EOG-VR

ElectroOculoGraphy (EOG) Eye-Tracking for Virtual Reality

MASTER THESIS APPENDIX

1/7/2019

FEDERICO ALTOBELLI

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

Graduate Student

Federico Altobelli

Student number: 4624858
Address: Oude Delft 174, 2611 HH Delft, The Netherlands
University email: f.altobelli@student.tudelft.nl
Personal email: federicoaltobelli@hotmail.com
Phone: +39 345 591 1109

University

Delft University of Technology

Industrial Design Engineering
MSc Integrated Product Design

Supervisory team

Chair

Dr. Huysmans, T.

Toon Huysmans - Expert in Ergonomics
Department of Industrial Design - Applied Ergonomics & Design
t.huysmans@tudelft.nl

Mentor

Ing. Kooijman, A.

Adrie Kooijman - Expert in Mechatronics
Department of Design Engineering - Technical Support
a.kooijman@tudelft.nl

Appendix 1 Context

1.1 Market overview - Eye trackers in VR

Headsets integrating eye-tracking

HTC Vive Pro Eye

Tethered headset integrating eye-tracking

1700 € (with controllers and motion tracking accessories)

Fove

Tethered headset integrating eye-tracking

Not yet on the market - Expected to cost around 540 €

Samsung Exynos VR III

Tethered Headset integrating eye-tracking

Not yet on the market

Varjo

Tethered headset integrating eye-tracking

Not yet on the market

Qualcomm 845 VRDK Headset

Standalone headset integrating eye-tracking

Not yet on the market

Looxid Labs - LooxidVR

Smartphone-based headset integrating eye-tracking and EEG

~ 2700 €

Magic Leap

Tethered augmented reality headset integrating eye-tracking

~ 2050 €

Tobii Pro VR Integration

Modified version of tethered headset (HTC Vive) integrating eye-tracking

Non-commercial product

Sync Think - Eye-Sync

Modified version of smartphone-based headset (Samsung Gear VR) integrating eye-tracking

Non-commercial product

Eye-tracking add-ons for VR headsets

7invensun - aSee VR Eye Movement Analysis System

Add on for tethered headset (HTC Vive)

Not yet on the market - Expected to cost around 200 €

Pupil Labs - HTC Vive Binocular Add-on

Add on for tethered headset (HTC Vive)

1400 €

Visual Camp

Add on for unspecified tethered headset

Not yet on the market

Appendix 2 Research - The visual system

2.1 Taxonomy

Taxonomy by parts

The eye is composed by an anterior segment and a posterior segment.

The anterior segment is omposed of (from front to back order):

- Cornea
- Iris
- Ciliary body
- Lens

The cornea is linked to the larger, approximately spherical posterior segment, composed of (from outside to inside order):

- Sclera (layer)
- Choroid (layer)
- Retina (layer)
- Vitreous chamber

Taxonomy by layers

The eye is made up of three layers, enclosing various anatomical structures.

The outermost layer, known as the fibrous tunic, is composed of:

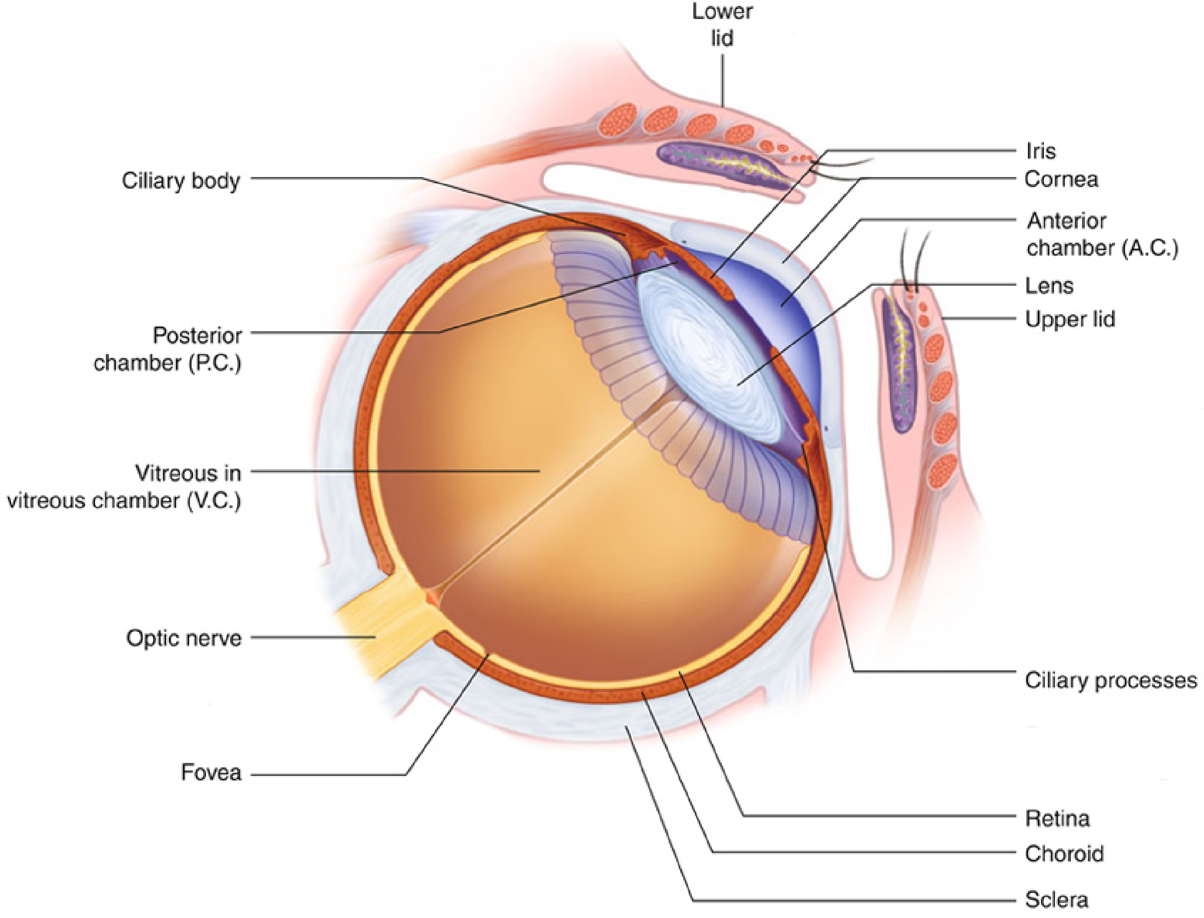
- Cornea / Limbus
- Sclera

The middle layer, known as the vascular tunic or uvea, consists of:

- Choroid
- Ciliary body
- Iris

The innermost layer is composed only by:

- Retina



Overview of eye parts (Ansari & Nadeem, 2016)

2.2 Average dimensions of the eyeball

Coronal section: ~ 24 mm

Transversal section: ~24.2 mm

Sagittal section: ~ 23.7 mm

Volume: ~ 6 cubic centimetres

Mass: ~ 7.5 grams

2.3 Description of parts

Sclera

The sclera is the white outer shell of the eye. It connects to the cornea by the limbus and provides also attachment for the extraocular muscles. The sclera is perforated by many blood vessels and by the optic nerve.

The thickness of the sclera varies from 1mm at the posterior pole to 0.3 mm at the frontmost part.

Cornea and limbus

The cornea is a transparent membrane that protects the iris and the lens, and also slightly focus the light rays. It is connected to the sclera; this circular connection area is called limbus. The cornea has the shape of the section of a sphere of about 11.5 mm in diameter, protruding of about 0.2 mm from the posterior segment.

Aqueous humour

Behind the cornea there is a transparent fluid called aqueous humour. It flows both in the anterior chamber (between the cornea and the iris) and in the posterior chamber (between the iris and the lens). Its main functions are to provide nutrients and oxygen to the surrounding tissues, and to generate a pressure that ensures the right geometrical configuration of the eyeball.

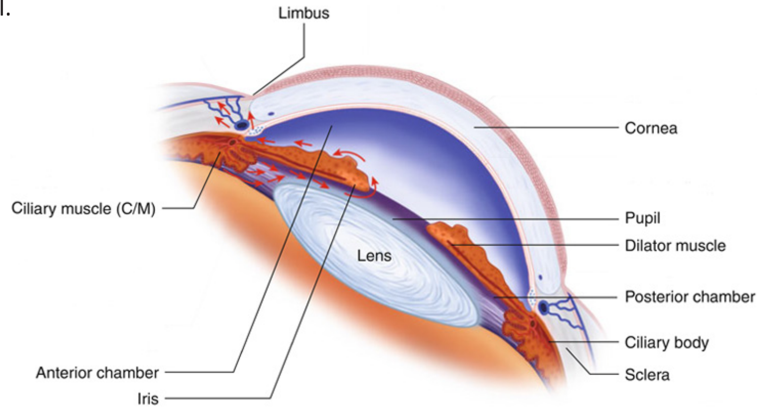
Iris and pupil

The iris is a pigmented circular structure covering the lens. The iris has a circular aperture in the center, called pupil, which regulates the amount of light coming into the lens and then reaching the retina. The size of the pupil (aperture) is regulated by concentric dilator muscles which can dilate or contract thanks to the Pupillary Light Reflex (PLR) to light. This mechanism is also part of the adaptation process of the eye to the intensity of environmental lighting. In fact, the size of the pupil increases up to 8 mm in diameter in the dark to let more light enter the eye; while it stays between 2 to 4 mm in diameter during normal daylight conditions.

Lens

Behind the iris and the pupil there is the lens (or crystalline lens), a transparent biconvex structure which can change its shape and curvature, in a process called accommodation, in order to bring to focus at the retina objects at different distances.

Detail of the anterior segment (Ansari & Nadeem, 2016)



Vitreous chamber

Between the lens and the back of the eye there is the vitreous chamber, also known as vitreous body. This approximately spherical chamber is filled with the vitreous humor, a transparent gel-like substance mainly composed of water. Its main function is to support the surrounding parts and layers of the eye.

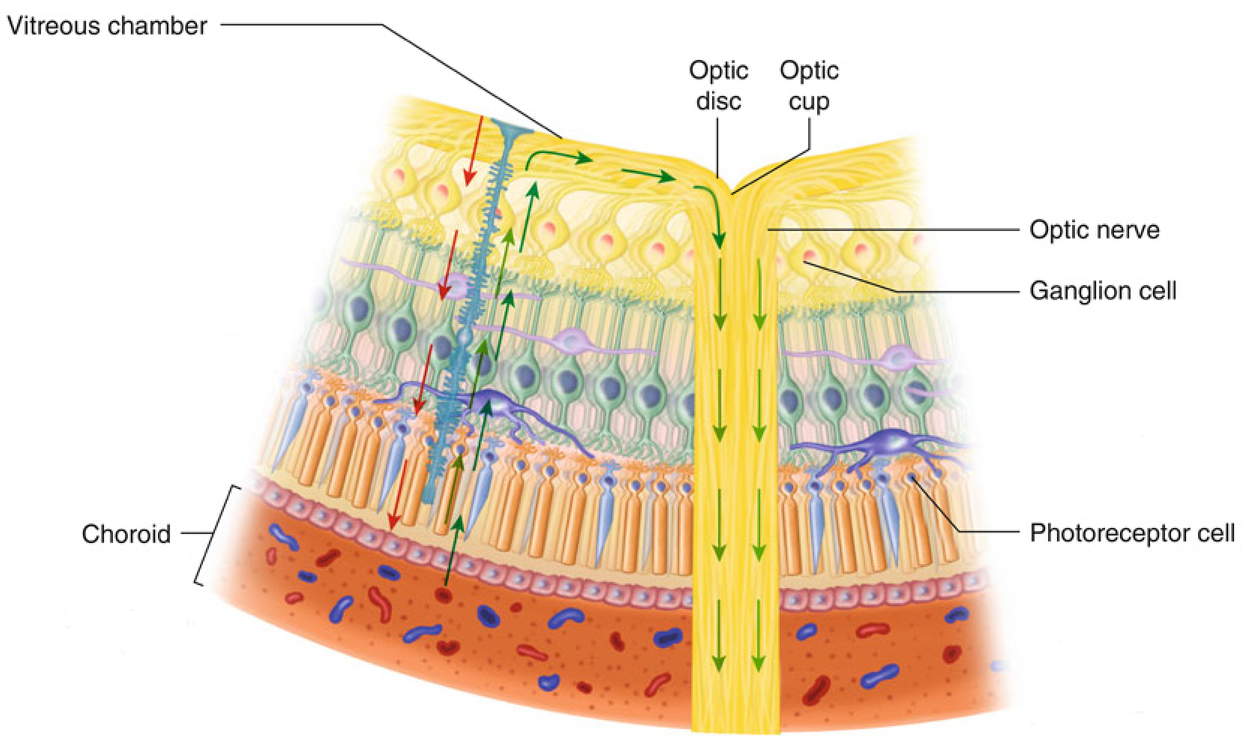
Choroid

The choroid is the layer of the eye lying between the sclera and the retina. Its function is to provide nutrients and oxygen to the retina. The choroid is thickest at the back of the eye (at 0.2 mm), and it narrows to 0.1 mm at the front.

Retina

The retina is the innermost layer of the eye which translates images into electrical neural impulses thanks to several layers of photosensitive cells (photoreceptors) and neural cells (neurons), connected by synapses, and mostly concentrated at the back. When excited by light, the photoceptors sends proportional outputs that are pre-processed by the neural cells and then transmitted to the brain through the optic nerve.

The collective activity of the retina sets up a potential field in the surrounding volume of the eye. This potential field, called corneo-retinal potential behaves as a dipole oriented from the retina (negative) approximately at the optic disk, to the center of the cornea (positive).



Detail section of the retina and the choroid (Ansari & Nadeem, 2016)

Photoreceptors

Specifically, the photoreceptors are of three types, differing in function, quantity and distribution on the retina.

- Cones
- Rods
- Photosensitive ganglion cells

Cones

Cones and rods contribute to image vision. The cones work best at bright light (as daylight), being less sensitive in the dark. They allow the perception of details, colours and rapid changes in images (photopic vision). Cones are of three types, each of them being sensitive to a different wavelength interval of the visible light spectrum (trichromatic vision). The signals of the different kinds of cones are interpreted by the brain as colours (blue green and red). Cones are more concentrated at the center of the retina (aligned with the optic axis) and produce detailed coloured central vision.

Rods

Rods are more sensitive in dim light and to movements, but have no role in colour vision. They allow monochromatic low-resolution vision in dark environments (scotopic vision). Rods are more concentrated at the outer edges of the retina and mostly contribute to peripheral vision.

In normal illumination conditions both cones and rods are contributing to image vision (mesopic vision).

Photosensitive ganglion cells

Photosensitive ganglion cells do not contribute directly to image vision, but provide information on the intensity of environmental illumination. This information is processed by the brain in order to regulate pupil size (Pupillary Light Reflex, part of the adaptation process) and control the production of melatonin, the hormone which regulates circadian rhythms.

Macula and fovea

The macula is a pigmented area near the center (aligned with the optic axis) of the retina with a high concentration of photoreceptors (mainly cones), thus responsible for the detailed coloured central vision. It has an oval shape of a diameter around 5.5 mm.

The central region of the macula is called the fovea. The fovea holds a large concentration (around 4000) of cones, and thus produces the highest detailed area of vision, corresponding to the central 0.6 deg to 1 deg of visual angle.

Optic disc

The optic disc, also known as optic nerve head or optic papilla, is a point of the retina where the nerve fibres of the retinal neurons come together, becoming the optic nerve, and leave the eye towards the brain. The optic disc is also the entry point for the blood vessels that supply the retina.

The optic disk is placed 3 to 4 mm medially from the fovea. It appears as a vertical oval area with a diameter of about 2 mm. In this area there are no photoreceptors, this corresponds to a small blind spot for each eye.

Optic nerve

The optic nerve is a beam of retinal neurons nerve fibres which transmits information produced from the retina to the brain. After perforating the layers of the eye at the optic disc, the optic nerve merges at the optic chiasm, where nerve fibres invert (left becomes right, and vice-versa), and then connect to three areas of the brain.

Brain

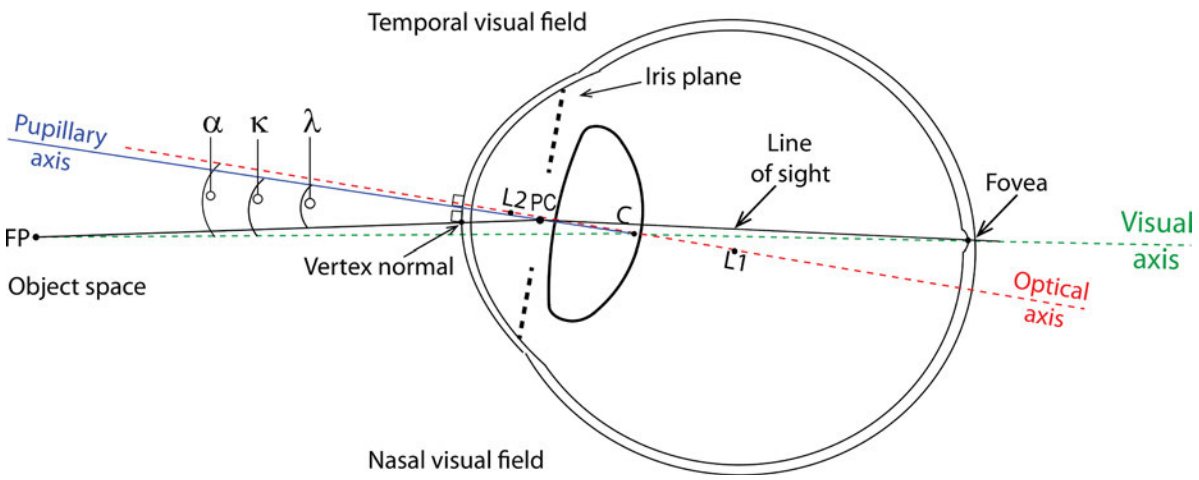
The brain carries out a number of complex tasks, including:

- Monocular perception
- Build-up of the binocular perception from the pair of monocular views
- Identification and categorization of visual objects
- Assessing distances
- Guiding body movements in relation to the objects in the surroundings

2.4 Centres of the optical elements of the eye

Since the parts of the eye are not exactly spherical, each optical element has its own geometrical center, center of curvature and optical axis. Moreover, these centres and axes are constantly displacing their location by one or two millimetres due to accelerations of the head and deformations of the parts of the eye itself. The centres of the optical elements of the eyes are:

- C - Center of curvature of the cornea (the cornea is so thin that the centres of curvature of the anterior and posterior surfaces are practically identical)
- PC - Geometrical center of the pupil (aperture of the iris). It varies in location as a result of fluctuations of the diameter of the iris (Nowakowski et al., 2012)
- L1 - Center of curvature of the anterior surface of the lens / L2 - Center of curvature of the posterior surface of the lens



Centres and axes of the eye (Nowakowski et al., 2012)

Optical axis

The line passing through the centres of the refractive elements of the eye:

- Center of curvature of the cornea (C)
- Center of curvature of the anterior surface of the lens (L1)
- Center of curvature of the posterior surface of the lens (L2)

Since these points are not perfectly aligned, the optical axis is as a line of “best fit”. Moreover, the optical axis divides horizontally the retina in two parts, the nasal side, and the temporal side, this last contains the fovea.

Visual axis

The visual axis represents the true path of light that comes from the fixation point and hits the fovea.

- Fixation Point (FP)
- Center of curvature of the cornea (C)
- Center of the fovea

A good approximation (for eye-tracking) is the line that connects the Fixation Point (FP) and the Center of the fovea.

Line of Sight (LoS)

The Line of Sight (LoS) is a broken line that joins:

- Fixation Point (FP)
- Pupil Center (PC)
- Center of the fovea

Pupillary Axis (PA)

The line through the Pupillary Center (PC) and the Center of the cornea (C)-

The PA and the optical axis are almost identical: they are displaced of maximum 0.5 mm, accordingly to pupil dilatation (Nowakowski et al., 2012).

Angles

According to Nowakowski et al. (2012) these are the definitions of the angles between the axes.

- Lambda (λ): the angle between the Pupillary Axis and the Line of Sight. Its values vary between +1.4° and +9° horizontally, with the PA temporal to the LoS.
- Alpha (α): the angle between the Optical axis and the Visual axis. The Visual axis is typically nasal to the Optical axis, with values that vary horizontally between +17° to -2°. It is often assumed to be about +5° (horizontally). Vertically the Visual axis is declined relative to the Optical axis by 2° to 3°.
- Kappa (κ): the angle between the Pupillary Axis and the Visual axis. The PA is temporal to the Visual axis.

2.5 Eye rotations terminology

All the following terminology is considered with respect to the subject.

Monocular eye movements

Movements of a single eye alone are called Ductions

Horizontal single eye movements

The terminology for horizontal rotations is symmetric.

- Outwards or Lateral (away from the medial line) - Abduction
- Inwards or Medial (towards the medial line) - Adduction

Vertical single eye movements

- Upwards - Supraduction or Elevation
- Downwards - Infraduction or Depression

Oblique rotations

Oblique rotations are a combination of horizontal and vertical rotations.

Torsional single eye rotations

Torsional eye movements are rotation movements of the eye about the line of gaze, and they are generally limited to angles of less than 10 deg.

Vertical (thus also oblique) eye movements may also have a small torsional component caused by the fact that vertical rotations are assisted by the two (superior and inferior) oblique extraocular muscles.

- Upper cornea of the eye rotates towards the medial line (medially) - Incyclotorsion or Intorsion
- Upper cornea of the eye rotates away from the medial line (laterally) - Excyclotorsion or Extorsion

Conjugate eye movements

Parallel equal Ductions of the eyes are called Versions.

Horizontal conjugate eye movements

- Gaze to the right - Dextroversion (Right eye abducted - Left eye adducted)
- Gaze to the left - Laevoversion (Right eye adducted - Left eye abducted)

Vertical conjugate eye movements

- Upgaze - Supraversion
- Downgaze - Infraversion

Torsional conjugate eye movements

- Dextrocycloversion - Right eye extorsion - Left eye intorsion
- Laevocycloversion - Right eye intorsion - Left eye extorsion

Disconjugate eye movements

Opposite equal (symmetric) Ductions of the eyes are called Vergences.

Horizontal disconjugate eye movements

- Convergence - both eyes adducted (Far-to-near)
- Divergence - both eyes abducted (Near-to-far)

Vertical disconjugate eye movements

Vertical disconjugate eye movements are not naturally possible without the presence of a disorder of the oculomotor system

Torsional disconjugate eye movements

- Incyclovergence - both eyes intorsion
- Excyclovergence - both eyes extorsion

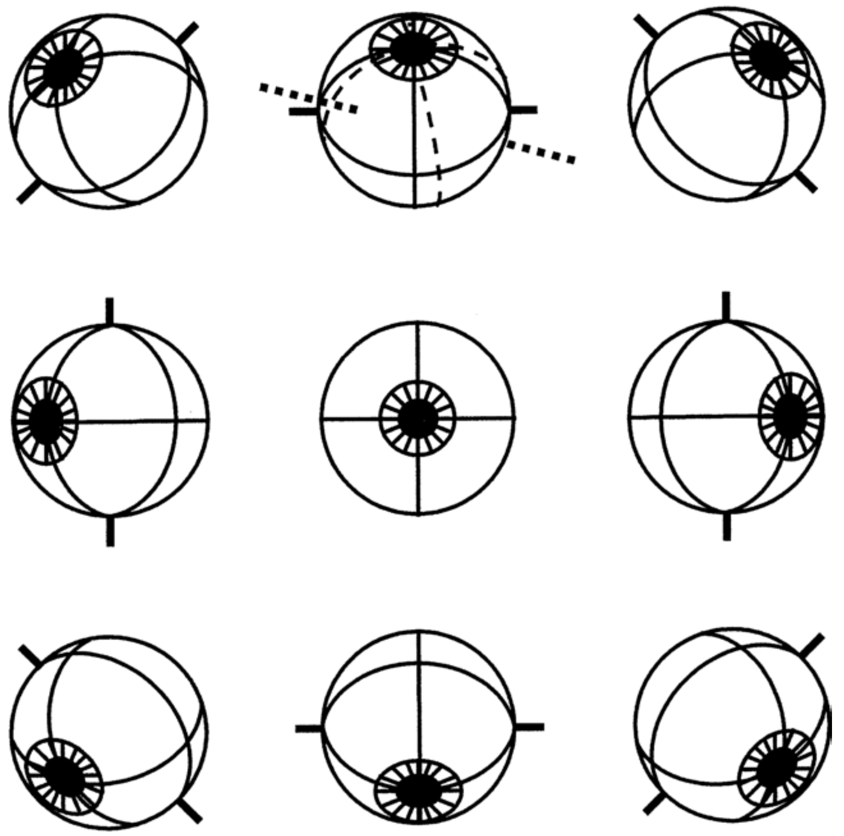
2.6 Primary position of the eyes and Listing's law

In theory, for any gaze direction the eye could assume an infinite number of torsional positions. In reality, Donders (1848) observed that the torsional component is specific to each gaze direction, independently on how the eye reached that particular gaze direction. He also observed that the eyes do not tilt (gain a torsional component) at rotations along a single axis (horizontal or vertical), and tilt only at tertiary positions of gaze (i.e., right-up, right-down, left-up, or left-down). In short, Donders' law states that for any gaze direction, the eye always assumes the same unique orientation in 3 dimensions, but it does not specify what the torsional angle is. During 1855, Listing quantitatively defined the specific torsional angle for the eye orientations.

Listing's law states that the eye achieves all possible 3D orientations by starting from one specific primary position (orientation) and then rotating about an axis that lies within the plane orthogonal to the Line of Sight of the primary position. This plane is called Listing's plane.

According to Wong (2004), the primary position defined in Listing's law is not synonymous with the primary position used clinically. In fact, the primary position used clinically refers to the straight-ahead gaze position and roughly corresponds to the center of the ocular motor range.

The expression of Listing's law can be simplified by creating a coordinate system where the origin is primary position, the vertical and horizontal axes of rotation are aligned in Listing's plane, and the third (torsional) axis is orthogonal to Listing's plane.



Visual representation of the Listing's law (Wong, 2004)

Appendix 3 Research - Eye tracking methods

According to Duchowski (2017), there are three main categories of eye movement measurement methods.

- Scleral contact lens search coils
- ElectroOculoGraphy (EOG)
- Image/camera-based methods, which include Photo/Video-OculoGraphy (POG / VOG), and pupil-corneal reflection.

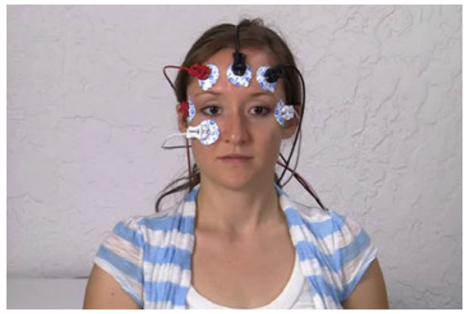
Furthermore, Morimoto & Mimica (2005) sort eye tracking methods into remote and intrusive techniques. Remote techniques are mostly camera-based, but can be intrusive if they require to be head mounted. Intrusive methods require the equipment to be put in physical contact with the user. These techniques include, for example, contact lenses, electrodes (EOG), and all Head Mounted Devices (HMDs).

This chapter reviews the principal methods for eye-tracking, explaining their principle of operation and their primary advantages and disadvantages.

Since scleral contact lens search coils method is extremely intrusive and rather out-dated (it was mainly in use for experiments on animals), its review was moved in the Appendix 2b.1 . Camera-based methods are reviewed in the following paragraph, but only EOG is discussed in detail.

(www.chronos-vision.de)

Dikablis Glasses 3 (www.ergoneers.com)



(www.youtube.com/user/BiopacSystems)

3.1 Image/camera-based methods - PhotoOculoGraphy (POG), VideoOculoGraphy (VOG) and Pupil-Corneal Reflection

Image-based tracking methods use a setup of cameras, optical or photosensitive devices and multiple illuminators to record eye movements. The eye gaze position is then estimated trough image processing software.

POG and VOG methods detect and track some distinguishable features of the eyes, typically the position and shape of the pupil and limbus (darker external ring of the iris). Often Infra-red (IR) cameras are used to increase the contrast between the pupil and the iris (see picture below-left).

The pupil and the limbus appear elliptical when viewed other than along the optic axis (see picture below-right), the ellipse eccentricity serve as a basis for eye angle measurement (Young & Sheena, 1975).

Some techniques exploit the reflections of fixated points from the four different layers of the eye structure. These four reflexes are called Purkinje images. The first Purkinje image from the external surface of the cornea is also known as corneal reflection. It is the most used because it is the brightest and easiest to detect and track.

A light source (usually infrared for the reason that it is invisible to the human eye, and hence non-distracting) is projected to the eyes. Its first Purkinje image looks like a dot, named “glint”. Approximating the eye as a sphere that rotates around its center, the position of the glint is constant during eye rotation, and therefore can be used as a reference point. The position and shape of the pupil and limbus is then measured relatively to the glint. Based on this information, and with an appropriate calibration procedure, these systems are capable of measuring the user gaze point.

According to Duchowski (2017), the above techniques are suitable for measuring eye movement but they provide the gaze point only in setups where the head is fixed. Head tracking must be used to disambiguate eye rotations from head movements.

Such a setup can be positioned on a desk in front of the user to track their eye gaze point relatively to a surface (usually a screen).

Another option is to integrate the setup on a Head-Mounted System to give freedom to the user to move in the surroundings. With head tracking and an additional outward-facing camera it is possible to record videos that combine eye-tracking data overlays.

Characteristics

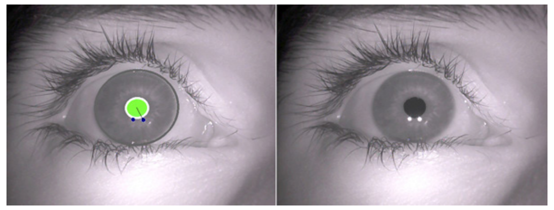
- Spatial resolution: up to 0.1 degrees
- Temporal resolution: up to 4000Hz

Advantages

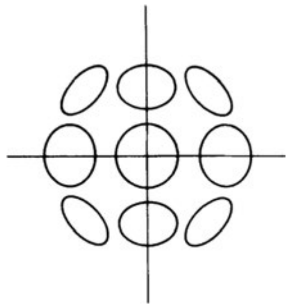
- Non-invasive

Disadvantages

- The necessity of using multiple cameras make these systems complex and expensive
- Blinking can cause false measurements
- It is highly dependent on the lighting conditions of the surroundings: reflexes on the eye from other illumination sources other lights can cause false measurements.
- Eyelashes and prescription glasses can occlude the view of the cameras.
- Dry eyes can create artefacts reflections.



The reflection glint is used as a reference (Drewes & Schmidt, 2007)



Shape of the pupil at different positions (Young & Sheena, 1975)

3.2 Scleral contact lens search coil

The subject wears a pair contact lenses that embed small search coils connected to electronic instrumentation trough wires that extend from the lens.

The subject sits inside a set of other large coils that generate electromagnetic fields. These fields induce voltages on the search coils proportionally to the angle between the plane of the search eye coil and the one of the magnetic fields. It is possible to estimate the x and y orientation components of the eye from the magnitudes of the received voltage signals.

A first version of this system is described by Robinson (1963) and improved by Collewijn et al. (1975).

Variations include one or two search coils on the lens and from one to three generated magnetic fields. By having a second search coil it is also possible to deduce the amount of torsional rotation about the Line of Sight. By increasing to up to three pairs of magnetic fields coils it also possible to derive eye orientation in the three dimensions.

Additional measurements need to be performed to know eye orientation in the head. Head orientation must be mapped to space coordinates and eye orientation to coil coordinates. To do this, the head must be rigidly fixed in space relative to the magnetic fields, or a separate set of search coils must be affixed to the head or a bite bar to track head movements, so that the coil signals can provide accurate coil-in-head information.

Characteristics

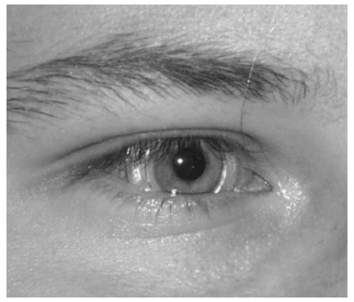
- Spatial resolution: up to 0.08 degrees

Advantages

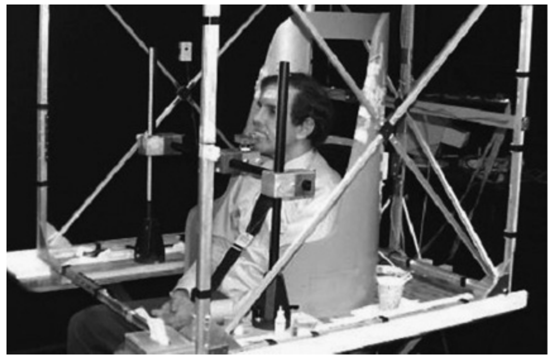
- Works in any illumination conditions
- Measures while eyelids are closed

Disadvantages

- Electrical wire connecting the eye coil are source of discomfort and slippage of the lens. They also break frequently
- Need to apply an anaesthetic before application of the lenses which may cause blurring of vision
- Since the lens limits the exchange of fluids across the surface of the eye, its use is typically limited to 1 hour
- External magnetic fields can interfere with the signals
- The large cubical frame that holds the field coils ranges in width from 1 to 2 m making it not suitable for portable applications
- Small or no freedom to the head



Contact ens search coil on the eye



Scleral contact lens search coil setup

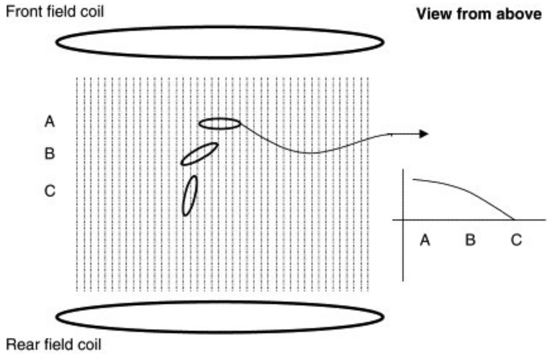


Illustration of a lens search coil in a magnetic field

All pictures (Shelhamer & Roberts, 2010)

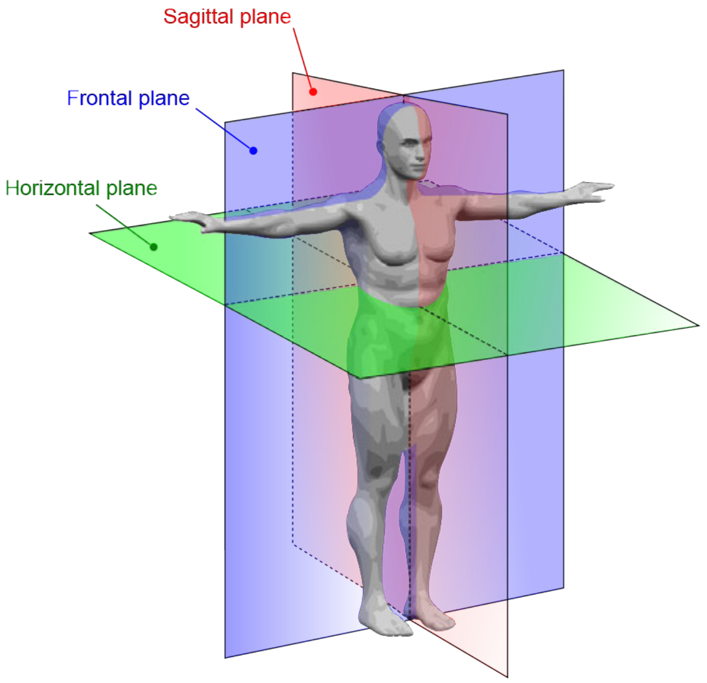
Appendix 6 Anthropometric study

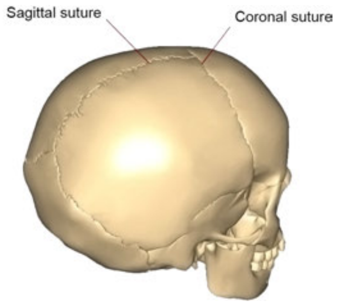
6.1 Anatomical planes and axes relative to the body, the head and the eye

Anatomical planes and axes of the body

An anatomical plane is a hypothetical plane used to transect the human body, in order to describe the location of structures or the direction of movements. In human anatomy, three principal planes are used:

The following terms are defined in reference to a human being in the upright orientation (standing), the underlined synonyms will be used in the rest of the report.





(www.wikipedia.org)

Name and synonyms	Parallel/Perpendicular	Fundamental plane	Separates
Sagittal Longitudinal Anteroposterior	Perpendicular to the ground and parallel to the sagittal suture of the cranium	**Midsagittal**	Separates the left side from the right side
Frontal Coronal Vertical	Perpendicular to the ground and parallel to the coronal suture of the cranium	Midcoronal plane	Separates the anterior/ventral from the posterior/dorsal
Horizontal Transverse Axial	Parallel to the ground	Umbilical plane	Separates the superior/ cranial from inferior/ caudal

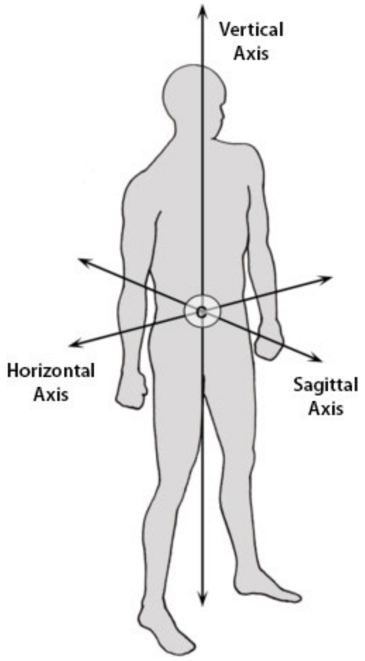
Midsagittal plane

The most relevant fundamental plane for this project is the midsagittal plane, which is the sagittal plane that ideally divides the body into left and right sides. It passes by the navel and the spine. Any sagittal plane other than the midsagittal plane is called parasagittal.

Axes of the body

The axes perpendicular to the anatomical planes are used to define a coordinate system, which origin can be chosen for a specific purpose.

Name of the axis	Direction	Perpendicular to	Intersection of
Horizontal Transverse	From side to side	Sagittal plane	Frontal/Transverse
Sagittal	Anteroposterior (from front to back or vice versa)	Frontal plane	Sagittal/Horizontal
Vertical Longitudinal	Craniocaudal (from superior to inferior or vice-versa)	Horizontal plane The ground plane	Sagittal/Frontal



(www.crossfit.com)

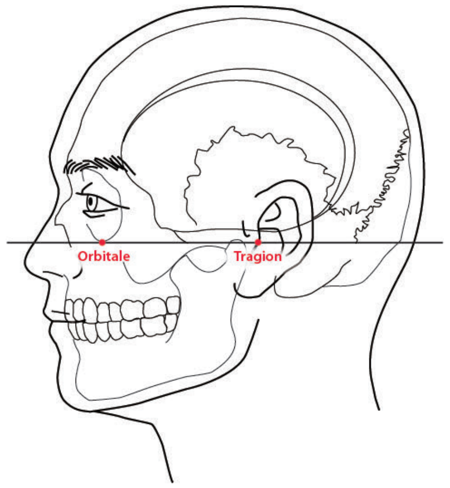
6.2 Planes of the body relative to head and eye components

Frankfort Plane

The Frankfort plane is defined by initially identifying the Frankfort line. The Frankfort line is the projection on the midsagittal plane along the horizontal axis of an imaginary line that connects the tragion(s) with the orbitale(s). The Frankfort plane is the projection of the Frankfort line along the horizontal axis.

Rest position of the head

The Frankfort plane is defined by initially identifying the Frankfort line. The Frankfort line is the projection on the midsagittal plane along the horizontal axis of an imaginary line that connects the tragion(s) with the orbitale(s). The Frankfort plane is the projection of the Frankfort line along the horizontal axis.



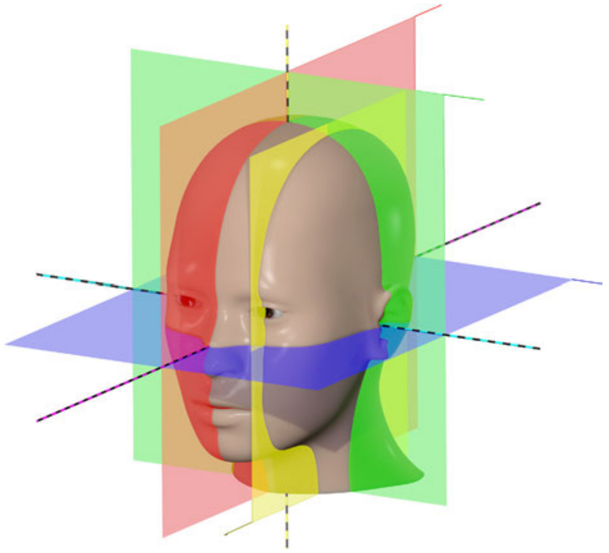
Frankfort plane (Ball, 2011)

Planes relative to the eyes

Other relevant planes relative to the eyes are:

- Parasagittal planes passing through the center of the pupil of both eyes
- Plane parallel to the Frankfort plane passing through the center of the pupil

  Ideally (symmetrical face) there is only one plane for both eyes



(www.courses.lumenlearning.com)

Appendix 8 User tests

8.1 Video stimuli description

1) Horizontal Steps Center Right - 2) Horizontal Steps Center Left - 3) Vertical Steps Center Bottom - 4) Vertical Steps Center Bottom

- Evaluate the EOG signals during saccades towards one side at a time (left, right, top, bottom)
- Evaluate the positivity or negativity of the signal respect to each side
- Evaluate the effect of increasing angles of rotation

1. The point alternates CENTER and RIGHT at each repetition the point will move one step further

   Start 0:08.00 - End 0:18.30 - Duration 0:10.30

2. The point alternates CENTER and LEFT at each repetition the point will move one step further

   Start 0:26.00 - End 0:36.30 - Duration 0:10.30

3. The point alternates CENTER, and TOP at each repetition the point will move one step further

   Start 0:44.20 - End 0:50.10 - Duration 0:05.90

4. The point alternates CENTER and BOTTOM at each repetition the point will move one step further

   Start 0:58.10 - End 1:04.00 - Duration 0:05.90

5) Horizontal Steps Center Alternate - 6) Vertical Steps Center Alternate

- Evaluate the EOG signals during saccades from side to side, passing to the center
- Evaluate the effect of increasing angles of rotation

5. The point alternates CENTER, RIGHT and LEFT at each repetition the point will move one step further

   Start 1:11.20 - End 1:32.10 - Duration 0:20.90

6. The point alternates CENTER, TOP and BOTTOM at each repetition the point will move one step further

   Start 1:40.10 - End 1:49.30 - Duration 0:09.20

7) Horizontal Steps NOCenter Alternate - 8) Vertical Steps NOCenter Alternate

- Evaluate the EOG signals during longer and wider saccades from side to side, without passing to the center
- Evaluate the effect of increasing angles of rotation (wider angles)

7. The point alternates RIGHT and LEFT mind that it does not appear in the Center!

   Start 1:57.30 - End 2:08.10 - Duration 0:10.80

8. The point alternates TOP and BOTTOM mind that it does not appear in the Center!

   Start 2:16.10 - End 2:21.30 - Duration 0:05.20

9) Horizontal Smooth - 10) Vertical Smooth

- 8.Evaluate the EOG signals during smooth pursuit movements in the horizontal and vertical direction

9. Follow the point in the HORIZONTAL direction

   Start 2:29.30 - End 2:35.30 - Duration 0:06.00

10. Follow the point in the VERTICAL direction

    Start - 2:43.30 - End 2:46.30 - Duration 0:03.00

11) Oblique Center Bottom-Right / Top Left - 12) Oblique Center Top-Right / Bottom-Left

- Evaluate EOG signals during saccades which are a combination of horizontal and vertical rotations.
- Evaluate the effect of increasing angles of rotation on complex movements

11. The point alternates CENTER, BOTTOM-RIGHT and TOP-LEFT at each repetition the point will move one step further

    Start - 2:54.30 - End 3:05.00 - Duration 0:10.70

12. The point alternates CENTER, TOP-RIGHT and BOTTOM-LEFT at each repetition the point will move one step further

    Start - 3:13.10 - End 3:23.80 - Duration - 0:10.70

13) Oblique NOCenter Bottom-Right / Top Left - 14) Oblique NOCenter Top-Right / Bottom-Left

- Evaluate EOG signals during saccades which are a combination of the horizontal and vertical component.
- Evaluate the effect of increasing angles of rotation on complex movements (wider angles)

13. The point alternates BOTTOM-RIGHT and TOP-LEFT mind that it does not appear in the Center!

    Start - 3:31.30 - End 3:36.60 - Duration 0:05.30

14. The point alternates TOP-RIGHT and BOTTOM-LEFT mind that it does not appear in the Center!

    Start - 3:45.10 - End 3:50.40 - Duration 0:05.30

15) Right Gaze - 16) Left Gaze - 17) Top Gaze - 18) Bottom Gaze

- Evaluate the minimum and maximum amplitude of the EOG signal during extreme rotations of the eyes in each direction
- Evaluate the EOG signal of the opposite movement performed to look back to the center of the screen

15. Move your eyes completely to the RIGHT for few seconds then look back to the CENTER

    Start - 3:54.10 - End 3:59.30 - Duration 0:05.20

16. Move your eyes completely to the LEFT for few seconds then look back to the CENTER

    Start - 4:03.00 - End 4:08.20 - Duration 0:05.20

17. Move your eyes completely to the TOP for few seconds then look back to the CENTER

    Start 4:11.20 - End 4:16.40 - Duration 0:05.20

18. Move your eyes completely to the BOTTOM for few seconds then look back to the CENTER

    Start 4:20.10 - End 4:25.30 - Duration 0:05.20

19) Top-Right Gaze - 20) Bottom-Right Gaze - 21) Bottom-Left Gaze - 22) Top-Left Gaze

- Evaluate the minimum and maximum amplitude of the EOG signal during extreme rotations of the eye which are a combination of horizontal and vertical rotations
- Evaluate the EOG signal of the opposite movement performed to look back to the center of the screen

19. Move your eyes completely to the TOP-RIGHT for few seconds then look back to the CENTER

    Start 4:29.10 - End 4:34.30 - Duration 0:05.20

20. Move your eyes completely to the BOTTOM-RIGHT for few seconds then look back to the CENTER

    Start 4:38.00 - End 4:43.20 - Duration 0:05.20

21. Move your eyes completely to the BOTTOM-LEFT for few seconds then look back to the CENTER

    Start 4:46.20 - End 4:51.40 - Duration 0:05.20

22. Move your eyes completely to the TOP-LEFT for few seconds then look back to the CENTER

    Start 4:55.10 - End 5:00.30 - Duration 0:05.20

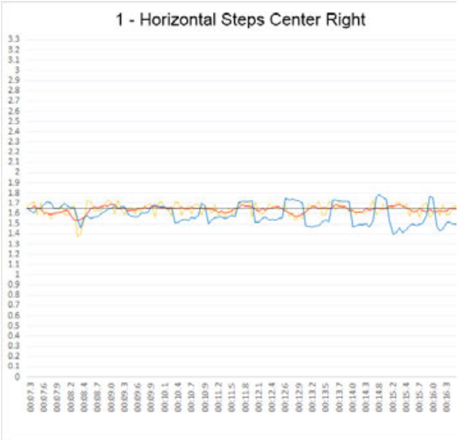
23) Blinking 3 times

- Evaluate the effect of blinking on the horizontal and vertical EOG signals

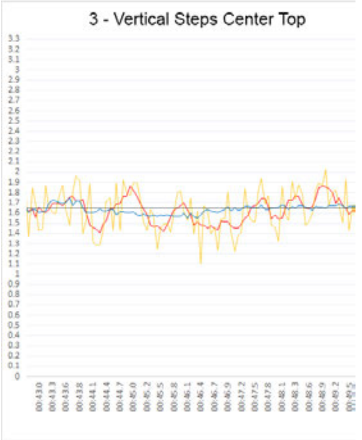
23. Blink three 3 times

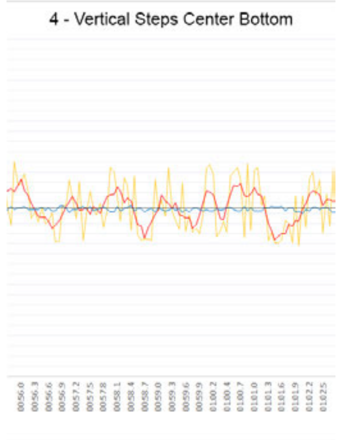
    Start 5:04.00 - End 5:10.10 - Duration 0:06.10

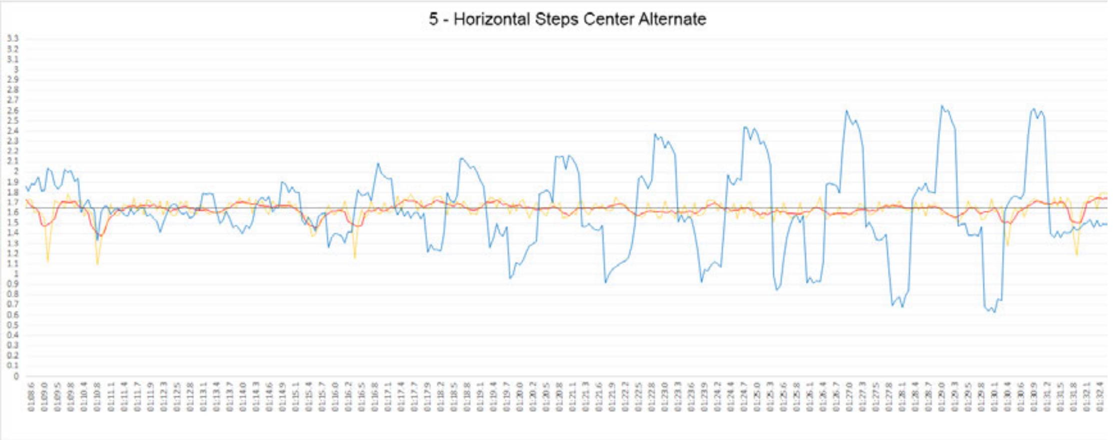
8.2 Signal plots of all exercises

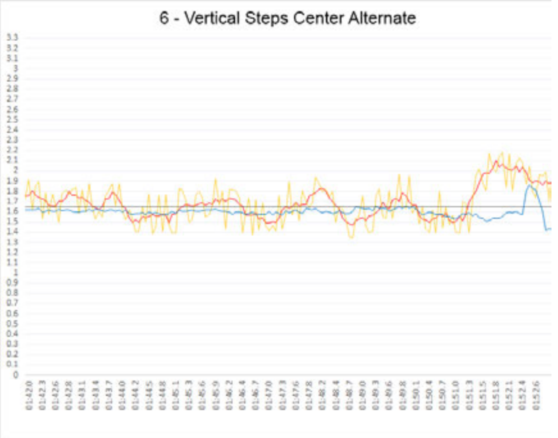

1 - Horizontal Steps Center Right

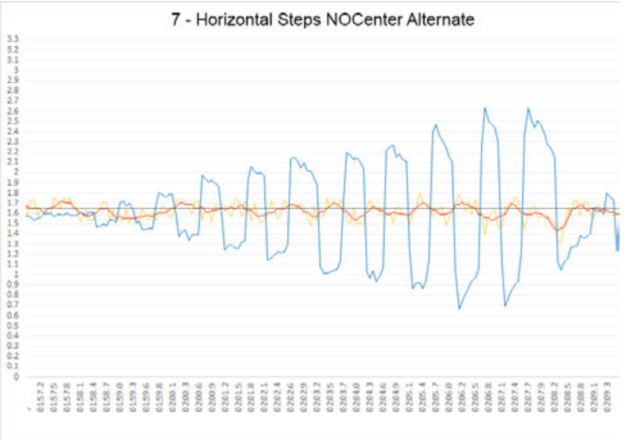

2 - Horizontal Steps Center Left


3 - Vertical Steps Center Top

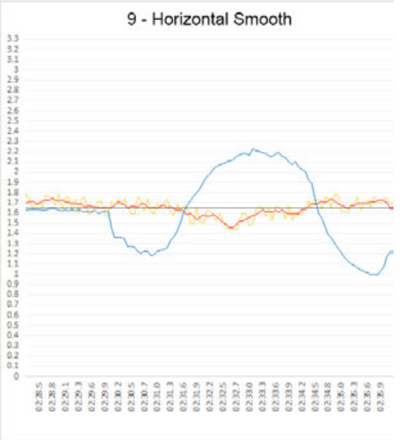

4 - Vertical Steps Center Bottom


5 - Horizontal Steps Center Alternate

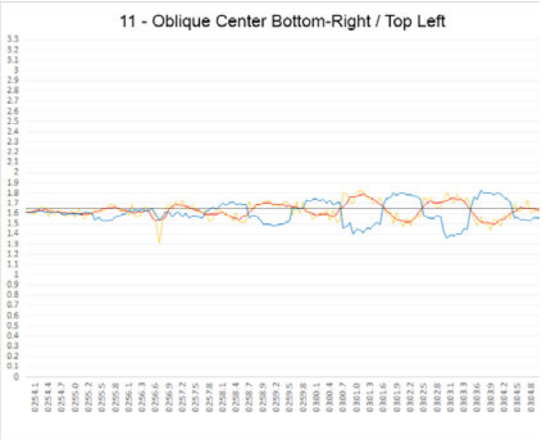

6 - Vertical Steps Center Alternate

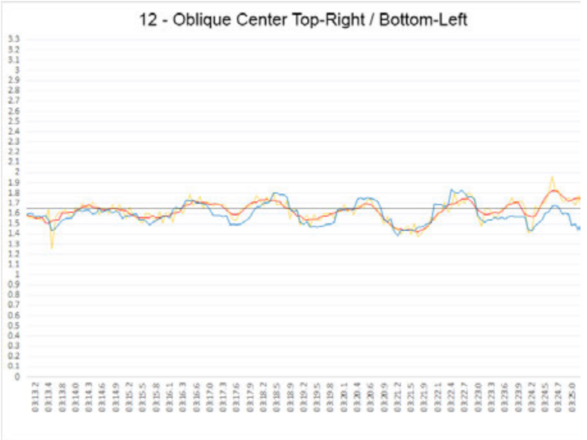

7 - Horizontal Steps NOCenter Alternate

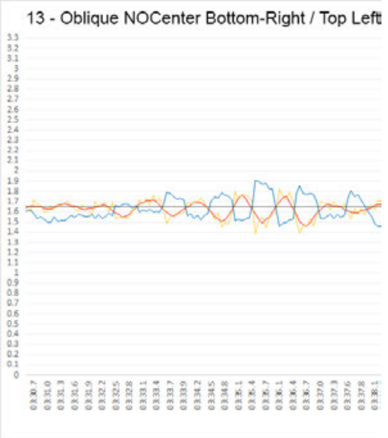

8 - Vertical Steps NOCenter Alternate

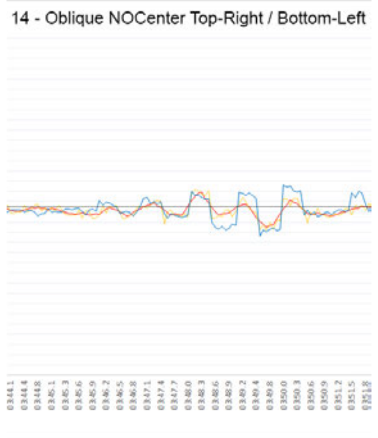

9 - Horizontal Smooth


10 - Vertical Smooth


11 - Oblique Center Bottom-Right / Top Left


12 - Oblique Center Top-Right / Bottom-Left


13 - Oblique NOCenter Bottom-Right / Top Left


14 - Oblique NOCenter Top-Right / Bottom-Left

15 - Right Gaze

16 - Left Gaze

17 - Top Gaze

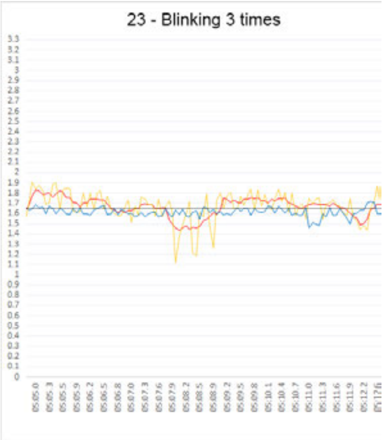
18 - Bottom Gaze

19 - Top-Right Gaze

20 - Bottom-Right Gaze

21 - Bottom-Left Gaze

22 - Top-Left Gaze



23 - Blinking 3 times

8.3 Results per subject

Subject 2

- Size(s) that were providing EOG signals: L

The sizes S and M were not contacting in multiple points (the whole forehead and the cheeks for the S size and center of the forehead for the M size) and were rated low in overall comfort; more specifically they caused severe discomfort especially on the canthi area (S size) and on the forehead (M size).

The overall comfort of the L size was rated as moderate. Nevertheless, the subject still noted high pressure on the canthi (slight discomfort) and on the cheek area (severe discomfort).

The horizontal component provided signals that were rather clean close to each exercise ideal. On the other hand, signals were extremely disturbed in the vertical component and were recorded even during exercises that did not expect vertical rotations of the eyes.

Subject 3

Size(s) that were providing EOG signals: M - L

The size S was not contacting in multiple points (whole forehead) and was rated low in overall comfort; more specifically the subject felt high compression in the canthi area.

The sizes M and L were able to contact the skin at all points and were rated relatively good in overall comfort: moderate for the M size and very high for the L size, with no relevant levels discomfort at specific areas. Indeed, the L size was identified by the subject as the best fit for his face.

The test resulted in similar results from both sizes, with stable and clean signals of the horizontal and vertical component. Notable facts were that the amplitude of the signal stayed between a rather small range between 1.1V (-0.55V) and 2.1V (+0.45V) in both sizes.

Subject 4

Size(s) that were providing EOG signals: S – M

Even if the size S was able to contact all points and result in EOG signals, it was rated very low in overall comfort, with reported high discomfort in the canthi areas (very severe discomfort) and in the cheeks (medium discomfort).

The size M was also able provide contact and signals and was rated moderate in overall comfort, with no relevant areas of discomfort reported.

The size L failed to contact in many points (sides of the forehead and canthi) but received moderate score in overall comfort, with medium discomfort at the cheeks.

The test resulted in relevant differences in the signals of the two sizes. Regarding the S size, it was the only case where the horizontal signals were noisier compared to the vertical. Nevertheless, it is still possible to recognize the patterns of each exercise and evaluate the effect of increasing angles of rotations. Regarding the preferred (in terms of comfort) M size, a relevant fact was that vertical signals were not stable around the ideal zero but were present also during exercises where no vertical rotation of the eyes was expected.

Subject 5

Size(s) that were providing EOG signals: S

Even if the size S was able to contact all points and result in EOG signals, it was rated extremely low in overall comfort, with perceived discomfort in the cheek areas (very severe discomfort) and the sides of the foreheads (medium discomfort)

The size M and L were not able to provide contact and signals …

The horizontal component provided signals that were rather clean close to each exercise ideal. On the other hand, signals were extremely disturbed in the vertical component and were recorded even during exercises that did not expect vertical rotations of the eyes.

Subject 6

Size(s) that were providing EOG signals: S - M - L

All the sizes were able to contact all points and provide stable EOG signals.

Size

8.4 Questionnaires scans

EOG in Virtual Reality User Test

Test number: 2 / Date: ______ / 05 / 2019

Name: [redacted] / Surname (facultative): [redacted]

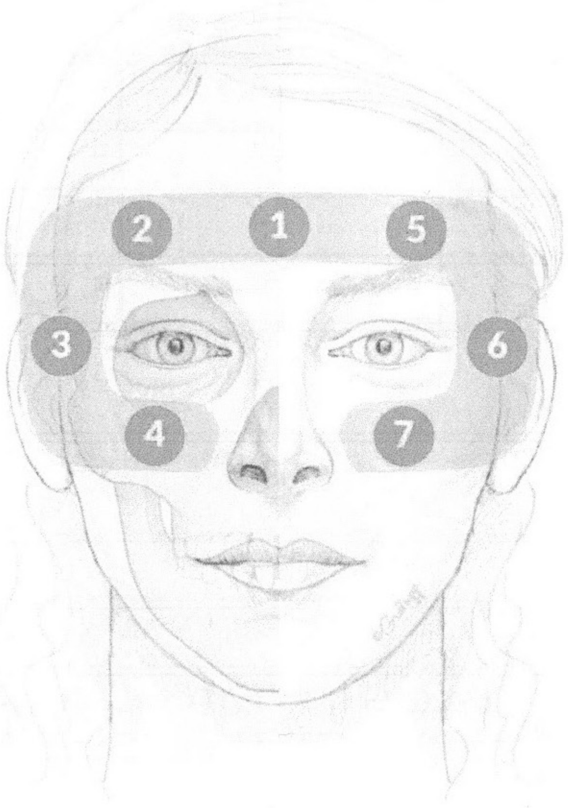
Age: 23 / Stature (facultative): 176 cm / Weight (facultative): 75 kg .

Gender: ☒ Male / ☐ Female

Nationality: Indian

Nationality father: ☒ Same as myself / Other: ________________

Nationality mother: ☒ Same as myself / Other: ________________



I agree to allow the researcher Federico Altobelli to record videos and sensor signals during the experiment.

[redacted]

Size S

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☒	☒	☐	☒	☒	☐	☒

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☒	☐	☐	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☐	☐	☐	☐	☐
2	Right forehead	☐	☒	☐	☐	☐	☐
3	Right canthus	☐	☐	☐	☐	☒	☐
4	Right cheek	☐	☐	☐	☐	☐	☐
5	Left forehead	☐	☒	☐	☐	☐	☐
6	Left canthus	☐	☐	☐	☐	☒	☐
7	Right cheek	☐	☐	☐	☐	☐	☐

Do you have any comments?

General	
1	
2	
3	TOO HEAVY PRESSURE LATERAL PRESSURE
4	
5	
6	
7	

Size M

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☒	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☒	☐	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☐	☐	☐	☐	☐
2	Right forehead	☐	☐	☐	☐	☒	☐
3	Right canthus	☐	☐	☐	☒	☐	☐
4	Right cheek	☐	☐	☒	☐	☐	☐
5	Left forehead	☐	☐	☐	☐	☒	☐
6	Left canthus	☐	☐	☐	☒	☐	☐
7	Right cheek	☐	☐	☒	☐	☐	☐

Do you have any comments?

General	LITTLE HEAVIER ON RIGHT SIDE
1	
2	LOT OF PRESSURE
3	
4	TOO HEAVY
5	
6	
7	

[✓ Size L]

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☒	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☐	☐	☐	☐	☐
2	Right forehead	☐	☐	☐	☐	☐	☐
3	Right canthus	☐	☐	☒	☐	☐	☐
4	Right cheek	☐	☐	☐	☐	☒	☐
5	Left forehead	☐	☐	☐	☐	☐	☐
6	Left canthus	☐	☐	☒	☐	☐	☐
7	Right cheek	☐	☐	☐	☐	☒	☐

Do you have any comments?

General	THE BOTTOM PART IS HEAVIER GOES TOO MUCH LOW
1	
2	
3	
4	TOO MUCH PRESSURE
5	
6	
7	

EOG in Virtual Reality User Test

Test number: 3 / Date: ______ / 05 / 2019

Name: B[redacted]n / Surname (facultative): [redacted]

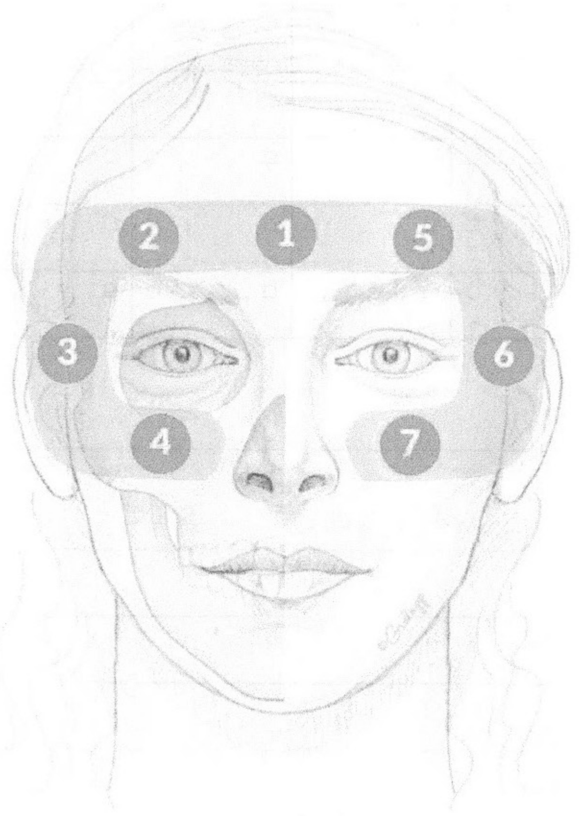
Age: 25 / Stature (facultative): 1.80 / Weight (facultative): 78

Gender: ☑ Male / ☐ Female

Nationality: TURKISH

Nationality father: ☑ Same as myself / Other: ____________

Nationality mother: ☑ Same as myself / Other: ____________



I agree to allow the researcher Federico Altobelli to record videos and sensor signals during the experiment.

[redacted]

Size S

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☑	☑	☐	☐	☑	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☑	☐	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☑	☐	☐	☐	☐	☐
2	Right forehead	☐	☑	☐	☐	☐	☐
3	Right canthus	☐	☐	☐	☐	☑	☐
4	Right cheek	☑	☐	☐	☐	☐	☐
5	Left forehead	☐	☑	☐	☐	☐	☐
6	Left canthus	☐	☐	☐	☐	☑	☐
7	Right cheek	☑	☐	☐	☐	☐	☐

Do you have any comments?

General	TOO SMALL FEELS LIKE COMPRESSING PRESSING
1	
2	
3	
4	
5	
6	
7	

Size M

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
V	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☒	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☒	☐	☐	☐	☐	☐
2	Right forehead	☒	☐	☐	☐	☐	☐
3	Right canthus	☒	☐	☐	☐	☐	☐
4	Right cheek	☐	☐	☒	☐	☐	☐
5	Left forehead	☒	☐	☐	☐	☐	☐
6	Left canthus	☒	☐	☐	☐	☐	☐
7	Right cheek	☐	☐	☒	☐	☐	☐

Do you have any comments?

General	BETTER THAN S
1	
2	
3	
4	
5	
6	
7	PRESSURE

Size L

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☐	☐	☒	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☒	☐	☐	☐	☐	☐
2	Right forehead	☒	☐	☐	☐	☐	☐
3	Right canthus	☒	☐	☐	☐	☐	☐
4	Right cheek	☒	☐	☐	☐	☐	☐
5	Left forehead	☐	☐	☐	☐	☐	☐
6	Left canthus	☒	☐	☐	☐	☐	☐
7	Right cheek	☐	☐	☐	☐	☐	☐

Do you have any comments?

General	LARGE IS THE BEST THE FIELD OF VIEW IS BETTER
1	
2	
3	
4	
5	
6	
7	

EOG in Virtual Reality User Test

Test number: 04 / Date: 23 / 05 / 2019

Name: [redacted] / Surname (facultative):

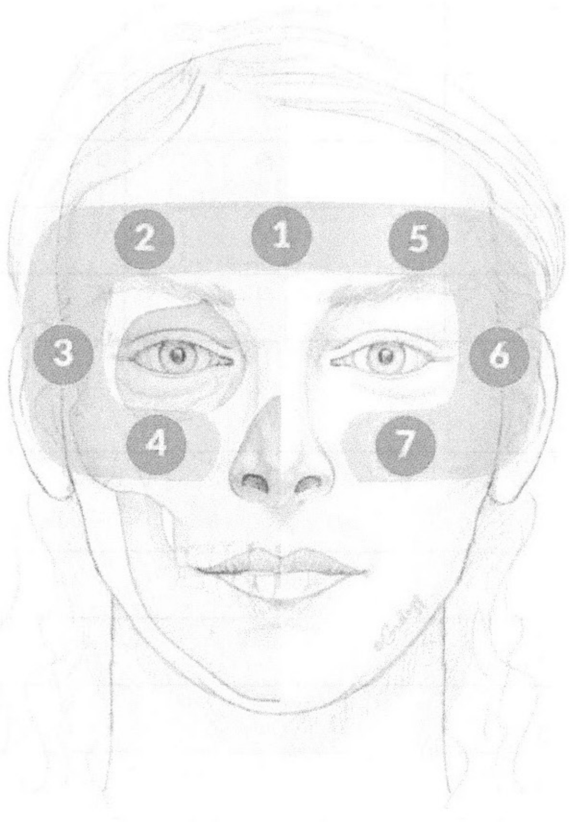
Age: 25 / Stature (facultative): ~~10~~181cm / Weight (facultative): 73

Gender: [✓ ☐ Male] / ☐ Female

Nationality: GERMAN

Nationality father: ☑ Same as myself / Other:

Nationality mother: ☑ Same as myself / Other:



I agree to allow the researcher Federico Altobelli to record videos and sensor signals during the experiment.

[redacted]

Size S

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☒	☐	☐	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☐	☒	☐	☐	☐
2	Right forehead	☐	☐	☒	☐	☐	☐
3	Right canthus	☐	☐	☐	☐	~~☒~~ →	☒
4	Right cheek	☐	☐	☐	☒	☐	☐
5	Left forehead	☐	☐	☒	☐	☐	☐
6	Left canthus	☐	☐	☐	☐	~~☒~~ →	☒
7	Right cheek	☐	☐	☐	☒	☐	☐

Do you have any comments?

General	THE DISCOMFORT INCREASES OVER TIME
1	
2	
3	TOO SMALL
4	
5	
6	
7	

Size M

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☒	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☐	☒	☐	☐	☐
2	Right forehead	☒	☐	☐	☐	☐	☐
3	Right canthus	☒	☐	☐	☐	☐	☐
4	Right cheek	☐	☐	☒	☐	☐	☐
5	Left forehead	☒	☐	☐	☐	☐	☐
6	Left canthus	☒	☐	☐	☐	☐	☐
7	Right cheek	☐	☐	☒	☐	☐	☐

Do you have any comments?

General	BETTER THAN S NOT SO MUCH PRESSURE
1	X
2	
3	
4	AFTER SOME MINUTES
5	
6	
7	

Size L

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☒	☒	☐	☒	☒	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☒	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☐	☒	☐	☐	☐
2	Right forehead	☒	☐	☐	☐	☐	☐
3	Right canthus	☒	☐	☐	☐	☐	☐
4	Right cheek	☐	☐	☐	☒	☐	☐
5	Left forehead	☒	☐	☐	☐	☐	☐
6	Left canthus	☒	☐	☐	☐	☐	☐
7	Right cheek	☐	☐	☐	☒	☐	☐

Do you have any comments?

General	NO COMMENT TOO BIG
1	
2	
3	
4	
5	
6	
7	

EOG in Virtual Reality User Test

Test number: 6 / Date: 24 / 05 / 2019

Name: [redacted] / Surname (facultative):

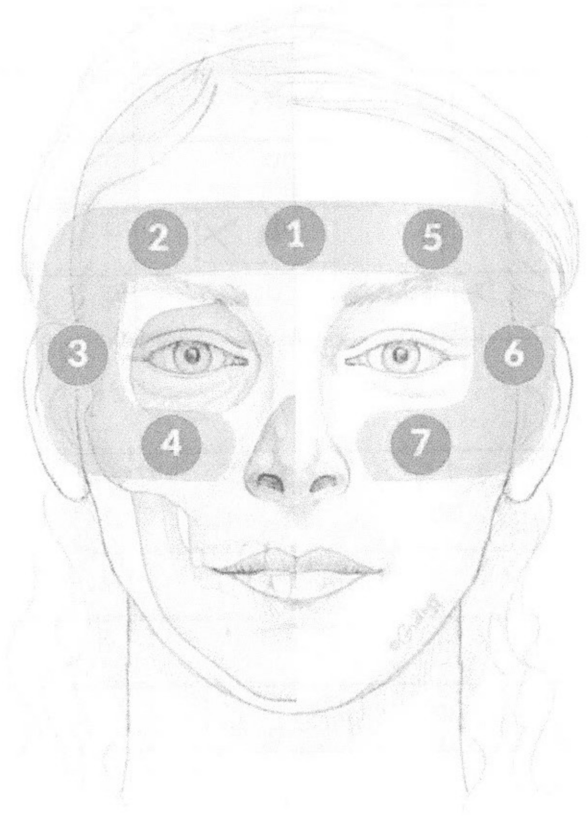
Age: 25. / Stature (facultative): 176 cm / Weight (facultative): 63 kg

Gender: ☑ Male / ☐ Female

Nationality: Dutch

Nationality father: ☐ Same as myself / Other: Ukranian

Nationality mother: ☐ Same as myself / Other: Ukranian.



I agree to allow the researcher Federico Altobelli to record videos and sensor signals during the experiment.

[redacted]

Size S

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☒	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☒	☐	☐	☐	☐	☐
2	Right forehead	☒	☐	☐	☐	☐	☐
3	Right canthus	☐	☐	☐	☒	☐	☐
4	Right cheek	☐	☐	☒	☐	☐	☐
5	Left forehead	☒	☐	☐	☐	☐	☐
6	Left canthus	☐	■	■ ✗	☐	☐	☐
7	Right cheek	☒	☐	☐	☐	☐	☐

Do you have any comments?

General	TOO SMALL TOO CLOSE TO EYES AND EYEBROWS
1	
2	
3	
4	
5	
6	
7	

Size M

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☒	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☒	☐	☐	☐	☐	☐
2	Right forehead	☒	☐	☐	☐	☐	☐
3	Right canthus	☐	☒	☐	☐	☐	☐
4	Right cheek	☐	☐	☒	☐	☐	☐
5	Left forehead	☑	☐	☐	☐	☐	☐
6	Left canthus	☐	☒	☐	☐	☐	☐
7	Right cheek	☐	☐	☐	☒	☐	☐

Do you have any comments?

General	FEELS LESS TIGHT BUT NOT MUCH MORE COMFORTABLE
1 /	DISCOMFORT IS IN DIFFERENT POINTS
2	
3	
4	
5	
6	
7	

Size L

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☑	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☒	☐	☐	☐	☐	☐
2	Right forehead	☒	☐	☐	☐	☐	☐
3	Right canthus	☒	☐	☐	☐	☐	☐
4	Right cheek	☒	☐	☐	☐	☐	☐
5	Left forehead	☐	☒	☐	☐	☐	☐
6	Left canthus	☐	☒	☐	☐	☐	☐
7	Right cheek	☐	☐	☒	☐	☐	☐

Do you have any comments?

General	FIT BETTER BUT SIDES WERE ALMOST OFF
1	
2	
3	
4	
5	
6	
7	

EOG in Virtual Reality User Test

Test number: 5 / Date: 26 / 05 / 2019

Name: [redacted] / Surname (facultative): [redacted]

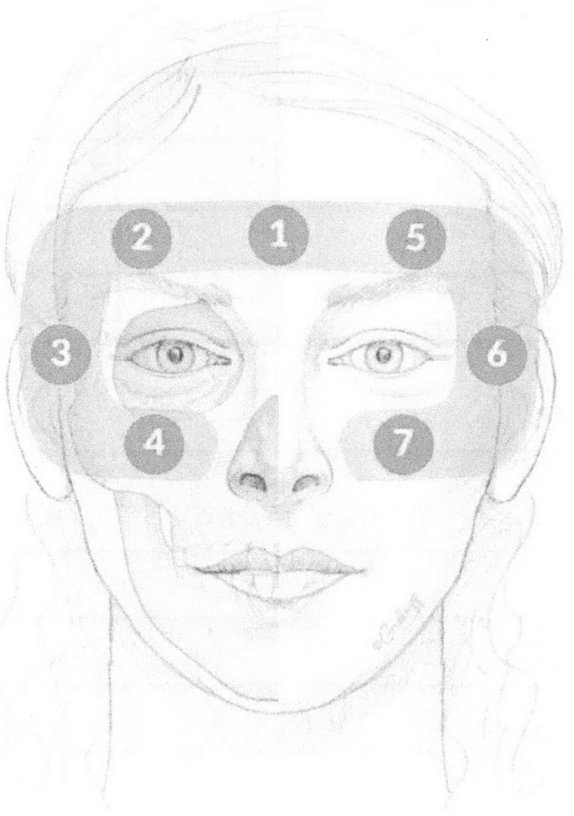
Age: 22 / Stature (facultative): 168 cm / Weight (facultative): 55 kg

Gender: ☐ Male / ☑ Female

Nationality: Turkish

Nationality father: ☑ Same as myself / Other:

Nationality mother: ☑ Same as myself / Other:



I agree to allow the researcher Federico Altobelli to record videos and sensor signals during the experiment.

[redacted]

Size S

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☒	☐	☐	☐	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☐	☒	☐	☐	☐
2	Right forehead	☐	☐	☐	☒	☐	☐
3	Right canthus	☐	☒	☐	☐	☐	☐
4	Right cheek	☐	☐	☐	☐	☐	☒
5	Left forehead	☐	☐	☐	☒	☐	☐
6	Left canthus	☐	☒	☐	☐	☐	☐
7	Right cheek	☐	☐	☐	☐	☐	☒

Do you have any comments?

General	THE CHEEKS PULLS FACE DOWNWARDS LIKE THAT DOG
1	
2	
3	
4	
5	
6	
7	

EOG in Virtual Reality User Test

Test number: 7 / Date: 24 / 05 / 2019

Name: O[redacted]R / Surname (facultative): [redacted]

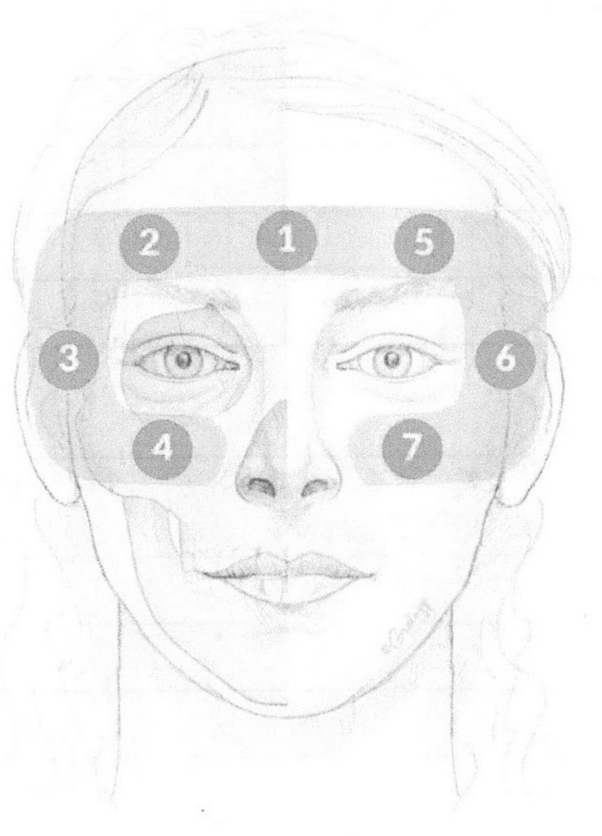
Age: 26 / Stature (facultative): 169 / Weight (facultative): 72

Gender: ☑ Male / ☐ Female

Nationality: ITALIAN

Nationality father: ☑ Same as myself / Other:

Nationality mother: ☑ Same as myself / Other:



I agree to allow the researcher Federico Altobelli to record videos and sensor signals during the experiment.

[redacted]

Size S

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☑	☑	☐	☐	☑	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☑	☐	☐	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☑	☐	☐	☐	☐
2	Right forehead	☐	☐	☑	☐	☐	☐
3	Right canthus	☐	☐	☑	☐	☐	☐
4	Right cheek	☐	☐	☐	☐	☑	☐
5	Left forehead	☐	☐	☑	☐	☐	☐
6	Left canthus	☐	☐	☑	☐	☐	☐
7	Right cheek	☐	☐	☐	☐	☑	☐

Do you have any comments?

General	[illegible] THE MASK IS SQUEEZING THE [illegible] EYES THE MASK IS FALLING SLOWLY
1	[illegible] REALLY FAR
2	
3	
4	
5	
6	
7	

Size M

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☐	☐	☐	☐	☐

What is the level of comfort that you feel while wearing the prototype?

Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☐	☑	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☑	☐	☐	☐	☐	☐
2	Right forehead	☐	☐	☑	☐	☐	☐
3	Right canthus	☐	☐	☑	☐	☐	☐
4	Right cheek	☐	☐	☐	☑	☐	☐
5	Left forehead	☐	☐	☑	☐	☐	☐
6	Left canthus	☐	☐	☑	☐	☐	☐
7	Right cheek	☐	☐	☐	☑	☐	☐

Do you have any comments?

General	[illegible] MY EYES GOT TIRED FROM THE PRESSURE SOME TASKS I DID NOT UNDERSTAND
1	
2	
3	
4	PRESS A LOT
5	
6	
7	

Size L

What are the areas that are not contacting the face?

Center forehead 1	Right forehead 2	Right canthus 3	Right cheek 4	Left forehead 5	Left canthus 6	Left cheek 7
☐	☐	☑	☐	☐	☑	☐

What is the level of comfort that you feel while wearing the prototype?

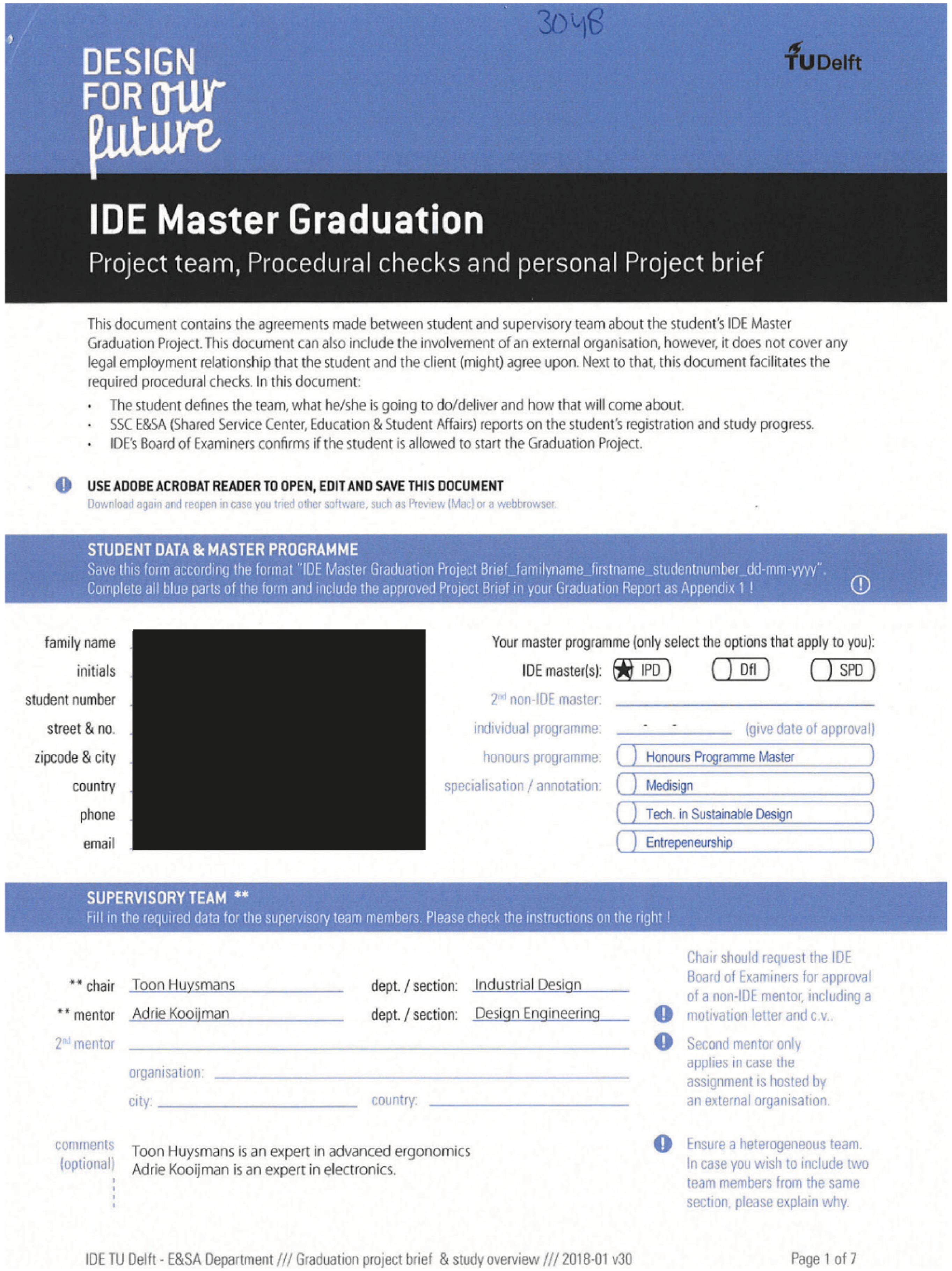
Extremely low	Very low	Low	Moderate	High	Very high	Extremely high
☐	☐	☑	☐	☐	☐	☐

What are the areas where you feel discomfort? Can you describe the level of discomfort that you feel in that area?

		No discomfort	Very slight discomfort	Slight discomfort	Medium discomfort	Severe discomfort	Very severe discomfort
1	Center forehead	☐	☐	☑	☐	☐	☐
2	Right forehead	☐	☑	☐	☐	☐	☐
3	Right canthus	☑	☐	☐	☐	☐	☐
4	Right cheek	☐	☐	☑	☐	☐	☐
5	Left forehead	☐	☑	☐	☐	☐	☐
6	Left canthus	☑	☐	☐	☐	☐	☐
7	Right cheek	☐	☐	☑	☐	☐	☐

Do you have any comments?

General	IT'S NOT PERFECTLY STABLE
1	
2	
3	
4	
5	
6	
7	



3048

DESIGN FOR our future

TUDelft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name
initials
student number
street & no.
zipcode & city
country
phone
email

[redacted]

Your master programme (only select the options that apply to you):

IDE master(s): ● IPD ○ Dfl ○ SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ○ Honours Programme Master

specialisation / annotation: ○ Medisign

○ Tech. in Sustainable Design

○ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair Toon Huysmans dept. / section: Industrial Design

** mentor Adrie Kooijman dept. / section: Design Engineering

2nd mentor

organisation:

city: country:

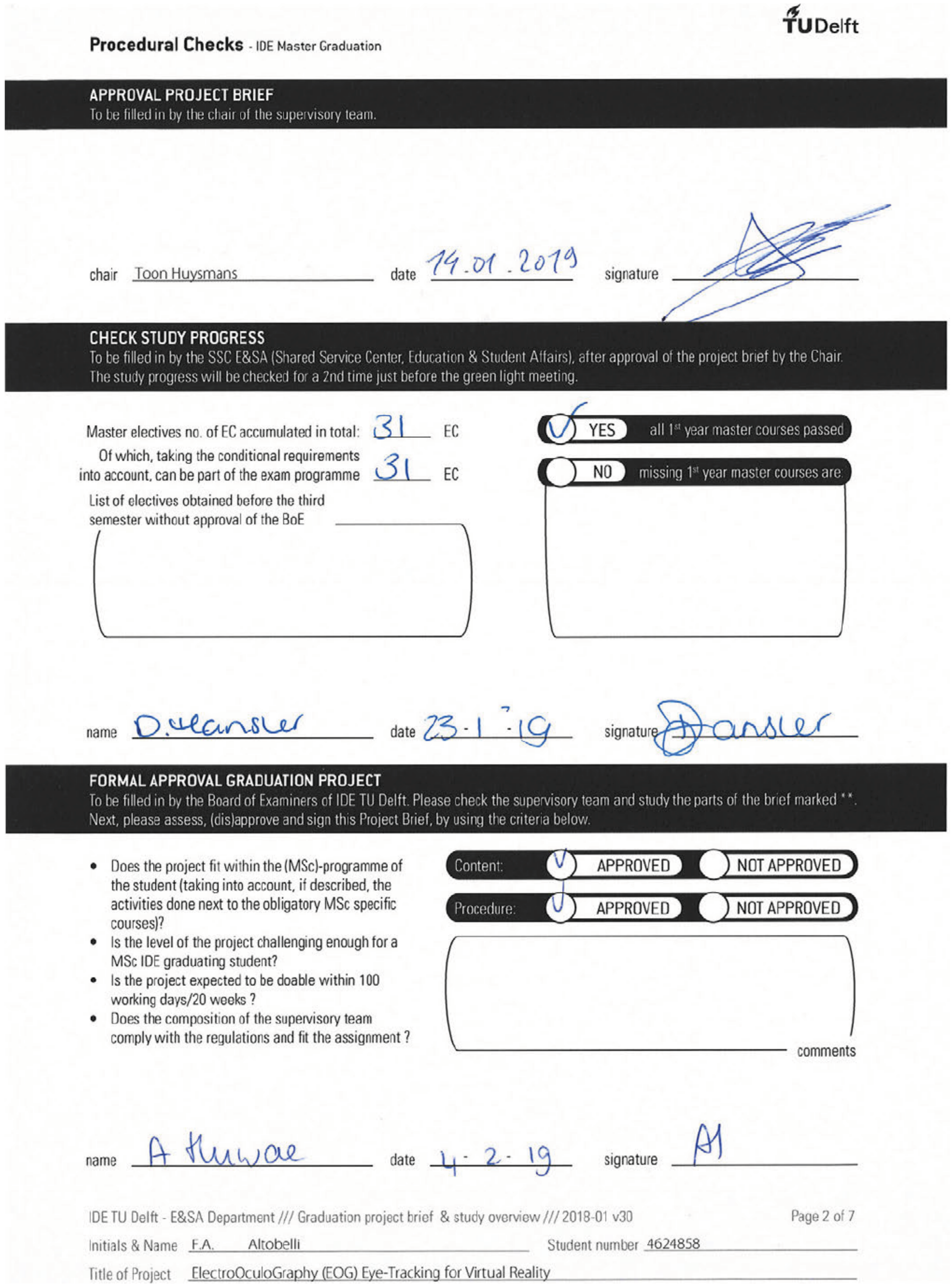
comments (optional) Toon Huysmans is an expert in advanced ergonomics
Adrie Kooijman is an expert in electronics.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7



TUDelft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Toon Huysmans date 14.01.2019 signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 31 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 31 EC

List of electives obtained before the third semester without approval of the BoE

☑ YES all 1st year master courses passed

○ NO missing 1st year master courses are:

name D.Hansler date 23-1-19 signature Hansler

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ☑ APPROVED ○ NOT APPROVED

Procedure: ☑ APPROVED ○ NOT APPROVED

comments

name A Huwae date 4-2-19 signature AH

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 2 of 7

Initials & Name F.A. Altobelli Student number 4624858

Title of Project ElectroOculoGraphy (EOG) Eye-Tracking for Virtual Reality

ElectroOculoGraphy (EOG) Eye-Tracking for Virtual Reality project title

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

start date 03 - 12 - 2018

17 - 05 - 2019 end date

INTRODUCTION **

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

Virtual reality (VR) is an immersive computer simulation of a three-dimensional environment where the user experiences visual, auditory and sensory feedbacks and can interact with the surrounding through various kinds of controllers. Virtual Reality is achieved through VR headsets that project images with a pair of displays and lenses placed few centimetres from the user's eyes in order to create the illusion of a three-dimensional world. Most diffused VR headsets are HTC Vive, Oculus Rift and Oculus Go.

The key factor for the success of VR is immersion, which is the condition where the user loses awareness of being in an environment which is not real. Immersion is achieved by virtually replicating human senses stimuli. One of the biggest factors for achieving a high level of immersion is the ability to accurately simulate human vision.

For this purpose, new technologies are been developed to achieve higher screens resolutions and bigger fields of view. In this context, eye-tracking is taking place in virtual reality. Eye tracking is the ability to sense the position of user's eye gaze point in the surroundings. In virtual reality, it then comes to being able to live track the coordinates of the eye gaze point on the screen(s) placed in front of the users' face.

Such eye-tracking can bring many advantages to virtual reality. One of them is foveated rendering, which consists on the possibility to render parts of the VR 3d scene that are not focused by the user's eyes at a lower resolution, resulting in big savings of computational power. Moreover, it is possible to control VR interfaces with eyes, or conduct more accurate researches on consumers' focus and behaviour. Other applications are training people for complex jobs (for example astronauts or surgeons) or enhancing virtual avatars with human-like eye movements,

Eye tracking is achieved through three methods: tracking contact lenses, camera systems and ElectroOculoGraphy (EOG). The first two provide accurate results but are relatively expensive, big, and battery/computation hungry while EOG appears to be also suitable for compact products (as virtual reality headsets) at reduced costs.

EOG consists on capturing and analysing the electrical properties of the skin around the eyes through small electrodes placed in strategic points of the user's face. (image 1). Since virtual reality headsets integrate a mask that makes large contact with the user's face (image 2), it is possible to integrate the necessary electrodes to enable EOG.

space available for images / figures on next page

---

introduction (continued): space for images

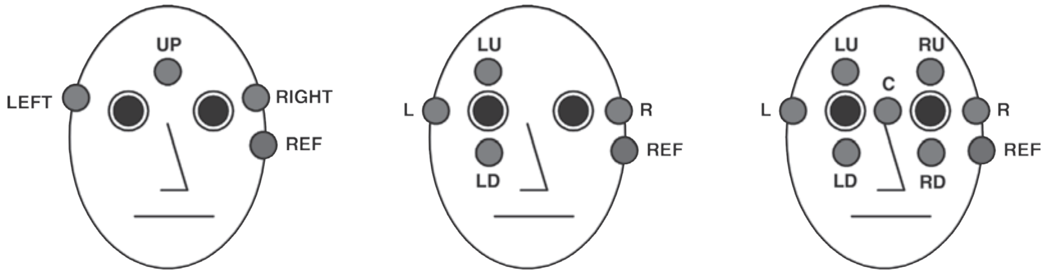


image / figure 1: Illustration of EOG electrodes contact points configurations. (Krupiński & Mazurek, 2012)

image / figure 2: HTC Vive face mask. (www.vive.com, 2016)

PROBLEM DEFINITION **

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

Companies operating in the virtual reality field develop and produce headsets that are sold globally and that are targeted to a vast variety of people of both sexes, different ages and different nationalities. This results in a high variability of the face shapes among the end users. Moreover, the headset might be worn for up to several hours, both in static situations and during rapid head and body movements. Common issues are that the mask gets hot and humid of sweat, causing slippage and requiring the user to take a break and put the headset back in place.

For these reasons, the design of the contacting parts with the user's face require special attention on anthropometric ergonomics. Since EOG eye-tracking method makes use of electrodes that need to make good contact with the user's face, the challenges lay on ensuring the quality of the captured signals, while maintaining high wear comfort and stability also during motions. A special attention is also required on the choice of the materials in order to address thermal comfort and durability issues caused by prolonged use and sweat.

Finally, the envisioned product is intended to be targeted to the consumer market, meaning that it is required to analyse and optimise the parts and materials with the costs and the end price in mind.

Knowledge and tools will be shared by the supervisory team in order to facilitate and speed up the processes, and increase the quality of the content. Advanced ergonomics software will be used as a tool to generate simulation 3d models of the human head. Since the product is targeted to adults, a selection will be performed on relevant anthropometric data.

Electronics, in particular electrodes sensors, and the eye-tracking software will be designed and developed to test the working principle of EOG in a relevant selection of possible applications.

ASSIGNMENT **

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

I am going to research the most effective solution regarding the quantity and the positions of electrodes to enable EOG eye-tracking for a selection of virtual reality applications. I am going to evaluate state-of-the-art anthropometric head digital models in order to balance the EOG eye-tracker's signal quality and wear comfort.

Starting with research I will build knowledge on the topic by studying scientific literature on human vision and anatomy of the eye. Furthermore, I will research on eye-tracking methods with a focus on EOG. I will then analyse the applications of eye-tracking with a focus on virtual reality in order to select one or multiple applications of interest. This will put a base for the requirements to consider throughout the whole design process.

The literature study will put the base for an explorative research on ergonomics and electronics, relatively mainly regarding 3d statistical head tools and electrodes sensors. Test rigs will be used to ideate multiple solutions (concepts) regarding the amount and position of the electrodes on different relevant subjects. Data will be collected and analysed in order to set a focus on one or multiple most promising applications.

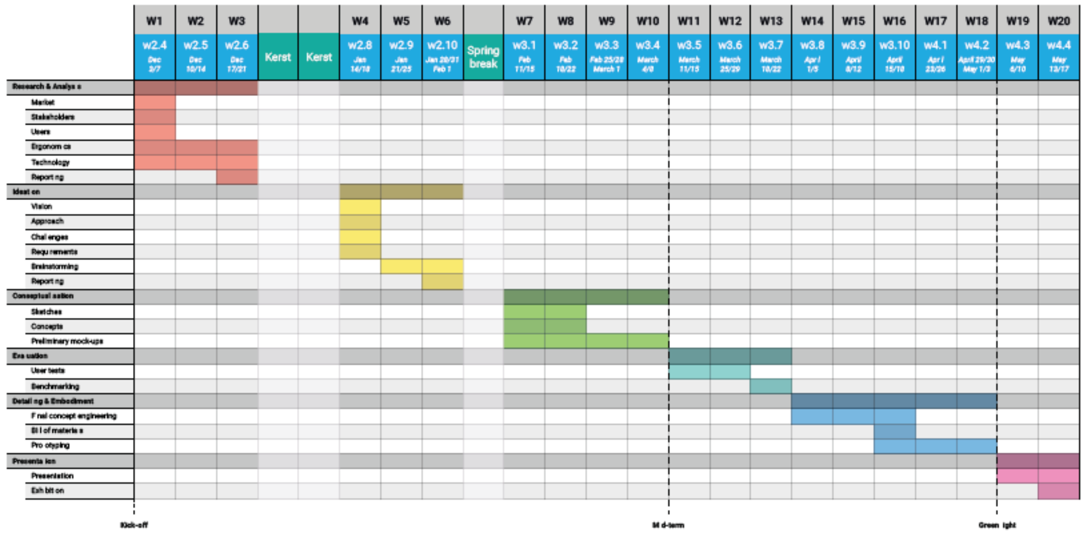
Through an iterative process, I will produce, compare and validate and solutions. I picture the result as an inclusive design with possibly different configurations, or a scalable design with multiple sizes.

A demonstrational prototype with the desired characteristics will be finally built. A VR headset already existing on the market will be connected to the prototype of the EOG eye-tracker to demonstrate in a tangible way the qualities of EOG for the chosen application(s), ideally in a self-programmed virtual reality environment. Ultimately the product proposal will be discussed in detail, including its feasibility and costs but excluding the relative software.

PLANNING AND APPROACH **

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

start date 3 - 12 - 2018 17 - 5 - 2019 end date



The proposed plan aims to realise an EOG eye-tracker for VR applications in 20 weeks.
Four different phases and multiple meetings with the supervisory team have been planned in order to organise, validate and iterate the outcomes.
0. Planning – Activities and meetings are planned. All the involved parties meet at the kick-off and agree on the project brief.
1. Research and Analysis (3 weeks) - Research regarding relevant topics of the subject will be performed on scientific literature and reported.
2. Ideation (3 weeks) - Knowledge built during R&A will be used to formulate a vision. A preliminary list of requirements and wishes will be compiled in order to perform effective brainstorming and generate broad ideas.
3. Conceptualisation (4 weeks) - Ideas will be filtered, combined and narrowed to multiple concepts. Preliminary mock-ups will be built to concretise concepts into tangible test-rigs. During the mid-term evaluation (W 10) the progress and the quality of the project will be discussed.
4. Evaluation (3 weeks) - Mock-ups will be used to perform user-tests on different relevant subjects. Results will be evaluated and discussed in order to narrow down ideas to a feasible direction. A final concept with the desired features and characteristics will be defined.
5. Detailing & Embodiment (5 weeks) - The concept will be finalised and discussed in its details. During the green-light meeting (W 18) the progress of the project will be checked. Finally, CAD models and electronics prototypes will be detailed to build a final working prototype.
6. Presentation (2 weeks) - The final presentation will be prepared and discussed at the graduation ceremony.

MOTIVATION AND PERSONAL AMBITIONS

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

As an industrial designer I am fascinated by new technologies development and their impact on the society. During my bachelor and master formation I took the chance to work at multiple project in the fields of wearable technologies, home automation and virtual reality.

To me, exploring virtual reality means exploring reality as well. It stimulates to take consciousness of the world and how we interact with it, through our brain and our body, to the intent of virtually reproducing the senses. I believe that virtual reality has the potential to be breakthrough in our society. While it is still in early stages, I am grateful to be part of its development and to bring it one step further.

A fundamental assumption motivates the development of eye-tracking technologies, which is that the eyes are looking at what's most important to us now. Being able to know where they are looking is extremely intriguing and motivates me to take this challenge.

My goal for this graduation project is to grow both as a designer and as a person. I would like to become a more interdisciplinary designer, able to operate on multiple fields. In order to do so I have the ambition to broaden and improve my skills and my creative thinking.

- I want to learn new design methodologies and tools to be able to support my choices with solid research and/or testing. Most important I want to learn how to work advanced ergonomics tools as the 3d head statistical models.
- I want to learn how to work in collaboration with different stakeholders and manage their interests while meeting optimal results. Improve communication, organisation and collaborative behaviour between parties.
- I want to be able to prepare a feasible planning and respect it by setting weekly and monthly goals.
- I want to develop a working prototype that can demonstrate the working principles and the feasibility of a product.
- I want to improve my sketching skills and knowledge on electronics and programming.

I am confident about the fact I am very suited for this graduation project and I have the interest and passion, as well as a strong background to achieve brilliant results.

FINAL COMMENTS

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

Initials & Name F.A. Altobelli Student number 4624858

Title of Project ElectroOculoGraphy (EOG) Eye-Tracking for Virtual Reality