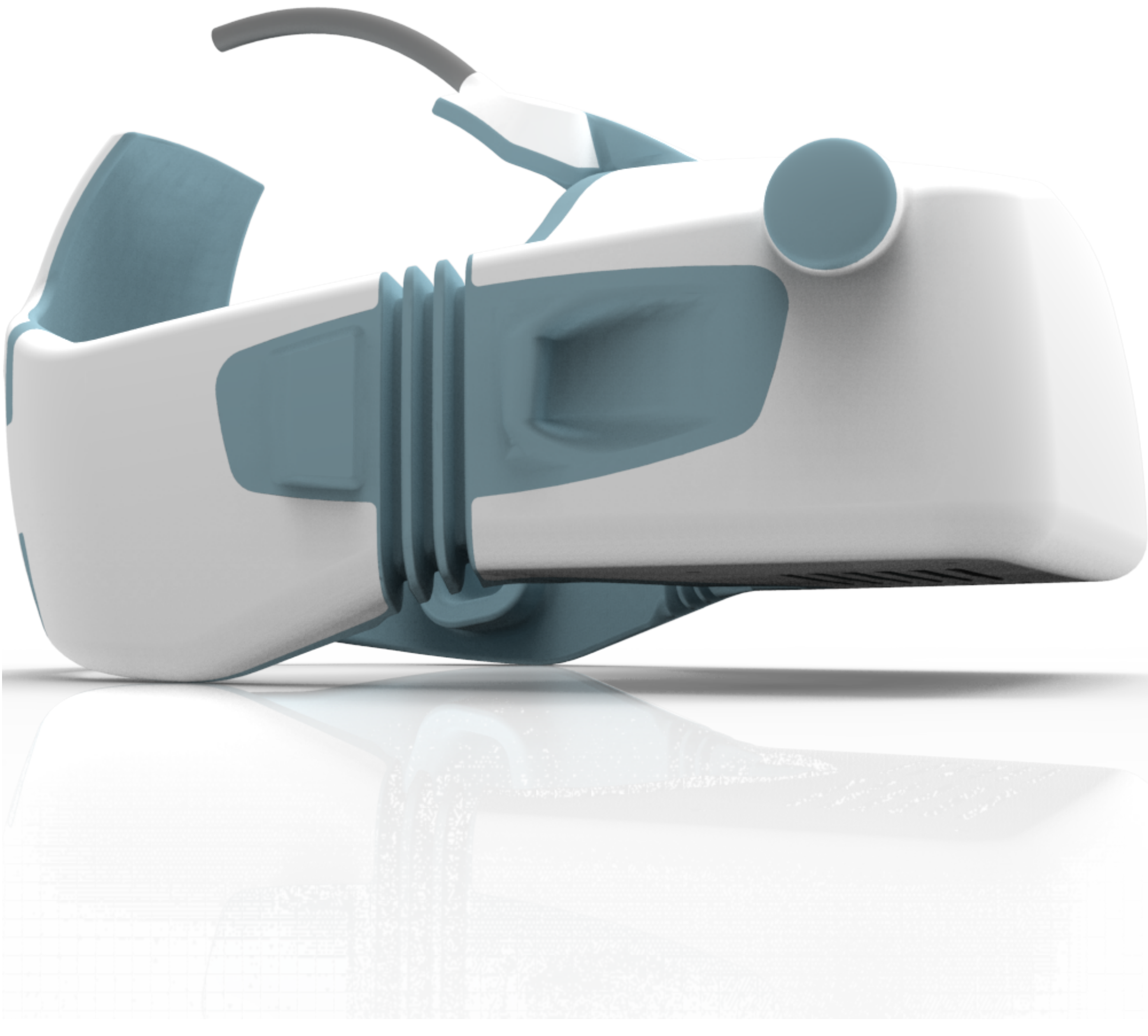
CASING DESIGN FOR HEAD MOUNTED DEVICE

Joep van de Zandt
Bachelor assignment at **Cybermind Interactive Nederland**
Bachelor Industrial Design at **Universiteit Twente**



CASING DESIGN FOR A HEAD MOUNTED DEVICE FOR USE ON CHILDREN DURING A BURN WOUND TREATMENT

Joep van de Zandt | s1196367

Bachelor Industrial Design
Universiteit Twente

Oral exam: **20-8-2014**

Bachelor assignment at **Cybermind Interactive Nederland**

Assesment panel
Chairman: **Prof.Dr.Ir. A.O. Eger**
UT concomitance: **Msc R.G.J. Damgrave**
Cybermind concomitance: **Msc P. Borgstein**

PREFACE

This report describes the design process through which a concept design has been formed for a new Cybermind HMD. This concept design has been delivered to Cybermind for further development of the design into a final product. The assignment has been executed for Cybermind as a support for the industrial designer MSc P. Borgstein at Cybermind. My Tutors MSc P. Borgstein and MSc R.G.J Damgrave have helped me throughout this design process in understanding the design problems from different perspectives and guide me throughout the bachelor assignment. Next to that BSc R. Storcken has helped out a lot in communication with internals and externals of Cybermind and keeping up with the progress of the assignment. After these three months I can say that I am content with the accomplished result and looking forward to seeing what results Cybermind draws from it over time.

Enschede, july 2014

Joep van de Zandt

SAMENVATTING

In deze opdracht is voor Cybermind Interactive Nederland (Cybermind) een ontwerp gemaakt voor de behuizing van een Head Mounted Device (HMD). De opdracht is onderdeel van het Gravilo project, een samenwerking tussen Cybermind, Universitair Ziekenhuis Leuven en stichting Help Brandwonden Kids. Hierin wordt gewerkt aan een betere behandeling van kinderen met brandwonden door het gebruik van virtual reality. De opdracht heeft als doelstelling om een ontwerp af te leveren wat beter aansluit bij de gebruikers en de omgeving waarin de HMD gebruikt zal worden. De HMD zal gebruikt worden als middel van pijn-afleiding bij brandwonden behandeling bij kinderen in een ziekenhuis. Momenteel wordt er in meerdere brandwondencentra getest met een oude HMD van Cybermind, deze werkt niet optimaal in de behandelingsomgeving.

Uit deze doelstelling volgt een hoofdvraag die leidend is binnen het ontwerpproces, deze luidt als volgt: "Welke aspecten spelen een rol in het gebruik van een HMD bij de brandwonden behandeling en aan welke eisen moet worden voldaan om dit gebruik te optimaliseren?"

Een vooronderzoek was de eerste fase van deze opdracht. Hierin is gekeken naar de gebruiksaspecten en beperkingen vanuit de brandwonden behandelingsomgeving. De fysieke en mentale grenzen van de gebruikers, kinderen en behandelaars, zijn ook onderzocht. Daarnaast is gekeken naar de huidige HMD's van de consumenten en professionele markt, hierbij is gelet op gebruiksaspecten en mogelijkheden in combinatie met de brandwonden behandeling. Ook is gekeken naar de interne componenten van de HMD die vanuit Cybermind zijn vastgelegd. Als voorbereiding op de volgende fase is gekeken naar mogelijke oplossingen voor het vergemakkelijken van het inefficiënte reinigingsproces. Dit proces is als een van de grootste knelpunten van het huidige ontwerp bevonden. Dit vooronderzoek is afgesloten met een programma van eisen en wensen (PvE) waarin de belangrijkste aspecten waaraan het ontwerp dient te voldoen zijn gekwantificeerd.

Na het vooronderzoek is door een iteratief ontwerpproces gewerkt aan het ontwikkelen van drie verschillende concepten. Deze concepten bieden verschillende oplossingen voor het gestelde ontwerpprobleem. In de ontwikkeling van deze concepten is gericht gekeken naar gebruiksaspecten als het opzetten en afstellen, reiniging en de balans van de HMD. Dit zijn aspecten die naar voren zijn gekomen uit het vooronderzoek als aspecten waar de meeste verbetering nodig is en aspecten die het meeste de uiteindelijke ervaring beïnvloeden. Deze concepten zijn grof uitgewerkt tot een punt waar de ontwerpoplossingen eenduidig zijn. In een evaluatie met experts binnen Cybermind en aan de hand van een evaluatie aan het PvE een keuze gemaakt voor het verder te ontwikkelen eindconcept. Hierin is het tweede concept als basis genomen maar zijn de beste aspecten uit andere concepten in meegenomen. Het eindconcept is uitgewerkt in de detailleringsfase, hierin is zijn mechanismen, materialen, vormgevings- en gebruiksaspecten tot in detail uitgewerkt. Dit eindconcept is vervolgens in Solidworks omgezet naar een 3D model om een basis te creëren voor het functionele prototype wat via rapid prototyping is geproduceerd. Vanwege het lange productieproces voor het prototype is ook nog een simpel schuimmodel gemaakt om een beeld te krijgen van de proporties en gebruiksgemak met betrekking tot op en afzetten van het ontwerp.

ABSTRACT

In this assignment a casing has been design for a Head Mounted Display for Cybermind Interactive Nederland (Cybermind). This assignment is part of the Gravilo project, which is a collaboration between Cybermind, University Hospital Leuven and the Help Brandwonden Kids foundation. The goal of this project is to improve the treatment of burned children with the use of virtual reality. This assignment has the goal to deliver a HMD design that better fits the environment in which it will be used and the people that use it. the HMD will be used for pain-distraction during burn treatment on children in the hospital environment. At the moment several burn centers are working with an old HMD from Cybermind, this does not work very well in the burn treatment environment.

This goal produces a research question to guide the design process; the research question is the following: "Which aspects play a role in the use of an HMD during burn treatment and which demands have to be met to optimize this use?"

The first part of the assignment is research. This research focuses on usage aspects and limitations of the burn treatment environment. Research has also been done on the physical and mental limitations of the users; these are both the child patients and the practitioners. The HMD's currently on the consumer and professional market have been researched for their usage aspects and their possibilities in the burn treatment environment. The internal components of the HMD have been looked at; these components have been determined by Cybermind. In preparation for the next phase several possible solutions for facilitating the inefficient cleaning process have been looked at. This process has been deemed as one of the largest bottlenecks in the design. The research phase is wrapped up with a program of demands and wishes (PoD) in which the most important aspects of the design are quantified.

After the research phase a design has been created through an iterative design process. Three concepts have been created to provide different solutions to the stated design problem. The development of these concepts has been focused on the usage aspects of the design; mounting and setting up the HMD and cleaning and balance of the HMD. These are aspects where, according to the research phase, the most improvement is needed or where the most influence of the effectiveness of the overall design can be made. These concepts have been developed to the point where their functioning is clear. In an expert evaluation within Cybermind and an evaluation to the PoD the second concept has been chosen as the basis for the final concept. The best aspects of the other two concepts have been integrated in this final concept. In the detailing phase this final concept is further developed. Here design choices have been made concerning the mechanisms, materials and design- and usage aspects. This has resulted in a detailed final concept.

For production of the functional prototype the final concept has been transformed into a 3D model, using Solidworks. Because the production of the prototype takes several weeks a simple foam model has also been made to provide a better view on the proportions and ease of usage of the final concept, this mainly concerns the mounting and dismounting of the HMD.

CONTENTS

1

INTRODUCTION

This report describes the process and design choices made throughout this bachelor assignment. The goal was to create a design for the casing of a HMD. This design has been developed on the basis of research that has been done in the beginning of the assignment, the research phase. This research has delivered a direction for the design process in the form of a program of demands and wishes and a set of design guidelines. Through an iterative design process a concept design and prototype have been created. The first step is an ideation phase in which ideas have been created and developed. Here the focus lies on creating ideas that provide solutions to the problems found in the research phase. The phase of concept generation shows a bundling of similar or compatible ideas to form concept designs, these concepts are further developed to create several coherent design solutions. Concept evaluation is the next phase in which the concepts are evaluated side by side by experts and the program of demands and wishes. The chosen concept is further developed in the detailing phase where design choices on materials, mechanisms, user aspects and production are further elaborated on. This detailed final concept is transformed into a 3D model for production of the prototype through rapid prototyping. This report is wrapped up with a chapter of conclusions and recommendations where the final design proposal and design process are evaluated and recommendations for further development of the design are described.

To keep the report concise some of the more elaborate parts of the process are kept separate in the appendices.

To allow this report to be used by Cybermind as a reference for the created design this full report is in English, with the exception of the Dutch summary.

2

RESEARCH

INTRODUCTION

The goal of this research phase is to expand the knowledge on the subject on Virtual Reality, Head Mounted Devices and the treatment of burn patients. This will allow the design process to progress in the right directions. It is important to have some knowledge of the concept of virtual reality and burn wounds to be able to design for this goal. Therefore a background analysis will be done on these subjects. This project is about creating a redesign of the current HMD system that better fits the hospital environment and the child burn patients. Therefore knowledge is needed about the characteristics and demands of the user's. In the user analysis the patient will be studied both as a child and a burn patient, the other users will be studied as well. The hospitals restrictions and possibilities will be analyzed to make sure the design will be allowed in the hospital and function effectively here. A large part of this will be hygiene regulations, these will be researched. For a good design the functioning of the components and the connections between each other and with the user should be as effective and efficient as possible. Cybermind provides the VR technology for this product, these components cannot be changed. To be able to create a good casing design knowledge on these components' functions and specifications is important.

This forms the basic research phase that is used in a design process. Before going in to the next phase of idea and concept generation some more design research has been done on user aspects and previous parts of the research phase. Research on modular design has been done as a possible solution to the challenges created by hygiene regulations, in this paragraph it is validated to what extent modularity is fit as a solution to the design problems created by the hospital environment. To create inspiration on the user aspects of the HMD concerning its mounting several other devices from the professional and consumer market have been studied. To create a product that is fit for all concerned users and markets a study on design styles, of product for these users and markets, has been done. This also forms a bridge to the next phase, together with the program of demands and wishes.

The research phase is finalized with a set of demands and wishes for the new HMD casing that has been designed in this project.

2.1 BACKGROUND ANALYSIS

This paragraph describes the main subjects discussed and researched in this project. The basics of these subjects are explained to help with researching and facilitate reading the rest of the report.

2.1.1 VIRTUAL REALITY

Virtual reality (VR) is the creation of a simulated three-dimensional world in which the user is immersed trough visuals and interaction with the environment (Strickland, 2007). The first attempts at VR have been made in the 1960's by Ivan Sutherland with the "ultimate display". This display has guided most of the developments on VR to how it is described today. His system was mostly used for vehicle simulations by the military, NASA and airlines (Strickland, 2007).
Immersion for the user is the goal of VR. Immersion is the feeling of being inside or part of a world, combined with interaction this is called telepresence. Computer scientist Jonathan Steuer proposed depth and breadth of information as the two main components of immersion.
Depth refers to the quality of the information the user receives, i.e. the pixel density of a display. Breadth defines the number of sensory dimensions simultaneously presented, i.e. only visuals or also the sound of the environment. VR systems that incorporate sense of touch and give force feedback to the user are called haptic systems.
Another part of immersion is being unaware of the real world; therefore the user should be able to interact with the virtual environment without hindrance by the real world. For effective the interaction with the virtual environment the user should not experience any latency between physical input; movements of the user, and virtual output. Also the display's frame rate should be at least 20-30 fps for a convincing experience.
In project Morpheus Sony has setup six elements that a VR system needs to achieve (tele)presence: Sight, sound, tracking, control, ease of use and content.
VR can be achieved with a wide range of hardware; the most common is a head mounted display (HMD), often in combination with other hardware; in this project a HMD is used.

2.1.2 HEAD MOUNTED DISPLAYS

A head mounted display is exactly what it says; one or multiple displays that are mounted on the user's head close to the eyes to fill the user's field of view (FOV) as much as possible with the display, creating immersion. LCD or OLED displays are the most common technology used in HMD's today. Using one display for each eye creates an illusion of depth. These displays preferably have a high pixel density for more realism. The current Cybermind HMD uses this principle. For different users interpupilary distance (IPD) and focal length, of the optics used with the displays, are important settings. IPD is used to adapt for differences in distance between pupils of different users. Without variable focal length users with glasses would have to wear these with the HMD.

2.1.3 BURN TREATMENT AND REHABILITATION

Burn wounds are among the most severe and painful wounds in the medical world. The rehabilitation process is also very painful. Patients with burn wounds often suffer from both physical and psychological trauma due to by the burning. The life quality of a burn victim can be greatly reduced because of the many physical complications that can occur with burns, mainly because of pruritus (Willebrand et. al 2004). Treatment is therefore necessary and since the treatment is very painful, pain management is very important. By reducing pain during the treatment the patient can be more effectively treated. In this project VR is used because its analgesic effect lowers the pain levels for the patient during the treatment.

2.2 USER ANALYSIS

The users of the HMD are children who are hospital patients, the design aspects that have to be taken into account because of this are described below.

2.2.2 DESIGN GUIDELINES

The users of the HMD are children who are hospital patients, the design aspects that have to be taken into account because of this are described below.

Children

The first aspect to take into account when designing for children is the body dimensions; children have smaller heads and different proportions than adults, therefore standard devices might not be fit for use by children. Children have less strength and smaller hands than adults, this reduces their ability to grasp, hold and manipulate objects compared to adults. These limitations should be taken into account in the design. For very young children, below 7 years (Brooks, 2012) (Steenbekkers, 1993), the cognitive skills differ very much from adults, the children might not immediately understand what the purpose of the HMD is and how to deal with it, lack of experience also plays a role here. Human machine interaction should therefore be as simple and intuitive as possible. The third aspect to designing for children is the physical appearance of the products they are used to. Children's toys are often more colorful, playful and have a more simple design. In paragraph 9 a children's products collage is shown. It should be noted that it is not the intention to create a product that looks like a children's toy because this would degrade the quality image that Cybermind has and the ability of the hospital personnel to work with the device. The product will have a friendly design that children will feel comfortable around.

Burn patients
Being burned often traumatizes burn patients. It is important that this mental trauma is taken into account in the treatment procedure. Physical trauma can limit the patient's freedom of motion, with burned hands also the ability to use the hands. This can make it difficult to put on the HMD; this should also be taken into account in the design process. The HMD cannot be used by patients with burns on the head because of the pain and the impossibility to treat the head when wearing the HMD.

2.2.3 CONCLUSION
The user as child and burn patient bring quite a few important design aspects to the table. Smaller body dimensions and limited physical capabilities; strength and range of motion, compared to adults a big part of this. Children below 7 years old have significantly less cognitive skills as well, therefore human machine interaction should be as simple and intuitive as possible. To make the children feel comfortable the device should have an intuitive, non-intimidating, child friendly design.

2.3 STAKEHOLDER ANALYSIS

2.3.1 STAKEHOLDERS

Patient
The patient has been hospitalized for treatment of burns to aid the healing process and prevent infections. Because treatment is very painful VR is used to achieve analgesia. Although the VR treatment is not addictive, contrary to opioids, the patient experiences more pain under VR than with opioids. Therefore the patient has a strong interest in a VR system with a maximized effectiveness to achieve the benefits of the opioids without the drawback of addiction. In this project the patient is a child who might be extra sensitive to stimuli and changes because of the traumatizing experience of being burned. Therefore it is important that the system adds a minimal amount of stress to the standard treatment procedure. Optimal would be for the patient to experience less stress in a VR treatment than a treatment without VR. Some treatments may need the patient to move; therefore the HMD should not restrict the user in its freedom of motion.

Practitioner
A nurse, physiotherapist or doctor will perform the treatment; the term practitioner is used as an all-encompassing term for this stakeholder. The treatment could be changing the bandages and washing the wound or stretching the burned skin by doing movement exercises; this prevents infection of the wound and stops the skin from becoming hard. Often there is only one practitioner performing the treatment. During the treatment the practitioner should keep an eye on the status of the patient, considering the analgesic effects of the VR game. By changing variables of the game the practitioner can keep the patients pain levels stable. The practitioner has an interest in a system that is easy to use. It is also important for the practitioner to be able to verbally communicate with the patient during the treatment. In case the patient is not able to put on the HMD by himself, the practitioner should be able to do this for the patient. The HMD should therefore give the practitioner a clear view of how the HMD is mounted on the patient's head for an optimal fitting.

Help Brandwonden Kids
The Help Brandwonden Kids foundation is a client of Cybermind. This foundation financially supports the treatment of child burn patients. HBK also gives lectures on safety and prevention of burns. HBK wants a new VR system that has a stronger analgesic effect during the burn treatment and better fits the general demands of the children.

Hospital
The VR system will eventually be used in a hospital; the hospital will buy the system, partly paid by HBK. For the system to work properly in the hospital and not obstruct the other procedures and systems running parallel to it, it is important for the system to be able to be integrated well in the hospital environment.

Stakeholder	Interests
Patient	Comfort Ease of use Freedom of motion Immersion in VR
Practitioner	Ease of use Clear in use
HBK	Analgesic effect Cost
Hospital	Ease of integration Analgesic effect

figure 2.1 stakeholders and interest

2.3.2 CONCLUSION
For the stakeholders in this project to following aspects have to be taken into account. The HMD should not restrict the range of motion of the patient. The practitioner should be able to verbally communicate with the patient during the treatment and have an insight in the mounting and settings of the HMD. A good integration in the hospital is important for optimal efficiency of the treatment and procedures running parallel. ***Figure 2.1*** gives and overview of all the stakeholders and their interests.

2.4 USAGE ANALYSIS

SCENARIO

This scenario starts with the patient being in the room where the treatment will take place. First the treatment is setup, depending on the treatment the time required may vary. The treatment setup is mostly equipment needed for treatment; scissors, bandages, cleaning fluids for cleaning the wound and a moveable table to carry this equipment on. When this is all setup next to the patients bed the HMD setup begins. The HMD and externals should already be in the room, ready for use. First the VR system is placed next to the bed. The HMD will be mounted on the patients' head; settings of the HMD are changed, preferably before mounting the device. The mounting and functioning of the VR system is checked by the patient and practitioner, if all is correct the VR system can be switched on and the treatment can begin.
During the treatment the patient plays a video game using the HMD and an external clicker. At the same time the practitioner performs the treatment on the patient; replacing the bandages or performing physical exercises on the patient. The treatments last around 15 minutes. At the end of the treatment the HMD is taken off by the patient and practitioner. The patient is now finished using the HMD. The practitioner will clean the HMD or replace/remove contaminated parts. The treatment equipment and the VR system are cleared away and the patient is taken back to its room.

CONCLUSION

The required functions in the redesigned casing from a user point of view mainly concern the required steps for setting up the device. As said in the previous paragraph the practitioner should have an insight in the settings of the HDM, the settings that can be made are IPD, focal length, placement of the speakers and the mounting of the HMD. These should be variable in the range of body dimensions of the patients; these are quantified in the PoD. For user comfort these settings should be variable with very little effort of the user. Correctly setting the mounting of the HMD prevents it from moving around relative to the user's head during treatment. User comfort is very important in the immersion, therefore the HMD has a distributed load on the least sensitive and strongest points on the head, with this the patient should be able to wear the HMD comfortably for the duration of the treatment; ca. 15 minutes.

2.5 SETTING ANALYSIS

The setting of VR system will be a hospital treatment room, this poses many regulations and challenges to the design of the VR system. This analysis has been made to set up a list of characteristics and demands from the environment.

2.5.1 HYGIENE

Hospitals have many regulations concerning hygiene. Because the treatment involves working with open wounds the strictest regulations apply. These regulations are described in the next paragraphs.

Disinfection

The settings hygiene regulations are comparable to an IC or endoscopy room. This means that surfaces, furniture and utensils need disinfection against vegetative bacteria, yeast and, in case of contamination with blood, also against viruses. A common disinfectant used in hospitals is 70% ethanol; this kills yeast and most vegetative bacteria within 10 seconds and both lipophilic and hydrophilic viruses within 1 minute. In preparation to sterilization an instrument-washing-machine can be used to kill a large part of the micro-organisms beforehand, this replaces the use of ethanol but takes more time. These machines usually work in a range from 60°C to 100°C (Hoge Gezondheidsraad 2009). The ethanol disinfection is often done manually with a cleaning cloth; to make sure this is done properly it is important that HMD is easy to clean. The casing redesign could therefore be designed to minimize hard to reach spots; seams and connection points. (Werkgroep Infectiepreventie, 2009).

Sterilization

The preferred method of sterilization in hospitals is with moist heat; steam. The maximum temperature is reached in an overkill procedure; 134°C. The material used in the HMD should be able to cope with this temperature for a period of more than 3 minutes; the process' duration. The goal of this process is sterility; to kill or deactivate all microorganisms to a max chance of a microorganism per unit = 1/106). Only the parts of the HMD that make direct contact with the patients skin need to be sterilized, it is therefore useful to make these parts easy to clean or disposable. Making the HMD water-resistant would mean that it can be put in the sterilization washer. Another option is to make components that need sterilization detachable so they can be sterilized separately (Werkgroep Infectiepreventie, 2009).

The chosen material for the casing has to cope with these high temperatures, or be sterilized with other methods like EO gas or radiation sterilization; however steam sterilization is preferable because of the low environmental impact compared to the other two methods. High density PE and PET are materials used in biomedical appliances, they have no medical toxicity drawback and have sufficient melting temperatures making them useful for the steam sterilization process (Ratner et. Al 2004). PE and PET are widely used in products on the consumer market although mostly in film or low thickness forms. (CES 2014) Further research on the required material for the casing and contact points with the patient has to be done but PE and PET are possible materials. It is important to note that the internals are not fit for steam sterilization a solution to the sterilization or cleaning procedure in general should be found.

2.5.2 CONCLUSION

In the hospital environment hygiene is very important. The treatment room has an IC level hygiene regulations, therefore the product will be cleaned with cleaning cloths containing 70% ethanol. Sterilization is also used but only on parts that make direct contact with the patient. Sterilization occurs at 134°C in a medical washing machine. High density PE and PET are the recommended materials for the casing in these situations. The parts that need cleaning should have a minimal amount of hard to reach places like seams and holes to facilitate the cleaning process. Although sterilization is a preferred method of cleaning due to its effectiveness it takes much more time and energy than disinfection and is therefore not applied unless absolutely necessary, this applies to the Leuven hospital, whether this is also the case for other hospitals is not known.

2.6 FUNCTION ANALYSIS

2.6.1 COMPONENTS

The HMD's components functionalities and characteristics are explained in this paragraph. In the section 'external' the remaining functions of the VR system are explained to complete the overview of the total VR system. Some of these parts are confidential, descriptions of these parts can be found in **Confidential appendix A**.

Audio

The audio devices create the sound that helps the patient be more immersed in the game. They are low power speakers comparable to those in a headphone. The speakers receive their input signals from the electronics and indirectly the external components. The speakers are disks that need to be placed flat to the user's ears. ***Figure 2.2***

Motion tracker

To create a stronger feeling of immersion a tracking system is used to link the head movements of the patient to the movements of the character in the game. An accelerometer, a magnetic field sensor and gyroscopes are used for this. For a more accurate measurement the sensor should move as much in sync with the patient's head as possible. The sensor has an operating temperature of 0° to 50° C and a size of 36.6 mm x 27.7 mm x 13.8 mm (InterSense). to facilitate calibration and reduce the chance of errors the motion tracker should be place parallel to the direction the user's face is pointing. ***Figure 2.3***

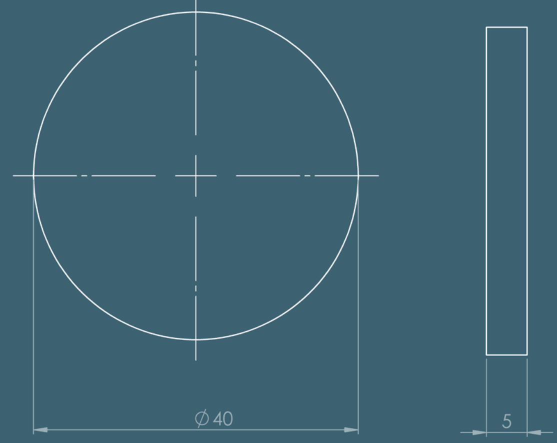


figure 2.2 Speakers

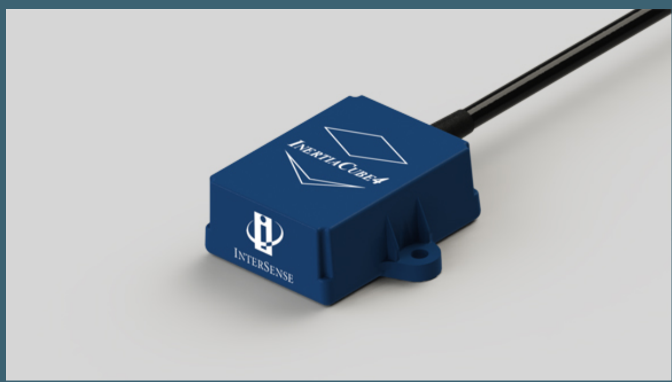


figure 2.3 InterSense Inertiacube4

Settings mechanisms
There is a minimum of settings that the HMD should have. The patient should be able to adjust the strap/mounting of the HMD, the IPD for the optics and displays, and the focal length of the optics. For more comfort a possible setting could be the choice between headphones or earphones and the placement of these. To keep the size of the HMD down it is important that these mechanisms are kept as compact as possible. Possible design solutions for these mechanisms are discussed in paragraph 8.

Casing
All of the previously mentioned components are held together inside the casing. The casing provides the structural strength of the HMD and gives it its shape and esthetics. Within this project a redesign of the Visette 45 SXGA will be made that is optimized for the current internal components. The casing should have an exterior that invites the patient to put the HMD on and guides the patient through setting up the HMD according to his or hers personal preferences. The patient should be able to set up the HMD so the patient can't see outside the HMD and minimize hearing sounds from the surroundings.
The current casing cannot easily be taken apart; for the purpose of hygiene a modular design of the casing will be researched in paragraph 9 of this chapter, this part of the research is a request from Cybermind. Balance and comfort are very important to the strength of the immersion, these aspects will be studied in the design process.

Externals
All of the other components of the VR system are named as external. A Microsoft surface pro 2 tablet runs the VR game and displays the user interface for the practitioner to monitor and alter the VR world as seen by the patient. An external battery forms the power source for the VR system, because of hospital regulations a battery is used instead of a power plug, making the system wireless. A bundled cable transfers power and data between the Externals and the HMD. The placement and design of the connection between the HMD and the Externals could be a large obstruction in the freedom of motion of the patient. Keeping this cable out of the way is therefore a point of interest. The user plays the game with a mouse or clicker as a trigger to shoot, if this component is not wireless it might be wise to attach the cable to the HMD to keep the VR system more compact.

2.6.2 USERS
Patient
The main function of the HMD is to create an immersive VR experience for the patient; this function can be split up in several sub-functions according to the different aspects that create the immersive experience. The main aspect of the VR experience is the visuals that the patient perceives. The HMD shows the patient an image of a virtual world. This immersion can easily be broken by the patient when he/she moves because then a latency between the real world and the virtual world becomes clear. To avoid this problem the HMD registers the movements of the patient's head and translates this to movements of the character in the VR world. The patient now perceives an image that corresponds with what the brain expects to see when it moves only the image is still only in 2D. Therefore the HMD shows a different image to each eye to create an illusion of depth, creating a seemingly 3D VR world. With the correct settings the patient should now see quite a convincing VR world through the HMD, because not all patients are the same these settings will be variable. The HMD allows the patient to change the IPD of the optics and the focal length of the lenses.
These functions cover all the visual aspects of the HMD. Another part of the immersion provided by the HMD is audio, corresponding with the VR world. The HMD has stereo sound to give the patient a sense of 3D sound. Just like the optics settings, not all patients have the same demands for audio. The HMD allows the patient to change the audio volume and the placement of the speakers.
With the imaging and audio covered the patient has an optimal experience of the VR world, however to prevent the immersion from being broken by distractions from the real world there are a number of functionalities. To make sure the HMD fits correctly on the patient's head and stays there the mounting of the HMD can be adjusted and secured by the patient according to its demands. The mounting is also strong enough to cope with the patient's movements and does not let the HMD slide around when the patient moves. The HMD distributes the physical load over the patient's head taking pressure away from the nose and focusing on the forehead and back of the head because these points can take the most pressure. The HMD does not limit the patient in the movements that have to be made during the treatment or within the VR world. The HMD minimizes any reduction in comfort experienced when the patients leans his/her back of the head against any surface; most commonly a pillow or mattress.
The design has to be created with design limitations of the child user in mind. To make sure the device does not intimidate the patient and possibly scares the patient away from using the HMD, it has a non-intimidating child friendly design, the design of the HMD makes the patient understand how to put it on and how to use it. This can be achieved by the esthetics of the HMD and ergonomics; i.e. general shape and use of color, button placement and apparent complexity. This is expanded on in paragraph 11.

Practitioner
On the side of the practitioner there are also several functions the HMD must fulfill. Most of these have to do with hygiene and cleaning the device. Because of hospital regulations the HMD must be disinfected and sterilized according to the regulations that apply to IC hospital equipment. As was stated before in the setting analysis the HMD or parts of the HMD must resist 70% ethanol and water temperatures of 134°C. The parts that need manual cleaning have a minimal amount of hard to reach places

like seams and holes to facilitate the cleaning process and decrease the chance of infections, or can be detached for easier cleaning. Besides the hygiene the HMD should also give the practitioner feedback on the quality of the fitting of the devices on the user's head.

2.6.3 CONCLUSION

The technology inside the HMD creates immersion through stereoscopic images, 3D sound and head tracking. The settings functions named in the usage analysis will be for the mechanisms inside the casing and the casing itself; these settings allow the immersion to be maximized. The previously described functions for hygiene will mostly apply to the casing and mechanisms. An overview of the components and their relations can be found in ***Confidential appendix B***.

2.7 PRODUCTION

Although the design to be created in this project is not a production ready product it is useful to take a look at production and manufacturing. This project will produce a prototype of the new Cybermind HMD that is functional and can be used for user testing. To keep the cost down but not reduce the quality of the product, both functionally and esthetically, the preferred production method is 3D printing. The exact method will be determined later in the process dependent on the characteristics of the final concept. When creating a product for 3D printing it is important to take in mind the limitations of the materials that can be used, 3D printed materials can be of comparable strength to their basic material counterparts. However not all materials can be 3D printed and this may conflict with the preferable material for the functional purposes of the design. The materials named in paragraph 5.2; PE and PET are preferable for their applications in the biomedical world. Both of these materials have been proven to be useful in 3D printing (Whiteclouds),(Giugno 15, 2013). In a later phase of the design process the materials should also be examined from a hygiene perspective. The available materials might not all be suitable for the chemicals used in the hospital cleaning procedure.

The production numbers for this product will be very low; the current Visette is produced at 15 units per year, due to a low number of customers. Therefore 3D printing is a possible production method for the final product. 3D printing is mostly limited by wall-thickness, depending on the production method different wall-thicknesses can be achieved, with 0,3mm being the minimum using Laser sintering (William). It is also important to notice the different levels of quality with different printing methods, with laser sintering accuracy in very small geometries may go lost with increasing wall thicknesses. With fused filament printing this problem does not occur.

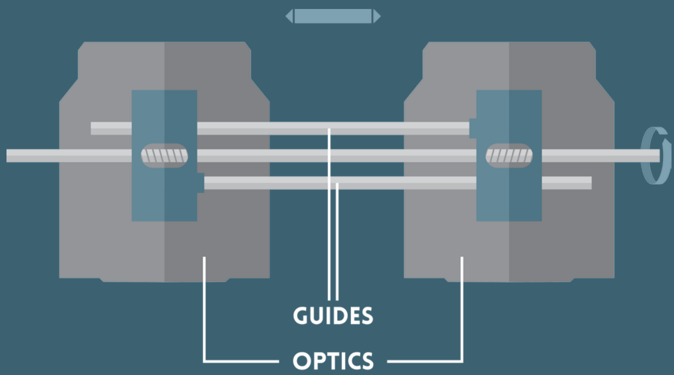


figure 2.4a IPD mechanism Cybermind Visette

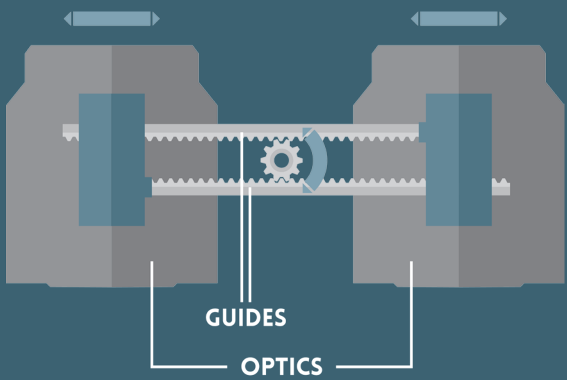


figure 2.4b IPD mechanism Sony Morpheus

figure 2.5 Speaker adjustment mechanism

2.8 IPD MEASURING AND SETTING

In ***figure 2.4a*** and ***figure 2.4b*** the current IPD mechanisms for two HMDs are shown, these could be integrated in the HMD redesign but it would be preferable to create an even smaller and simpler mechanism to allow the HMD to become smaller in total. It would be useful for the speed of setting up the system if the HMD could be pre-calibrated, before the treatment starts. Therefore the HMD should allow the practitioner to see the current IPD setting on the HMD and save the preferences of the different patients, this could also be applied to the focal length, speakers and mounting.

The setting mechanism for the focal length has already been developed; this mechanism has been explained in the 'video' part in function analysis. It is important that the practitioner is able to see the focal length setting on the HMD to be able to realize the previously explained idea.

For setting up the audio correctly a widely used adjustment mechanism can be used; ***figure 2.5***. This is a very simple and effective mechanism that keeps the speakers in the right place while also applying the right amount of pressure to the ears for good isolation. It is important that this mechanism also works within the hospital regulations.

2.9 ANALYSIS MODULAR DESIGN

2.9.1 GOALS

The goal of this project is to design a casing for the HMD that is fit for a variety of patients and allows the practitioners to be able to easily maintain a high level of hygiene for the device. Hygiene will be a key aspect to the final design and for this Cybermind is interested in the possibilities of using modular design as a means of solving the hygiene problem. This is because an advantage has been recognized in the using of modular design regarding the cleaning procedure of the HMD. This paragraph is an elaboration on the previously described research on the setting of the HMD; the hospital room. In this paragraph modular design will be researched as a solution to the hygiene problems faced in this project. Its usefulness will be examined. It should be noted that the modular design intended here is focused on the usage of the product, not manufacturing, assembly, recycling etc.

2.9.2 INDUSTRIAL DESIGN

Depending on the manufacturing capabilities of Cybermind it might be useful to setup a production line for components that need replacing after each treatment; this reduces cleaning time and effort, instead of cleaning the components a new component could be attached to the HMD. The components that need cleaning are the ones that come in direct contact with the patient, this are probably only the possibly soft pads that create comfort. If this is the case it might be feasible to make these replaceable. Although modular design often applies to manufacturing purposes there are quite a lot of products available that are modular for their usage, though no guidelines are available on this subject. This paragraph serves as a source of inspiration on modular industrial design.

Often modular industrial design is used to allow expansion of products, like furniture systems (Mocoba®) ***figure 2.6***, these systems often are one or several basic parts that can be repeated infinitely to create large and diverse products. Modularity can also be used to make components interchangeable a great example of this is the Motorola Ara "Phone blocks" project (Google, 2014) ***figure 2.7***. Here a phone is build up from interchangeable parts, allowing the user to compose the perfect phone for its demands at that moment and to change it when the demand changes. Each module has a function, such as CPU or camera but the modules specifications may vary.
In this project modularity could be used to facilitate the cleaning of the device or maybe even the setting up of the device; IPD (Parker), focal length etc. To facilitate the first time setting up of the device it might be useful to "build" the device around the user's head and saving the settings for a later time.
Removability or maybe interchangeability of components that need cleaning could therefore be useful. These components should be removable with ease but still conform to the hygiene regulations and demands of the hospital. Magnets would provide a good solution for this but cannot be used, due to the sensitivity of the head tracking device. Also things like Velcro or hooks, latches etc. are not preferable due to their complicated geometry which makes cleaning difficult. For this a solution has to be found in the next phase. An example of modularity with hygiene in mind is the Thermoscan® by Braun ***figure 2.8***. This is a thermometer for use in patients' ears, it has a plastic cover over the parts that goes inside the ear, this cover can be placed and removed without touching it ***figure 2.8*** (Braun). It uses a click connection that can be released by pressing a button on the device.

9.3 CONCLUSION
In the design process that follows this research phase the focus should lie on creating a product that has interchangeable components to improve hygiene and ease of use. For this inspiration can be taken from the products named in the previous paragraph.
Although the focus of this project is not on manufacturing it is important to keep this in mind when looking at modular design because design choices made on this subject can greatly influence the cost and complexity of the manufacturing process. Therefore several guidelines, methodologies and principles should be taken into account ***Appendix A***.

figure 2.6 Mocoba modular furniture systems

figure 2.7 Motorla Ara modular cellphone concept

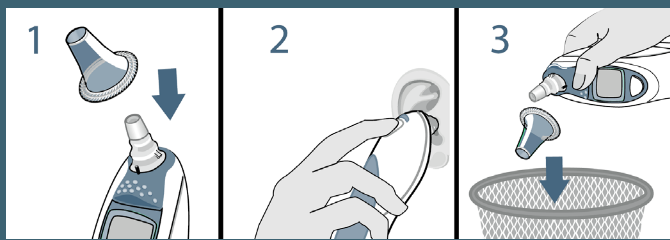


figure 2.8 Braun Thermoscan usage scenario

2.10 HMD MOUNTING ANALYSIS

In this paragraph further research on usage aspects concerning the mounting of the HMD has been done. Technologies are not the subject here. A look will be taken at the consumer market and the professional market. Expect for the nVis all of the products below are still in development, therefore their design might still change.

2.10.1 CONSUMER PRODUCTS

Oculus Dk2

The Oculus Development Kit 2 (DK2) ***figure 2.9*** is a VR platform mainly aimed at the gaming industry, this will rarely require the user to move while using the HMD. The internal technologies are very high end while the mounting is very simple. The inside looks like a ski goggle with foam padding going all the way around the face ***figure 2.10***. This allows for great exclusion from the real world and a comfortable wear, the nosepiece is not padded and seems to be an uncomfortable pressure point, assuming that it touches the nose. A very simple adjustable strap goes over and around the sides of the head. This keeps the HMD in place but because all the weight is at the front, this device is unbalanced, making it less comfortable. The DK2 provides a wide IPD range instead of an actual setting.
The Oculus DK2 is not wireless and does not have integrated audio.

figure 2.9 Oculus Development Kit 2

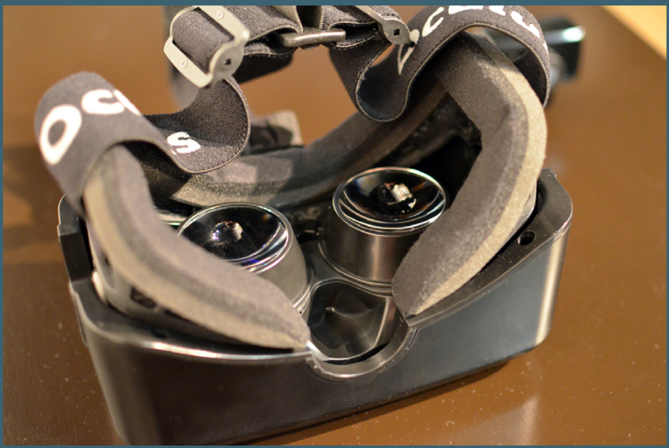


figure 2.10 Oculus Development Kit 2 inside

Sony Morpheus

The Morpheus, also intended for gaming has a more innovative mounting. A flexible material is used to seal the face, it encloses the entire FOV. The Electronics are hung on a solid headband that rests on the forehead and the lower back of the head just above the neck; this provides a strong mounting on the head ***figure 2.11***. Pressure is taken away from the nose and moved to the points that are stronger and less sensitive ***figure 2.12***. The Morpheus is not wireless and does not have integrated audio. .

figure 2.11 Sony Morpheus

figure 2.12 Sony Morpheus inside

Avagant glyph

The Glyph by Avagant is an HMD designed for a VR multimedia experience ***figure 2.13***. The mounting of the Glyph is very simple; it hangs on the ears like a pair of headphones and rests on the nose like a pair of glasses. While the device is rather light and small the weight on the nose can become uncomfortable. The Glyph not meant for the full immersive experience of gaming HMD's, the view of the user is therefore not sealed from the outside world. The Glyph is not wireless but does have integrated audio.

2.10.2 PROFESSIONAL MARKET

Sensics piSight

Sensics Inc. is a HMD company that specializes in panoramic HMD's. Sensics has a wide range of corporate customers in government, defense and academic research applications. It has a number of products in these categories. Concept designs have been released on the mounting of the pSight; ***Figure 2.14*** this complex mechanism seems to be variable and allows the user to firmly fix the HMD on its head and blocking out light from the surroundings with a soft enclosure. Though this mounting seems very strong and balanced the large knob on the backside would be very unpractical in this project's application. The piSight is not wireless and does not have integrated audio.

nVis nVisor SX111

nVis is a manufacturer of VR displays meant for training, simulation and research applications around the world (nVis, 2013). nVis provides a range of products in the categories head mounted displays, helmet mounted displays, binocular hand-held displays and simulated military devices. nVis has one VR head mounted display, called the nVisor SX111. Compared to the previously described devices it has a more basic mounting design ***figure 2.15***. The optics are separated from each other but can be adjusted for IPD. The optics are attached to the casing which goes around the head with a rigid band and a strap going over the top. It has a very basic and rugged design. Although esthetically it might not be fit for children the basic design might be useful for modular construction of the HMD. The nVisor is not wireless and does not have integrated audio.

2.10.3 CONCLUSION

Although there are much alternatives for the products developed by Cybermind the company defines itself as a developer for the professional market, explicitly not the consumer market. Cybermind provides solutions fit for very specific situations with high quality components. Because of the very specific development the Cybermind products are more expensive than their consumer market counterparts and better fit the demands of the customer. Much inspiration can be taken from the products described above on the user aspects of the product that is to be designed in this project.

The companies from the professional market; Sensics and nVis work in the same markets as Cybermind, they have the expertise and resources to make products for the intended use in this project. While these companies do not form direct competition in this project it is useful to look at their designs for inspiration on the mounting of the HMD and other usage aspects.

figure 2.13 Avagant Glyph

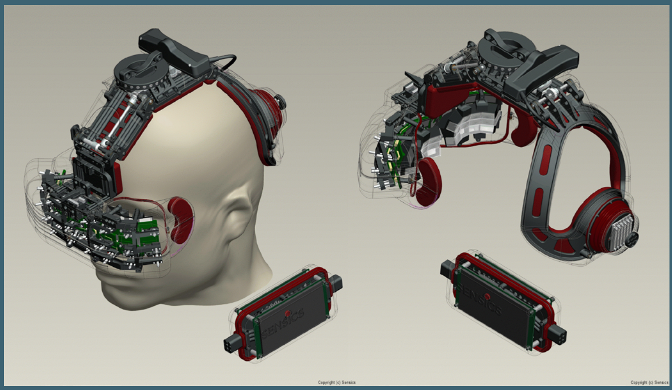


figure 2.14 Sensics piSight

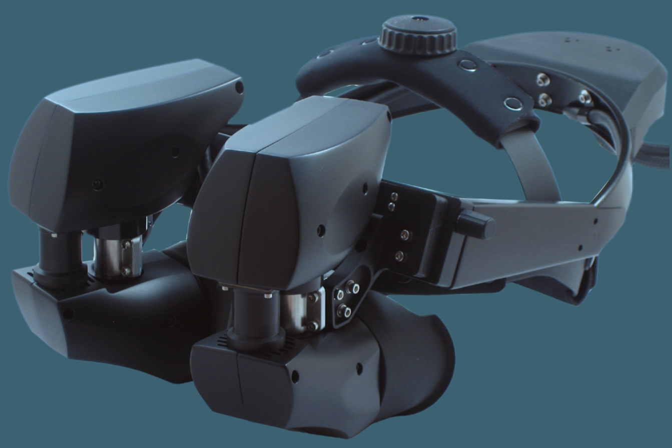


figure 2.15 nVis nVisor SX111

figure 2.16 collage of medical devices

figure 2.17 collage of HMD devices

2.12 DESIGN & STYLE ANALYSIS

2.12.1 MEDICAL DEVICES

A collage has been made to capture the design characteristics of medical devices. These devices can often be described using the words in the collage. For its need for a high level of usability these devices typically have a clean design with white or light grey as a base color and relatively bright colors, preferably a shade of red blue or green. These indicate points of interest such as the base of a devices, displays, buttons, switches, connectors etc. the design is often kept simple to promote the usability. Another factor is mobility; most devices should be mobile to be able to keep them near the patient or because it might be needed somewhere else. For this medical devices are either easily carried by hospital personnel or can be attached to or placed on a movable object, such as a cart or IV pole. ***figure 2.16***.

2.12.2 VIRTUAL REALITY DEVICES

Above several successful HMD's designs are shown. From the style perspective it is clear that black, white and blue are popular base colors for these kinds of devices. The devices often have a simple and rather directional design that implies the intended usage. Most likely due to technological reasons most of the devices have an apparent weight in the front. There are some notable differences in the sizes of the devices; the bigger devices often have a tracking system or a stronger immersion compared to the smaller devices.

From an ergonomics standpoint the devices above also provide a wide range of solutions. Most devices are mounted to the head with straps going around, this can be a simple and effective solution in a lightweight system. However, heavier devices might need more compensation for the weight in the front, to relieve the pressure from the nose. The Sony HMD's both have a strap that goes around the lower back of the head to maintain balance and a soft pad above the displays to move the pressure from the nose to the forehead. The seemingly bulky headphone from Avagant has an apparent weight on the ears and nose, which means it would most likely be very light to assure comfort. Lastly, Sensics' Smart Goggles distribute the load over the top and back of the head with an innovative but rather bulky mounting. One of their earlier concepts contained a complex variable mounting system to firmly fix the HMD to the user's head. ***figure 2.17***.

figure 2.18 collage of childrens´ products

figure 2.19 collage of medical devices for children

2.12.3 CHILDREN'S TOYS

Because the primary users are children a collage of children's products has been made, mostly toys. What is clear are bright colors and more exaggerated shapes that make the products more attractive to children, this might also help them distinguish between objects because of the high color contrast. ***figure 2.18***.

2.12.4 MEDICAL DEVICES FOR CHILDREN

To connect the design aspects of children's products to those of medical devices a collage has been made on medical devices for children. This collage shows a combination of the design aspects that have been deducted from the related collages. Medical devices aimed at children are often modified in dimensions and proportions to make them fit the children better and make them more likable by children; smaller and lighter devices, softer / rounder shapes, oversized components of interaction and a simple instructive design. The same color scheme as used in medical devices can be applied here; children require an instructive device that also displays a certain playfulness. Therefore a white or light gray base color with a contrasting color on interaction components. A good example is the Kitten scanner by Philips; this is a child sized CT/MRI scanner that teaches children the CT or MRI procedure on their own level. ***figure 2.19***

2.12.4 CONCLUSION

The collages provide a set of guidelines and characteristics on designing for the different users and markets. For the medical world a simple, clean and light design with color accentuations; preferably red, green or blue, on points of interaction is useful for the needed high level of usability. Mobility is also important in also for the sake of usability. VR devices often come in black white and blue as base colors, a simple and directional design is common and indicates the intended usage. Size often goes hand in hand with more depth and breadth of immersion. Possible mounting solutions are varied; this is elaborated on in paragraph 9.

Children's products tend to be very colorful and high in contrast, the shapes are often exaggerated compared to reality, and this gives them a cheerful look and helps with the interaction.

In medical products for children the previously named characteristics are combined. These products are often smaller, softer and more rounded versions of their adult counterparts, they have the same color schema as medical devices, this and oversized interaction components create a simple and instructive design.

2.13 PROGRAM OF DEMANDS AND WISHES

All of the functions listed throughout the research phase are put in the program of demands and wishes (PoD). These functions have been converted to demands and wishes, not all demands are paired with a wish. Although all demands need to be met for the optimized functioning of the final product not all demands are needed for the minimal functioning and some demands have a greater influence on the design aspects and functioning of the final product. To quantify this difference in importance the demands and wishes are weighed on a scale of 1 to 5. This produces a balanced PoD, which is necessary when evaluating the concepts at the end of the concept phase. Because most of the internal components of the HMD and all of the externals are not to be changed, the PoD mainly refers to the functions of the casing that is to be designed. Quantitative demands have been determined using the sources in the PoD. ***Figure 2.20*** gives a short overview of the most important design demands in the PoD. The full PoD can be found in ***Appendix B***.

PROGRAM OF DEMANDS AND WISHES

Demand	Weight
End usage	
The load of the HMD is distributed over points on the head most capable of taking loads	5
The HMD has contact points with the head that are comfortable to the wearer	4
The points of interaction (buttens, knobs etc.) must be clearly indicated on the device using a contrast in shape, color or material	3
The esthetic design is simple and has minimal distracting features such as complex shapes and buttons/knobs	3
The HMD shows the settings values to the practitioner	3
Integration of the HMD in the hospital environment must have no need for changes to the HMD or already present hospital equipment	5
None of the parts of the HMD that come into contact with the 70% ethanol are damaged by the 70% ethanol	5
All of the parts of the HMD that are manually cleaned are designed with minimal external seams, holes and geometric shapes in which dirt or other particles could get stuck in	4
The parts of the HMD that come in direct contact with the patient must be able to be removed from the device for the cleaning procedure following each treatment	4
The HMD has a minimal number of components that come into direct contact with the patient	3
The parts of the HMD that come in direct contact with the patient must be able to be replaced with new parts	3
The parts of the HMD that come in direct contact with the patient must be able to be mass produced	3
Replacable parts, parts that come in direct contact with the patient, must be very low cost	3
The HMD's center of gravity must be as close as possible to that of the user's head	4
The casing blocks out as much as possible of the user's view of the immediate physical environment	4
The esthetics of the HMD must be congruent with those of the medical devices collage	2
Production	
The casing is fit for 3D printing processes	2
...	...

figure 2.20 overview of PoD

3

IDEATION

INTRODUCTION

In the ideation phase ideas are generated for different aspects of the final design. Ideas on each aspect of the design have been sketched out separately creating a structure of block of sketches concerning one specific aspect. Hygiene, interaction and mounting as well as physical styling and design of the device are important aspects the have been integrated in this phase. By taking sketches from all blocks varying concepts can be created with solutions on all design aspects integrated.

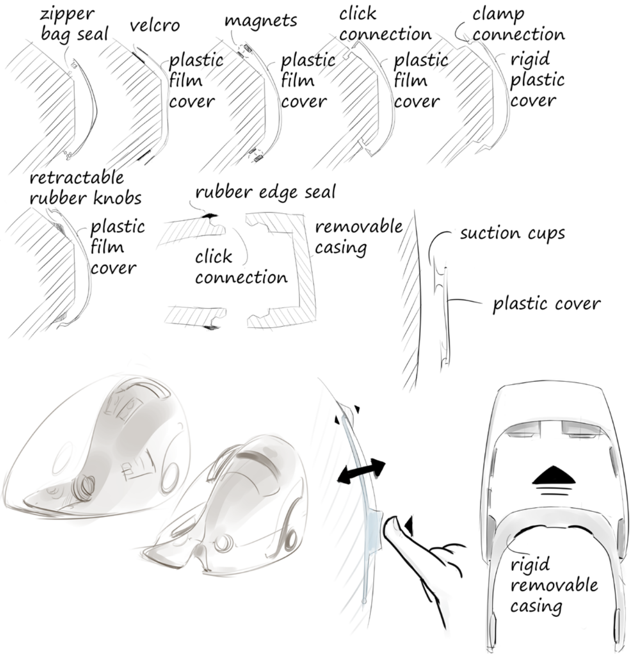


figure 3.1 Sketches of modular connections

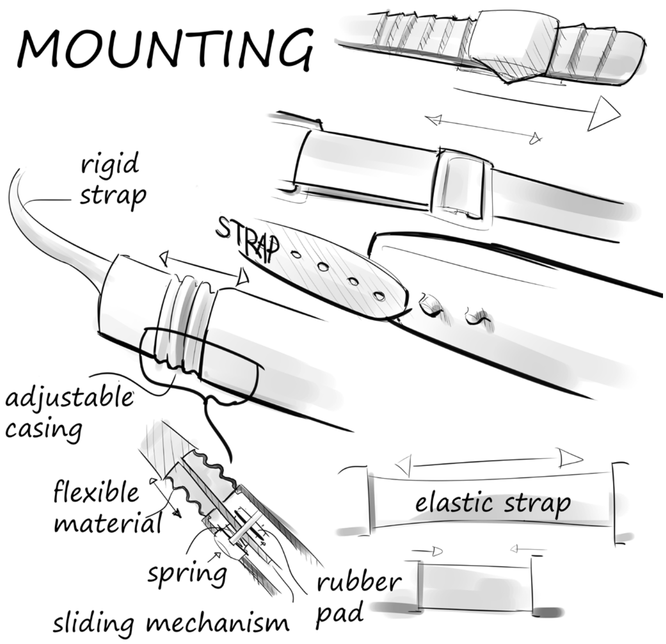


figure 3.2 Sketches of mountign options

Several important aspects of the design have been explored in this ideation phase. A large part of the design will be focused on hygiene.

In ***figure 3.1*** possibilities for using modularity as a solution for hygiene have been explored. Different possibilities of fastening a possible inner casing to the main casing have been sketched. To allow for more inspiration a wide variety of connections has been sketched, some may not be possible or preferable.

Figure 3.2 block shows different methods for fastening or mounting the HMD. Because this is a major obstacle in the Visette SXGA45, the HMD currently used during burn treatment, it is important to find a solution for this part. Again a wide variety of possibilities has been explored, to

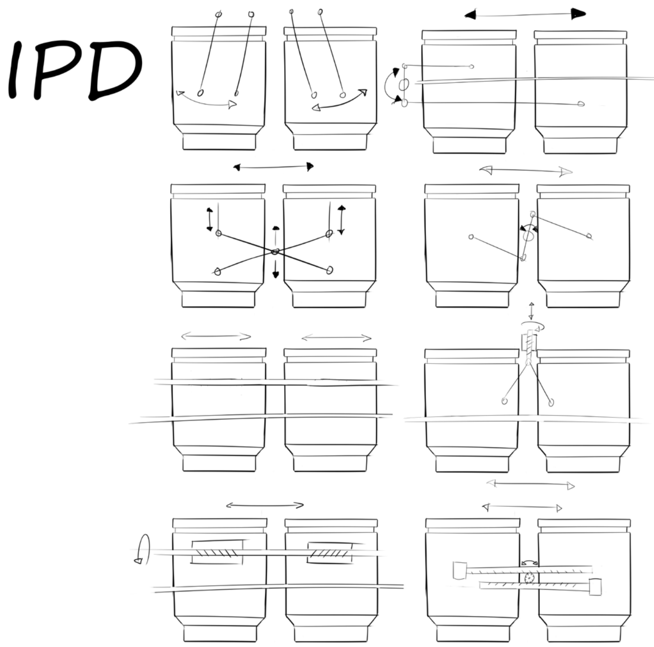


figure 3.3 IPD mechanisms

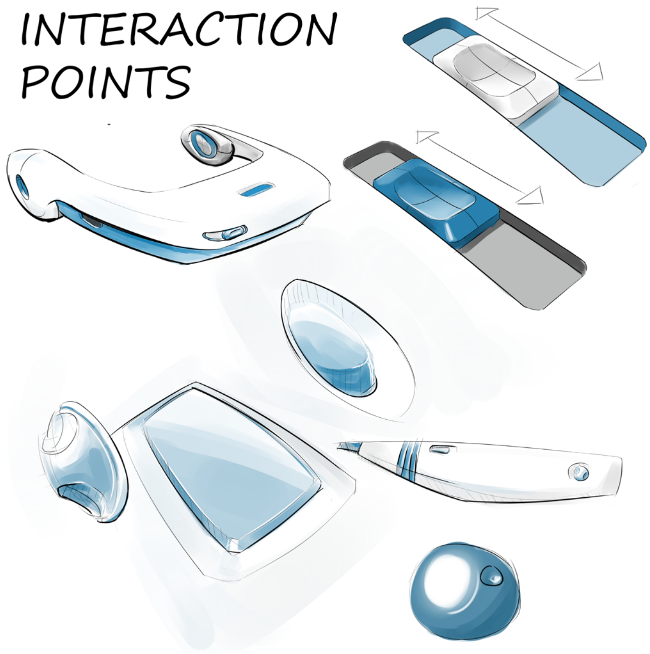


figure 3.4 Shape and color study of points of interaction

create a broad palette of design directions.

Another part of the design is the IPD mechanism; this has been explored in the third block. In the research phase two IPD systems have been looked at, these are both very compact but do still take up a lot or room in the casing. Different mechanisms have been explored for a possible size reduction of the mechanism and for a change in the method of interaction; sliding, turning etc. ***Figure 3.3***.

Because an intuitive interaction with the HMD could help in the effectiveness of the treatment for the patients some possibilities for highlighting interaction points have been explored. These include a variety of ways to accentuate interactive parts using color, shape and placement. ***Figure 3.4***.

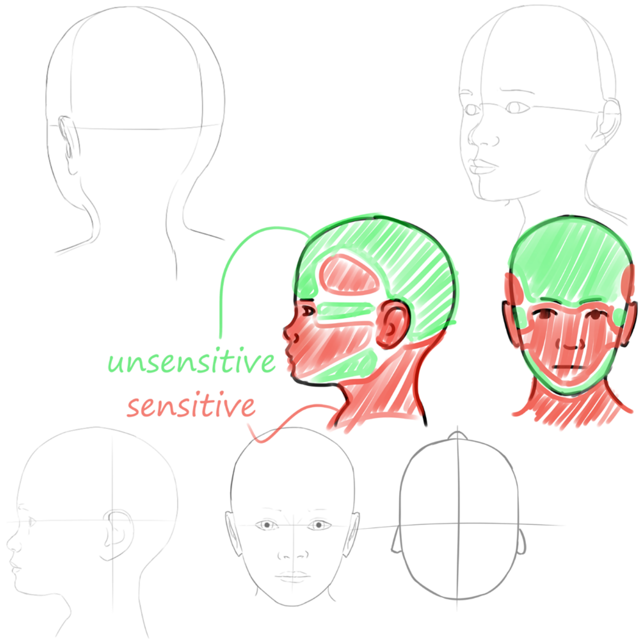


figure 3.5 Sensitiveness of the head

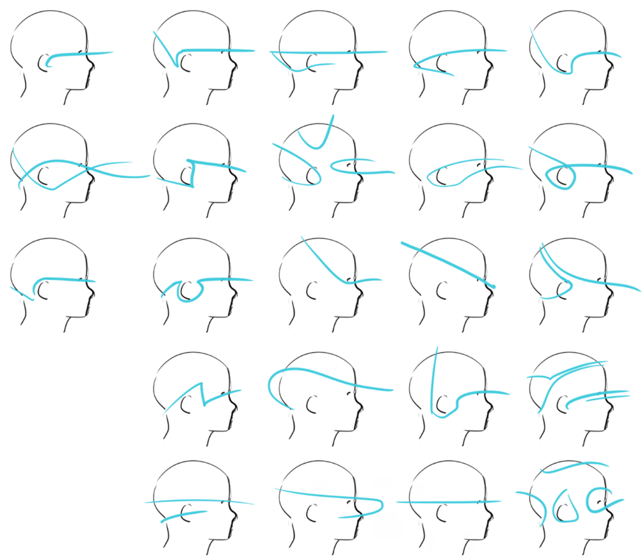


figure 3.6 Abstract sketches of general form

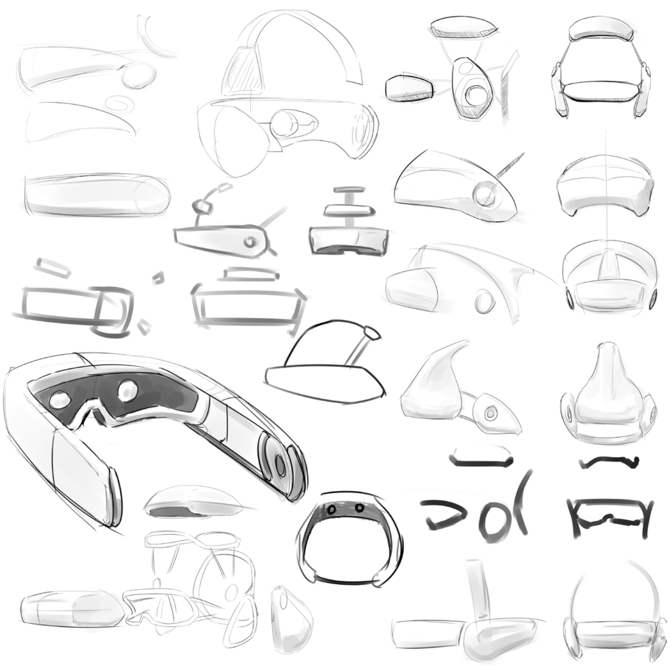


figure 3.7 General Shapes and component distributions #1

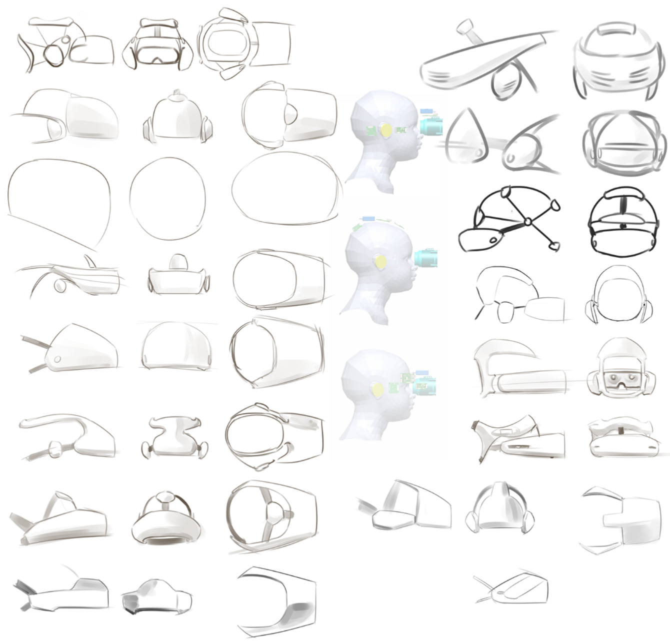


figure 3.8 General Shapes and component distributions #2

The comfort of the HMD could make or break the immersion; therefore a look has been taken at the sensitivity of different points on the head. This results in a distribution of the head in sensitive and insensitive spots on the head. The face, temple and ears are points to avoid. ***Figure 3.5***.

Next an abstract form study has been made on possible distributions of the HMD on the head. This creates a sense of possible general shapes and component distributions around the head. ***Figure 3.6***.

In the next two blocks a number of possible shapes and mountings have been explored on the basis of the previous block and different distributions of the components on a 3D

figure 3.9 Sketches after hospital toys collage

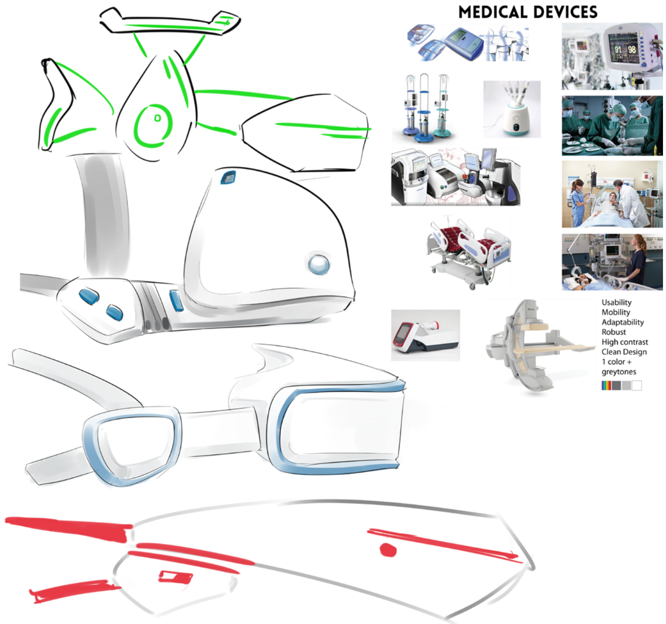


figure 3.10 Sketches after medical devices collage

model. This wide variety of possible mountings and shapes creates a good structure for developing different concepts. ***Figure 3.7*** & ***figure 3.8***.

To create a sense of the design styles for medical devices sketches have been made with the collages from the research phase as a basis. ***Figure 3.9*** & ***figure 3.10***.

4

CONCEPT GENERATION

INTRODUCTION

The goal of this phase is to take the ideas created in the previous chapter and form these into concept designs. The concepts will focus on the problems recognized in the research phase and the demands formed in the PoD. Hygiene and usability are the most important aspects of this redesign. The concepts will be developed to a point where the ideas are transformed in technical mechanisms, systems and principles. Their workings will be explained. The reasoning behind the design choices made in the concepts' development will be explained as well, this concerns both technical and styling aspects. Exact dimensions and parameters of the components will be determined in chapter six; detailing.

Because all concepts have the same basic aspects that have been developed the descriptions of the concepts have the same basic structure. First the concept is introduced with its primary idea or principle. Next the settings of the concept are explained, these are mechanisms and adjustment possibilities. To create a view on the usage aspects of the concept a visual scenario listed for the concept's usage procedure. For production matter a basic idea is given of the used materials through a short explanation. Because hygiene is an important aspect the concept's solution to this problem is also explained. Comfort represents the passive usability of the concept; the reasoning behind this is explained in each concept. The last part is styling, the styling influences the patient's first reaction and impression of the HMD, making this reaction as positive as possible helps the treatment to become more effective.

The concept phase is followed by the concept evaluation where one of the concepts or a combination of aspects of several concepts is chosen for further development in the detailing phase.

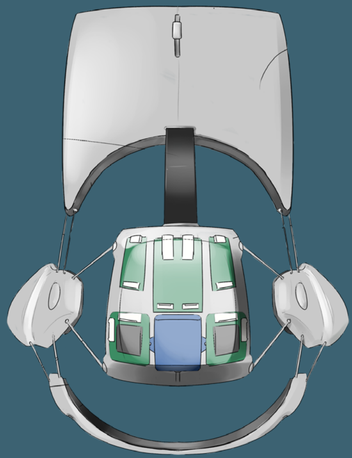


figure 4.1 top view of concept 1

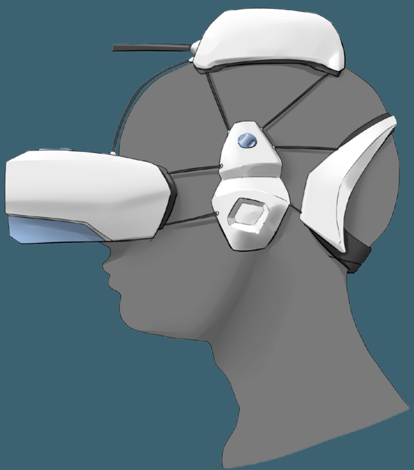


figure 4.2 side view of concept 1

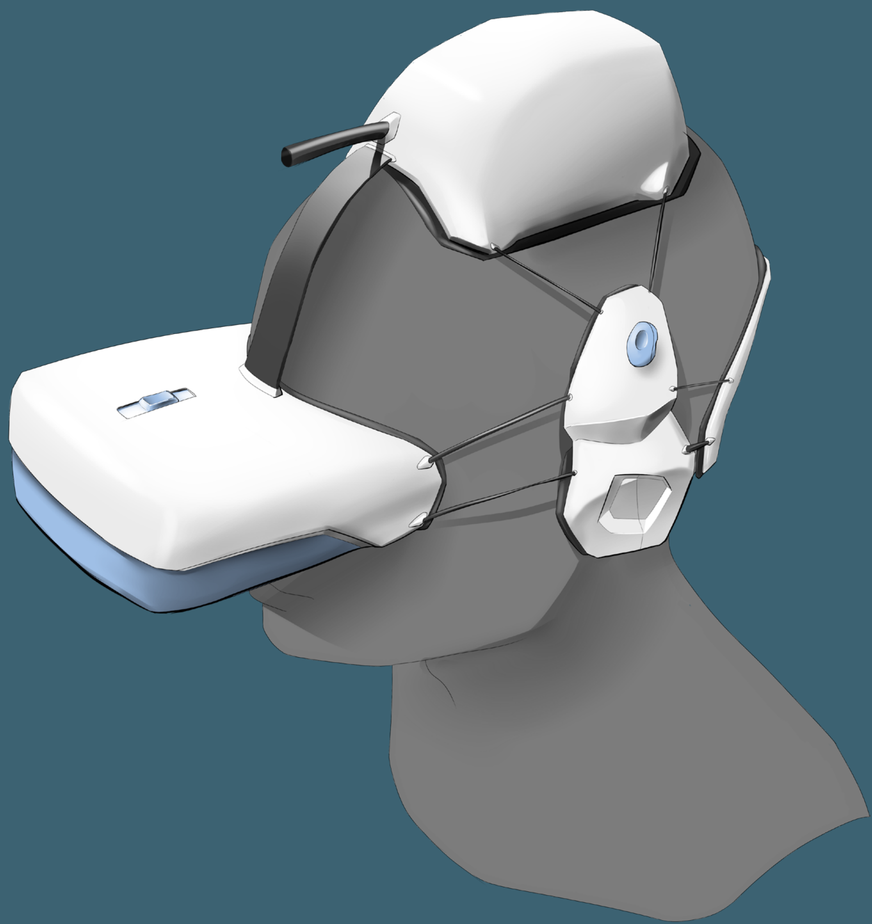


figure 4.3 presentation drawing of concept 1

4.1 CONCEPT #1

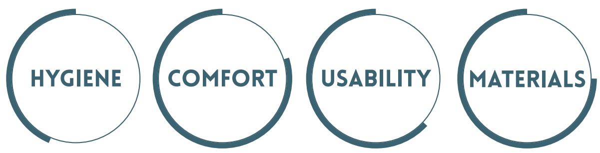
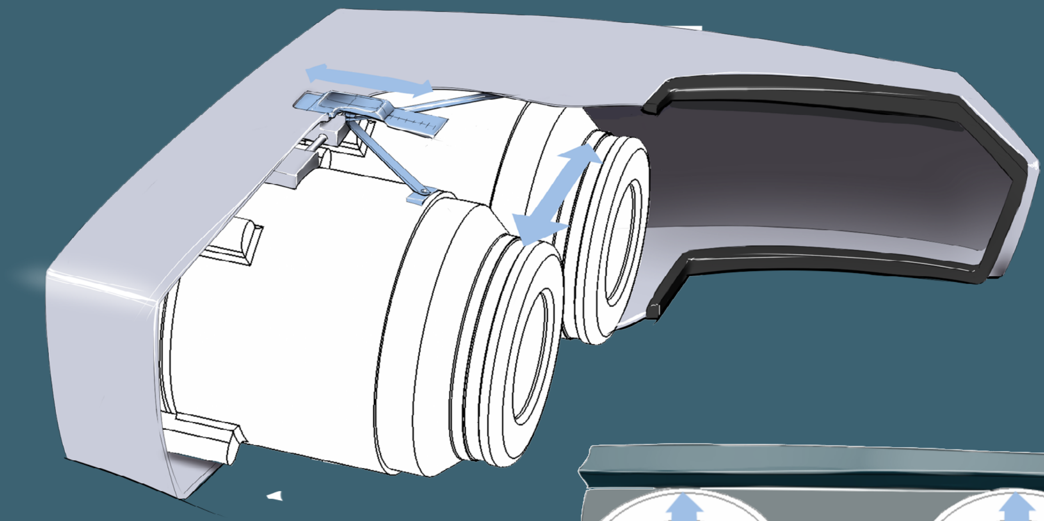


figure 4.4 Graphic representation of concept qualities

4.1.1 INTRODUCTION

This concept focuses on providing a simple and easy user experience for mounting the HMD, thereby solving the usability issue of the present HMD. The concept has a modular building allow the user to mount and adjust the HMD without the heavy weight of the optics attached, this weight was perceived as a problem in previous evaluations.
figure 4.4

figure 4.5 IPD mechanism



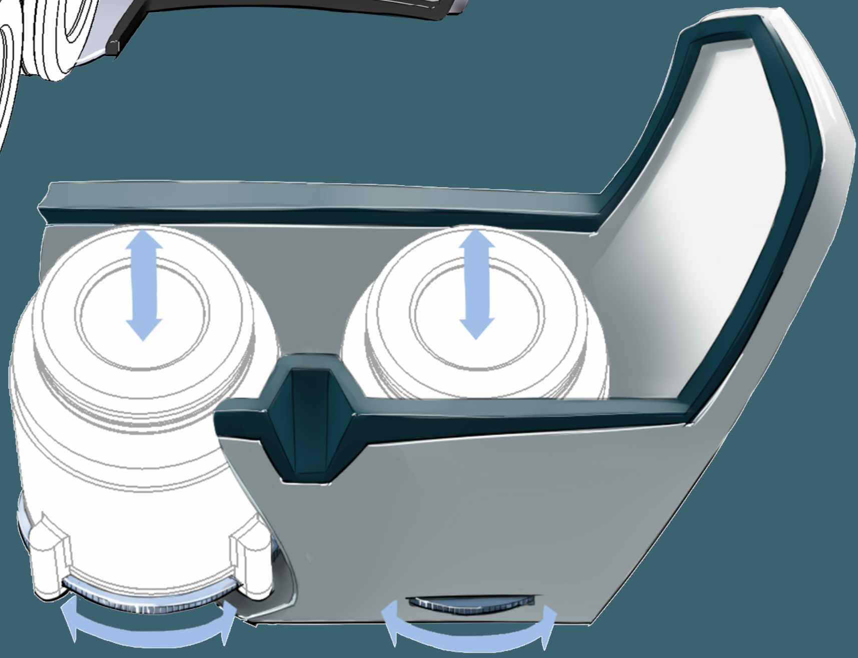


figure 4.6 diopter mechanism

4.1.2 SETTINGS

The user can adjust the IPD and diopter of the optics, the placement of the speakers and the tightness of the mounting. All of these settings are executed with simple actions like turning or sliding or directly moving an object around. This one-action adjustment simplifies and facilitates the adjustment procedure, as was stated as a demand in the PoD.

IPD is adjusted with the slider on top of the optics module, moving it forward lowers the IPD and vice versa ***figure 4.5***. The IPD value is shown as a ruler in the slider space; this facilitates setting up the IPD. It also reduces the time the patient has to wear the HMD because this setting can be changed before the patient wears the HMD; the same advantage goes for the diopter adjustment. This time reduction creates a more pleasant experience for the user.

Adjusting the diopter is as easy as turning a ring on the bottom of the optics module, this can be done individually. Markings on the gear show the current Diopter of each optics module. ***Figure 4.6***

Placing the speakers is done be placing the middle part of the mounting frame over the ears for a comfortable fit before tightening it. ***Figure 4.10***.

Tightening is done by turning the knobs on the sides of the HMD figure xx. This rolls up the cables that hold the other parts of the mounting frame together, pulling them closer to the middle part. By pressing the knob the tension is released. The mechanism behind this is similar to that of a snowboard boot lace-tightening mechanism ***figure 4.7***. The difference is in the amount of cables being pulled at the same time. Each module has two cables connected to the center module for improved stability. ***Figure 4.3*** & ***figure 4.8***.

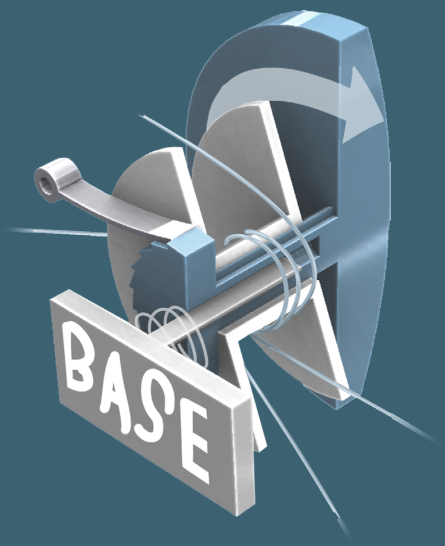


figure 4.7 tightening mechanism

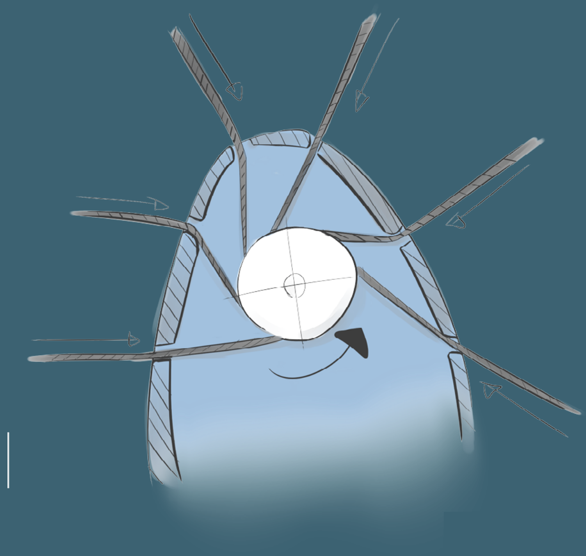


figure 4.8 tightening mechanism side view

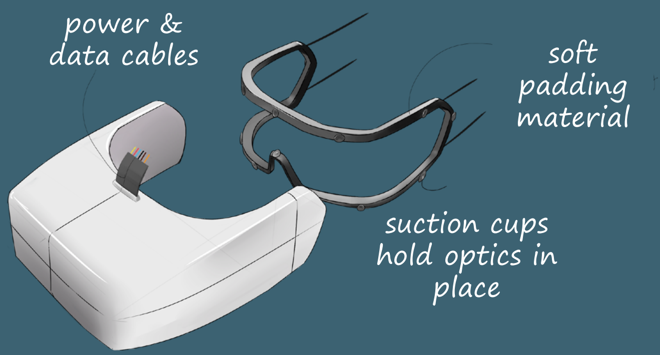


figure 4.9 connection system with suction cups

4.1.3 MATERIALS

Since 3D printing is the desired production method the used materials for the design are limited. The casings and knobs and some parts of the mechanisms will be made from PE or PET this gives strength and rigidity. As was researched in the research phase these materials are fit for the medical environment. Materials that come in contact with the head will be plastic foams for more comfort with a smooth outside for hygiene purposes. Making the padding disposable removes the hygiene problem. This padding would need to be mass produced and effortless to apply and remove. The cables used for tightening will be twisted steel cables with a PE shell; this provides the required strength while still allowing easy cleaning with a medical cleaning agent.

4.1.4 HYGIENE

Because of the detachable electronics and smooth surfaces on contact with the head the HMD is easy to clean, although the large surface area increases the cleaning time. To prevent dirt from entering the tightening mechanism openings for the cables on the middle module of the mounting frame are sealed with rubber rings. It is recommended that the cables are thoroughly cleaned in there extended position.

4.1.5 COMFORT

As found in the research phase discomfort is created by hard materials pressing against (sensitive parts of) the head, an unbalanced HMD and the large backside of the HMD. Therefore this concept uses soft padding materials against the head and draws pressure away from sensitive parts like the nose by moving the weight more to the top and created a rigid mounting structure in the back to compensate for the weight in the front. This mounting structure avoids the far most back of the head for comfortable use while lying down. The cable to the externals is placed high on the HMD near the vertical turning axis of the head, therefore reducing the disturbances created by the cable. The electronics are placed in the top part of the head following its curvature. The IntertiaCube4 is placed parallel to the horizontal plane of the head with the cable pointed backwards; this assures optimal functionality but makes the top module larger.

The user first mounts and adjusts the lightweight mounting frame before attaching the heavy electronics. The IPD and focal length are adjusted before mounting the electronics. The electronics modules are attached to the mounting frame with suction cups. Suction cups create a strong connection perpendicular to their flat side while still allowing effortless cleaning ***figure 4.9***.

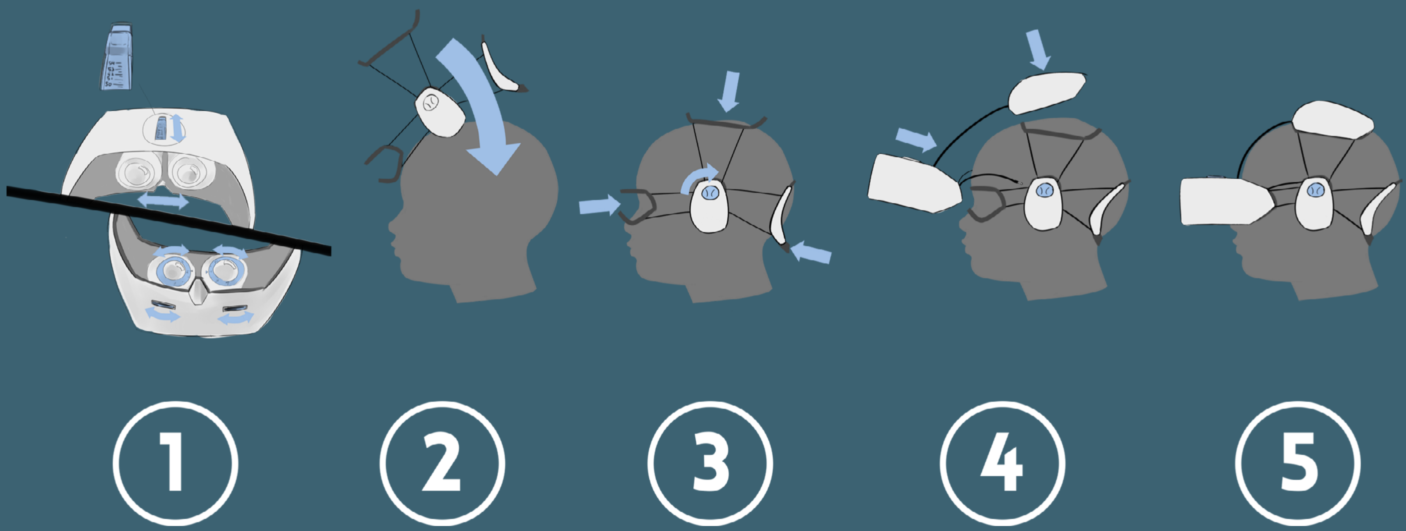


figure 4.10 usage scenario

4.1.6 SCENARIO

figure 4.10

1. The IPD and diopter are adjusted by the practitioner according to the demands of the patient.
2. The mounting frame is placed over the head and the speakers are placed over the ears.
3. Tightening is done by turning the knobs on the sides of the frame.
4. The electronics are placed on the front and top of the mounting frame, the audio is connected
5. The HMD is now ready for use.

4.1.7 STYLING

The modular design of this first concept creates an open and transparent look; this open look is also part of the usage aspects of the HMD, because the patient's view is not blocked by the optics when mounting the frame in the first step. To fit in with the devices that are used in a modern hospital room the concept is styled with hard but rounded shapes, chamfered edges and colorful surfaces. As stated as an important aspect in the research phase the points of interaction have been marked with bright colors, this makes the usage scenario more intuitive and easy for the practitioner. The used buttons, knobs and rings indicate their intended use by their shape. The tightening knob for example can be pinched and twisted with two fingers but also pressed. This is indicated by its two dents for the fingers and the direction of these dents; pointed towards the inside of the casing, which is the require direction to push. The concept has a soft light grey base color to express cleanliness and friendliness. The blue interaction points and surfaces have high contrast and are thereby highly visible and are congruent with the Cybermind corporate identity for the medical environment ***figure 4.3***.

figure 4.11 views concept 2

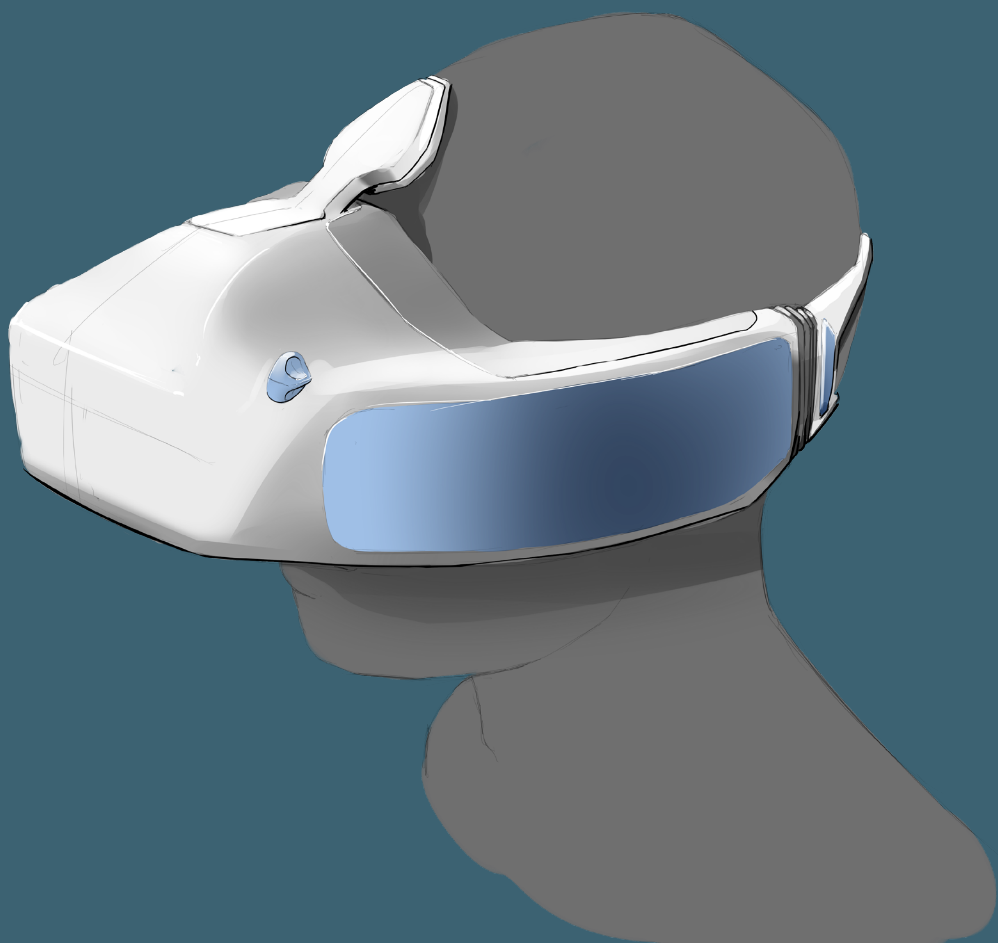


figure 4.12 presentation drawing for concept 2

4.2 CONCEPT #2

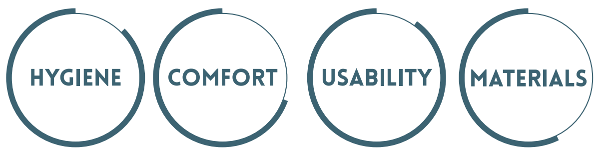


figure 4.13 Graphic representation of concept qualities

4.2.1 INTRODUCTION

This concept provides a high level of usability concerning hygiene and primary use. Its soft and one-module build allows for easy cleaning and gives a striking but calm look. The internal components are wrapped around the head in the longitudinal plane; this keeps the HMD compact and simple. There are no openings and very few seams to the HMD except for the holes for the optics, this promotes effortless cleaning ***figure 4.13***.

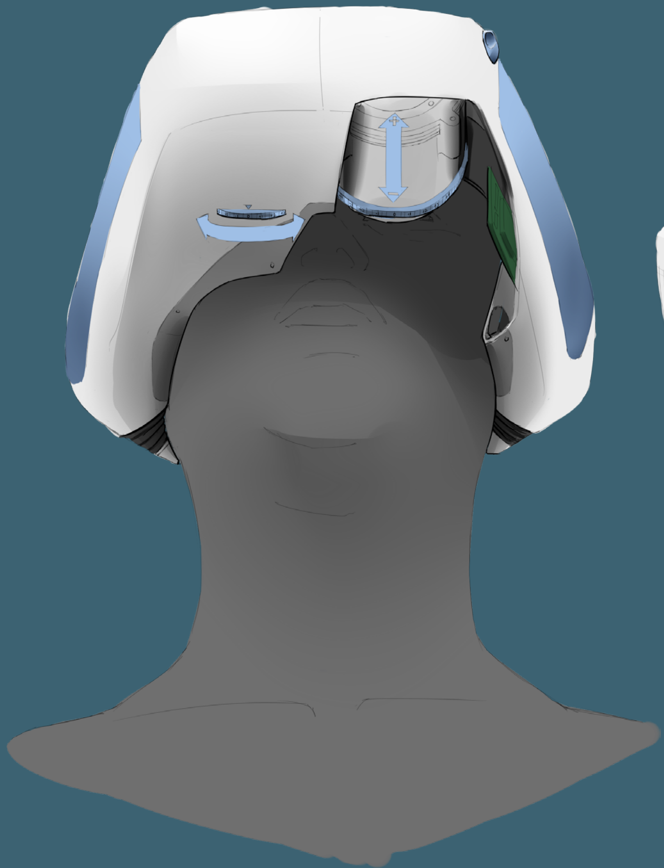


figure 4.14 diopter mechanism

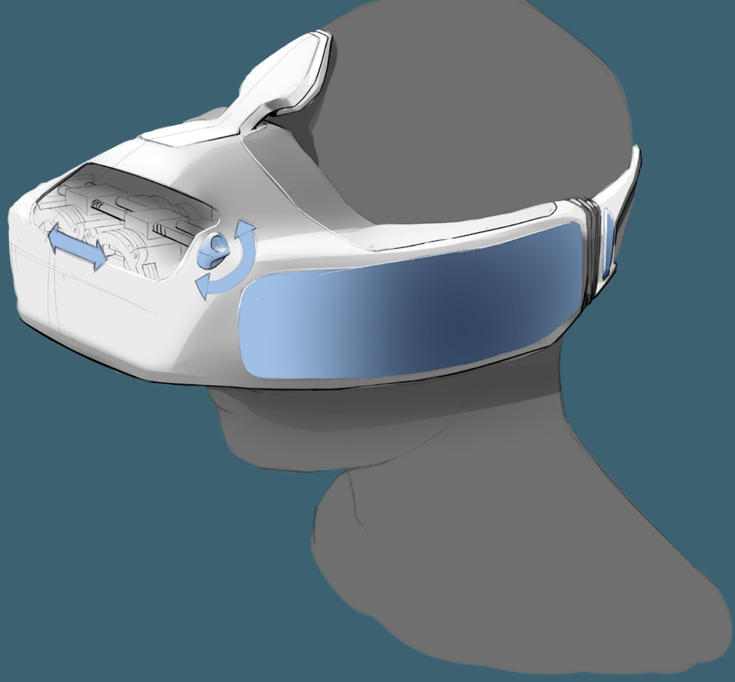


figure 4.15 IPD mechanism

4.2.2 SETTINGS

Just like this first concept, the diopter is adjusted with rings on the bottom of the HMD. The diopter is indicated on the rings to make adjustment by the practitioner before mounting the HMD possible ***figure 4.14***.
A turning knob on the side adjusts the IPD; this is the same as the current system. The IPD value is shown on the knob to facilitate the setup ***figure 4.15***.
The speakers can be moved internally by sliding them forward or backward on a sliding mechanism. This allows for users of different sizes. By grabbing the sides of the HMD on the buttons in the back and the gripping point on the side the user can adjust the size of the mounting ***figure 4.16*** & ***figure 4.17***. By pulling these together the size of the HMD is adjusted down. When the buttons in the back are released the setting is fixed. Internal cables hold the front and back together, by pressing the back buttons this friction connection is released. To release the mounting the user pushes the buttons on the back while pulling back on the straps. This simple system is very intuitive because the required action is very similar to the demanded result; pulling two parts together to make something smaller. Because the moving parts are all covered, with the exception of the buttons the mechanism has very few cluttering points for dirt and bacteria, the mechanism is effortless to clean, improving the usability for the practitioner.

4.2.3 MATERIALS

This concept uses PE or PET for the outer casing, knobs, buttons and diopter mechanisms, this is strong and rigid. PE and PET are materials that meet the demands of the medical world. The inner padding is soft foam. This part is sealed by the inner casing and does therefore not need cleaning. The material therefore only needs to be soft and flexible to assure a comfortable fit. A flexible foil like plastic will be used for the inner casing; this might pose a problem in 3D printing production. A foil has been chosen because it provides a seal for bacteria and is easy to replace while allowing deformation along the contours of the head. The flexible inner casing therefore provides the comfort and hygiene that is looked for in the redesign.
For the connection between the front of the HMD and the back strap a flexible rubber like material will be used. This allows the tightening mechanism to be adjusted without a seam in which bacteria could be trapped out of reach of a cleaning cloth. Rubber can also be 3D printed, by printing the rubber in the same print as the outer casing the seam between these parts can be minimized, this improves hygiene.
Twisted steel cables ***figure 4.18*** are used for the tightening mechanism, these provide the strength and grip necessary for the mechanisms to function properly.

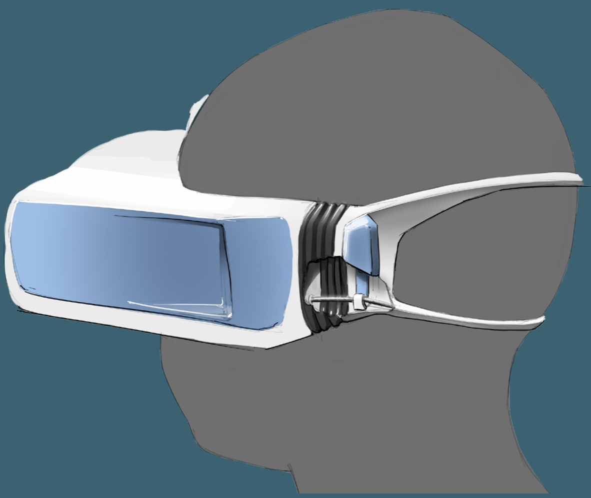


figure 4.16 tightening mechanism

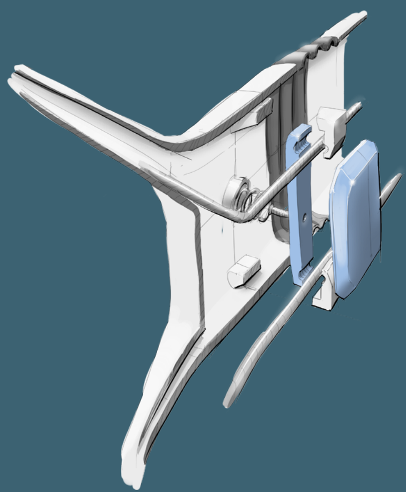


figure 4.17 tightening mechanism explode

figure 4.18 steel cable

figure 4.19 inner casing

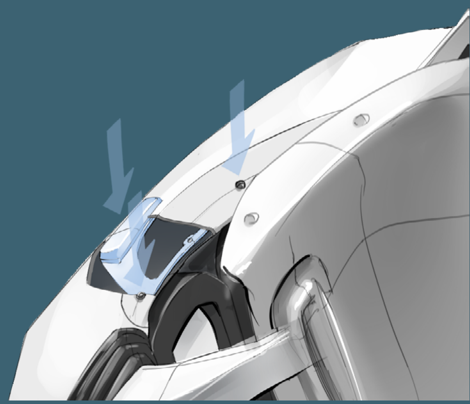


figure 4.20 inner casing removal mechanism

4.2.4 HYGIENE

Cleaning the HMDs is very simple for its smooth shape and few seams. An inner casing can be taken out by pressing the top buttons around the ears; this inner casing can then be cleaned separately or replaced with a new one. The inner casing and the back straps are the only part that comes in contact with the head. This reduces the complexity of the cleaning process. The flexible part around the tightening mechanism reduces the number of hard to clean spaces. When stretched out the bumps and curves of this part are minimized, making it effortless to clean. ***Figure 4.19*** & ***figure 4.20***.

4.2.5 COMFORT

The flexible inner casing covers the soft padding around the inside of the HMD; this padding provides a comfortably wearable HMD. The extension on the forehead of the HMD removes pressure from the nose, creating comfort. The back straps avoid the far back of the head and are small, this allows to user to lie down comfortably. The lower back strap prevents the HMD from shifting forward onto the nose; this also helps create a more comfortable wear. The comfort of the HMD is one of the bottlenecks of the current design that break the immersion. The above described solutions should create more comfort for the patient; this minimizes the distraction from the game by the HMD itself and allows a stronger immersion.

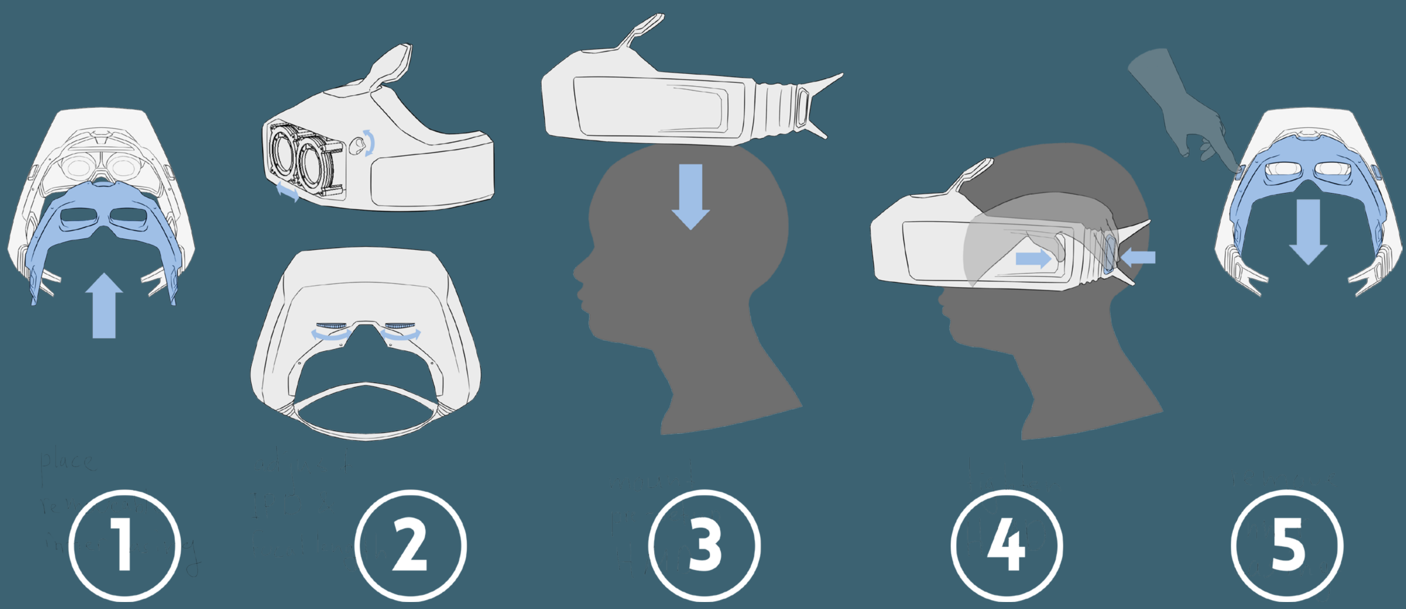


figure 4.21 usage scenario

4.2.3 SCENARIO

figure 4.21

1. A clean inner casing is placed and clicked in place by the practitioner.
2. The IPD and diopter are adjusted by the practitioner according to the demands of the patient.
3. The user ready HMD is placed over the head with the back straps extended to their maximum.
4. The patient or the practitioner tightens the HMD on both sides of the HMD.
5. The HMD is now ready for use.
6. After the treatment the practitioner removes the inner casing by pressing the top buttons around the ears and then lifting it out.

4.2.7 STYLING

This concept carries the same color scheme as the first concept with the same underlying motives; to create a clean and friendly looking device and clear interaction points for high usability. The general shape of the device expresses a very soft but robust feel due to its thick but rounded shape. The shape flows around the head starting big and robust at the front and flowing around the head dispersing into smaller lines; the straps and head rest on the top. This also indicates the use and focuses the attention on the front. The big blue surfaces on the side form around the grip for the size adjustment. They run through to the back adjustment button as one big blue surface to indicate the interaction that takes place on the side. The blue surfaces also add a playful and vibrant feeling to the device. The highly recognizable black rubber cover piece indicates its flexibility through its corrugated shape and its color; this also indicates the possible adjustment of the back part. The inner casing is a darker grey than the outer casing to indicate its removability. Its shape follows the inside of the HMD and wraps around to the outside, indicating its cover functionality. The corrugated parts around the ears indicate the place where the ears are meant to go. The padding is divided in several large areas whose shape indicates their purpose; around the eyes a ski goggle like padding assures a comfortable fit, around the ears the padding is similar to that of a set of headphones, indicating the location of the speakers and ears.

figure 4.22 views concept 2

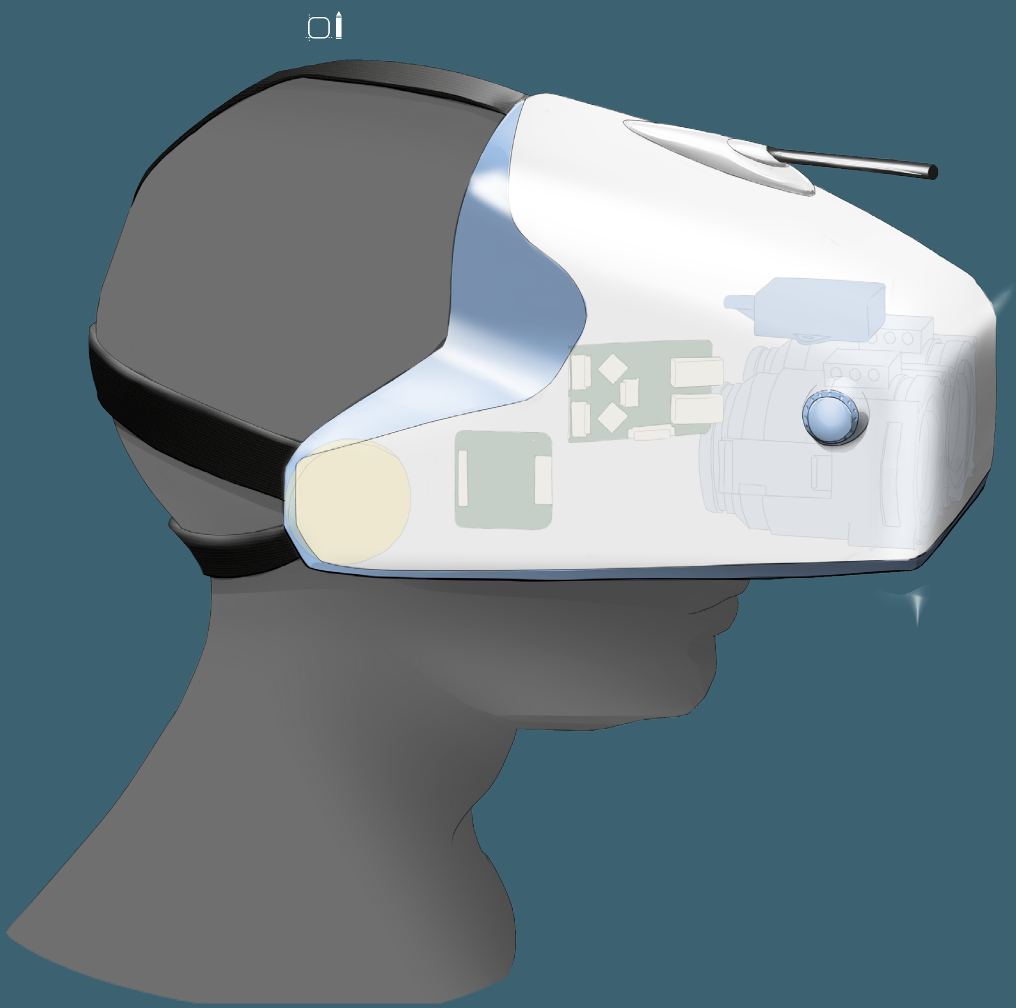


figure 4.23 presentation drawing for concept 2

4.3 CONCEPT #3

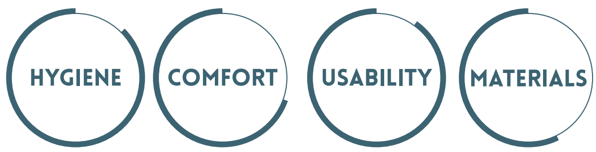


figure 4.24 Graphic representation of concept qualities

4.3.1 INTRODUCTION

This third concept has a simple design with the weight and mounting in the front and an inner casing in the front, this facilitates the usage and cleaning of the HMD. its mounting is very basic to simplify the usage scenario. Contrary to the previous concepts this design is more on the face than around it, this creates a less intimidating look and simplifies the concept's shape, increasing usability and hygiene ***figure 4.24***.

figure 4.25 IPD mechanism

figure 4.26 diopter mechanism

4.3.2 SETTINGS

IPD and diopter adjustment are the same as the second concept however the knob for IPD adjustment is provides more grip from the side compared to the round knob with two large dents for the fingers of the second concept. This knob indicates its use by the grippy side edge. ***Figure 4.25***. This concept has elastic straps going over and around the sides of the head to provide a secure fit for a wide range of users. ***Figure 4.23***. Although the straps might need to be adjustable the interaction and mechanism would be very simple. This helps with the usability of the design.
The inner casing can be taken out by pressing the buttons on the back of the HMD ***figure 4.28*** & ***figure 4.29***. Because the knobs in the back are the only thing holding it in place the practitioner should not have to touch the contaminated inner casing when taking it out. This allows for a very clean usage scenario concerning the hygiene of the HMD.
The speakers are fixed in place, contrary to the other concepts the padding is only on the ear, not around it. Fixing the speakers simplifies the design but the speakers need to disperse the sound over a wider range to deliver the sound to patients with different dimensions. Fixing the speakers allows for a better seal by the inner casing, increasing hygiene.

4.2.3 MATERIALS

The casing for this concept will be 3D printed out of PE or PET, this provides rigidity and strength to the HMD, and these materials are fit for use in the medical world. The inner casing will be made out of a flexible foil like material to cover up the internals for hygiene but provide a comfortable surface. The internal padding will be soft foam. This foam will not come in contact with the patient and does therefore not have to meet hygiene demands. The elastic straps will be made of an elastic plastic rubber fabric composite. The used materials are focused on creating an easy to clean or comfortable surface.

figure 4.27 Mounting on backside

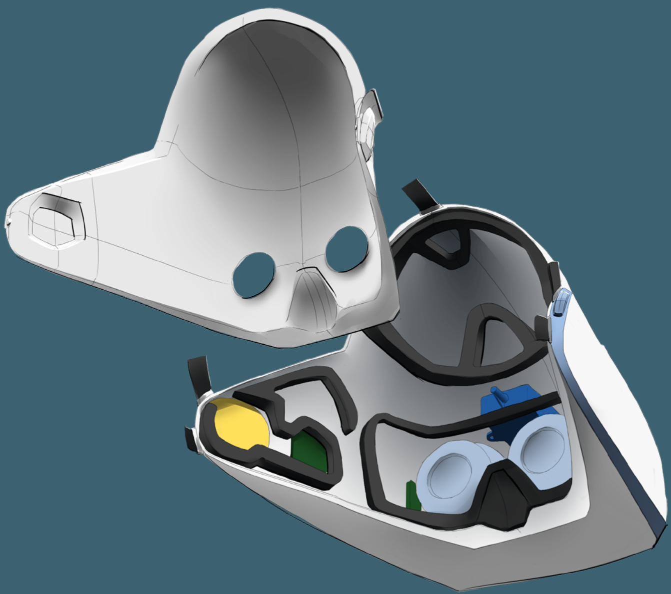


figure 4.28 inner casing

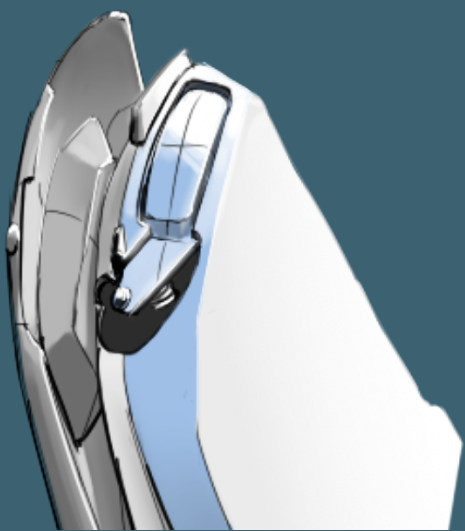


figure 4.29 close-up inner casing mechanism

4.2.4 HYGIENE

The removable inner casing facilitates cleaning the HDM. The straps' fabric like structure will make them hard to clean by hand, disposable straps could provide the solution. The design has few buttons and knobs this decreases the number of seams and openings which facilitates the cleaning process. ***Figure 4.28***.

4.2.5 COMFORT

Because of the shape of the HMD most of the weight and pressure is distributed over the forehead and back of the head, the wearer will be able to use the HMD in comfort. The inside is lined with a soft padding material to assure this comfort for a wide variety of users. The soft mounting straps evenly distribute the load over their surface, this provides a comfortable fit. The top strap helps distribute the weight of the optics over the forehead and back of the head and prevents the HMD from sagging in the front. A comfortable wear is very important for a good immersion in the game because distraction due to discomfort could break the immersion.

figure 4.30 usage scenario

4.2.3 SCENARIO

figure 4.30

1. A clean inner casing is placed and clicked in place by the practitioner.
2. The IPD and diopter settings are adjusted beforehand
3. The HMD is placed over the head with the elastic strap pulled back
4. The elastic strap is slowly released and the HMD is secured on the head
5. The HMD is now ready for use, after use the inner casing is removed by pressing the buttons on the back of the HMD.

4.2.7 STYLING

This concept is shaped around the internal components and the chosen pressure points, this creates a shape that hugs the face and leans on the forehead. This creates a soft and inviting look which helps decrease the negative barrier the patient might feel when seeing the HMD. Again a light grey base color is used for a sterile and calm look, in combination with blue knobs, buttons and surfaces to indicate the points of interaction. The blue edge dividing the inner and outer casing emphasizes the face hugging look and the removability of the inner casing. The blue edge also breaks up the large block the casing would be without it. The cable exit point is subtle but present; it breaks up the large plain surface on top of the HMD ***figure 4.23***

5

CONCEPT EVALUATION

INTRODUCTION

During the second milestone with the experts from Cybermind and with an evaluation of the concepts to the program of demands and wishes a concept has be chosen to further develop in the next phase.

5.1 EVALUATION WITH EXPERTS

During the second milestone the results of ideation phase and the different concepts have been explained. With the experts at Cybermind these concepts have been evaluated.

The mounting of concept 1 was found useful but the rest of the concept was too complicated for optimal VR use and cleaning. The placement of most of the electronics on top of the head would create a better balance, but the flexible cable connection between the different modules was thought to lack the rigidity and support needed to balance the HMD.

The second concept was received positively for its simple shape and design and focus on hygiene. The mounting mechanism was expected to be problematic because it could easily be pulled asymmetrically, this should be improved. For comfort the straps behind the head should be wider and flatter, giving a better weight distribution. Because most of the weight is in the front of the HMD a better balance should be found with more support on top of the head, like that of concept 1.

CONCEPT EVALUATION TO PROGRAM OF DEMANDS AND WISHES

Demand	Weight	Evaluation		
End usage		Concept 1	Concept 2	Concept 3
The load of the HMD is distributed over points on the head most capable of taking loads	5	5	4	5
The HMD has contact points with the head that are comfortable to the wearer	4	5	4	4
The points of interaction (buttens, knobs etc.) must be clearly indicated on the device using a contrast in shape, color or material	3	4	4	4
The esthetic design is simple and has minimal distracting features such as complex shapes and buttons/knobs	3	3	5	5
The HMD shows the settings values to the practitioner	3	4	5	5
Integration of the HMD in the hospital environment must have no need for changes to the HMD or already present hospital equipment	5	3	3	3
None of the parts of the HMD that come into contact with the 70% ethanol are damaged by the 70% ethanol	5	3	5	5
All of the parts of the HMD that are manually cleaned are designed with minimal external seams, holes and geometric shapes in which dirt or other particles could get stuck in	4	2	5	3
The parts of the HMD that come in direct contact with the patient must be able to be removed from the device for the cleaning procedure following each treatment	4	3	4	4
The HMD has a minimal number of components that come into direct contact with the patient	3	2	5	5
The parts of the HMD that come in direct contact with the patient must be able to be replaced with new parts	3	1	5	5
The parts of the HMD that come in direct contact with the patient must be able to be mass produced	3	3	4	4
Replacable parts, parts that come in direct contact with the patient, must be very low cost	3	2	4	4
The HMD's center of gravity must be as close as possible to that of the user's head	4	4	3	2
The casing blocks out as much as possible of the user's view of the immediate physical environment	4	5	5	5
The esthetics of the HMD must be congruent with those of the medical devices collage	2	3	4	4
Production				
The casing is fit for 3D printing processes	2	4	3	3

figure 5.1 Concept evaluation to program of demands and wishes

The third concept was also received well but some problems were found. The elastic band of concept 3 could be disposable; this would reduce the expected difficulties with cleaning it. As with concept 2 a balance problem occurs due to the weight being in the front of the HMD. Here a better balance should be sought by changing the mounting structure. The band going over the top of the head is a good start for this, compared to concept 2.

5.2 EVALUATION TO POD

In addition to the evaluation with experts from Cybermind the concepts have been evaluated to the PoD. This evaluation is merely used as a further confirmation of the arguments found in the previous paragraph. Due to the vague correlation between the quantitative evaluation of the concepts and the quantitative effectiveness of the concepts this evaluation should not be viewed on its own.

The evaluation to the program of demands and wishes concluded in 460 points for concept 2, 456 points for concept 3 and 400 points for concept 1. Each demand has been weighted on a scale of 1 to 5 and each concept has been evaluated to the extent to which the demand was met, again on a scale of 1 to 5. On these scales 5 means a demand is very important or very well met and 1 being the opposite. For demands that cannot be evaluated yet; demands concerning exact dimensions and loads, an evaluation value of 0 has been marked. ***Figure 5.1***.

5.3 GENERAL IMPROVEMENTS

Several points of improvement have been found that apply to multiple concepts. The current distribution of sensitive and insensitive points on the human head have been assumptions, these should be translated into scientifically supported claims based on human anatomy. The developed concepts have some pressure points on sensitive points of the head. The ends of the fifth brain nerve and the bone structure of the head provide a good guideline for pressure points on the head for the final concept.
The cable placement and guiding is an aspect that requires more attention. It is recommended to point the cable connection backwards for better balance, placing it on top of the head is still a valid option.

The focus mechanism that is used in all concepts is unlikely to work; the adjustment rings will increase the diameter of the optics modules and thereby increases the minimum IPD. This is a problem since the current minimum IPD is barely lower than the minimum needed IPD.

For better balance a second guiderail is crucial in the IPD mechanism.

The last improvement found during the evaluation is the ventilation of the face. The full enclosure of the FOV leads to a lack of ventilation of the area around the eyes; this can create a loss of comfort for the patient and fog up the lenses of the optics. Ventilation around the eyes should therefore be taken into account.

5.4 CONCLUSION

This evaluation has led to choosing one of the three concepts. Concept 2 has been chosen as a basis for the final concept. The simple, easy to clean and easy to use design have helped made this choice. Therefore the basic mechanisms and form factor of this concept will be implemented in the final concept, with the above described improvements. For production matters the inner casing should be developed further to assure a feasible production of a component that increases both the hygiene and the comfort of the HMD. For comfort the balance of the HMD also requires more attention, more support on top of the head is the most likely solution. ***Figure 5.1***.

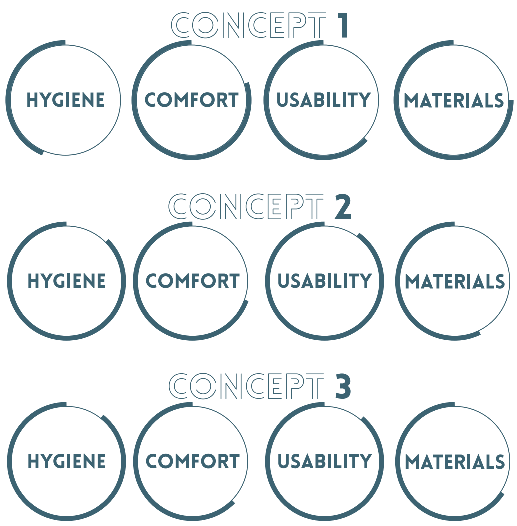


figure 5.2 graphical representation of concept preformance

6

DETAILING

INTRODUCTION

In the previous chapter a concept has been chosen for further development. The points of attention found in the evaluation of the concept will guide the focus of the development phase. The goal of the detailing phase is to create a final concept that is ready to be turned into a 3D model for rapid prototyping. Therefore aspects of the design that influence production will be developed further.

As hygiene is an important part of this design process this is one of the aspects that will also be further developed, the goal here is to create a design that fits the demands of hygiene regulations in the hospital as good as possible without compromising the other important design aspects.

Comfort and usability is also very important, therefore the model of sensitivity on the head will be reviewed and revised. Materials for the prototype will be chosen according to the usage aspects and clean ability and production properties. The body dimensions of the users influence a lot of the design choices made for the final concept, the model used for dimensions of the head has therefore been developed further.

In addition to the research phase an interview with experts from the Burn treatment ward of the UZ Leuven. This interview has provided new information on the above named design aspects.

This phase ends with an explanation of all the changes and points of attention on the final concept summarized in ***figure 6.19***.

6.1 EXPERT INTERVIEW LEUVEN

Via Skype an interview has been held with the head nurse and kinesthesist concerning the burn wound treatment. The interview has provided important information on the aspect of hygiene and usage during the complete treatment procedure. Some of the information confirmed previously made assumptions while others have been rejected. These aspects are discussed below. The full interview can be found in ***Appendix C***.

The procedure for cleaning the HMD is less complicated than previously assumed. According to the experts in Leuven the cleaning procedure for the HMD consists of using a cloth and cleaning agent to wipe of the HMD after the treatment. A sterilization procedure is not needed; heat resistance to 134° C is therefore no longer a demand for the HMD. Cleaning the HMD should be simple and fast because hospital personnel are on a very tight schedule. This was correctly assumed in the research phase. Therefore the design guidelines of smooth surfaces and minimal seams still apply.

According to the experts the HMD is mounted by hospital personnel; however the patient has the tendency to try and do it himself. Allowing the patient to do it would facilitate the procedure, however the mounting steps should be simple enough for the patient and the device should be light enough for the patient. Putting the patient in control of the mounting while a hospital personnel holds the weight would be a good solution.

The most logical placement for the holder will be at the foot of the bed, because of the space required by the practitioner and kinesthesist. There is no possibility to hang the cable above the bed, it should therefore pass by the side of the bed or underneath the patient to the external controller. ***Figure 6.1*** & ***figure 6.2***.

It should also be noted that contrary to the previous understanding, there are three people standing around the bed; the practitioner, the kinesthesist and someone to monitor the child's actions in the VR world and control the game.

This new information will be incorporated throughout the rest of the detailing phase.

6.2 REVISION OF HEAD SENSITIVENESS

The scheme used in the ideation phase ***figure 3.5*** for sensitive and insensitive parts of the head was primarily based on assumptions, using anatomy of the human head these assumptions have been revised to a more anatomically and scientifically correct model of sensitivity on the human head. Below the points that require attention in the design of the mounting are described and motivated.

figure 6.1 Hospital bed in UZ Leuven

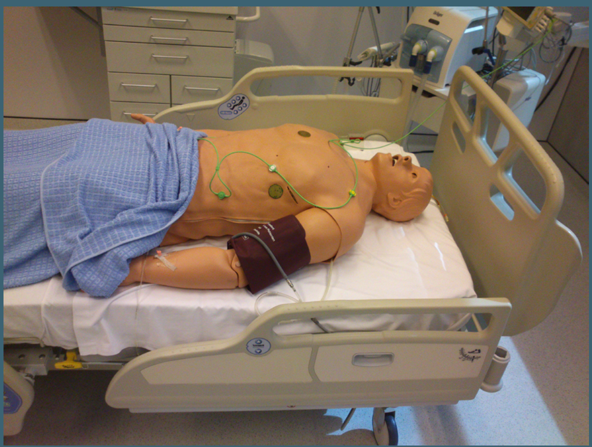


figure 6.2 Hospital bed

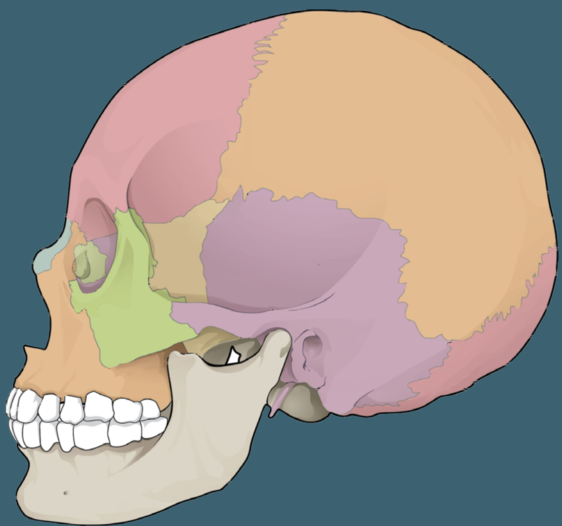


figure 6.3 human skull schematic

BONE STRUCTURE & MUSCLES

The main guide used in ***figure 3.5*** is the bone structure of the head. Parts of the head covered with a relatively thick layer of muscle and nerves are qualified as soft and are to be avoided. In addition to this, the head also has weaker bone structures, these should also be avoided.
As is visible in the ***figure 6.3*** the human skull consists of many segments connected by seams, these seams form weaker points on the head. The temple lays further inward and is a junction of several parts of the skull. A layer of muscles and a thin bone structure make this part of the head extra sensitive. The facial area below the cheekbone is covered in muscle and must be able to move because of the mouth, this part of the head should be avoided. The top of the neck is where the muscles are connected to the skull ***figure 6.4***, this part is weak and should be avoided or bear only a minimal load.

NERVES

Previous HMD designs from Cybermind have indicated the sensitivity of the nose. Applied pressure should be minimal or preferably completely avoided. The weight of the optics would most likely be too much for the nose to carry. The frontal belly muscles run over the forehead spreading apart as they go over, this leaves a V shape in the middle of the forehead; the epicranial aponeurosis ***figure 6.5***. This region is less sensitive than its surroundings due to the lack of muscles and nerves; therefore it provides a good surface to apply pressure to.
Next to the mechanical strength of the head, superficial nerves of the brain create sensitive points on the head. The trigeminal nerve or CN V, ***figure 6.6***, is responsible for the senses in the face and the majority of the senses on the rest of the head. This nerve has three branches on either side of the face. These branches cause sensitivity around the edge of the lower yaw, over the cheekbone, over the eyebrow and around the temple. (Gladwin, 2014)

CONCLUSION

In conclusion, the distribution of the loads of the HMD should be on the green areas of ***figure 6.7***; the red areas should be avoided for they are softer and more sensitive. Therefore the concept design should be made wider around the ear to avoid pressure. The exact shape of the foam piece around the eyes is also important because it should fit a variety of users on the correct point of the face.

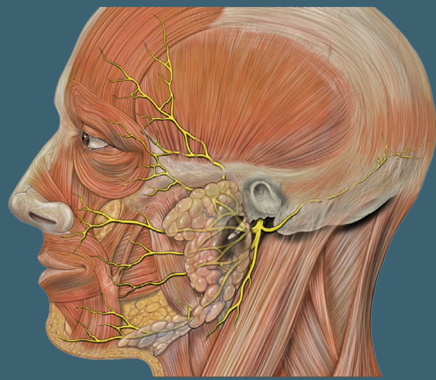


figure 6.4 nerves and muslces on the head

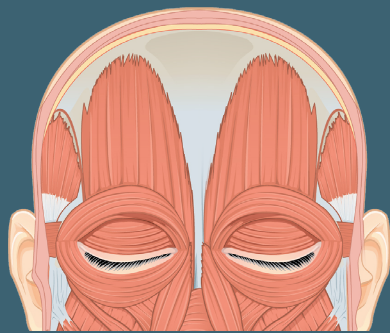


figure 6.5 Epicranial aponeurosis

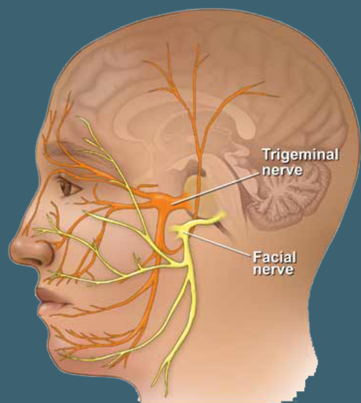


figure 6.6 Trigeminal and facial nerve

figure 6.7 sensitivity of the head

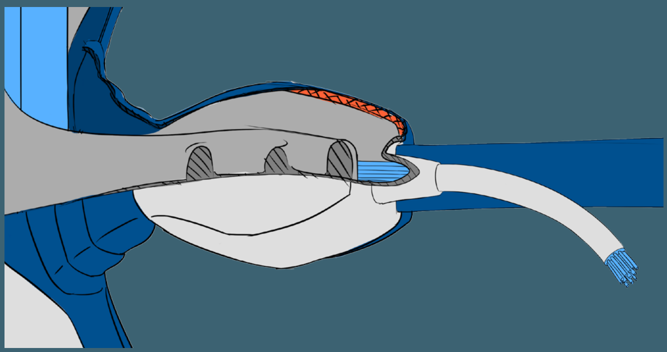


figure 6.8 External cable connection

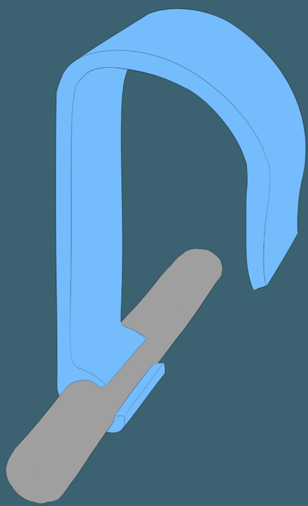


figure 6.9 Cable hook

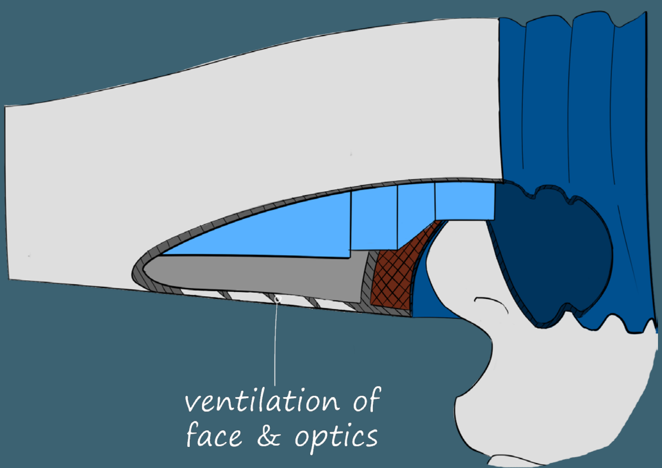


figure 6.10 Ventilation in front of HMD

6.3 EXTERNAL CABLE

To optimize stability the data & power cable exits the HMD on the pad on the patient's forehead. The cable is pointed backwards to use its weight as compensation for the optics ***figure 6.8***. For the purpose of hygiene a smooth cable is preferred. Cable hooks ***figure 6.9*** can be used to attach the cable to the hospital bed and prevent it from obstructing the practitioner.

6.4 VENTILATION

Ventilation of the front of the HMD is required to prevent the optics from fogging up allow the patient's face to keep cool and dry. A ventilation grid has been integrated in the bottom of the HMD to provide this ventilation. The face of the patient is sealed off for the most part to keep the light out to optimize the immersion. Light coming in through the ventilation grid could break this immersion, to minimize this effect the grid openings are pointed away from the patient's eyes, minimizing direct light hitting the patient's eyes ***figure 6.10***. The grid slots have a slight inward draft to allow for production by casting or molding.

6.5 DIMENSIONS

The target user group of 8 to 16 year old men and women create a large spread in dimensions of the head. To create a more exact view on the size of this gap a visualization of the largest and smallest head size has been created. For this silhouettes of a young child and an adult like figure have been used in combination with the dimensions determined in the research phase; ***figure 6.11***.
From this figure it can be deducted that only an adjustable backside is not enough to provide a comfortable fit to all patients. The width of the head also varies a lot; therefore a flexible part has been integrated in the sides of the HMD. To compensate for the variation in the eyes to top-of-the-head distance the head pad is attached with a flexible arm in the final concept.
The size adjustment mechanism has been determined to have a minimum travel distance of 24mm, the difference between the head depth of the largest and smallest head.

6.6 INNER CASING

The inner casing is a production bottleneck of the chosen concept; this component must be flexible to provide the comfort of the padding behind it while providing a smooth cleanable surface. Next to that it must be able to withstand the chemicals used in the medical cleaning procedure. The concept design had an inner casing made from a plastic foil, although this would meet the demands stated above, the production would become very complicated for it would need to be a preformed foil. This foil would need high flexibility in most parts and have rigid parts to fix it to the outer casing.

To avoid production problems several materials have been looked at that conform better to the production possibilities, without compromising the functionality of

the component. This section is about the final production of the concept. The prototype delivered at the end of this assignment will be 3D printed; this section does not apply to the production of the prototype. Because the design is not yet ready for final production and because of a lack of knowledge about the production processes used by Cybermind this section only describes recommended materials.
materials.

PLASTICS

In the research phase materials have been shortly described. The medical world uses a lot of different materials and hold high demands and regulations for these materials. PP and PET are highly used in the medical world. Polymer or vacuum casting can be used for small scale production of plastic components. These processes are mainly meant for thermosets but some thermoplastics can be molded as well (CES Edupack, 2013).

RUBBER

The flexible material used as an inner casing and for connecting the front and back of the HMD could be a rubber like material. Rubber provides a soft, flexible and cleanable surface, however it should be suitable for vacuum molding. Alternatives for rubber could be TPE or thermoplastic elastomer. This is a flexible and elastic material often used in medical appliances among which invasive medical equipment which must conform to the highest medical standards. TPE also has the advantage of being latex free which is preferable considering the fact that the inner casing will make direct skin contact with the patient. Natural rubber is not latex free. Hexpol TPE is a manufacturer of TPE products, among which medically certified TPE products under the mediprene® trademark name. It might be useful to further investigate in this manufacturer for possibilities in TPE manufacturing.

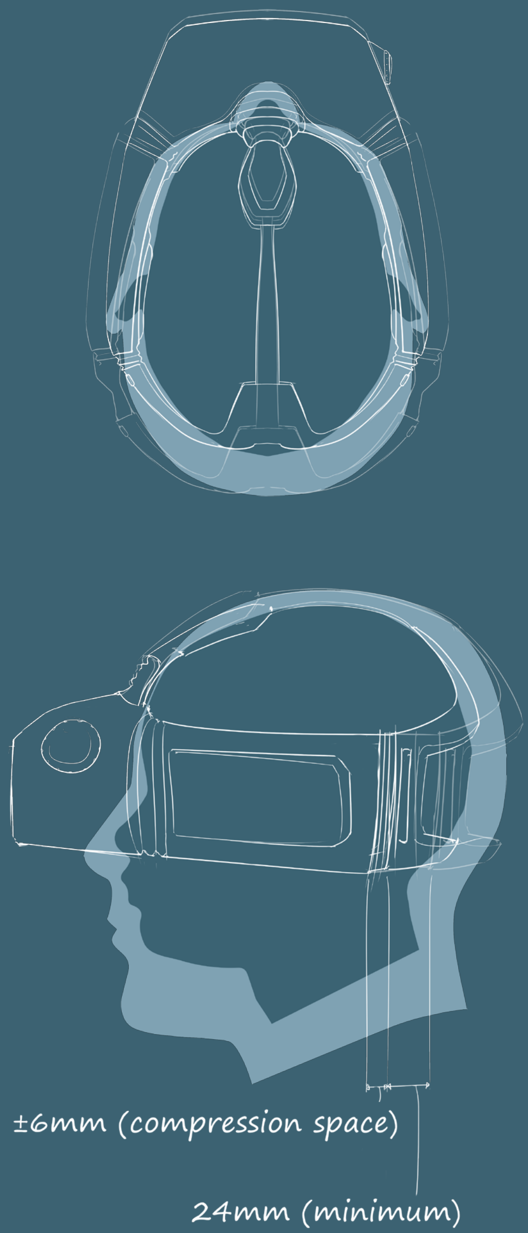
COATING

Cybermind has contacts within the NivoGe group, a company with a department for coatings; these could replace the medical requirements for the used materials.

MATERIAL GUIDELINES

The HMD prototype will have to conform to the 93-42-EEG guideline for medical appliances. Due to its noninvasive design it will be categorized as a class I medical appliance; non-invasive medical appliance. An example of a class I medical appliance is a stethoscope. The HMD is an active therapeutic appliance for its need for electricity to function and intention to alter or support biological functions and structures, i.e. the pain level experienced by the patient. Because the continuous usage period of the HMD is less than 60 minutes the HMD is 'temporary' (European Parlement, 2007).

According to the 93-42-EEG guideline the device should guarantee the safety of the patient using it. Concerning



HEAD BREADTH: 134mm - 156mm
HEAD DEPTH: 178mm - 202mm

figure 6.11 Range of user's head dimensions

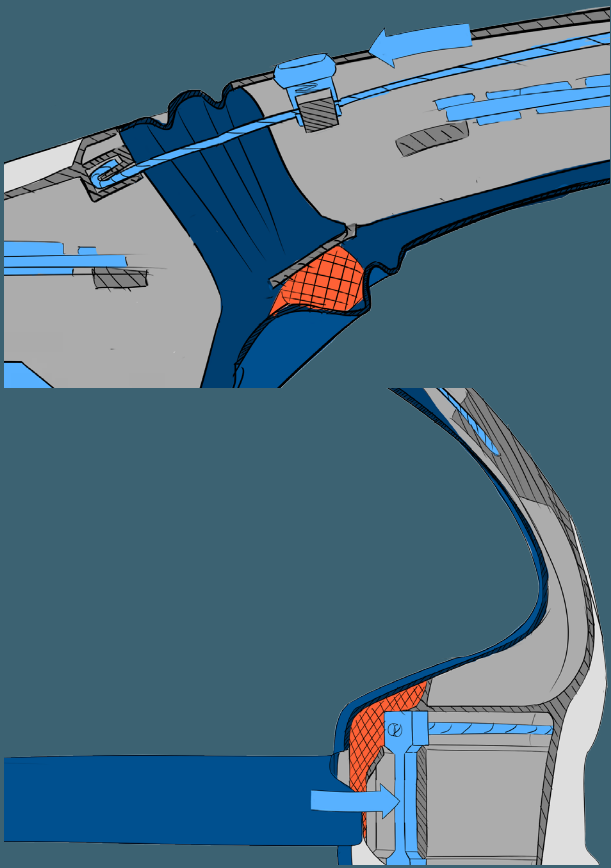


figure 6.12 Size adjustment mechanism

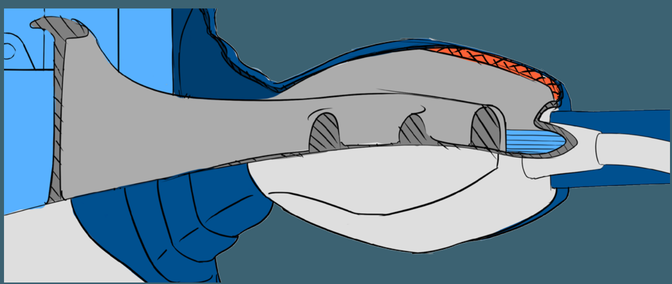


figure 6.13 Flexible headpad

the used materials this means the materials should not be toxic or flammable to an extent that would hurt the patient. To guarantee this safety the materials should be tested. (Appendix I, I. General demands, 93-42-EEG).
The used materials should cope with the cleaning chemicals used in the hospital; these are described in ***Confidential appendix C*** for the chemicals used in the university hospital of Gent. The process and chemical descriptions in Appendix B are too vague to draw direct conclusions for the materials used for this concept. Whether the recommended materials are fit for the hospital environment should be further researched through testing and communication with the involved hospitals.

6.7 SIZE ADJUSTMENT MECHANISM

The mechanism for size adjustment of the HMD has remained relatively the same from the concept design. One important added feature is the mechanism to keep the adjustment parallel on both sides of the HMD. This system keeps tension on the cables on both sides. The tight fit of the cables in their casing leave no room for folding or bending, therefore when one cable is pulled on by the adjustment mechanism the other one is pushed in the same direction by the mechanism in the back. The HMD will therefore always be adjusted in parallel ***figure 6.12***.

A closer look at the human head for different age users showed that the distance between the ears and the back of the head remains relatively the same as the person grows, it is therefore more logical to place the mechanism in front of the speakers. This allows the speakers to move back as needed for larger users.

The user adjusts the size by pinching the HMD by the backside buttons and the dent on the side around the speakers. The distance between these two points is small enough for children to grab on to. Tension and pressure on the head holds the HMD in place, the foam padding acts as a spring that applies pressure to the head when the HMD is tightened firmly. For a proper fit on the head the HMD should be tightened to a point where it is firmly attached to the patient's head.

6.8 STRAPS

To improve comfort the back straps have been widened and lined with some padding. Because of the cables running through them these straps cannot be made very thin ***figure 6.13***. The top strap distributes the weight of the optics to the back of the head and helps keep balance, to allow for variable head dimensions the top strap is made of very thin elastic TPE. A seperate adjustment system for the top strap is therefore not necessary ***figure 6.12***.

6.9 FLEXIBLE HEAD PAD

The pad on the user's forehead takes most of the weight of the nose, to allow for variable dimensions of the users the head pad is mounted to the casing on a flexible arm

figure 6.13, this bends under the weight of the HMD to the correct point. Between the pad and the main part of the casing lies a connection of flexible TPE to avoid seams in the structure.

6.10 FLEXIBLE SIDES

Because of a large variety in head width a flexible strip allows the HMD to bend at around the side of the face to create a comfortable fit for each the patient. Flexible TPE is used to bridge the gap between the front and side of the HMD, to allow them to move independently **figure 6.14**.

6.11 SPEAKER CUPS

The HMD has very wide cups for the patient's ears; this allows users with varying dimensions and proportions to comfortable wear the HMD. The inside of the HMD is covered with flexible TPE. Around the eyes and ears the TPE covers foam padding to create a comfortable seal of sight and sound **figure 6.15**.

6.12 IPD HAPTIC MECHANISM

A standard knob mechanism is used with an integrated haptic clicking system. This secures the IPD setting during the treatment and allows the practitioner to effortlessly adjust the IPD with fixed intervals.

The demanded IPD range is very important to the dimensions of the HMD. The diameter of the optics determines the minimum IPD at 50mm. The maximum IPD is determined by the user with the largest IPD. It has been statistically proven that men have larger than women. The mean and max. IPD for the age group of 14 to 16 year old men are 63mm and 70mm respectively (Dodgson, 2004). Little more information is available because the original study is not available. The used data has been collected on children from California and Mexico in 1986. These people are statistically smaller, or at least shorter than the Belgium target group (Disabled world, 2008). Combining this with the statistically significant difference between near and far IPD (roughly 3mm) (Dodgson, 2004), allows an estimation of the mean maximum IPD. The maximum IPD for the target group of 8 to 16 year olds has been estimated at 69mm, this includes the difference between near and far IPD, the height difference between the measured test subjects and the target group and a compensation for standard deviation. Due to a lack of hard values this is still a very rough estimate.

6.13 FOAM PADDING

Foam padding creates comfort for the users; this padding is covered by the flexible inner casing to create a smooth effortlessly cleanable surface. To compensate for the varying head dimensions the foam is extra thick around the ear cups and the eyes; 12mm because of the variation in head breadth of 22mm **figure 6.15** & **figure 6.16**. Because the padding on the forehead and back straps only provides comfort and does not compensate for the varying head

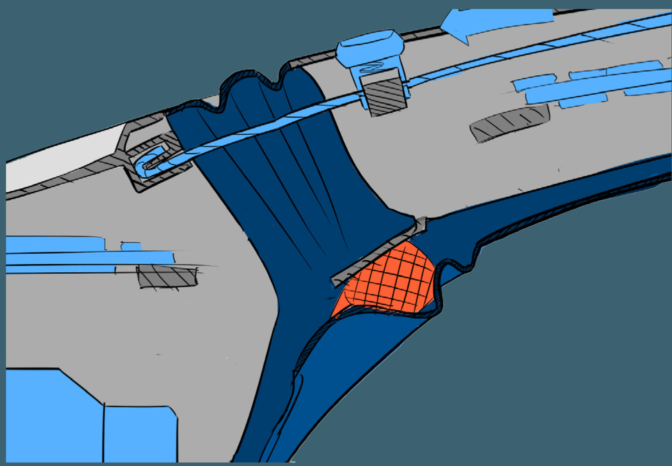


figure 6.14 Flexible sides of HMD

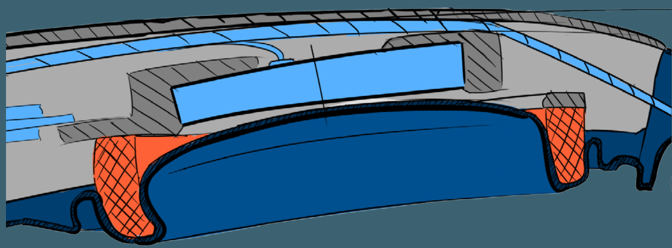


figure 6.15 Speaker cups

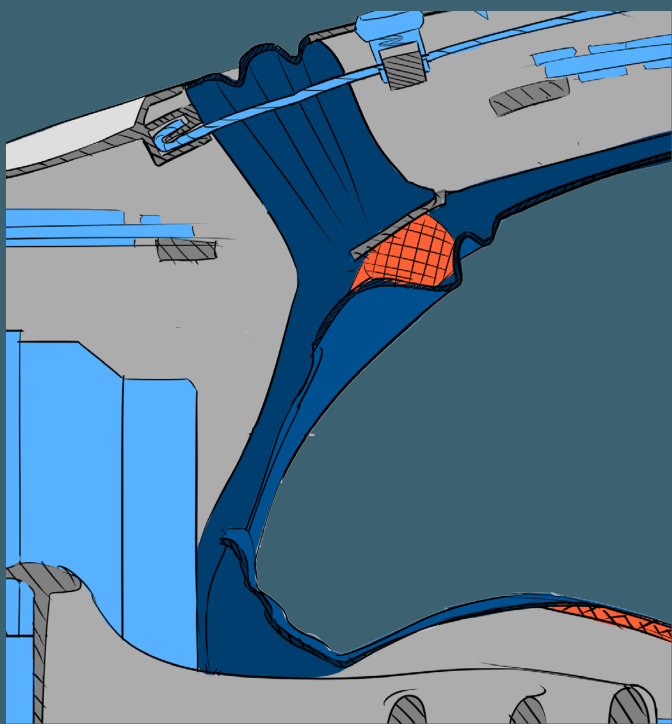


figure 6.16 Foam padding around eyes

dimensions this padding is only 5mm thick. In the final product a balance between more surface area for a softer fit or less surface area for better ventilation of the head should be found to optimize comfort. It is likely that due to the short usage period of 15 minutes the lack of ventilation of the head will not create major discomfort or other negative effects.

6.14 STANDARD COMPONENTS

Because the deliverable for this project is a concept design fit for rapid prototyping not all components will be specified to the point of final production. The design uses several standard components for mechanisms and assembly these components will be shortly described below.

As explained in the IPD mechanism paragraph the mechanism gives haptic feedback to the user when turning the adjustment knob, for this a standard knob component with haptic feedback should be used. The display of the IPD value could be in the form of digits and a pointer on the knob and casing if the knob only needs to turn 1 turn, for more a counting mechanism could be implemented in the casing.

The tightening mechanism uses a cable to connect the front and back, this cable could be similar to a bicycle brake lead ***figure 6.17*** Along with its tubing it could be held in place around the back of the casing without allowing any play in the mechanism. The chosen cable should allow the tightening mechanism to grip it and be rigid enough not to buckle in the non-covered part between the front and back, minimizing play in the mechanism.

figure 6.17 bicycle brake cable

Screws will be used to fix several components to the casing. All of the circuit boards, the speakers and the Inertiacube will be screwed on the inside of the casing to provide a secure fit, these screws bear a small load and are preferably short, this helps in the assembly. The service hatch at the bottom of the device allows the internal components to be accessed and removed. The service hatch is secured with four screws around the corners, these must be no longer than 4mm because of limited space inside the casing. Click connections would also be possible but these would most likely complicate the production and the process of replacing internal components. For the service hatch it would make the device harder to clean.

6.15 USER SAFETY

Because of the child users and the hospital environment, safety for the user is very important and regulations are very strict. The potential for the device to harm the patient or any other user should be minimal. Because this project concerns a wearable device for the head obvious concerns are the patient's hair getting stuck in the device or too much pressure being applied to certain points on the head. This design deals with those problems by minimizing seams or small gaps that could constrict the patient's hair. Furthermore the padded inside provides a comfortable fit of all patients within the user group. In case of trauma to the head of the patient, caused by the HMD or not it is important that the HMD is taken of as quickly as possible without further trauma being induced. Due to the simple tightening mechanism a simple push on the side buttons releases the tight fit and allows the HMD to be taken off with ease.
Overheating of the face could be a problem in the HMD, the ventilation grid in the bottom of the HMD should prevent this from causing trauma to the patient.

Along with the other hospital regulations this product should be tested and developed further beyond this short design process to assure that all regulations are met.

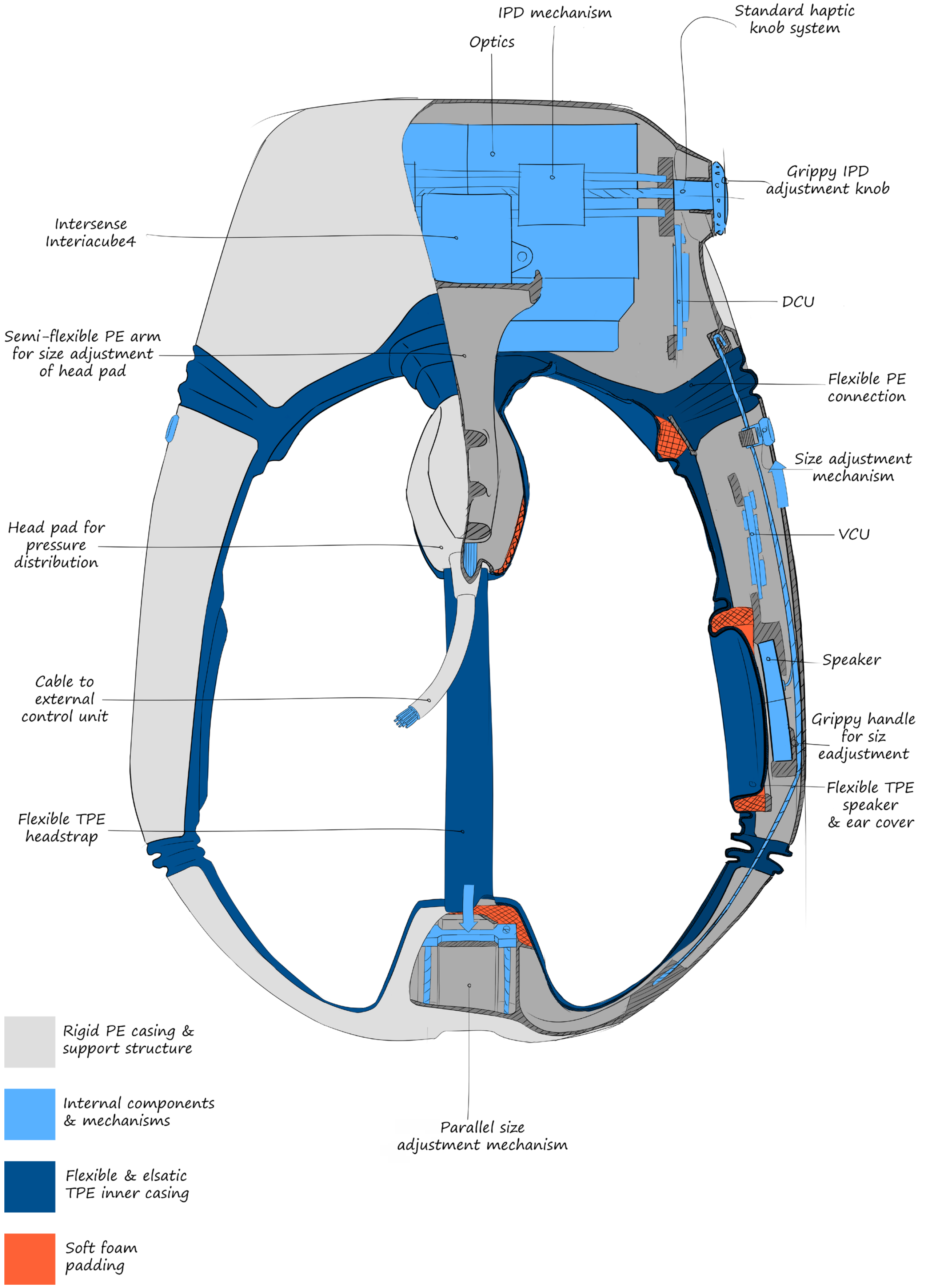


figure 6.18 Overview of final concept

7

PROTOTYPE

INTRODUCTION

In the modeling phase the final concept is transformed into a 3D model. For this assignment Solidworks is used to create this model. The goal of the model is to be turned into a functional prototype using 3D printing. The model is not fit for final production because important details like exact wall thicknesses, strengthening ribs and screw dimensions are missing. The need for these details will be discovered when working with the prototype and through finite element analysis performed on the 3D model. These details are not part of this assignment but recommendation on further development for final production will be made. Due to a lack of knowledge about the influencing parameters concerning the above named details it is also not possible to further investigate the values of these details.
This chapter describes the production of the prototype using the 3D model. Because the prototype was only created after this assignment it was not possible to write this chapter around the finished prototype.

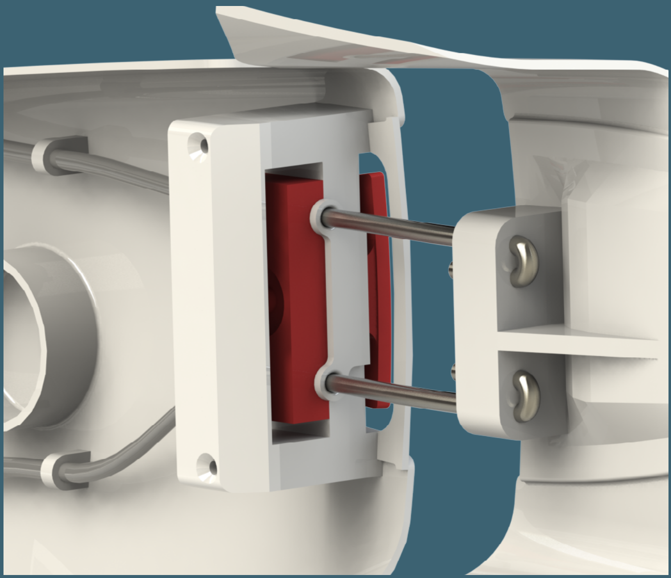


figure 7.1 screws in tightening mechanism

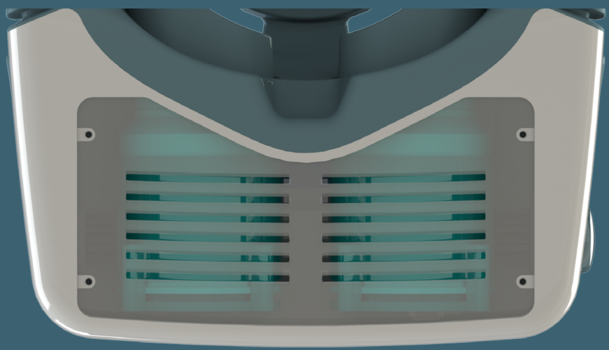


figure 7.2 screws in servicehatch

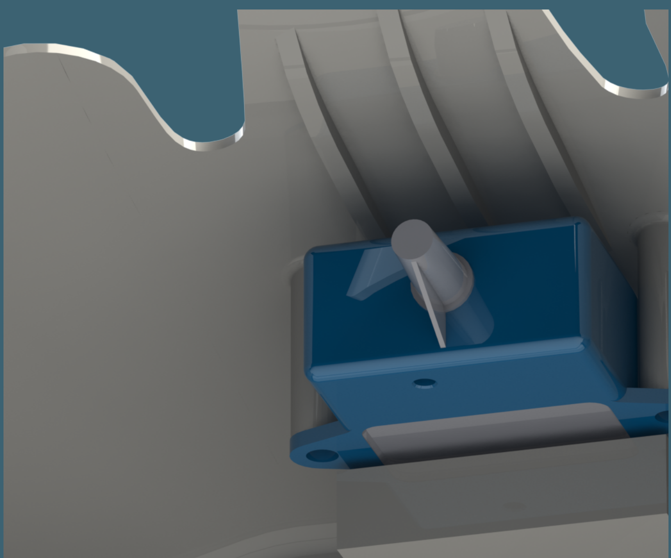


figure 7.3 screws in inertiacube

PROTOTYPE PRODUCTION

The first prototype will be produced through 3D printing technology. This gives a lot of freedom in designing the prototype because complex shapes can more easily be produced than with conventional production techniques. The prototype will still require some assembly. Recommendations for prototype production are described in this chapter.

7.1 PART PRODUCTION

For the prototype the four parts of the casing, the IPD knob, the service hatch and the parts for the size adjustment mechanism need to be printed. A full list of all parts with images can be found in Appendix D. These parts needs to have a wall thickness of at least 2mm to create strong enough parts this value has been concluded in a conversation with an expert at Cybermind. 3D printing allows for very complex products that cannot be made with conventional molding or casting techniques. To avoid the need for support material in the printing process the preferred manufacturing technique is selective laser sintering (SLS). The flexible inner casing will have to be printed using fused deposit modeling (FMD) because it is not possible to print flexible materials using SLS. Due to the geometry of the inner casing some support material will most likely be needed, to keep the outside smooth the Inner casing will be divided in a front and backside with a flat split line. This split line will be used as the starting point for printing, therefore the support material will be on the inside of the casing with the exception of some parts of the back straps. This support material needs to be removed after printing and will negatively affect the looks of the part.

7.2 SCREWS

Although 3D printed screw threads are possible they are often barely functional due to low strength of the printed material and large gaps between the threads. Therefore it is recommended to use straight hole and self-tapping screws to hold the part together. This technique has been applied to multiple Cybermind prototypes. The hole diameter should be M2, this provides a strong enough connection without taking up to much space in the casing. Screws will be used for the assembly of the tightening mechanism, the service hatch, the Inertiacube and the PCB's; ***figure 7.1***, ***figure 7.2*** & ***figure 7.3*** & ***figure 7.4***.

7.3 GLUE

The inner and outer casing will be fixed together using glue. These parts do not take allot of stress along their connection, glue will therefore suffice. The speakers will also be glued on. To stop the external cable from moving around in the head pad it is recommended to also glue the cable to the head pad. Before placement of the inner casing foam padding should be fixed to the outer casing using glue. Because glue complicates disassembly for repair or recycling it is preferred to use other techniques than glue, because of limited time these alternatives have not been explored, it is however recommended to further develop these aspects of the product to optimize production, repair and recycling.

7.4 FRICTION

The ends of the cables and the IPD adjustment knob will be held in place using friction and physically limiting geometry, ***figure 7.1*** & ***figure 7.5***.

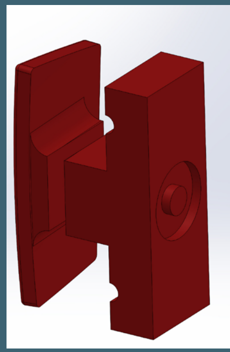


figure 7.4 tightening mechanism

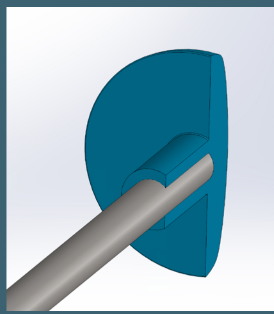


figure 7.5 IPD adjustment knob

7.5 ASSEMBLY

The order of the assembly is very important; the easiest order is to place the internal components first, ending with the optics and the IPD mechanism. The tightening cables should be placed before the speakers because the speakers cover up one of the guide holes for the cables. A strong spring should be added to apply pressure on the tightening cables; this spring should be added when screwing the bridge component to the outer casing ***figure 7.1***
When all internal components have been properly installed the flexible inner casing can be glued on, completing the assembly. A list of components can be found in ***Appendix D***. for an overview of the complete prototype see ***figure 7.6ab*** and ***Confidential appendix E***.

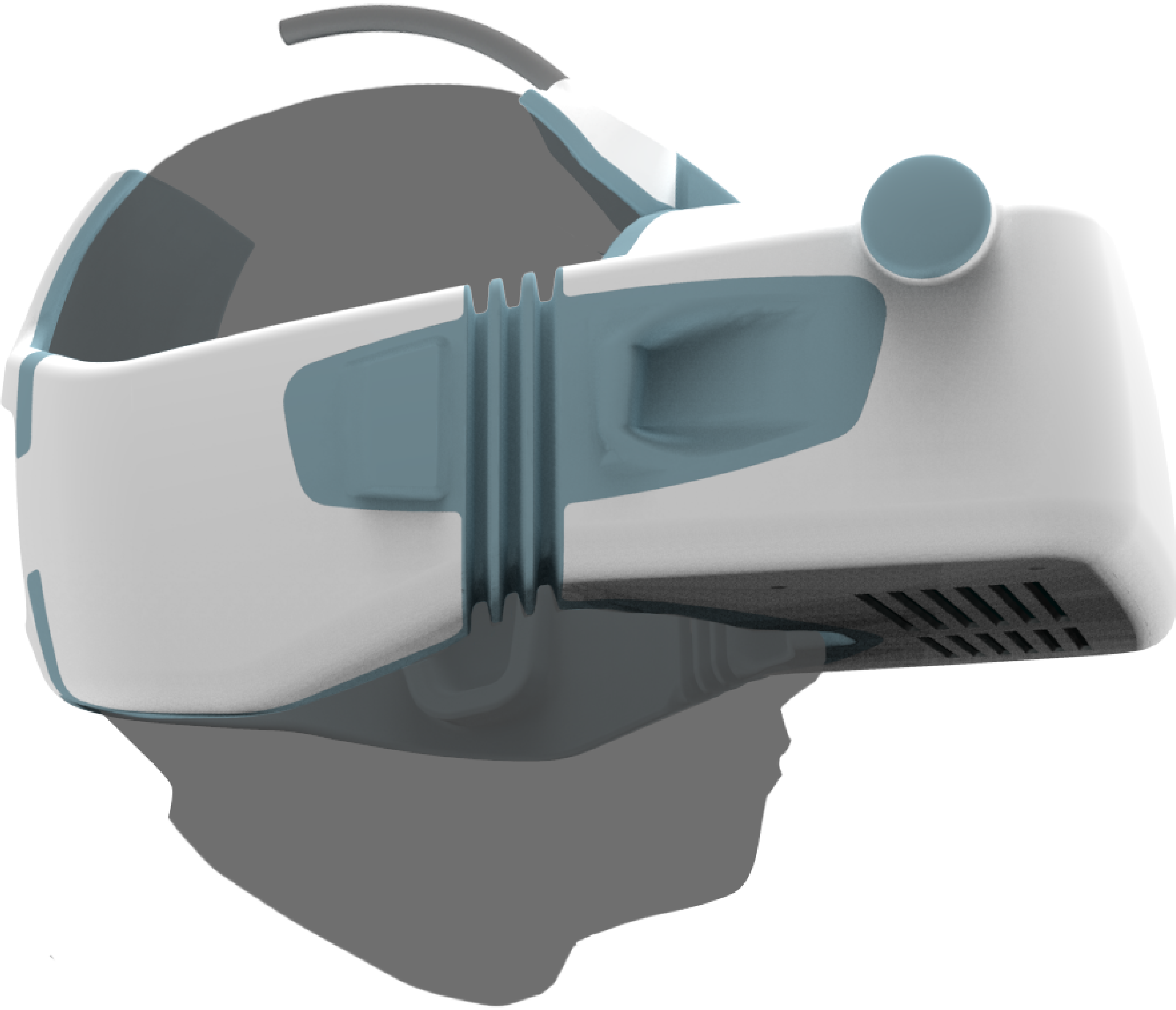


figure 7.6a Overview of final concept prototype with wearer

figure 7.6b Overview of final concept prototype top view

8. CONCLUSION

Throughout this assignment a concept has been created for a HMD specifically intended for hospital use. The concept design combines flexible and non-flexible materials to create an easy to clean and easy to use device that suits both the users and the environment. Because of the timespan of only 3 months the final product is a concept design that is not ready for final production. This is further elaborated on in the recommendations.

The final concept provides a possible solution for optimizing the treatment of burn children using VR. This design creates an advantage over the products currently available on the consumer and professional market. This advantage comes from a simpler usage scenario that is aimed at hospital personnel and children. The cleaning procedure is facilitated with the smooth and enclosed design. The styling of the design expresses its simple usage aspects and appeals to children with the soft shapes and light colors. This styling also fits in with the styling of most new hospital devices.

In the research phase the modularity of the design was an important aspect of the design process. The goal of modularity was to improve the usage scenario and cleaning procedure. In the concept phase it was found that the chosen form of modular design would form a production bottleneck and would add several complicated features to the design. Turning the modular design into a fixed design has simplified the production and usage scenario of the concept.

Looking back to the PoD this final concept satisfies almost all of the demands with the exception of the demands concerning modularity and demands that require testing of the concept before evaluation.
The production cost of this concept in its totality is very hard to estimate. The costs of the internal components are not known and because the concept needs further development the 3D models are also not ready for final cost estimation. A very rough estimate is a price of several hundreds of euros for production of the components that have been designed throughout this assignment.
Overall this assignment has proceeded on schedule and for the most part according to plan, this has led to a complete and detailed concept design fit for further development by Cybermind.

9. RECOMMENDATIONS

As was said in the conclusion the delivered concept is not fit for final production. For development of the concept to a final product there are a several recommendations. First it is important to test the prototype to its functioning and production. Here the focus should lie on production aspects of the final product, strength tests should be performed on the load bearing parts of the concept, and the goal of this is to optimize the casing to the desired strength with a minimal weight. The tightening mechanism should be tested to its usability and effective functioning and changed accordingly if necessary. The prototype and final product need to be certified; therefore the concept needs to be changed to meet all the standards and requirements of the medical industry. This research should focus on the materials of the HMD and user safety.

Next a functional prototype could be integrated in the hospital environment for further user testing. These tests should focus on the cleaning procedure of the HMD and the integration with the other devices and objects in the treatment room. Feedback of these user tests can be used to further develop the concept. By now the production procedure should be known for the most part, after processing the feedback of the user tests a more final production can begin.

10

REFERENCES

Braun. (sd). Braun Thermoscan user manual.

Brooks, A. (2012). Cognitive development in babies and children. Opgeroepen op april 2014, van kidspot.com.au: http://www.kidspot.com.au/discoverycentre/Joy-of-discovery-Development-Cognitive-development-in-babies-and-children+5357+553+article.htm
CES Edupack. (2013).

Disabled world. (2008). Height Chart of Men and Women in Different Countries. Opgehaald van disabled-world: http://www.disabled-world.com/artman/publish/height-chart.shtml

Dodgson, N. A. (2004). Variation and extrema of human interpupillary distance. Cambridge: University of Cambridge.

European Parlement, d. r. (2007, 9 21). RICHTLIJN 93/42/EEG VAN DE RAAD betreffende medische hulpmiddelen.

Gershenson, J., Prasad, G., & Allamneni, S. (1999). Modulare product design: a life cycle view. Journal of Integrted Design and Process Science.

Gladwin, R. (2014). trigeminal-nerve. Opgehaald van rahulgladwin: http://www.rahulgladwin.com/noteblog/neurology/trigeminal-nerve.php

Google. (2014). Project ara. Opgehaald van projectara.com: http://www.projectara.com/

Hoge Gezondheidsraad. (2009, December). Instrumentenzorg. Aanbevelingen i.v.m. de infectiebeheersing tijdens de verzorging buiten de verzorgingsinstellingen (thuisverzorging en/of op een kabinet).

InterSense, L. (sd). InertiaCube4™. Opgehaald van intersense.com: http://www.intersense.com/pages/18/234/

M. Willebrand, A. L.-A. (2004). Pruritus, personality traits and comping in long-term follow-up of burn-injured patients. Acta Derm Veneriol.

Mediprene. (2014). Mediprene 500M. Opgehaald van hexpoltpe.com: http://www.hexpoltpe.com/en/mediprene-s.htm

Mocoba. (sd). Mocoba ®. Opgehaald van mocoba.com: http://www.mocoba.com/public/home.html

nVis. (2013). About NVIS. Opgeroepen op mei 2014, van nivisinc.com: http://www.nvisinc.com/about.php

Parker, W. (sd). Measure your pupilary distance (PD). Opgehaald van pd.warbyparker.com: http://pd.warbyparker.com/

Ratner, B. D., Hoffman, A. S., Schoen, F. J., & Lemons, J. E. (2004). Biomaterials Science. London: Elsevier.

Steenbekkers, L. (1993). Child development, design implications and accident prevention. Delft: Delft University Press.

Strickland, J. (2007, June 29). How Virtual Reality Works. Opgehaald van How stuff works: http://electronics.howstuffworks.com/gadgets/other-gadgets/virtual-reality.htm

Werkgroep Infectiepreventie. (2009, juli). Beleid reiniging desinfectie en sterilisatie.

WhiteClouds. (sd). HIGH-DENSITY POLYETHYLENE (HDPE). Opgeroepen op april 2014, van whiteclouds.com: https://www.whiteclouds.com/3dpedia-index/high-density-polyethylene-hdpe

William. (sd). Design rules and detail resolution for SLS 3D printing. Opgehaald van shapeways.com: http://www.shapeways.com/tutorials/design_rules_for_3d_printi

APPENDIX

A

APPENDIX A.
DESIGN GUIDELINES

Several of the guidelines, principles and methodologies found on manufacturing applications of modularity which seem to be applicable to end usage. According to Ulrich & Tung (1991) modular design can be split in to two main characteristics; 1) the similarity between the physical and functional architecture of design and 2) Minimization of incidental interactions between physical components. Although this mostly applies to manufacturing of products with many components it might also be useful to the design for the end user. Minimizing relations between different subsystems of the product it becomes easier to create interchangeable parts because taking one part away will not influence the performance of other parts.

Gershenson, Prasad & Allamneni (1999) created an algorithmic model for modular design and a set of guidelines that can be extracted from the algorithm. Modular design is has the goal to create a design in which functional and physical independence are related to each other. It is a matter of minimizing dependences and similarities between modules and maximizing dependencies and similarities within modules. The guidelines to this process are comprised of four steps.

1. Eliminate unnecessary modules
2. If the whole module cannot be achieved then look to eliminate components within the module.
3. If elimination is impossible, then try to shift the components to other modules or into new modules to increase the overall modularity value.
4. If reconfiguration is not possible, redesign the attributes of the components to decrease or eliminate similarities or dependencies with outside components or increase similarities with components of the same module.

The input for this process is the outcome of the algorithm for calculating the modularity of the product. The steps above apply to the least modular module according to the algorithm. This cycle of steps is repeated until the highest total relative modularity (RM) is achieved.

The process of determining the RM of the system consists of calculating the similarities and dependences in and between modules in several steps.

The goal in this design methodology is to minimize the amount of modules and remove all unnecessary parts to eventually bring the design back to a minimally complex system. By making the system less complex the amount of interfaces decreases which improves the interchangeability of the system. These guidelines could be taken into account for production matters, by optimizing the modularity production cost and time can be reduced.

B

APPENDIX B.
PROGRAM OF DEMANDS AND WISHES

Function	Demand	Wish	Weight
	End usage		
Minimize the level of pain experienced by the patient during the treatment	The indicated level of pain during the treatment is reduced to 1/10th of the indicated pain withouth VR	the patient feels no pain during the treatment	
The HMD can be properly mounted on the user group of 8 to 16 year olds, male and female	The HMD should fit a minimum head breadth of 134mm and a maximum of 158mm*		5
	The HMD should fit a minimum head depth of 178mm and a maximum of 206mm*		5
	The HMD should fit a minimum head circumference of 510mm and a maximum of 591mm*		5
The patient should be able to lift the HMD	The necessary gripping force to hold and adjust the HMD should not exceed 100N**		4
The HMD rests on the head of the patient without exceeding comfort levels	The load of the HMD is distributed over points on the head most capable of taking loads	the load excerted by the HMD is thusfar low that the patient does not notice it.	5
	The HMD has contact points with the head that are comfortable to the wearer		4
the intended interaction with the HMD is made clear to the patient on his/her cognitive level.	The points of interaction (buttens, knobs etc.) must be clearly indicated on the device using a contrast in shape, color or material		3
The HMD has a child friendly design	The esthetic design is simple and has minimal distracting features such as complex shapes and buttons/knobs		3
The HMD does not intimidate the burn patient	The colorscheme of the device is calm & light; light colors, few different colors, low saturated colors		2
The HMD is useable within the burn patient's range of motion	Units for setting up the HMD must be as much in the front of the device as possible		1
The patient's range of motion is not limited by the HMD			3
The HMD allows the practitioner to verbally communicate with the patient	The patient must be able to understand what the practitioner says	the practitioner must be able to directly verbally communicate with the patient without interference of electronics	4
The HMD blocks out as much of the sounds of the surrounds as possible	The patient must not hear sounds from the surroundings		3
The HMD gives the practitioner insight in the settings of the devices and whether it fits the patient correctly or not.	The HMD shows the settings values to the practitioner		3
The HMD is a product fit for HBK both esthetically and functionally	The HMD is highly effective in creating an immersive experience for the patient		5
The HMD as part of the VR system can be integrated well in the hospital environment	Integration of the HMD in the hospital environment must have no need for changes to the HMD or already present hospital equipment		5
	The Presence of the HMD must not interfere with the already present and running systems and procedures in the hospital room		5
The VR system can easily be moved from one room to another for treatment on different patients	Moving the VR system must take no more than 5 minutes + traveling time at walking pace to the other room	The VR system can be instantly moved to another room without preceding procedures to prepare the system for transport	2
The HMD meets hospital regulations on hygiene and cleaning			
a) The parts of the HMD that come in direct contact with the patient can be whiped of with 70% ethanol	None of the parts of the HMD that come into contact with the 70% ethanol are damaged by the 70% ethanol		5
b) The parts of the HMD that come in direct contact with the patient can be sterilized at 134° Celsius	None of the parts of the HMD that are heated to 134° C are damaged by this		5
c) The external parts of the HMD can be manually disinfected with ease by the practitioner	All of the parts of the HMD that are manually cleaned are designed with minimal external seams, holes and geometric shapes in which dirt or other particles could get stuck in		4
The parts of the HMD that come in direct contact with the patient can be removed from the HMD for cleaning.	The parts of the HMD that come in direct contact with the patient must be able to be removed from the device for the cleaning procedure following each treatment		4
	The HMD has a minimal number of components that come into direct contact with the patient		3
The parts of the HMD that come in direct contact with the patient can be replaced with new parts to omit the cleaning procedure	The parts of the HMD that come in direct contact with the patient must be able to be replaced with new parts		3
	The parts of the HMD that come in direct contact with the patient must be able to be mass produced		3

	Replacable parts, parts that come in direct contact with the patient, must be very low cost		3
The HMD allows the user to adjust the size of the strap/band with ease according to its personal preferences	The size of the strap/band must be variable and adjustable by the user with no more than one action		3
The HMD allows the user to adjust the IPD with ease according to its personal preferences	The IPD value must be variable and adjustable by the user with no more than one action		3
The HMD allows the user to adjust the audio units with ease according to its personal preferences	The placement of the audio units must be variable and adjustable by the user with no more than one action		3
The HMD allows the user to adjust the diopter of the optics in the device with ease according to its personal preferences	The value of the diopter of the optics must be variable and adjustable by the user with no more than one action		3
The casing of the HMD keeps all the internal components in place throughout the life of the device	The casing must be physically fixed to all main internal components		4
	The casing must not allow internal components, that should not move, to move		4
The casing of the HMD allows internal components to be replaced with newer components with ease	The connection between the casing and the internal components must be removable		4
	Taking out an internal component must not take more than 3 actions		3
The motion tracker detects movement of and rotation of the user's head	The motion tracker must be placed parallel with the direction of the user's face		4
The casing allows all the internal components to be placed within it.	The casing must have space for all necessary internal components		5
The HMD create a strong immersion by being physically balanced on the user's head	The HMD's center of gravity must be as close as possible to that of the user's head		4
The HMD and externals do not limit the user's freedom of motion	The cables running from the HMD to the external components must not limit the user's freedom of motion		3
The casing creates immersion by blocking out the user's view of the immediate physical environment	The casing blocks out as much as possible of the user's view of the immediate physical environment		4
The esthetics of the HMD are congruent with those of the hospital room	The esthetics of the HMD must be congruent with those of the medical devices collage		2
Production			
The casing is fit for 3D printing processes	The casing is fit for 3D printing processes		2

Sources

C

APPENDIX C.
EXPERT INTERVIEW WITH LEUVEN

Interviewee: Head nurse & Kinesthesist at Burn center UZ Leuven
Interviewer: Cyriel van Oorschot

1. Where is the VR setup stored when not in use?
The VR setup is stored outside the treatment room for cleaning. The treatmentroom is the bed-/bathroom of the patient.

2. Who is responsible for setting up the VR setup, And when is it setup?
The installer is responsible for setup an monitoring of the VR setup. The VR setup enters the room after everyone else and leaves first because of its size.

3. How much space is there on and around the bed to place or hang equipment?
Currently the VR setup is on one side of the bed and the practitioner and his equipment on the other side.
On the ceiling hangs an arm with a computer/monitor installation.

The foot of the bed is free to be used for the VR setup, this is preferable because then the practitioner and head nurse can each have one side of the bed.

It is possible to lead the cable underneath the patient from HMD to external tablet.

A side table is another option for the external tablet to rest on.

4. How much space is there in the room in general?
The VR setup is on the door side of the room
Electrical interference with the other present devices does not happen as long as the VR setup does not wirelessly transmit information.

5. Is it possible to lead the cable from HMD to external tablet over the bed?
It is preferable to lead it underneath the patient from head to the foot of the bed.

6. Who is present during the treatment?
The installer: sets up the VR setup, the practitioner cannot do this due to sterility.
The Kinestesist: performs the exercises on the patient.
The nurse: monitors the patient's pain.

7. What steps are taken during the procedure and how is the VR setup involved?
Calibration, this used to take a long time however with the integration of the motion sensor this is no longer a problem. This saves alot of time. The calibrationbutton is preferable on the external tablet (the newer system already has this part integrated in the game user interface)

8. What interaction does the patient have with the HMD besides playing the VR game?
Mounting the HMD is done for the child, the child does have the tendency to grap the HMD.
It would be an improvement to show to the child in advance what is going to happen.

9. Is there any communication between the practitioner or installer and the child and how does this go wit hand without the HMD?
From time to time the child is asked something about the treatment of the game but the immersion is more important. The treatment procedure is verbally explained step by step.

10. What is the cleaning procedure for the electronic devices in the treatment room?
A foamspray for the devices. Disinfectioncloths in a jar are used for whiping clean the HMD and other devices. Cleaning only takes place after treatment.

11. Would usage instructions be usefull for the procedure?
It would be useful to keep the manual at hand for troubleshooting and cleaning procedures. Simple usage would also help.

Sidenotes:

- *It is not only about the distraction from the pain, the VR setup provides motivation to not be afraid. Fear for the treatment slows down the rehabilitation process. Which causes more stress in patients and more negative feeling on the long term*
- *Non-scientific Hypothesis from nurse: Anesthesia indirectly slows down the healing process: more anesthesia --> less sleep --> less hunger --> less calories --> delayed wound healing*
- *When the pain limit is exceeded the treatment is stopped.*
- *Problems with integration of VR in the hospital*
  - o *Not many mostly the cleaning procedure.*
  - o *People need to be trained to work with the VR setup this takes time and money.*
- *Pro's and Con's of VR*
- *Pro: distraction*
- *Con: naussia, lack of concentration because of pain therefore difficult to find a suitable game that is not to complex but does require attention.*

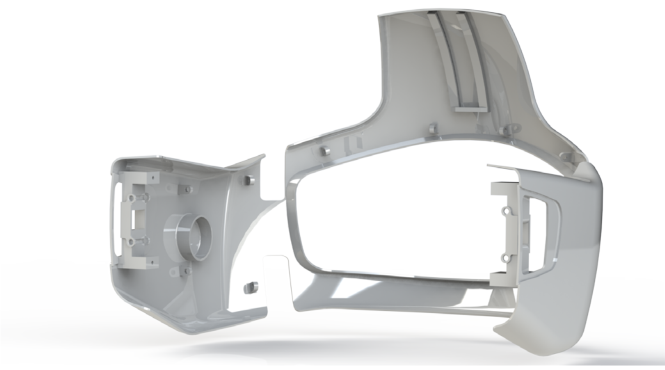
D

APPENDIX D.
PROTOTYPE COMPONENTS

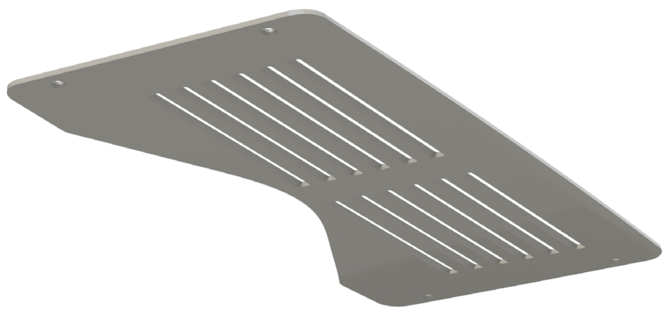
Casing

Outer casing front

Inner casing back

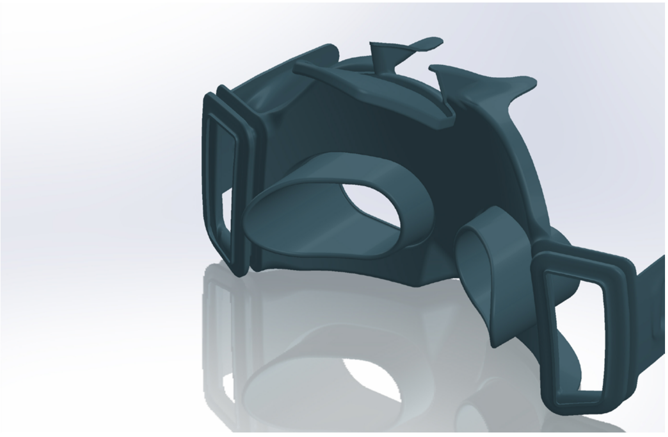


Outer casing back

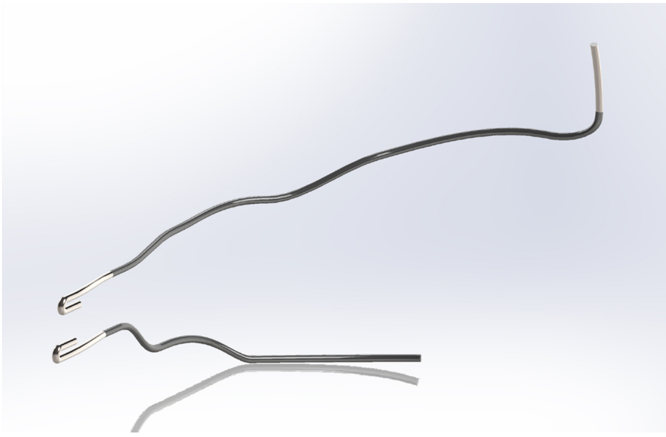


Servicehatch

Mechanisms

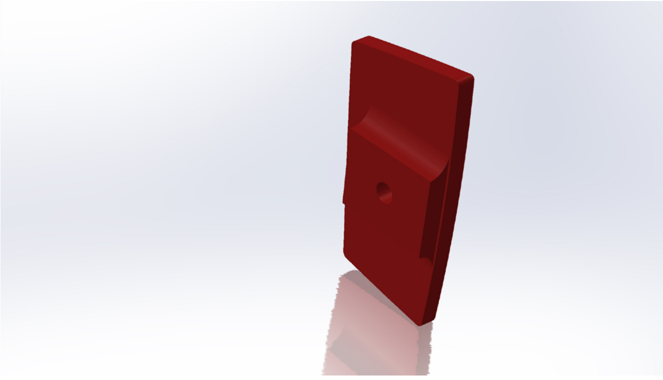


Inner casing front

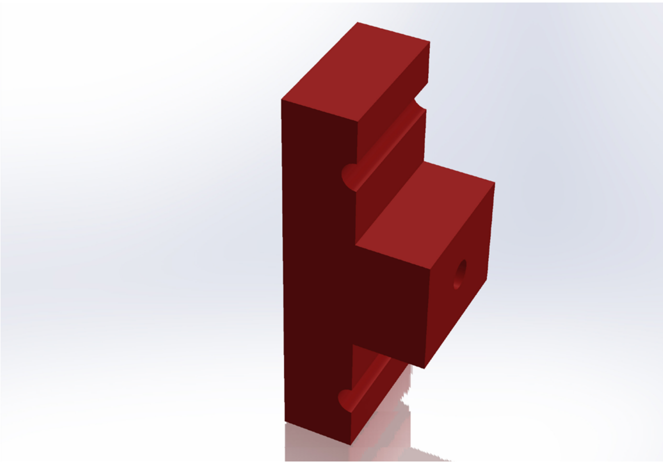


Tightening cable x2

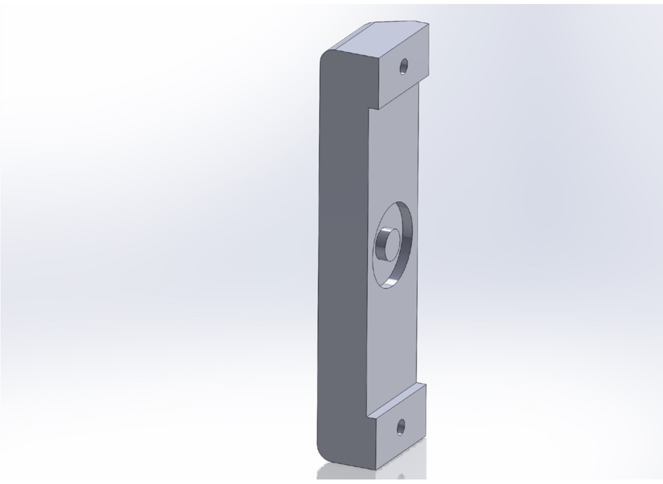
Tightening mechanism spring x2



Tightening mechanism button x2



Tightening mechanism moving part x2

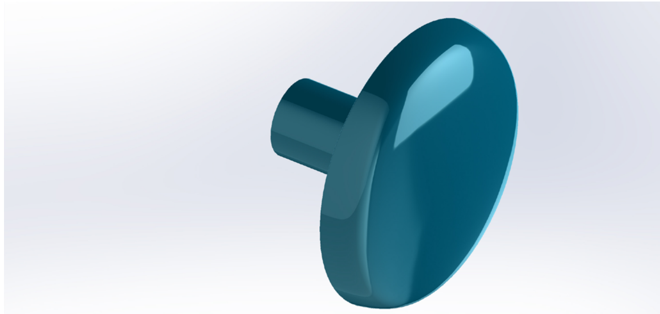


Tightening mechanism casing part x2

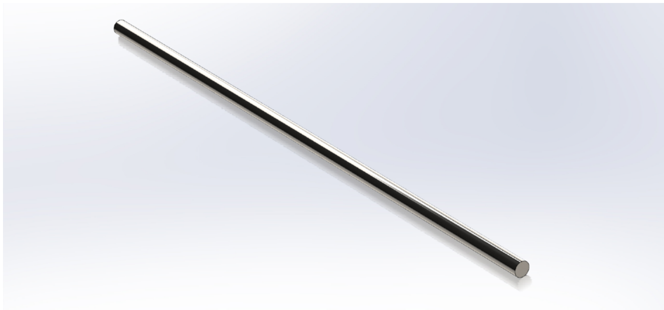
Assembly parts

Srews

Glue



IPD adjustment knob



IPD adjustment rod / Optics stabilization rods

Electronics

Inertiacube4

Cables & wires

Cable to external tablet