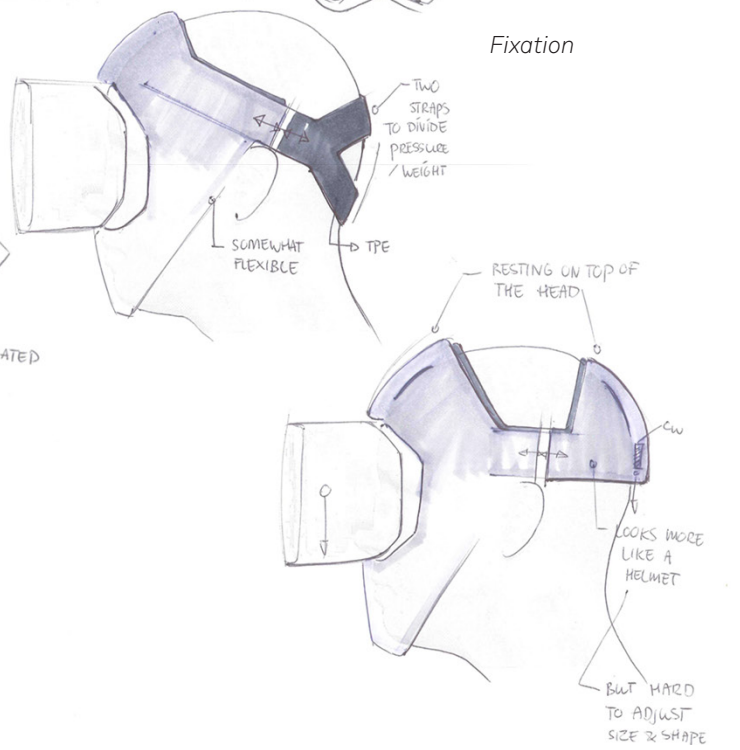
Pressure sensitivity

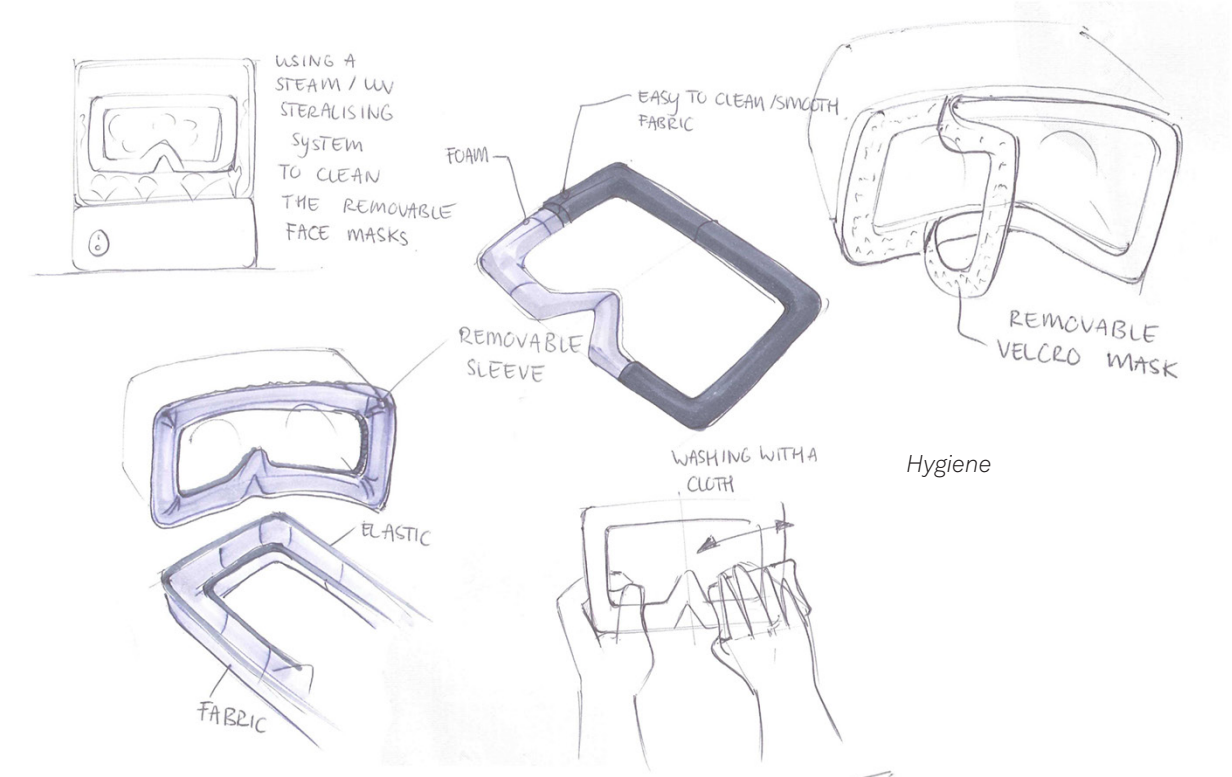


Thermal comfort

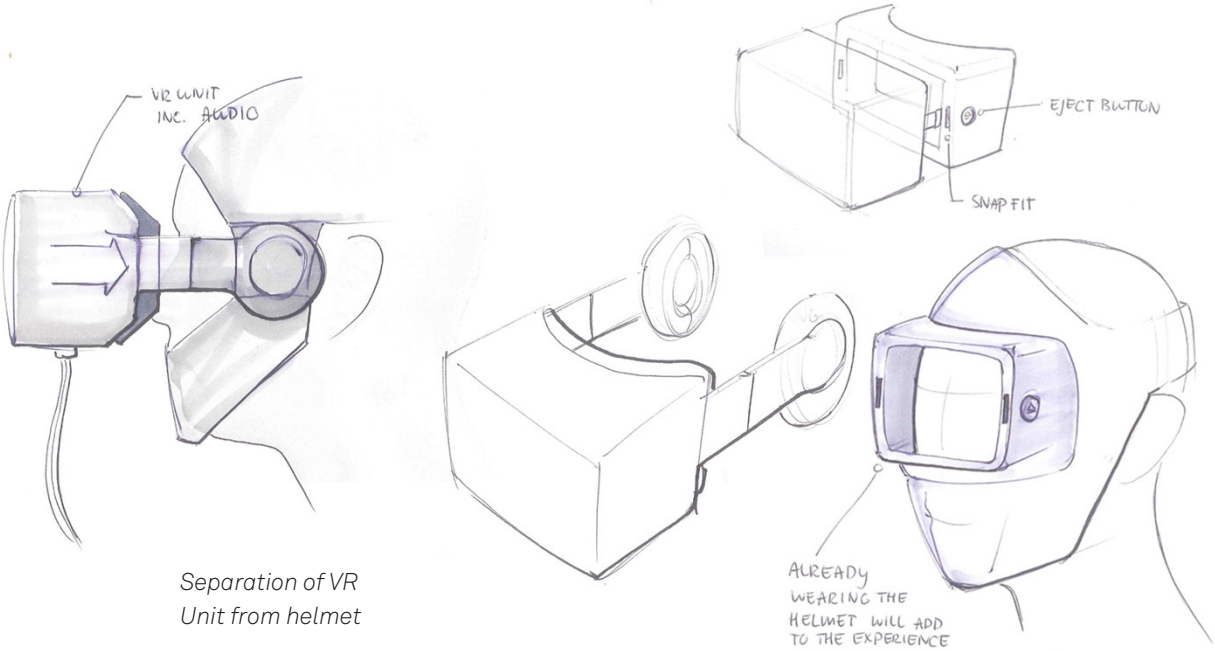


Fixation





Hygiene



Separation of VR Unit from helmet

H CONCEPTUALISATION RESEARCH

This appendix contains the set-up and results of the user test regarding the product experience of the VR helmet concepts.

Research plan

Why?

To start, it's important to clarify why the product experience of the VR helmet concepts is user tested. First, Product experience (PE) is an important aspect of the new VR helmet. The VR helmet will be designed for motorsport simulators for the entertainment industry. In this context, the experience of the attraction is everything. The VR Helmet can play a part in enhancing the overall experience of the attraction. Furthermore, the VR helmet is a new type of product, which is an integration of a Helmet and VR headset, which each have two different product experiences (see chapter 1.7 'Product experience' of the analysis chapter). It is unclear what the desired product experience of the VR helmet should be. The product experience does have to fit in the current motorsport experience of the simulator, but this still leaves a lot of design freedom. This design freedom is explored in the concept phase and resulted in two concept directions. Two concepts are developed, based on these concept directions. By user testing these two concepts, insights can be gathered what the desireable product experience is.

Product experience

Then, 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:

- Aesthetic pleasure (gratifying senses: look, feel, etc.)
- Attribution of meaning (symbolic association)
- Emotional response (feeling & emotions elicited)

Concepts

Two concepts are designed that will be tested. Both concepts are designed to elicit the same feeling & emotions (emotional response) as when wearing a normal racing helmet (confident and feeling prepared to race). Furthermore, both concepts should both have a symbolic association with a racing helmet (attribution of meaning). These two components of the product experience are already fixed, because it adds to- and fits the current simulator experience. However, designing for achieving this emotional response and attribution of meaning can be done with different approaches, more specifically by varying on the look, feel and interactions of the product. During the design process, two different concept directions emerged. Figure 129 shows a small preview of both concepts. In paragraph 2.2 both concepts are discussed thoroughly.

Figure 129 Concepts 1 & 2

Research Questions

Q1: What is the desired product experience of a VR Helmet for racing simulators for racing enthusiasts in an entertainment context?

- 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?

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?

Method

The user test is a qualitative research and is divided in two parts:

- Part 1: User giving feedback about the ideally intended product experience by being presented artist impressions and a storyboard of each concept, followed by a semi-structured interview.
  - Goal of this first part is to convey the intended product experience and get feedback before they try on somewhat imperfect prototypes, which could affect their judgement on aspects of the concepts.
- Part 2: User testing the product experience of the concepts by using prototypes of the concepts in a mimicked context.
  - Goal of the second part is to get feedback about the product experience when they actually wear and try prototypes of the concept. Besides getting feedback about the product experience, observations and feedback can be retrieved about the practical use of the concepts as the concepts will be used in the same manner as they would have been used in a real simulator attraction, as they will be used in a simplified and mimicked context.

Stimuli

- Part 1
  - Sketched artist impressions and storyboards of each concept. Opposed to photorealistic CAD renderings, sketches are more appropriate for this research. This is done in order to give participants the feeling that it's not a finished end-product, which is stimulating to be more critical and that they can think along about the end-result.
- Part 2
  - 3D-printed prototypes (see below) of each concept with the ability to view a racing VR movie through the use of a smartphone.
  - A seat combined with a gaming steering wheel and pedals (see image below) that represent the racing simulator.

Figure 130 Stimuli

Procedure

- Introduction – max 5 min.
  - Purpose of this research
  - Short summary of the graduation assignment and context in which the VR helmet will be used
  - Explain the structure of the research and what is being asked of them
  - Before starting the research, the following questions are asked
    - Age/Gender of the participant
    - The amount of affinity the participant has with racing/motorsport
- Part 1 – max 10 min.
  - Start explaining each concept by using the artist impressions and storyboard.
  - After explanation, the following interview questions are asked. The participant is asked most of the times to answer on a bipolar adjectives scale.
    - Regarding the emotional response
      - How would you rate each concept on a scale of exciting - boring to use? Why?
      - How would you rate each concept on a scale of confident-distrustful to wear? Why?
    - Regarding the association
      - How would you rate each concept on a scale of fitting - non-fitting for the racing simulators? Why?
      - Do you think it's important that the VR helmet looks like a real racing helmet? Why?
- Part 2 -10 min.
  - The 3D printed prototypes are presented to the participant
  - Each concept prototype will be put on and will be used in the following order (based on the fact how they will be used in the simulator attraction). The participant is asked to think out loud when they notice something positive/negative.
    - Concept 1
      - At the start, the participant will stand next to simulator
      - Then, the prototype will be put on by the participant himself with the visor open
      - When the prototype is put on, the participant can take place in the mimicked simulator
      - When seated, a fake video/audio cable will be attached to the prototype by the researcher.
      - The participant will put down the visor and starts to race for ± 1 min.
      - After this, the visor will be put up again, the video/audio cable will be disconnected by the researcher and the participant can step out the mimicked simulator and will take off the prototype.
    - Concept 2
      - At the start, the participant will stand next to simulator
      - Then, the prototype will be put on by the participant himself and will adjust the the size of the prototype himself
      - When the prototype is put on, the participant can take place in the mimicked simulator
      - When seated, the researcher will attach the VR/Audio unit (including video/audio cable) on the helmet
      - The participant will race for ± 1 min.
      - After this, the VR/Audio Unit will be detached by the researcher, the participant can step out of the mimicked simulator and will take off the prototype.=
    - After using both concepts, some interview questions will be asked:
      - How would you rate now both concepts on exciting-boring to use? Why?
      - How would you rate now both concepts on confident – distrustful to use? Why?
      - How would you rate both concepts on comfortable – uncomfortable to use? Why?
      - How important is the aspect of comfort when comparing it to the aspect of excitement?
      - How would you rate both concepts on practical – impractical to use?
- Round-up 5 min
  - Ask whether they have some questions / last remarks
  - Thank participant

Participants

10 participants.Participants are consisting of students of the TU Delft and employees of Cruden. The aim is to have as much as participants as possible that are racing enthusiasts or have an affinity with racing.

Apparatus

- Interview guide
- Forms for filling in answers on bipolar adjectives scale.
- Digital camera for observation (images/movies)

Measures

- Scores on bipolar adjective scales on ideally intended product experience (artist impressions)
- Scores on bipolar adjective scales on actual product experience (prototypes).
- Quotes/remarks on explaining the scoring on adjective scales.
- Answers of additional questions

Results

Participant	Male / Female	Age	Score Affinity motorsport	Boring - Exciting						Insecure - Confident						Non-fitting - Fitting			Should VR helmet resemble a racing helmet?	
				Artist impressions			After use prototypes			Artist impressions			After use prototypes			Artist impressions				
				Score C1	Score C2	Why?	Score C1	Score C2	Why?	Score C1	Score C2	Why?	Score C1	Score C2	Why?	Score C1	Score C2	Why?	Yes/No	Why?
Eloy	M	24	3	6	5	C1, + Looks less traditional (open space top of the head) + more control	7	2	C1, + Shutting VR unit yourself + Preparing for race C2, - Forced to go into VR world	6	3	C1, + looks like 1 piece (solid) C2, - cannot know if VR unit is attached properly	6	3	C1, + You can see where everything is before racing C2, - less control attaching VR unit	6	6	C1, + VR unit is integrated + helmet like C2 - VR unit is less integrated, + More	Yes	Approaching the feeling/interaction of helmet will provide more immersion
Dirk	M	25	4	6	5.5	C1, + All-in-one + Shutting VR unit yourself C2, - less exciting that VR unit is placed	6	6	C1, + Automatic size changing + More closed off while driving	6	5	C1, + Automatic changing size (Always right, you cannot do wrong) + Shutting VR unit yourself	6	5	C1, + Feeling more immersed	6	5.5	C1, + looks more like a helmet	Yes	Not that important
Bart	M	24	5	6	5	C1, + Real helmet experience C2, - Less exciting that VR unit is placed - Headphone	3	5	C2, + is different/new way of using	6	3	C1, + Interaction is familiar + Automatic changing size C2, - Manual changing size	7	2	C1, + Interaction is how it should be + Independent C2, -	6	4	C1, + Familiar shape & use C2, - Complicated use	Yes	Experience-wise this is important. Perception of protection
Matthijs	M	25	6	6	5	C1, + Integrated VR visor + attaching cable is futuristic	6	5	C1, + Shutting VR unit yourself + More closed off while driving	5	6	C2, + Manual changing size gives more control	6	6	C1, + Pressure on face + Closed off C2, + Manual changing size	5	5	C1, + Interaction/use C2, + Cool Appearance Both looking futuristic	Yes	Better immersion
Jelle	M	25	4.5	5.5	3.5	C1, + Automatic size changing + Doing more yourself C2, - Different use - Dependent on	6	5	C1, + Surrounds head better + Pressure on face C2, + Interaction Jaw feature is cool	4	5	C2, + More configuration features	5	3	C1 + heavier	6	3	C1, + Helmet-like and futuristic C2, - VR unit looks clumsy + Jaw feature looks cool	Yes	Creates a better immersion
Marieke	F	-	5	6	5	C1, + All-in-one C2, - Less independent	6	4	C1, + More immersed	6	5	C1, + Looks like 1 piece (solid)	6	3	-	6	5	C1 + Better fit motorbike C2 is more sci-fi/super hero-like	Yes	
Martijn	M	-	7	6	5	C1, + Looks like 1 piece (solid) + interactions like normal helmet C2, - Multiple parts	7	5	C1, + Intuitive use C2, - Struggling to put on	5	3	C1, + Looks like 1 piece C2, - Multiple actions before everything is set	6	2	-	5	5	C2, + Aesthetic aspects are cool/military Open parts VR helmets are less cool	Yes	It's the first association
Terry	M	-	7	5	6	C1, - Looks more like a mask C2, + Looks more like a helmet, more closed off	7	6	C1, + Putting on C2, - Felt more like mask, less immersed	6	5		7	5	C1, + Feels like 1 piece (solid) C2, - Feels less solid	7	7	-	Yes	In entertainment context, experience is everything, so it has to be close to the real thing
William	M	-	5	6	4	C1, +Ready in one go C2, ± More actions, like a ritual	6	3	C1, + Felt helmet-like (closed off) C2, - Disappointed	6	5	C1 + Automatic size changing, no need to worry C2, ± More to control	7	3	C1, +Feels like 1 piece (solid) C2, - Top heavy	5	5	C1 looks more like race helmet C2 looks more like a system helmet	Yes	It's an attribute in an act that feel as real as possible
Maikel	M	-	6	6	4	C1, + Looks more like a helmet C2, - More seperate parts	6.5	3.5	C1, + Felt helmet-like (closed off)	3	5	C2, + Sits more on top of your head C1, - You have to have faith that it stays where it is	6	3	C1 + Top part felt good only side cheek parts not entirely	6	4	C1 looks more like motorbike helmet	Yes	It has to be as real as possible
Results (avg.) =			**4,8**	**5,3**	**3,9**		**5,4**	**4,1**		**5,3**	**4,5**		**6,2**	**3,5**		**5,8**	**4,4**		**Yes**	

Uncomfortable - Comfortable			Comfort vs Real racing experience		Unpractical - Practical		
After use prototypes					After use prototypes		
Score C1	Score C2	Why?	Comfort/Racing exp	Why?	Score C1	Score C2	Why?
5	7	C1, - less comfortable C2, + almost unnoticeable on head	Comfort	You already know that it's not a helmet	6	5	C1, + less actions (e.g. Automatic fitting) C2, - More complicated, too
6	4	C1, + snug fit + slightly heavier but feels like helmet + Pressure on face is not annoying	-	-	6	5	C1, +faster C2, - Dependent on someone else
4	2	C1, - Automatic size change is not nice + Pressure cushions C2, - Felt heavier than C1	Racing experience	The extra adrenaline takes away the discomfort	6	3	C1, + logical C2, - too complicated - dependent on someone else
6	6	C1, + snug fit + Firm feeling also due to weight	Racing experience	Will provide better immersion, want to approach safe feeling of helmet	6	5	C1, + Automatic size changing works well/handy C2, - Dependent on someone else
6	3	C1, + weight distribution C2, +put on helmet - weight distribution	Racing experience	Comfort is important, but a little discomfort is ok	3	3	C1, - Automatic fit mechanism (what's happening?) C2 + put on helmet part, not VR unit
6	3	C2, - Top heavy	Comfort	A lot of new impressions in simulator, comfort is important	6	5	C2, + principle of concept is very practical
6	3	C1, - Weird feeling of dividing mass (unlike headphone) C2, + Manual changing size	Racing experience	Is part of the helmet experience, having grip/tight feeling on your head	6	2	C1, + more independent C2, - Dependent on operator
7	5	C1, + Weight distribution + snug fit	-	-	7	5	C1, + Less cable entanglement + More independent C2, + More actions, more parts sensitive
7	3		-	-	7	3	C2, - More dependent on operator
7	5	C1, + Everywhere padding	-	-	6	3	C1, + all-in-one C2, - seperate parts
6	**4,1**		**Racing Experience (has slight edge on comfort)**		**5,9**	**3,9**	

TRACKING ISSUES

In this appendix additional information concerning the redesign of the final concept can be found.

VR Unit – Tracking

As explained in section 3.1.1, during the teardown of the Oculus Rift it became clear that only the front facing IR LEDs could be reused in the VR helmet. The IR LEDs are important for tracking the head movement. That's why there are IR LEDs located at the front, in the housing and at the back (see Figure 131). The IR LEDs in the housing and the back cannot be reused since they are glued together.

This raised the first question, are only the front facing IR LEDs sufficient for tracking in a racing simulator environment? A quick test was conducted on the motorbike simulators to see whether this is the case. The motorbike simulator was chosen for this test, because on this simulator the most head movement occurs. If the front facing IR LEDs are sufficient in this context, they will also be sufficient for the F1 racing simulator, which has more limited head movement compared to the motorbike simulator.

In order to only test the tracking of the front facing IR LEDs of an Oculus Rift, the IR LEDs of the housing and back are covered up by cardboard, laminated with aluminium foil (see Figure 132). The aluminium foil will reflect the light and ensure that only the front facing IR LEDs are received by the tracking camera.

Figure 131 IR LEDs in Oculus Rift headset

Figure 132 Covering the IR LEDs in the housing and back

Figure 133 Various head movements IR tracking test

The test was conducted with various head movement situations (see Figure 133), such as looking downwards, looking backwards and looking from left to right. The test showed that when looking downwards and looking back the tracking has slight issues. This is noticeable after looking in these positions and coming back to the front facing position. When the tracker picks up the front facing IR LEDs again, the system recalibrates and a slightly noticeable glitch in the image is experienced. For normal head movement, looking left to right for example, the front facing IR LEDs are sufficient. So in the case of the F1 simulator, the front-facing IR LEDs could be sufficient. In case of the motorbike simulator, it probably doesn't.

J COST PRICE

This appendix will cover the detailed cost price calculation of the final detailed VR Helmet concept.

Table 6 shows the detailed cost price calculation. The cost price calculation has taken the following aspects into account:

- Material/production costs
- Purchase part costs
- Stickering/painting costs
- Assembly costs
- Development costs

The cost price calculation has taken a batch size of 20 pieces into account. This is also the maximum batch size for the silicone moulds used for vacuum casting.

In the following sections the separate cost price calculations for each category will be supported with additional information.

Material/production costs

Plastic parts

Most of the parts that need to be produced are plastic parts that will be vacuum casted. Price per parts are calculated by contacting prototyping companies (RP2 , SKM Rapid Modeling and Promoac) and getting detailed quotes for several parts. For vacuum casting, costs are made for making making mastermodels (3D printed parts and post-processed (sanding, painting), which are then used to make the silicone moulds. Finally, the actual casting of the parts in these moulds also costs some amount per part. In the detailed cost price calculation all these types of costs are included in the price per part. Based on the cheapest quote (RP2) the costs per part are calculated.

Padding

The costs of the padding are calculated by getting online quotations (maatkussens.nl and onlinemaatkussens.nl) at several companies who are specialised in making custom cushions.

Purchase Parts

The various costs of the purchase parts are retrieved at various online companies. The following prices of the products are found here:

- Oculus Rift & HDMI Cable – Coolblue.nl
- Rail & Carriage (IGUS Drylin N 17 mm) – RS-online.com
- Mylar Audio driver/Microphone - Mouser.com
- Safety Helmet (3M Peltor G3000) – Toolstation.nl

Stickering/Painting

The colour and texture of the helmet can already be determined during the vacuum casting process. After this, there are various options to customise the helmet for the client. First option is to put some stickers on the helmet (up to €100). Next, the helmet can be painted in simple or complex designs, which can be quite costly (€400 – €900). The prices of these three options are determined through personal communication with Tjello Creations (Tjellocreations.com) and JVH Designs (JVHdesigns.com).

Assembly costs

The costs for assembling are divided in four categories: disassembling the Oculus Rift, Preparing/modifying the Oculus Rift package for re-integration, assembling the actual VR Helmet and testing the VR Helmet before delivering the product. The hour rate (€22/hour) of assembling is based on an hour rate an assembling company (CentWerk.nl) in the Netherlands charges. The hours for each assembly jobs is estimated.

Development costs

It's debatable whether the development costs of the future VR Helmet should be calculated in the cost price, but it's something to take into account when expecting low volume sales. It is estimated that at least €30k is necessary for future development of the VR Helmet. The developing costs (in-house or outsource to design/engineering agency) compromise man hours and costs for prototypes.

Material / Production costs				
Name part	Production process	Cost / part	Amount	Total cost per product
VR Unit - Outer Housing	Vacuum casting	€ 82,00	1	€ 82,00
VR Unit - Inner Housing	Vacuum casting	€ 78,00	1	€ 78,00
VR Unit - Rotation Part	Vacuum casting	€ 66,00	2	€ 132,00
VR Unit - Ratchet part	Lasercutting	€ 3,00	2	€ 6,00
Front of housing - Outer housing	Vacuum casting	€ 106,00	1	€ 106,00
Front of housing - Inner housing (1/2)	Vacuum casting	€ 99,00	1	€ 99,00
Front of housing - Inner housing (2/2)	Vacuum casting	€ 70,00	2	€ 140,00
Top Flex parts	Vacuum casting	€ 64,00	2	€ 128,00
Top Adjustment straps	Vacuum casting	€ 60,00	2	€ 120,00
Side Adjustment straps	Vacuum casting	€ 67,00	2	€ 134,00
Top Adjustment housing	Vacuum casting	€ 65,00	1	€ 65,00
Side Flex parts	Vacuum casting	€ 64,00	2	€ 128,00
Back of housing - Inner housing	Vacuum casting	€ 77,00	1	€ 77,00
Back of housing - Outer housing	Vacuum casting	€ 77,00	1	€ 77,00
Padding - Cheeks	Cutting/Sewing	€ 25,00	2	€ 50,00
Padding - Top of Head (1/2)	Cutting/Sewing	€ 25,00	1	€ 25,00
Padding - Top of Head (2/2)	Cutting/Sewing	€ 20,00	1	€ 20,00
Padding - Back of Head	Cutting/Sewing	€ 25,00	1	€ 25,00
			Total	€ 1.492,00

Purchase part cost			
Name part	Cost / part	Amount	Total cost per product
Oculus Rift	€ 600,00	1	€ 600,00
VR Unit - Rail (600 mm)	€ 19,00	0,17	€ 3,23
VR Unit - Carriage	€ 3,60	2	€ 7,20
Mylar Audio driver 40 mm	€ 5,00	2	€ 10,00
Microphone	€ 3,50	1	€ 3,50
HDMI cable	€ 20,00	1	€ 20,00
Safety Helmet (for size adjustment ratchet part + knob)	€ 12,00	2	€ 24,00
Screws/Bolts are neglected (very low price, compared to rest)			
		Total	€ 667,93

Painting / Stickering			
Type	Cost per VR Helmet		Total cost per product
Simple (only logo stickering)	€ 100,00		
Simple (simple paintjob)	€ 400,00		
Complex (custom paintjob e.g. Max Verstappen helmet)	€ 895,00		
		Total	€ 100,00

Assembly				
Task	Hours	Cost/hour		Total cost per product
Disassembly Oculus Rift	1	€ 22,00		€ 22,00
Preparing Oculus Rift for reintegration	2	€ 22,00		€ 44,00
Assemblying VR Helmet	4	€ 22,00		€ 88,00
Testing	1	€ 22,00		€ 22,00
			Total	€ 176,00

Development cost			
Type of cost	Cost per VR Helmet		Total cost per product
Costs of current/future development and prototypes	€ 1.500,00		€ 1.500,00

Total			
		Total	€ 3.935,93
	Safety factor	1,2	€ 4.723,12
	Sales margin	1,5	€ 7.084,67

Table 6 Detailed Cost Price indication

K EVALUATION USER TEST

In this appendix additional information can be found, concerning the evaluation user test.

Goal

The goal of the validation user test is to validate the final detailed concept of the VR helmet. The final detailed concept is optimised, with respect to the concepts presented in conceptualisation phase, on a lot more aspects, such as comfort, ease of use (for user and operator), hygiene and adjustability for optimising the VR experience. This concept is deemed to be detailed on such a level that it can be compared to the current solution: the Oculus Rift CV1.

Benchmark: Oculus Rift CV1

As mentioned above, in order to validate the final detailed concept, a benchmark product is necessary. This benchmark product is the Oculus Rift CV1, the current solution that the company uses for their VR simulators. 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.

Research questions

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

Method

The research is qualitative and divided in two parts:

- Part 1: Following the process of intended use of the benchmark product and the final detailed concept. Goal of this part is to use and experience both products in the intended way. This is necessary for the participants in order to form an opinion.
- Part 2: Interview/Questionnaire. This opinion is captured by a scoring both products on various aspects and the participant is asked to explain scores in order to interpret them.

Figure 134 VR Helmet & OCulus Rift CV1

Participants

- 3 participants for focus on user perspective: fellow students with a high affinity with motorsport
- 3 participants for focus on operator perspective: employees at the company who have experience with operating a simulator at e.g. exhibitions/fairs etc.

Stimuli

- Alpha prototype
- Renders of final detailed concept
- Oculus Rift CV1

Apparatus

- Interview guide
- Forms for filling in answers on bipolar adjectives
- Digital camera for observation

Measures

- Scores on bipolar adjective scales on aspects related to experience, comfort and ease of use
- Remarks/quotes of the participant of explaining the scores

Procedure

- Introduction - Max 5 min.
  - Welcome
  - Indication of length research, 20 - 30 min.
  - Explain that research will be similar to previous user test (concept phase)
  - Goal of this research:
    - Validation of final concept by comparing it to current product that's used in VR simulators: Oculus Rift (Show both products).
  - Research will consist of two parts:
    - Part 1: Using both products (Oculus Rift and VR Helmet) the intended manner.
    - Part 2: Scoring both concepts on various aspects on a bipolar adjective scale (if necessary, explain this).
  - Asking the participant to speak freely and to be honest.
- Part 1: Trying both products in intended manner – Max 10 min.
  - Before using both products, explain the context in which both products will be used
    - Participant is waiting in line for a F1 VR Simulator attraction, in which 50 different people are wearing the same VR Headset/VR Helmet every day.
  - Use of Oculus Rift
    - Explain that the Oculus Rift will be handed to participant after the participant is seated in the simulator, then the Oculus is handed over and asked to adjust the fit of the Oculus Rift to his/her liking. If the audio is also placed correctly, the participant is asked to look in different directions in order to feel and observe the comfort of the headset.
  - Use of VR Helmet
    - Explain that before using the VR Helmet, a new balaclava is handed to the user. After putting on the balaclava, the VR Helmet is handed over (visor open) and the participant is asked to put on the VR Helmet and adjust the fit to his/her liking. After that, the participant can take a seat (in simulator) and the audio/video cable is plugged in at the back. If the participant is ready to race, he can flip down the visor and adjust the distance from eyes-lenses to his/her liking. Finally, the participant is asked to also make head movements in order to feel the comfort of the helmet while moving the head.
- Part 2: Scoring both products on various aspects - Max 10 min.
  - Experience
    - Which product did you perceive as being more exciting? Why?
      - Focus on balaclava, design and use
    - Wearing which product did you feel more secure/confident? Why?
      - Focus on comfort and use
    - Which product did you perceive as being more hygienic? Why?
      - Focus on balaclava and material of padding
  - Which product felt more comfortable to wear?
    - Focus on weight, weight distribution, heat generation and pressure on head.
    - Is the potential discomfort negligible compared to the gain of e.g. excitement?
  - Which product did you experience as more intuitive/easy to use? Why?
    - Which product was easier to adjust to your size of your head?
    - Which product was easier to adjust the position of the lenses?
    - How did you perceive the attaching of the video/audio cable at the back?
    - How did you perceive the action of opening and closing of the Visor?
  - If you had a choice, which product would you choose? Why?
- Roundup - 2 min.
  - Thank participant for his time and feedback

Results

Participant	Male/Female	Score Affinity motorsport	Boring - Exciting			Insecure - Confident			Unhygienic - Hygienic			Uncomfortable - Comfortable		
			Score OR	Score VRH	Why?	Score OR	Score VRH	Why?	Score OR	Score VRH	Why?	Score OR	Score VRH	Why?
Maikel	M	6	5	6.5	OR, + Already special VRH, + Features such as balaclava, visor and plugging in + Contact with operator through mic audio	5	6	OR, - Only three contact points VRH, + Pression on almost entire head	3	6	Hygiene is very important, especially after years of use OR, - contact with facemask and straps VRH, - everything in	5	5,5	VRH, - Heavy / Top heavy - Pressure on cheek bones + not too hot at first instant
Reinder	M	5	5,5	6,5	OR, already used to experience VRH, + new + racehelmet experience	6	4,5	VRH, - Balaclava and Cushions is slippery - doesn't fully shut off the face OR, + fully shuts off the face	2,5	6	Hygiene is important, VRH, + Balaclava	4,5	6	OR, - feeling the straps, topheavy VRH, + pressure on almost entire head - Heavy - will likely be hot
Kay	M	6	5	6,5	VRH, + Experience leading up to VR moment is cool + Balaclava	5	7	VRH, + Feeling of protection/security, - Heavy (image will shake more)	3	6	VRH, + Removable cushions (maybe with pressing studs?)	5	5	VRH, + Mental feeling of protection - Heavy OR, + Airy, less heavy
Eloy	M	3	4,5	6	OR, + Already special VRH, + More actions leading up to race, sort of countdown	7	5,5	OR, + good/snug fit VRH, - Heavy, less snug fit and moves therefore a bit	3	5	VRH, +Balaclava, important that it gets totally cleaned after 1 day compareable to bowling shoes	5	7	VRH, - Heavy + Pressure on almost entire head OR, - top heavy + efficient
Bart	M	5	2	6	OR, - boring (does what it has to do) VRH, + Prep actions related to racing - Balaclava is annoying	7	3	VRH, - Indirect size adjusting - Heavy OR, +Direct size adjusting (straps) + More free	6	7	Hygiene is very important, + Balaclava	5	3	VRH, - Weight + More balanced weight distribution
Matthijs	M	6	5,5	6,5	OR, + Already special VRH, +More exciting on long term + involves you with entire race experience	6	5,5	VRH, - Weight, Moves a bit	4,5	5	Hygiene is important, especially for a helmet VRH, + Balaclava OR, + less contact area	4	5,5	VRH, + Confident feeling (enclosed, more balanced) - heavy
Results (avg.)		5,2	4,6	5,3		6,0	5,3		3,7	5,8		4,8	5,3	

VRH = VR Helmet
OR = Oculus Rift

Hard to use - easy to use		VR Helmet vs Oculus		Other remarks
Score VRH	Why?	Score	Why?	
6	OR, - Looking for Velcro adjustment straps VRH, + symmetrical size changing + rotation knobs were easily found	VRH	VRH, + Design / Graphics + Helmet-like	Maybe the plug in system at the side of the helmet, like F1 Helmet
6	OR , - not handy to adjust size VRH, + Adjustment knobs easy to find, + Plugging in was fine	VRH	VRH, + total experience	
5	VRH, ± not established interactions yet - connecting audio will produce not a nice sound	-		Heavy - moment when turning head Balaclava will cost quite some money, will operator invest in this?
7	OR, - Less intuitive using straps - two sides that need to be adj. VRH, + familiar adj. System + simple + using VR unit is logical	VRH	VRH, + entire experience OR is also exciting, but helmet more	
3	OR, + Intuitive - Velcro is unhandy VRH, +Putting on and VR unit intuitive - Size adjustment not intuitive	VRH	VRH, +entire experience, discomfort not important (racing = suffering) + sense of safety	
6	VRH, + adj. Knobs are easy to find + quick escaping from VR from VR world	VRH	VRH, + entire experience + sense of safety (heavy movements sim) + Intuitive adjustments	
5,5		VRH		