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**DEVELOPMENT AND ANALYSIS OF AN
EYE GYMNASTICS APPLICATION USING
EYE TRACKING FOR UNITY**

Master's thesis

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**SILMADE TREENINGU RAKENDUSE
LOOMINE JA ANALÜÜS KASUTADES
SILMAJÄLGIMISTEHNOLGOGIAT
UNITYLE**

Magistritöö

Juhendaja: Jekaterina Tšukrejeva
Tehnikateaduse
magister

Tallinn 2017

Author's declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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20.03.2017

Abstract

In my master's thesis *Development and Analysis of An Eye Gymnastics Application Using Eye Fracking for Unity* I write about creating an eye training application. I analyse how our eyes work. What the structure of an eye is and how our vision works. I analyse how eye tracking works taking the consumer version of a Tobii eye tracking system as an example. I create three applications for eye gymnastics in the Unity 5 developer environment and test them on volunteers. The applications are then evaluated using the Game Experience Questionnaire and the results are analysed and presented in text form as well as with tables. The final part summarises the work that was done and the results that were achieved in this thesis. Furthermore, suggestions have been made for what could be done to further develop this thesis and application.

This thesis is written in English and is 84 pages long, including seven chapters, thirty-three figures and six tables.

Annotatsioon

SILMADE TREENINGU RAKENDUSE LOOMINE JA ANALÜÜS KASUTADES SILMAJÄLGIMIS TEHNOLOOGIAT UNITYLE

Minu lõputöös Silmade treeningu rakenduse loomine ja analüüs kasutades silmajälgimistehnoloogiat Unityle mina kirjutan kuidas teha silmatreeningu rakenduse kasutades selleks silmajälgimissüsteemi. Mina analüüsin mis on nägemine, miks on see oluline ja kuidas meie silmad töötavad, mis on nende struktuur ja kuidas nägemine töötab. Selgitasin mis on silmade kõige olulisemad komponendid ja millised sarnased on fotoaparaadi ja meie silmadega. Mina analüüsin mis on ja kuidas töötab silmajälgimine kasutades selleks Tobii silmajälgimissüsteemi ja Tobii EyeX kontrolleri.

Mina arendasin kolm rakendusi silmade treenimiseks Unity 5 raamistikus ja testisin neid vabatahtlikega. Rakendused on analüüsitud kasutades Game Experience Questionnaire küsimustiku ja tulemused on näidatud nii kirjalikus vormis kui ka tabelites.

Leidsin ning märkasin sarnased tööd selles valdkonnas ja analüüsisin millega nad on seotud

Viimases osas on kirjutatud töö kokkuvõtte, mis oli tehtud lõputöös ja millised tulemused mina saavutasin Samuti oli pakutud võimalused süsteemi edasi arendamiseks.

Lõputöö on kirjutatud inglise keeles ning sisaldab teksti 84 leheküljel, seitse peatükki, kolmkümmend kolm joonist, kuus tabelit.

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1 Introduction

Vision is our main source of information. Our eyes provide a constant stream of data that surrounds us and help us in our everyday life from reading a book to crossing a road on the green light. They are an essential part of our lives and most of us cannot imagine living without the ability of seeing all the things that are around us. We are born with eyesight and it accompanies us throughout our life. We learn how the world works by using our eyes. We make first decisions based on what and how we see. We tend to trust everything we see because if we see it then it must be true. That is how most magic tricks work. They rely on the fact that our eyes and brain cannot process information as fast as the magician's hands move. Some tricks rely on the fact that our brain memorizes everything our eyes saw and that is what is being used against us. Almost everything we know about our world we have learned by using our eyes. We know that grass is green and the sky is blue. Psychology says that we react differently on different colours. For instance, staying in a blue room can make you feel calmer and more relaxed. On the contrary, painting the living room red is not a very good idea since it irritates our eyes and does not provide comfort and peace. [1] Our eyes can dictate our moves and our behaviour. We tend to return to things that are more pleasing to the eye than others.

A product can be the best in its class but if it doesn't look right or looks sloppy then not many people will buy it. The same goes for brands. A good brand should have a nice logo to accompany it. A lot of research goes into making products look good and look better than the competition. Not only that, all the products need to look good and be easy to use. Companies do not want to create things that are hard to manage because no one will buy them. Even a simple thing of creating a good logo for a company can take months and even years for highly skilled professionals to come up with a solution that would reflect on the company's values, priorities as well as make it distinguishable among others. Not only does a product must be well-designed, it must also be placed correctly in the store. Special people are being employed to make decisions where each product must be placed and how should it look.

We live in a world where having information is crucial to success and survival and most of it we get by using our vision. During an interview a lot depends on the way the interviewee looks and acts. People who can read body language and mimics can identify whether the person is scared, bored or openminded [2]. Our eyes show us the beauty of

the world as well as provide us with the necessary data that help us make decisions and react to changes.

The eyesight is, however, one of the most underappreciated senses that we have. People think of it as a given and cannot simply imagine a world where vision is not available to them. By just closing our eyes we can try to imagine what it feels like to not be able to see. The only exception is that we can always open them and try to do it as fast as possible. It is scary and strange at the same time. Suddenly even the basic tasks become almost impossible to accomplish when we do not know where the things are located and how to get them. We use our memory and experience to guess where things are located and what surround us.

Our eyes are our life companions but with the current type of lifestyle our eyes tend to be overloaded and stressed every single day. We spend most of our work time in front of computer screens and our free time in front of TVs and smartphones. We communicate through emails and chats and this has become an essential part of our lives. Eyes are not meant for constantly looking at static objects such as computer screens and as a result they get tired and our eyesight suffers. We are not able to see as well as we used to and our eyesight is no longer as sharp as it used to be. We do not see the things that are coming to us, we cannot read or write properly since everything is just a big mist. We cannot drive a car because we can cause an accident and we are potentially dangerous to other people. We cannot go to the cinema as we do not see what happens on the screen. It is making our lives more difficult.

The consequence is that people need to get prescription glasses and can no longer be without them. If the eyesight is not very bad then people usually wear them only when needed for instance to drive a car. However, this is only the beginning of a huge problem. As soon as a person gets prescription glasses his or her eyesight start to degrade even faster. After some period of time people can no longer be without glasses. They become an essential part of our lives. People who do not want to wear glasses but have bad eyesight tend to prefer contact lenses. Contrary to glasses the same pair of contact lenses cannot be worn for long periods of time. They need to be constantly changed as when you take them off they get dirty (Dirt is not allowed in the eyes as they must be crystal clear to provide ideal image. If for some reason something that is not supposed to touches our eyes they become irritated and start to produce tears). Changing them means that you always need to buy new pair of them. People who prefer contact lenses usually buy them

in bulk. Since we cannot wear lenses 24/7 and they are also very costly this is not a solution to the problem. When the eyesight becomes too bad and standard glasses no longer help or the person simply wants to restore eyesight to perfect condition surgery can help. Special correction clinics exist where eyesight can be restored with lasers and special equipment. The whole process does not take long and preparation is usually much longer than the surgery itself. The result is that eyesight restores to the same condition and the patient no longer needs to wear glasses or lenses. However, this is by no means a solution as laser surgery does not give 100 per cent result and is not always safe. If for some reason eyesight starts to worsen or the patient loses the ability to see altogether then there is no way of going back. It is impossible to revert the changes that were already made to the eyes. The patient would have to live the rest of his/her life without vision from that eye. The fact of potentially losing vision is a very strong argument against doing eye surgery. However, laser surgeons report that serious complications rate is below one per cent for those who had taken laser-assisted in situ keratomileusis. [3]

Opticians suggest that everyone should do eye gymnastics. This improves eye reaction time as well as trains eye muscles. This also helps them stay healthy and everyone should do it regularly to keep eye muscles healthy and fit. They're designed to strengthen eye muscles, help focus, ease eye movements, and stimulate brain's vision centre. They may be recommended by the optician if a patient has got blurred vision, eyestrain or increased light sensitivity [4]

It is a good idea to do sports. However, with modern life people do not have time to do sports neither do they do eye training. Long work hours without breaks tend to stress human even further. As a consequence, according to the Vision Council of America, approximately 75% of US population need some sort of eye correction [5] whether it is glasses, contact lenses or larger font on their PCs the tendency seems to be on the growing side.

One solution to this problem could be making people rest more. But this will not solve the problem of eye muscles weakening. A better option is to do eye gymnastics. It is a bit boring and needs determination. That's where eye tracking technology could be of help. By using the power of computers plus innovation in eye tracking technology games could be made that would encourage users to use their eyes as a gaming controller.

These exercises keep eyes healthy and are not meant to do as a remedy. While there is no scientific proof that eye exercises will improve your eyesight, they may help to counteract existing eye problems you may have and maintain your current eyesight level. [6]

Some companies advertise special methods of improving eye sight and claim that vision will get better and that there would not be any need for glasses or contact lenses after finishing the program. However, scientific proof was not found in these claims and most of the companies who produce these programs for improving eyesight have a disclaimer where it is noted that the rate at which eyesight improves because of doing this program will vary among individuals. This means that doing these programs may provide an effect on eyesight it may do nothing. Since there is no scientific proof that these types of programs improve eyesight to the point the patients do not need glasses or contact lenses at all they should not be suggested as a remedy to bad eyesight. [7]

Our eyes are enormously important to us. A series of experiments by Princeton psychologists Janine Willis and Alexander Todorov revealed that all it takes is a tenth of a second to form an impression of a stranger from their face. Judgments based on facial appearance play a powerful role in how we treat others, and how we get treated. Psychologists have long known that attractive people get better outcomes in practically all walks of life. People with “mature” faces receive more severe judicial outcomes than “baby-faced” people. And having a face that looks competent (as opposed to trustworthy or likeable) may matter a lot in whether a person gets elected to public office. [8] That is just one blink of an eye. But that does not mean only people. Everything we encounter we try to see and understand with our eyes. For example, red is a very eye catching colour and this makes it useful in case you want to draw some attention to yourself. It results in fast heartbeat and breathing rate as it stimulates the nervous system and may be cause of irritation. [1] On the other hand, green is known as a relaxing colour. Green can make you more relaxed and can help make vision clearer and that is one of the reasons why factory walls are painted in green and not red. We treat objects based on how they look and their colour. If the banana fruit is green then we know that it is not ripe and we probably should not eat it. On the other hand, if the tomatoes are red then we know that they are ripe and juicy. Judging by the shade of red we can guess if it is going to rot soon or not. People usually tend to believe more in things they can see rather than in things they can feel or hear. That is because we trust our eyes more than our ears or anything else. We get most of the information from our eyes thus we rely on them more. Most of the things we have learned in our life is done by using our eyes.

It is very hard to imagine living without eyesight. All the things we are used to are much harder when we cannot see the object we are trying to interact with. For instance, walking

seems to be quite easy and usually comes naturally. But everything changes when you exclude eyesight from the senses we normally rely upon while walking. Things start to get more difficult and even the easiest of steps can become a serious challenge when you do not see where you are going. We not only do not know the changes of elevation and obstacles that are in front of us but we cannot see things that can be potentially dangerous to us. For instance, a car moving in our direction is usually noticed by our eyes and then we hear it. That is because the speed of light is much faster than the speed of sound. Furthermore, cars must meet certain sound regulations as manufacturers are obliged to make them more and more quieter. This means that for instance an electric car is almost completely silent thus avoiding if not seeing could be very difficult. Some people remember everything by heart and use memory to orientate in the world. For sure it is easier to walk when you know the route by heart but what can a person do if he/she does not know where the destination point is located. Where should he/she go? How long is the route? What obstacles are ahead and how to interact with the world that is made by people who can see for people who can see. Nowadays, more and more outside objects are done for people with low vision in mind. Traffic lights now have special signals that indicate whether the person should or should not walk. All prescription medicine boxes have special dimples which can be read by hand. It is called Braille alphabet and is meant for the visually impaired people. Some street crossings are tactile tiles that help indicating where the crossing is. It is showing that the person needs to stop and be very careful when crossing the street. People with low vision can also use special voice assistants and talking clocks to make their lives easier. [9]

In 2015 researchers at the MIT Media Laboratory have built a prototype of a finger-mounted device with a built-in camera that converts written text into audio for visually impaired users. The device provides feedback to the user — either tactile or audible — that guides the user's finger along a line of text, and the system reads the text itself and generates the audio of the read text in real time. Special algorithms were developed that could distinguish the start of a sentence and translate letters into text in real time. This could potentially aid people and give them more freedom as with this device they could read even the text that was meant for those who have vision. [10]

Vision can degrade with getting older and having jobs that require having good vision or sitting in front of a monitor such as a programmer or a watchmaker. Nobody wants to have eyesight problems or wear glasses. People want to maintain their perfect eyesight

for the entire life and if vision is not ideal then to keep it stable so that it would not degrade over time. That is why it is important to do eye exercises. Sure, they may not improve your vision but they for sure would not hurt and may be beneficial to keeping your eyesight at the same level.

The purpose of this thesis is to analyse the benefits and drawbacks of creating and using an eye tracking system using a tracking controller from the Swedish company Tobii that would assist in doing eye gymnastics exercises.

2 How our eyes work

2.1 The basic principle

To create the system, we first need to understand how our vision works. It is a highly complex system and it works a little bit like a digital camera.

The eye structure itself is highly complicated. It has been called the most complex organ in our body after the brain. And it probably is considering its size and how many working parts it has. [11] By working in conjunction, they provide us with the miracle of eyesight. The basic principle of an eye is quite simple and reminds us of a typical digital camera. The light enters a chamber. It is then focused on the sensor by the lenses. The sensor then sends information to the processing unit. The processing unit using algorithms creates an image that can be seen on your screen. This is done at a constant speed to make pictures into a seamless video.

2.1.1 An eye and a digital camera

The first thing the light faces is the cornea of the eye. Much like a camera lens it is a clear front surface of the eye that is used for focusing the light. Since the amount of light varies during the day there needs to be a mechanism for controlling the light flow. In a digital camera, this is called a diaphragm. In a human eye this is the main function of the iris. It adjusts how much light enters our eyes at a given moment. It is done by adjusting the size of the pupil.

We usually do not notice how the pupil is constantly working. However, if we are in a dark room and we try to look at a bright object then our eyes start to hurt and we immediately want to close them and turn away since too much light enters the eye at a given moment and it cannot cope with it as it is too sensitive. As soon as the pupil gets smaller less light enters our eyes and we start seeing normally.

When the light enters the body of the eye it needs to be additionally focused to make the image sharper and clearer. This is done by the lens. It changes shape so that our eyes could focus on nearby objects and those that are approaching us. Digital cameras also use lenses but a typical lens in a smartphone consists of five or six element lenses and not just one.

When the light is properly focused, it reaches its destination - the retina. It is a light-sensitive layer at the back of the eye that converts optical information into electronic

signals which are transmitted to the visual cortex. It is the part of the brain that controls our sense of sight. In a digital camera, it is the sensor and an image processing unit respectively. They work in tandem to create the digital image which then appears on our screens. [12]

Now let us dive deeper in the inner workings of the eye.

2.2 Eye structure

2.2.1 Facts about our eyes

When we talk about vision the first thing that comes to mind are our eyes. Humans have a pair of eyeballs that are located horizontally in our head and are left and right respectively. The visible part of the eyeball makes up $\frac{1}{6}$ of the eye's total surface area, with the rest hidden behind the eyelids. [13] We use both our eyes to see at a wide field of vision. A standard horizontal field of vision for a human is approximately 120 degrees. The vertical field of vision is around 135 degrees. [14]

Our estimation on how far the object is from us is based on the information from both eyes. Since our eyes are about 6 cm apart (on average) from each other, it causes the photons from an object that we are looking at to arrive at different angles. The brain then combines the information from both eyes into a single three-dimensional image and gets the information about the depth field from the differences in the images from both eyes. [15] If we close one eye, our vision becomes much less three-dimensional, but there are still many clues that allow us to judge distances. You are still able to catch a ball, walk normally as well as read books. Some of the clues include the differences of vividness of colours at different distances and motion parallax which shows when we move our head. Those objects that are closer will appear to move more than those that are far away. And objects that are far away are typically less vivid. [16]

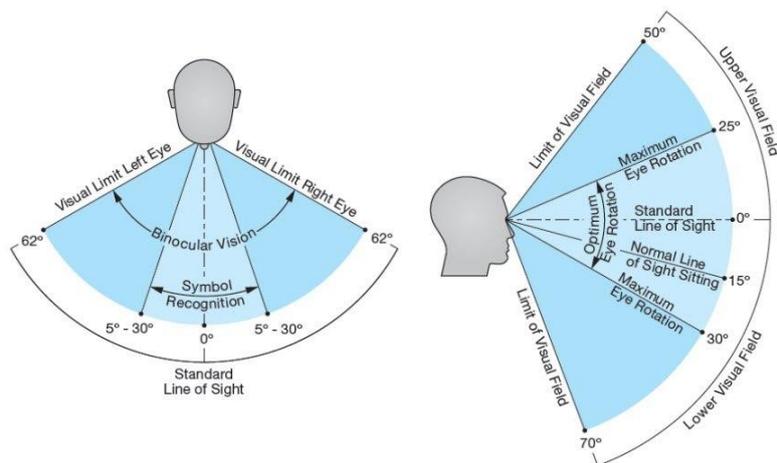


Figure 1 Human Visual Field (Source: <http://buildmedia.com/portfolio-items/what-are-survey-accurate-visual-simulations>)

2.2.2 The external mechanisms of the eye

Our eyes are protected from external factors by eyelids. An eyelid is a thin fold of skin that covers and protects the human eye. The levator palpebrae superioris muscle is located in the upper eyelid. It retracts the eyelid to "open" the eye. [17]

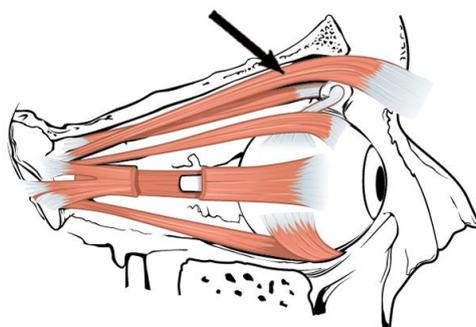


Figure 2 Levator Palpebrae Superioris (Source: <http://anatomyzone.com/anatomy-feed/levator-palpebrae-superioris/>)

To increase protection of the eye from debris and dust there is a row of eyelashes along the eyelid. Moreover, eyelids help keeping our eyes moist as the cornea must never be dry. When we blink, the eyelid spreads the moisture along the eye as well as removes all foreign bodies from the surface of the eye. Tears wash away dust and debris from the eye. They also protect our eyes from diseases. If anything gets on the eye the lacrimal

gland starts producing tears and our eye starts blinking in order to remove the debris as quickly as possible as it can potentially be very dangerous.

2.2.2.1 What makes our eyes move

Before we dive deeper in the inner structure of the eyeball we should first explore what makes our eyes move. But why do we need our eyes to move? We can just turn our head into the direction that we want to look at. Turns out that that our eyes move a lot faster than our head can and, since humans are predators by nature, we need to react quickly to everything that is happening around us. Moreover, constantly turning the head instead of moving your eyes is not only slower but produces more neck strain and can cause health problems.

As with all parts of our body, muscles are the ones responsible for eye movement in different directions. In total, there are six muscles that are attached to the eye and are in control of its movement. There are muscles that move the eye from left to right, help rotate it and move downwards and upwards. So, what are these muscles called?

The muscles that move the eye upward and downward are called the superior and inferior rectus. They are attached to the top and the bottom of the eye respectively.

If we want to move our eyes toward the nose then the medial rectus is being used. It is attached to the eye and near our nose. As it contracts our eyes move towards the nose. Opposite of the medial rectus is the lateral rectus which is connected to the side of the eye near the temple. All the muscles are extraocular i.e. they are attached on the outside of the eye.

The inward rotation from front to back is done by the superior oblique which comes from the back of the orbit. The muscle attaches to the top of the eye and travels near the nose. The superior oblique also helps to move the eye down.

The opposite of the superior oblique is the inferior oblique which is also an extraocular muscle. It arises in the front of the orbit. It then travels outward and attaches to the bottom part of the eyeball. As it is the opposite of the superior oblique it rotates the eye outward. The inferior oblique also helps to move the eye up. [12]

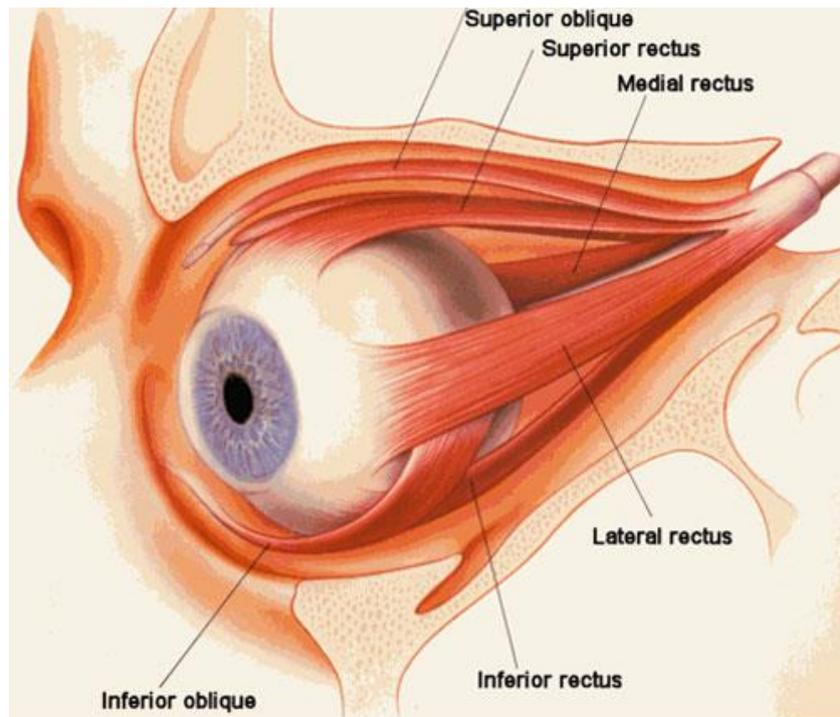


Figure 3 Muscles that are connected to the eye (Source: <https://www.aapos.org/terms/conditions/22>)

It is astonishing how coordinated these muscles are and how fast they can contract. They are very precise and all work in tandem. Now that we have found out about the extraocular muscles of the eye we need to know how an eye works inside and what are the mechanisms that make us see things and see not only in black and white but with deep colour and with fast focusing.

2.2.3 The structure of the eye

2.2.3.1 The external structure of the eye

The structure of the eye is fascinating not only on the outside, but on the inside as well. The amount of different parts that is located in this small sphere and how they work together to give us the miracle of eye sight is simply one of the nature's wonders.

Conjunctiva:

In front of the eye, in the area protected by the eyelids, the sclera is covered by a thin, transparent membrane. It is called conjunctiva. Conjunctiva also covers the moist back

surface of the eyelids and eyeballs. It becomes pink when it is infected or irritated. This condition is called conjunctivitis.

Cornea:

Cornea is a transparent dome over the iris. Its main function is to transmit and bend light focusing it on the retina. Cornea occupies the front centre part of the outer wall of the eye. Cornea consists of collagen fibres. They are arranged in a special way so that the cornea is clear. When we look into somebody's eyes we see the iris and the pupil through the cornea. Cornea is the first focusing mechanism of the eye that the light faces when it comes into our eye. People place contact lenses on the cornea as they help with light focusing as an additional lens.

Lacrimal Gland:

The lacrimal gland produces tears that lubricate the eye. It is located under the lateral edge of the eyebrow in the orbit. Tears help our eyes stay moist, healthy and clean.

Sclera:

The sclera is the white outer layer of the eye. That is the white part of the eye that we see. It is relatively tough and nearly covers the entire surface of the eyeball. The sclera consists of collagen fibres which makes it quite strong. Together with cornea they make our eyes' external protective layer. The extraocular muscles connect to the eye via sclera.

2.2.3.2 The internal structure of the eye

As for the internal eye structure, we are mainly interested in the iris, pupil, retina and the lens.

The iris is the coloured part of the eye. It has a shape of a disk with a hole in the middle. The hole in the middle is called the pupil. It is the only place in the eye that lets light in so the iris needs to filter the amount of light that enters the eye. There are several muscles in the iris that cause the pupil to constrict when it is bright and to dilate when it is dark regulating how much light enters the eye and reaches the back part of the eye. When we go from a dark room to a bright scene our pupil cannot dilate fast enough and too much light enters through the wide-open pupil. When light reaches the light sensitive area of our eye we feel pain as it is too sensitive to handle this much photons. Our natural reaction to this is to close our eyes until the pupil gets smaller so we can open them again.

When we go to an eye exam, opticians use special eye drops to make our pupil open wider so they can properly examine the inner structure of our eye.

The light travels from the cornea to the lens which does most of the focusing in our eye. The lens is surrounded by the ciliary muscles that help to change its shape for focusing on objects at different distances. The process of focusing is called accommodation. When we want to focus on an object the lens changes shape based on how far the object is from us.

The retina is located at the back of the eye. Its main function is to analyse the light that came into the eye much like a sensor in a digital camera. Our retina contains photoreceptors that sense light and transfer the information to the special part of the brain. Macula, which has millions of tightly packed photoreceptors (the type called cones) is the most sensitive area of the retina. Because the macula has a lot of cones stacked together it makes the image very crisp and detailed.

These are the components that form our eyes and make them work. The sheer number of different parts that need to work together in order to produce a single image is incredible. If any of these parts fails to work as it is intended we could potentially lose our eye sight. This means that we need to take care of our eyes, not to stress them too much and keep them safe and clean.

[18], [19], [20], [12], [21]

2.3 What happens when we stress our eyes too much?

When we sit in front of a computer or look at a cell phone screen our eyes stare at a static object. It does not change shape or go farther or nearer to us. That means that our eyes must focus on a single object for a long period of time. Our eyes are not designed for viewing static things for long periods of time. The object that we are looking at should change direction and come farther or nearer to us. We might look at a different object but our eyes must constantly work.

When we use our digital devices too much this causes our eyes to strain too much. This effect is called the digital eye strain. A large variety of electronic devices can cause digital eye strain, including televisions, computers and smartphones especially when they are used simultaneously. [22]

Several factors contribute to digital eye strain, including how close you are to your screen. People usually hold handheld devices 20 – 30cm away from their faces and by focusing

on the same object the blinking rate decreases dramatically. According to Justin Bazan, an optometrist and medical adviser to The Vision Council: *“Blinking is crucial to keeping the ocular surface well protected from environmental assaults and our eyes from drying out”*. *“They’ll become dry and irritated, and vision will become blurry as well.”* That’s where the urge to rub your eyes at the end of a long workday comes from. [23]

A typical Liquid Crystal Display (LCD) screen uses Light Emitting Diodes (LED) to create light. The diodes used are usually blue. However blue LEDs produce blue light and we need white in order to have the correct colour output, so they are covered by a phosphorus coating which makes the light white. [24], [25] *“That light is so close to ultraviolet, which has been known to cause damage on the cells of the eyes for years now”* Bazan says. *“Preliminary research is showing that blue light, like UV light, can cause damage to the cells inside of our eye, and retinal cells produce vision.”* [23]

One way to avoid this is to not use devices that emit blue light. A recent trend in smartphone technology has been in adding blue light filters to the phones. It is typically called “night mode” or a “reading mode”. It is suggested to use in the evenings and at night. The screen of the smartphone becomes yellowish or brownish by applying special filters to all the images that are displayed on the screen which should be more comfortable for the eye. As a result, our eyes get less strain and people can sleep more comfortably. Similar applications exist for personal computers and they make the screen go yellower during night time since there is no sun at night and artificial lighting is not as good as the sun. Moreover, having a screen that is brighter than the room is also not advisable. Having a night mode is not the panacea to the problem of eye strain. *“When we look at ink on paper, our eyes know at what distance the ink and paper is and we can lock the focus on.”* Pixels on a screen, on the other hand, are hard points of focus and compete for our eyeballs, he says. *“Since a pixel is a hard target, we see that our focusing system is always in a state of trying to find exactly where the pixel is. That constant focusing causes strain.”* If one wears glasses then special yellow-tinted computer eyewear exists, that physically reduces the amount of blue light that our eyes face as well as help focus on computer screen. And the safest distance to the computer screen is measured by reaching your hand to the monitor. [23]

2.4 What we need to train

So, our focus will be on the six muscles that make an eye move. The importance of these muscles cannot be underestimated. They are the workhorse that make our eyes as agile as they are and they suffer a lot with our current lifestyle. Because we spend a lot of our time looking at different static objects such as screens the muscles do not have much work to do and our eyes do not move as much as needed. The consequence is that eye muscles weaken which drastically decreases reaction time and is not very good for the health of our eyes.

According to the U.S. National Eye Institute in 2050 the number of people with low vision in America will increase to 8 million compared to 2 million that was in 2010 [26]

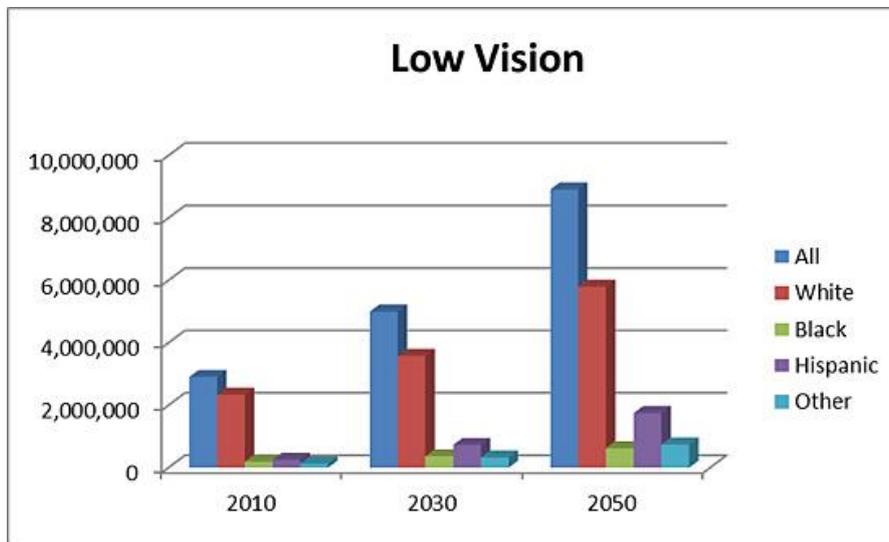


Figure 4 Projections for Low Vision in the US (2010-2030-2050) (Source: <https://nei.nih.gov/eyedata/lowvision#5>)

To prevent this from happening and as a general training measure people need to train their eyes by doing eye gymnastics.

This keeps them healthy, in shape and prepared for the challenges that could come their way.

Doing eye exercises is beneficial not only for those who spend most of their time in front of the computer but for everyone who want to maintain their level of eyesight and feel healthy. However, doing exercises requires time and a bit of effort. Not many people can find time to do these simple tasks as they do not feel the need to do this as well as it is a bit boring for them. The aim of this thesis is to make eye gymnastics fun and entertaining so people would have fun while doing it. Not only will this help people keep their eye healthy but also introduce people to the world of consumer eye tracking technology.

3 How eye tracking works

3.1 What is eye tracking?

Eye tracking is a form of measuring where the person is looking by using an eye tracker that consists of illuminators and cameras. The technology is used in psychology, clinical research, marketing, user experience as well as education. The technology can also be used for gaming and to control a computer with your eyes instead of using traditional keyboard, mouse or controller. [27]

But how to do it? One solution would be to strap cameras on the head of the examinee and record where the head of the person is looking. However, our eyes move independently of our head thus a person might be looking to the left but the head could be pointing to the right. So, we need to record where exactly the eyes are looking at. If we turn the cameras around and start recording eye movement we would be able to see eye movement by looking in which direction the iris is shifting. Digital cameras can recognize faces with different software algorithms. Advanced cameras can even track and focus on objects as they move. Although, this seems to be the right idea a standard camera is incapable of “seeing” where the eye is. This means that a human is needed to check how much the iris has moved and in which direction. This is an idea that is extremely hard to implement as humans can make large scale errors and it is very difficult to notice the smallest of movements (typically less than a few millimetres).

As a result, special hardware is needed that could see the eyeball, be calibrated to know the point of reference and check for any slight movement of the eye. A Swedish company named Tobii AB has entered the market with their eye trackers. Their eye trackers are used for research purposes as well as for playing games. Tobii AB positions themselves as the world leaders in eye tracking technology. [28]

So how do Tobii Eye Trackers work?

3.2 Reading eyes

The main principle focuses on the eyeball movement contrary to the calibrated centre. Special hardware is used to measure even the slightest eye movements to show the position of the eye on the screen or to perform different actions such as clicking or changing position. [29]

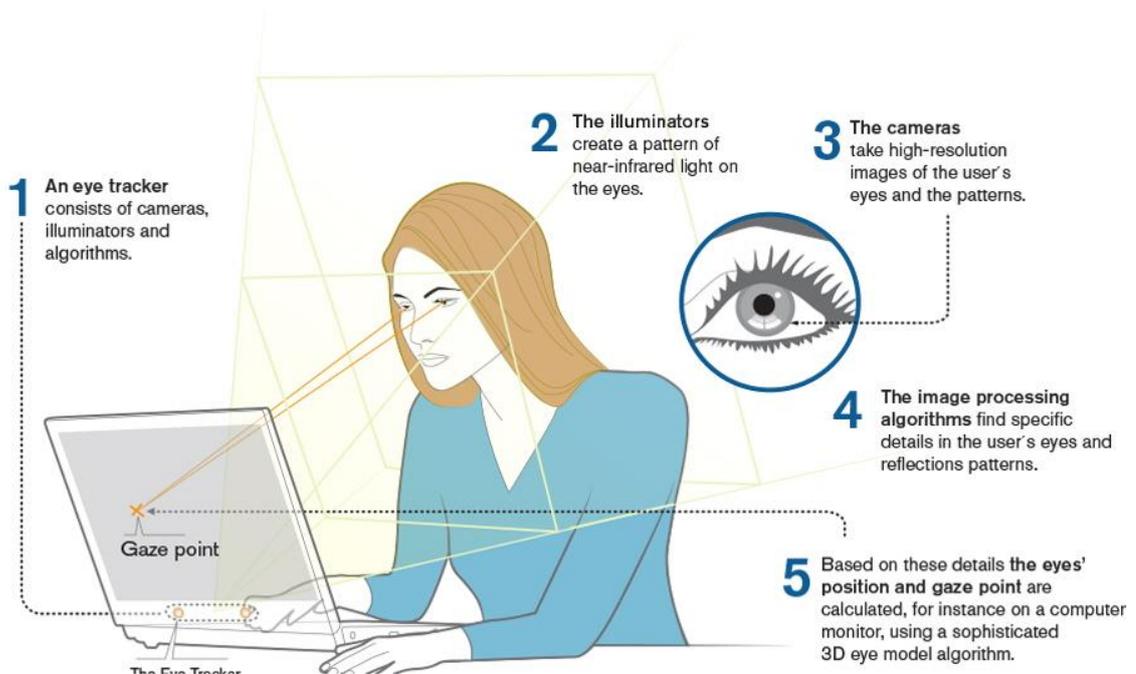


Figure 5 How an eye tracking solution looks like (Source: <https://www.tobii.com/learn-and-support/learn/eye-tracking-essentials/how-do-tobii-eye-trackers-work/>)

The basic idea is:

1. The eye tracker sends out near infrared light
2. The light is reflected in your eyes
3. Those reflections are picked up by the eye tracker's cameras
4. Through filtering and calculations, the eye tracker knows where you are looking

3.2.1 How Tobii eye trackers read eyes

There are several different techniques to detect and track eye movements. However, when it comes to remote, non-intrusive eye tracking the most commonly used technique is pupil centre corneal reflection (PCCR). The basic concept is to use a light source to illuminate the eye causing highly visible reflections, and a camera to capture an image of the eye showing these reflections. The image captured by the camera is then used to identify the reflection of the light source on the cornea and in the pupil. We can then calculate a vector formed by the angle between the cornea and pupil reflections. The direction of this vector, combined with other geometrical features of the reflections, is then used to calculate the gaze direction. [30]

For eye tracking to work accurately, the eye tracker must know as much as possible about the eye it is trying to read i.e. a virtual model of the eye should be created.

3.3 Eye tracker calibration

Calibration is the process of configuring an instrument to provide a result for a sample within an acceptable range. Eliminating or minimizing factors that cause inaccurate measurements is a fundamental aspect of instrumentation design. Calibration of an eye tracker is needed for an accurate gaze point calculation [31]

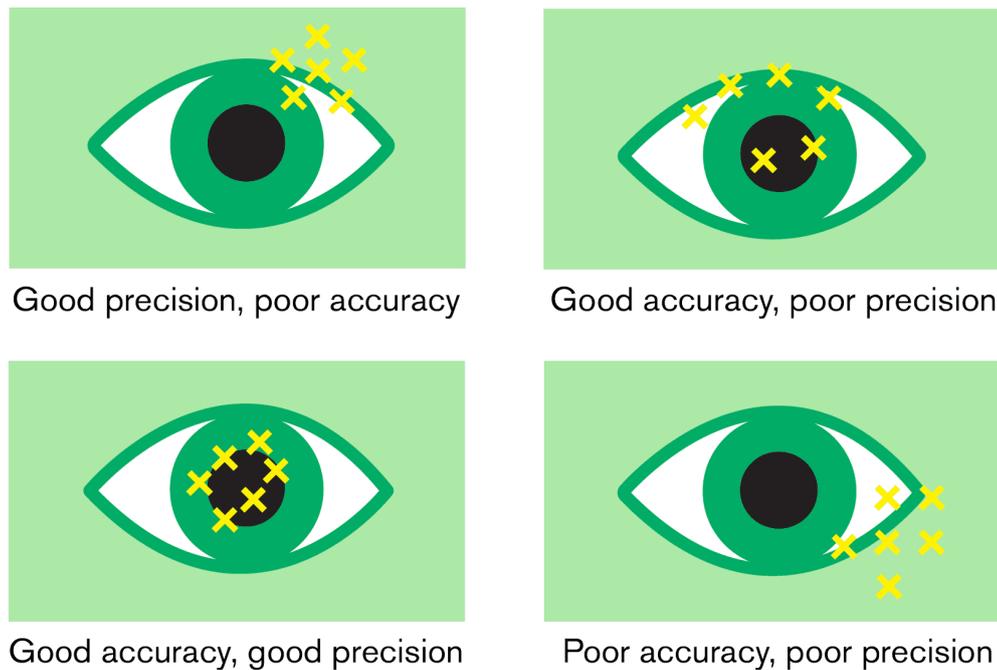


Figure 6 Different types of precision and accuracy for an eye controller (Source: <https://www.tobii-dynavox.com/about/about-us/how-eye-tracking-works/>)

Before the sensor can do anything, the user is taken through a mandatory calibration process of the tracker. During this procedure, the eye tracker measures all the necessary parameters of the user's eyes to create an anatomical three-dimensional eye model. This model combines information about reflection properties and light refraction of the different parts of the eyes.

The system shows a blank screen with specific points on the screen, also known as calibration dots which the user needs to look at. The dots disappear as the user looks at them. During this period, several images of the eyes are collected and analysed. [32]

When calibration is finished, it is possible to check how accurately the calibration has been done. This can be done in a submenu of the Tobii Eye Tracking desktop app under the user profile. The following window opens and provides the user with dots and circles around them.

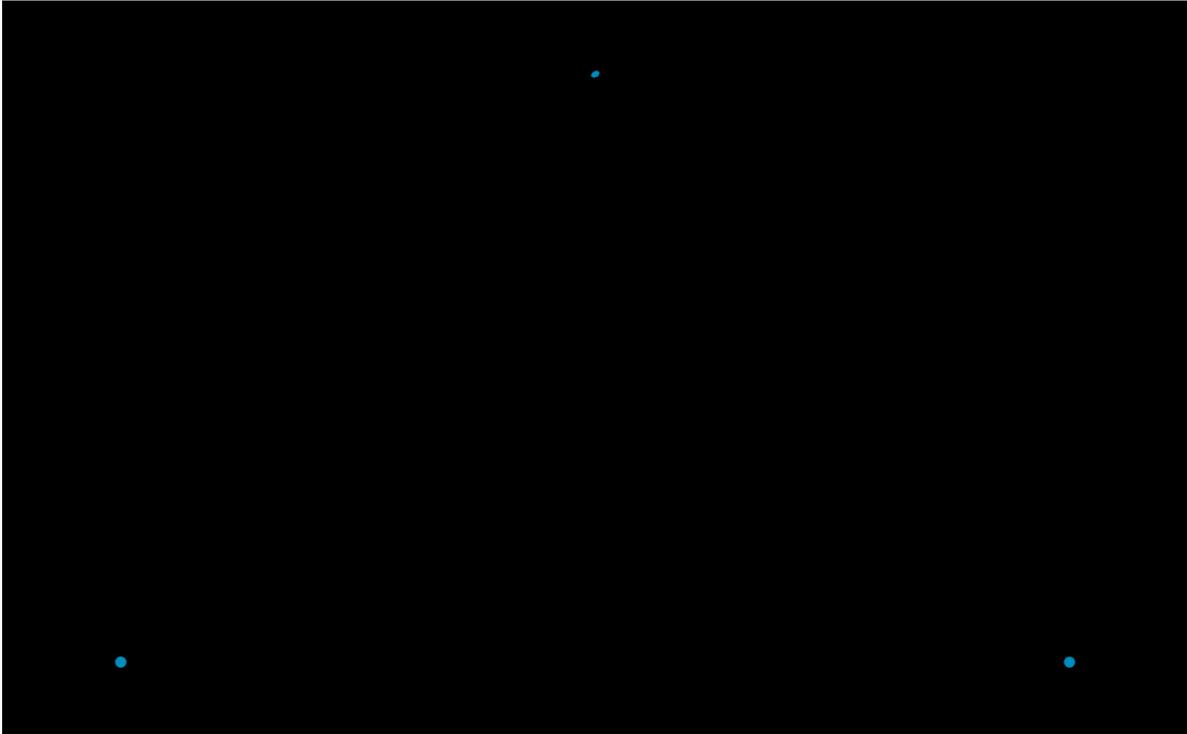


Figure 7 Calibration screen of the Tobii Eyetracking application

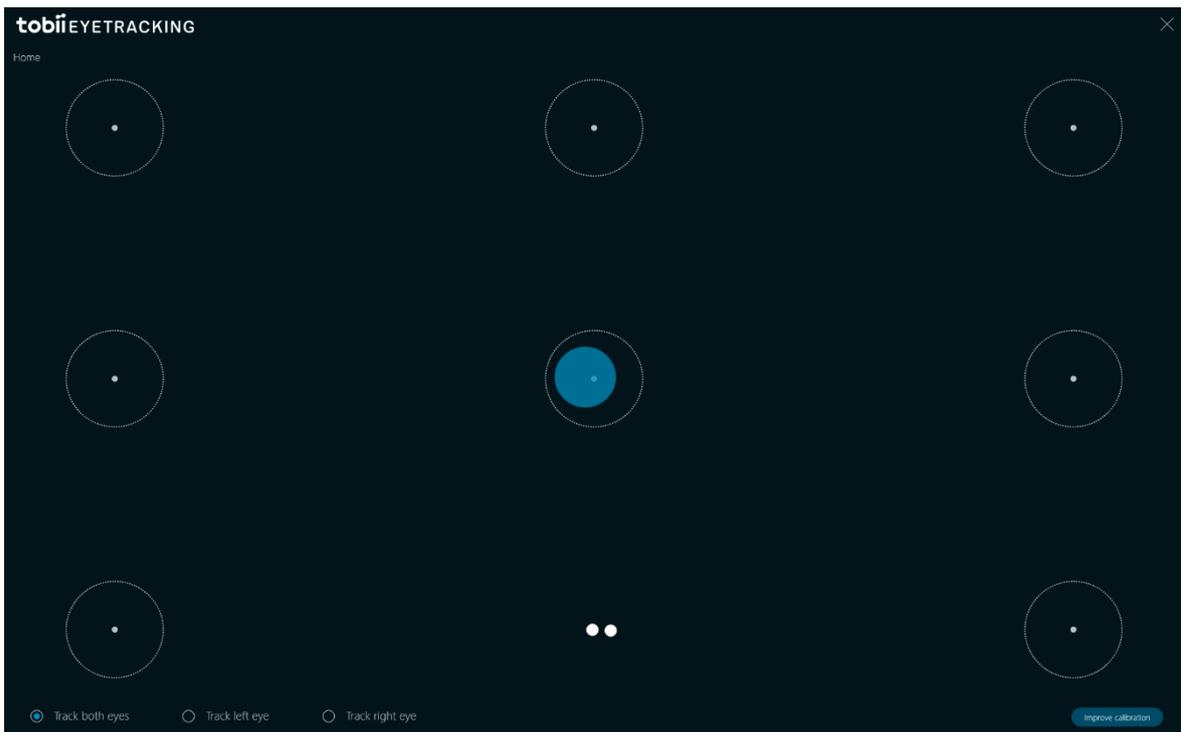


Figure 8 Screen for testing calibration

The tracker must be switched on during testing. When the tracker is switched on the glowing red lamps on the tracker itself indicate that it is working and reading for the user's eyes.

By looking at each of the dots it is possible to find how accurately the tracker is calibrated and how accurate the 3D model of the eye is. If user finds that the tracker is not sufficiently calibrated i.e. gaze info does not correspond to the position of the dots on the screen or wishes to recalibrate the tracker for additional precision then the button “Recalibrate” at the bottom of the screen should be pressed.

Calibration process is started then from scratch. Internally the system then creates a completely new 3D model of the eye that is used for determining gaze position on the screen. The user needs to keep his head still during calibration as head movement may hinder creation of the eye model.

3.4 Wearable eye trackers

Usually eye trackers are placed at the bottom of the screen so the surface area where the user is looking is quite small compared to our angle of view which is around 120 degrees. But what about scenarios when we need to track eye movement not on the screen but for instance outside or during a game of tennis. For this reason, portable trackers exist and they consist of glasses and a special unit for processing information. The drawing of a portable solution from Tobii can be seen below. It shows the eye tracker itself that looks like a typical pair of glasses with additional cameras and sensors. Connected to the glasses by wire is the base station where all the 3D eye model generation and analysis is done.

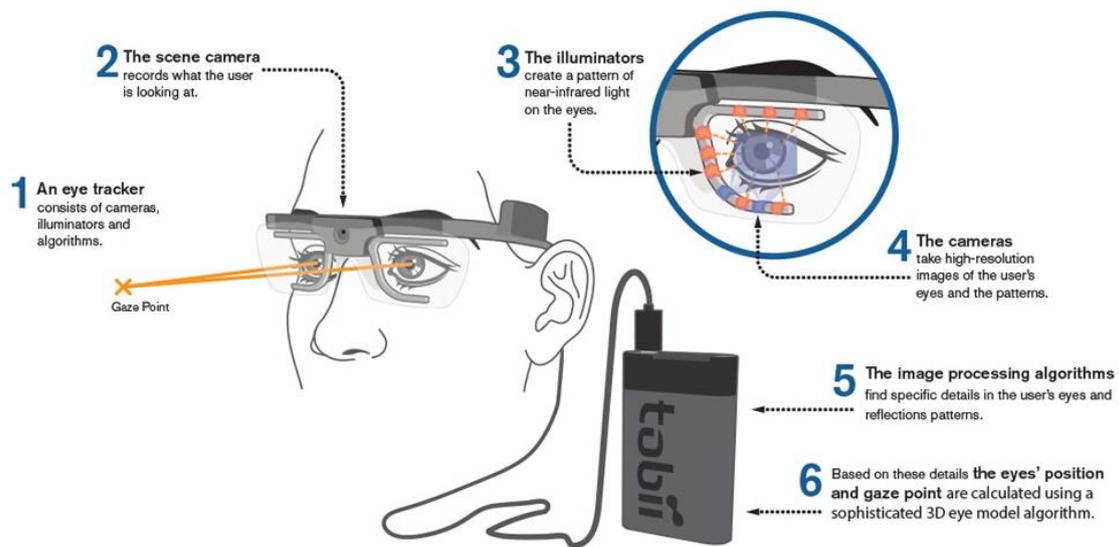


Figure 9 An illustration of a wearable eye tracker from Tobii (Source: <https://www.tobii.com/learn-and-support/learn/eye-tracking-essentials/how-do-tobii-eye-trackers-work/>)

The image above shows how a wearable eye tracker works. Just like those that are placed on the screen, a wearable eye tracker also is constructed using the same basic principle and components. At first the eye needs to be illuminated with infrared light by the illuminators, then the image is read by the cameras and finally a 3D eye model is constructed with gaze mapping algorithms. This model is then used to measure the eye movement. On the front panel above the nose a small camera is located in order to record the image in front of the person wearing eye tracking glasses. This is a very convenient way to record eye movement away from the monitor. [30]

4 Creating an application

4.1 Hardware

Eye tracking is currently not so popular due to the lack of apps that are created specifically for eye tracking devices. The technology also used to be very expensive to implement. The cheapest professional eye tracker cost around 5 000 euro [33] which is too expensive for an ordinary household. However, Tobii has created an affordable eye tracker called the Tobii EyeX. It is a consumer product that contains everything that is needed for a typical user to start his journey into the world of eyes tracking. [34] The unit can be used as a gaming controller or for developers to add additional features to their games and applications such as controlling the application with eye movement. The unit costs 109 euro plus shipping and is very affordable compared to the PRO versions that are meant mostly for research and highly accurate data gathering and are like 50 times more expensive. Tobii EyeX is not as fast and accurate as the Pro controllers such as Tobii X2-30 and does not have the ability to work with the Pro Studio which is a software for the analysis and visualization of data from screen-based eye trackers. It supports a complete set of tools to conduct research from the design of the test to conducting it and then analysing with heat maps and graphs. The Pro controllers do not need to be calibrated as they are a lot more accurate.

Moreover, Pro controllers can compensate for head movement and still be very precise even when the subject has moved his head. [35] Tobii Pro Studio as well as Pro controllers are primary meant for research and are not meant for gaming.

Since we do not need to record any data and are more interested in the concept of controlling the process of eye training with eye tracking we do not need the Pro controller nor the Pro Studio.

Recently Tobii AB has come up with a new controller. The Tobii Eye Tracker 4C is a new tracker from the Swedish company. It has mainly the same characteristics as the EyeX. The main difference is the addition of the eye tracking ASIC named Tobii EyeChip. This chip handles the processing of data thus reduces CPU load and the amount of data that is exchanged between PC and the controller. As a result, the controller consumes less power, does not require USB 3.0 anymore and reduces CPU load by up to nine per cent from previous 10%. Additionally, a feature from the Pro controllers has made its way to a consumer product. The feature in question is the head tracking support.

Tobii advertises this as the only PC gaming device that provides not only eye tracking but head tracking as well. This will provide additional accuracy. The controller costs 50 euro more. As it does not provide any significant changes from the EyeX I decided that EyeX is sufficient enough for this application. [36]

4.2 Software

There are two different types of SDKs that Tobii eye trackers use. The first one is called Tobii Gaze SDK. It consists of low-level APIs that provide access to the eye tracking data. Gaze SDK gives full control of how to process and use data. However, this also means that we would need to calibrate and configure the tracker ourselves. Moreover, the data needs to be processed and analysed in a special environment that we also must create ourselves. Since we already have a Windows environment with a ready to go implementation all the necessary components for tracking and are not planning to create any embedded systems we will need to use a different approach.

Luckily Tobii provides the Eye SDK that makes use of the EyeX Engine API which helps with getting started and creating applications that make use of high-level interaction events in addition to the low-level data from the eye tracker. The EyeX Engine takes care of calibration and screen setup. Furthermore, the Eye SDK can map objects and give information to the program as to what object the person is currently looking at. Specifically, the Eye SDK for Unity 5 makes use of unity objects and provides a flexible environment to create and control objects just by looking at them. Currently the Eye SDK is only available for Windows as a standalone application. [37]

The Tobii EyeX Engine is a software that is installed on top of an operating system. It knows all the commands that are needed to talk to the eye tracker. It can get information from the tracker itself and interpret it into user interactions. It is smart enough and can handle multiple client applications at the same time providing them with all the necessary information. On the other hand, Tobii EyeX Interaction is a piece of software built on top of the EyeX Engine, and offers a set of basic eye-gaze interactions available out-of-the-box such as Gaze Trace which shows in real time what you are looking at. It looks as a bubble that follows wherever the user is looking on the screen.

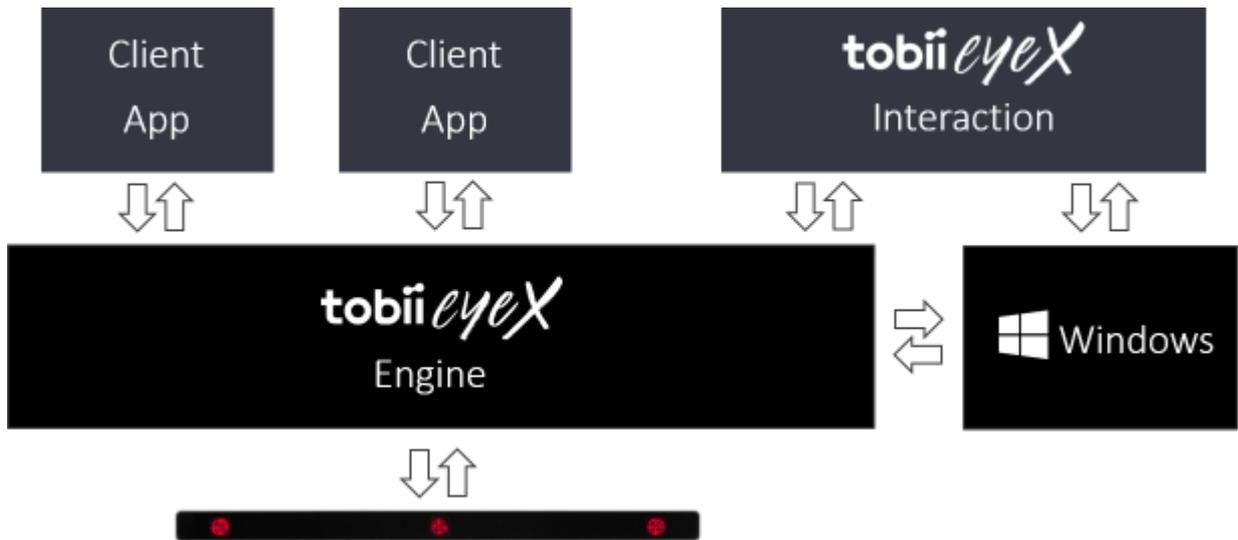


Figure 10 EyeX Engine Scheme (Source: <http://developer.tobii.com/an-introduction-to-the-tobii-eyex-sdk/>)

4.3 How the EyeX Engine knows what the user is looking at?

According to Tobii this is a step by step guide as to how the controller and software work together.

1. The user looks at the screen. The EyeX Controller calculates the x and y from the user's gaze based on the three-dimensional model that was created during calibration process. The EyeX Engine receives the coordinates and transforms them into exact pixel coordinates on the screen that are being looked at.
2. The EyeX Engine then uses information from the client application to find out what sort of object the user might be looking at based on the pixel coordinates and knowledge of the objects in the area surrounding the pixels. Let us assume that there are fields or buttons on the screen that can be pressed and are active. If they are well separated and are active this means that they can be selected using the user's eye gaze. The EyeX Engine now decides among available buttons in the area surrounding the pixel coordinates which of the objects is the most suitable. The Engine then highlights the chosen button and expects the user to somehow indicate that this is indeed the exact button that needs to be pressed. The more precise the controller is the smaller objects can be on the screen. [38]

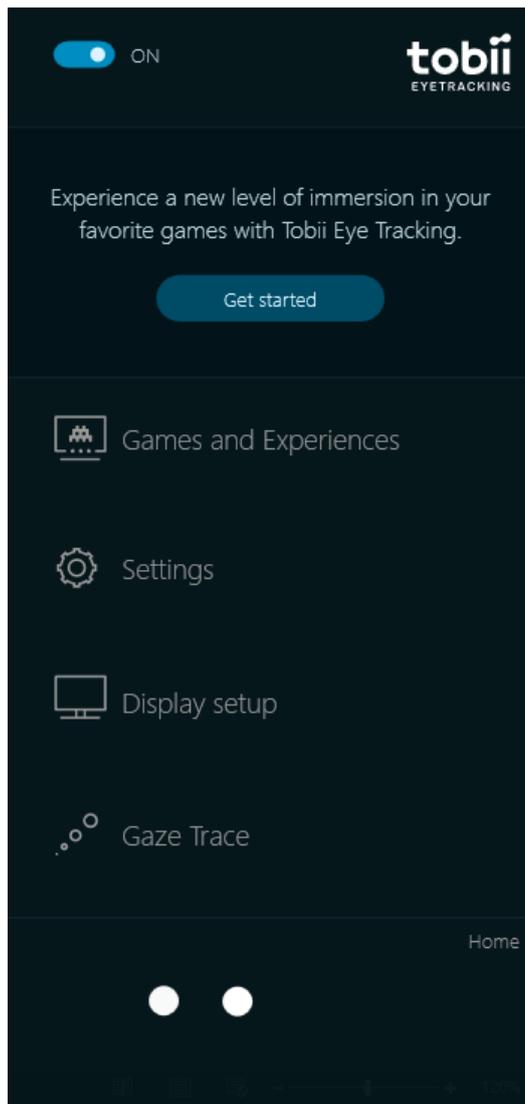


Figure 11 Tobii eyetracking application

Here is the view of the client application and the options that are available to the user upon opening the app. The two white dots at the bottom of the screen are the representation of the user's eyes with indication how clearly the device can see them. If for some reason only one eye is visible or none at all, then the tracker needs to be calibrated once more or the user needs to change his position relative to the screen and the tracker.

3. The client application may provide the user with diverse ways of actually clicking the button after it was selected using eye-gaze. It must always be some combination of looking at the object you want to click, and when it is selected giving a secondary input to produce the actual click. You first look at the menu

item you want to click and when it is highlighted you press the space bar the item will be selected in the menu.

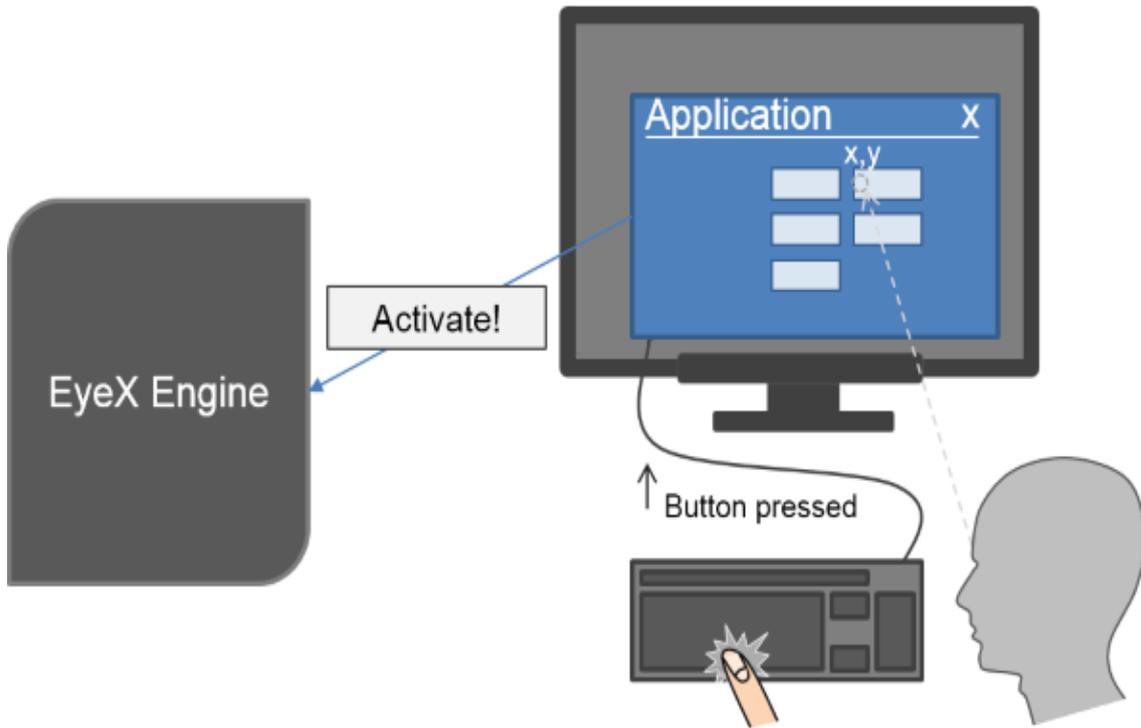


Figure 12 User has chosen the button and clicked (Source: <http://developer.tobii.com/an-introduction-to-the-tobii-eyex-sdk/>)

4. When the user presses a button while looking at an object that is selected. The client application sends an “activate” to the EyeX Engine.
5. An event is then generated by the EyeX Engine that informs the client application which button the user wants to activate.

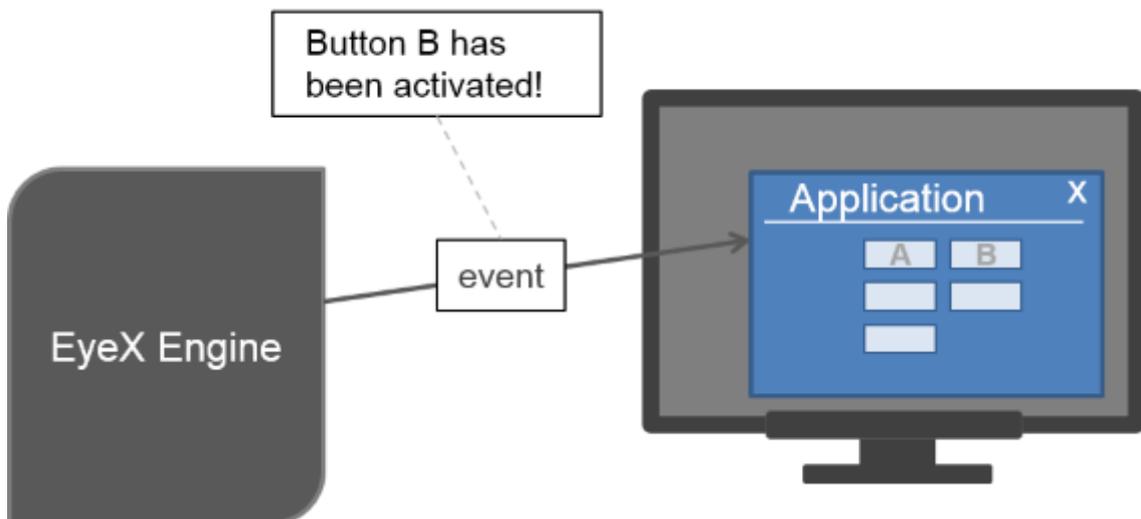


Figure 13 EyeX Engine activates the button (Source: <http://developer.tobii.com/an-introduction-to-the-tobii-eyex-sdk/>)

The Tobii EyeTracking SDK for Unity 5 provides seamless integration of the application and controller. The app developer creates all the necessary objects in the Unity developer environment and then adds behaviour to individual components whether they are supposed to be activated by eye-gaze or not. [38]

4.4 Setup

As for the system where everything is running, I am using my own personal computer. It is an Intel Core i5 7500 3.4GHz Quad-Core with 8GB of DDR4 2400 MHz single channel one stick memory. It is running Windows 10 Education Build 1607 on an Asus H270-PRO motherboard with Samsung 850 EVO 250GB Solid State Drive. The system is relatively new. In order to work Tobii EyeX enquires an USB 3.0 connector and at least a 2.0 GHz Quad-Core Intel i5 or i7 with 8 GB RAM. The new Tobii 4C controller has an integrated Tobii EyeChip which reduced CPU load and with USB 2.0 which widens compatibility. [39]



Figure 14 About page of the test PC

The screenshot above is the “About” section of the Windows 10 setting window which shows the essential parameters of the system.

The desktop computer is connected to the Dell U2415H 24” monitor. Since the eye controller does not have its own stand it is attached to the lower panel of the monitor as can be seen on the image from the Internet below.

The eye tracker selected is the Tobii EyeX which is an eye tracking device that uses near-infrared light to track the eye movements and gaze point of a user.



Figure 15 Mounting of the EyeX controller (Source: <http://www.pcworld.com/article/3014523/peripherals/tobii-eyex-review-the-eye-mouse-is-magical-but-just-not-for-everyone.html>)

The main parameters of the Tobii EyeX are the following: operating range is from 50 to 90cm. The data rate is above 60 Hz and the size is 20x15x230mm. The EyeX supports Unity, Unreal Engine 4, C++ as well as .NET. [34]

4.5 Exercise examples

All six muscles need to be trained regularly. This helps them stay healthy i.e. contract faster, sustain stress and loads as well as keep eyesight from degrading as well as potentially improving eyesight. It also helps them stay strong and react to changes. The best way to train them is to do different kinds of active sports so eyes can train naturally. As our modern lifestyle, often does not allow us to spend time doing sports, opticians have created alternative exercises that can be done anywhere. In order to train eye muscles equally, different types of exercises need to be done together. Optometrists recommend doing specific types of exercises. There are a lot of different methods that exist for eye training. They are very easy to master and do not take a lot of time. [40]

First exercise

This exercise does not involve moving your eyes. To begin with, it is recommended to let your eyes relax a little bit by putting the palms of your hands over your eyes and gazing in the darkness. This will help your eyes relax faster by taking the load off them. This exercise duration is around three minutes. When it is finished, you can proceed to the next ones.

Second exercise

The second eye gymnastics exercise involves moving eyes horizontally. The approximate duration is one minute. You should sit up right. Your head should not be turned and you should be looking straight. Without moving your head look to your right and focus on the rightmost object. Then look to your left and focus on the leftmost object. Repeat this exercise for around one minute.

Now let us analyse what happens when we do this exercise.

First of all, we need to find out what muscles are active when we look left and right. When we are looking left the lateral rectus contracts and moves our eyeball left. When we are looking right the medial rectus contracts and moves our eyeball to the right. Then the lens focuses on the object we want to look at by changing its shape so that light can be clearly focused at retina.

Third exercise

Third exercise involves moving the eyes vertically. The goal is to train superior rectus and inferior rectus which move our eyes up and down respectively. It is very important to do these exercises slowly as there is no need to rush and being fast does not equalize to overall good results.

To perform this exercise, you need to look up and focus on what you see. Then you look down and focus on what you see. Repeat this exercises for around one minute.

Fourth exercise

The fourth exercise involves rolling your eyes in a circular pattern. Look right then slowly move your eyes clockwise so that you will be looking down then left and finally up. Repeat this cycle ten times. This exercise trains all six muscles and is very beneficial for them. At first it may seem strange and unusual to do this kind of exercise since we are not used to doing these types of motions for long periods of time. However, by doing this exercise daily you will make your eyes get used to these types of workouts and further exercises will be a breeze.

Fifth exercise

In order to perform the fifth exercise, you need to sit up straight. Find an object that is far away from you. Position the index finger in front of your eyes around 20 cm in front of you. Now look at your index finger and focus on it. Then focus on the chosen object and try to see its details. Repeat this cycle ten times. This helps train all focusing mechanisms including ciliary muscles. The lens gets the most workout here as it is one of the most important focusing mechanisms. We need to be able to focus fast and determine the distance to other objects as it is one of the basic principles of a healthy and good life. For instance, if an eye cannot focus properly or is too slow at doing this then you are not able to see the object clearly and distinguish it from others.

Sixth exercise

Our eyes are fed with blood and good blood circulation is an essential part of good health. When our eyes stay at a constant position and all the movements are minor, they may get less blood and oxygen than usual. With lack of oxygen eyes start to get tired and muscles weaken even faster. The goal of this exercise is to improve blood circulation by massaging our eyes. You need to close your eyes and massage them with circular movements of the

fingers for up to two minutes. This can be done right after the first exercise to further relax the muscles, give them additional blood as well as prepare them for the challenges they will be facing.

Seventh exercise

It is very important for the lens to be healthy and focus light on the retina as fast as it can. An addition to the fifth exercise, you can put your hand in front of you with one finger pointing up. When you focus on it bring it closer to you face to about seven centimetres in front of you. Then stretch your arm to the longest position without leaving the focus from the finger. [6], [41]

4.6 Choosing the exercises to implement

All the exercises must be done properly. If people do them too fast or do not pay attention to how they are done then there is no point in doing them. They will not give any benefits and it will just be a waste of time. When creating an application, we need to choose which of the exercises mentioned above should we implement.

Since there is no way for a computer to tell whether you are holding your arms on your eyes or not or even massaging them the first and sixth exercise could not be implemented. These exercises users should remember to do themselves and then continue with the application. Personal computers also cannot move as they are stationary objects. Monitors, unfortunately, are not able to produce images that would imitate being far away from the object. This means that we can focus on an image shown on a monitor but the monitor does not move so the distance to the image does not change. Moreover, our tracker can only see what we are looking at on the screen so looking at an image on the screen and then shifting our focus to something that is not on the monitor is not an option. So, the fifth and seventh exercises will not be implemented.

What we can do is see what image the person is looking at if the image is on the screen. This means that if the exercise involves focusing on an object, moving it or moving our eyes it can be seen and traced by our tracker. Exercises two, three and four are the perfect candidates to be implemented and used with an eye tracker.

We should set criteria based on which our application should work. Firstly, they should implement these three exercises. This means that users will do similar eye movements as

those which are mentioned in the exercise descriptions. The first one should be focused on moving your eyes vertically, the second one – horizontally and the third one – in a circular pattern. Furthermore, these applications need to indicate somehow that the user is doing everything correct. They need to change the color of the object if the user looks at it. Moreover, they should be easy to use and simple. Most of the people are not tech-savvy and our goal is to attract people to eye tracking and not scare or confuse them. Applications should have a graphical user interface. They should run on Windows and be easy modified to add new features or change the design. Ideally, they should be self-explanatory and not require any previous experience with eye tracking. Finally, they need to seamlessly work with our eye tracking system.

4.7 Designing the tests

4.7.1 Choosing the framework

To create a basic prototype, we need to establish a concept.

Tobii Eye SDKs have support for Unity 5, .NET and C/C++. Each language has its own advantages and disadvantages. With C++ and .NET we have to create our own user interface and connect it to the eye tracker. Calibration is already implemented in the EyeX Engine so we do not have to worry about that. Since we need to create the graphical user interface ourselves it gives us more flexibility and control over the system. On the other hand, Unity already has a graphical user interface, objects and physics out-of-the-box. The main focus of Unity is to create very good games with tools that do not require additional special thinking and tinkering. Everything that is not available with properties can be added via a script written in C# or JavaScript. Unity is also more game oriented i.e. it provides all the necessary tools to get you started with creating games.

Since our games should not be very complex we can use Unity 5 as our framework of choice.

All the programs will be created using Unity 5. At the day of making prototype applications the latest version was 5.6.0f3.

4.7.2 About Unity

Unity is a game engine that is designed to create 2D and 3D applications for platforms such as Windows, MacOS and Linux. Moreover, Unity projects can run on different

consoles, phones as well as TV sets. Unity editor has a very clean and convenient user interface, making it easy to start creating applications with out-of-the box tools. An asset store is also available for those who want to purchase premade items and accelerate their work. [42] The interface is very easy to use and assists in creating easy and beautiful applications. Unity games can be found on platforms like Steam where developers can reach a very large audience of gamers and monetize their creations through the built-in store.

4.7.3 Unity environment

When creating an application Unity asks whether it should be a 3D or a 2D application. Depending on the choice a scene is created. It is either a three-dimensional space or a plain 2D field. All the objects that are in the scene are added to the chosen scene. After the objects are added to the scene they are assigned different properties and behaviour. Unity allows the developer to choose how objects should look and act to achieve the desired effect. If something cannot be done with GUI options then additional actions can be added via code. Unity accepts code in either C# or JavaScript. I will be using C# for my work.

If the developers face difficulties with application creation or have a question about how to better implement some of the features in their application then Unity has a forum dedicated to these kinds of problems. Those who are new to this ecosystem can get help from skilled developers who not only will provide the solution but also explain why exactly is this solution better than the others. The website is <http://answers.unity3d.com/index.html>. For a quick reference to the Unity API and to get info about the engine classes and behavior Unity has created a documentation page at <https://docs.unity3d.com/ScriptReference/Help.html>

The concept is entirely created in Unity 5 using Unity tools as well as Tobii SDK for Unity to get input from the eye tracker. Tobii SDK is free for use and can be downloaded from the Tobii developer zone at <http://developer.tobii.com/eyex-sdk/unity>. Tobii is constantly updating their SDK to fix bugs and improve stability and introduce new features. The latest version of SDK is 2.8.0 which was updated on the 19th of April 2017.

4.8 Creating the tests

The basic concept includes three different applications. They should be created separately so that they would not interfere with user's attention. Since the eye tracker provides only two coordinates at a time (i.e. the x and the y) there is no point in selecting a 3D scene. All the objects in the scene are flat, can move and be located within the x and y axis. They should bring the person into the world of Unity and eye tracking. The tasks should be easy to understand and very simple so that everyone could perform them.

4.8.1 First application creation

The first exercise involves horizontal eye movement. It should be very easy to master. Users must move their eyes from right to left and the back right again. The application would check that the gaze point has indeed reached the desired object and indicate this by changing colour and turning. After that the direction should be switched to the opposite site of the screen. This could be done by showing only one object at a time so users would not have to choose which of the objects they need to be looking at. The application should not promote the user to be fast as these types of exercises should be done slowly and thoroughly.

When we launch Unity, we are presented with a welcome screen giving us the ability to customize our project before creating it. We can choose whether the it should be a 3D or 2D project as well as add assets if we have any.

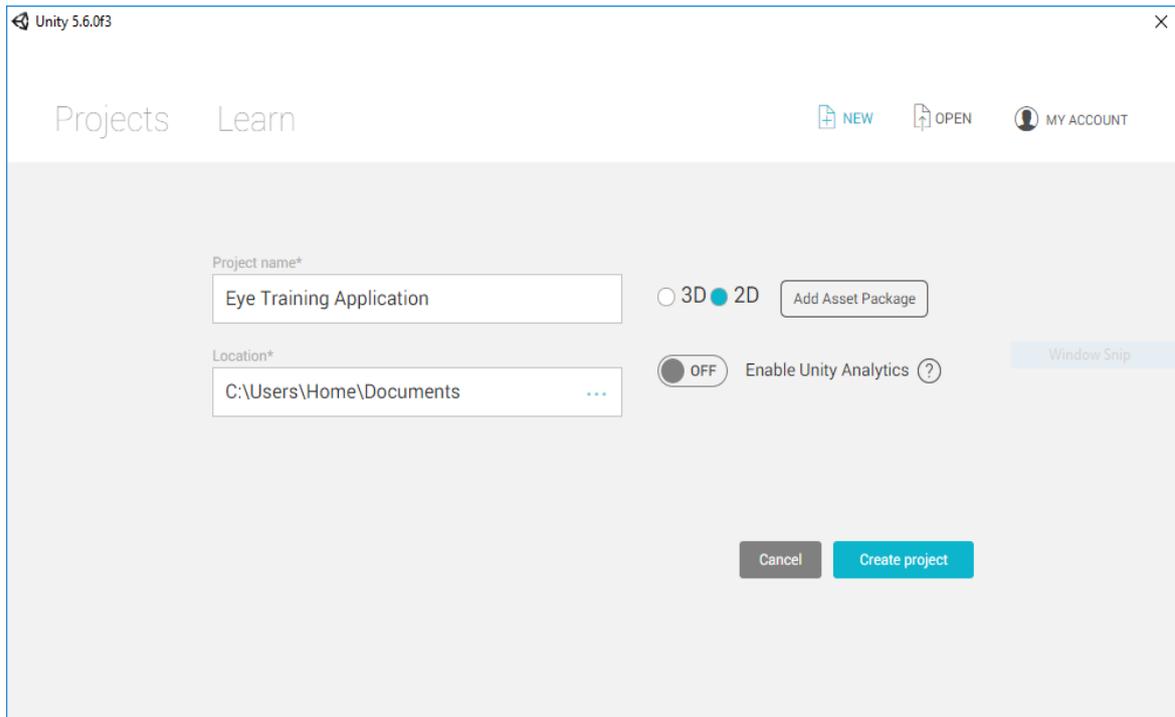


Figure 16 Unity start page

Since we have decided that there is no point in creating a 3D application a 2D scene is selected. The name of the project can be anything we want, but it is usually better to name projects with names that will be easy to understand and find. When all the necessary info was added, I created the new project.

We are then presented with the basic Unity interface. Here we can find all the necessary tools and information about our project. The Scene and Game tabs provide information about the position of the object and what kind of object we are dealing with.

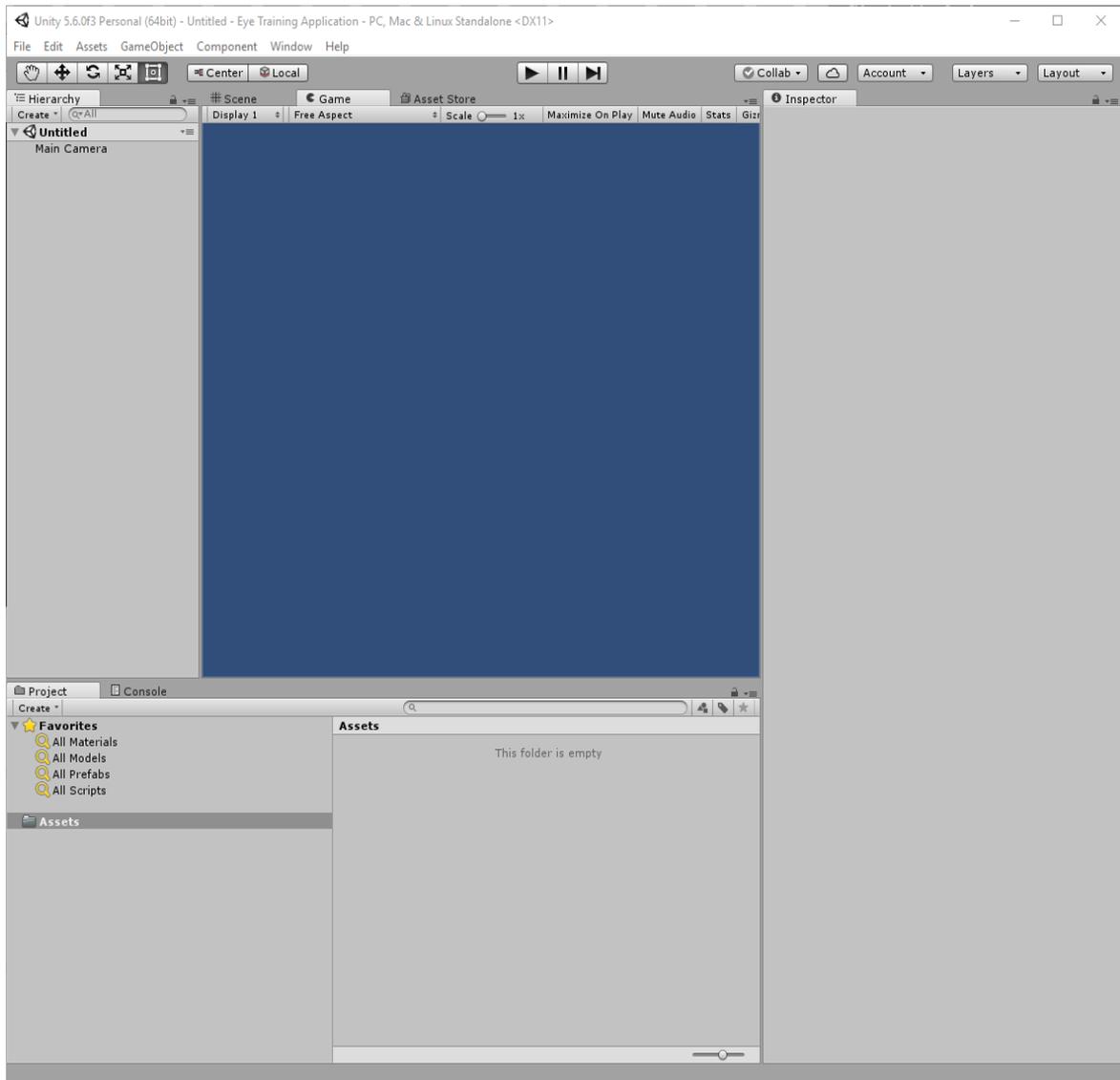


Figure 17 Unity developer environment

The Hierarchy tab provides an overview of all the object in our Project as well as their relation to each other. The Inspector tab allows us to see the properties of an object as well as add additional options such as appearance and behaviour. The Play, Pause and Step buttons are to play pause and progress the game one frame at a time. [43]. This is very handy if the developer wants to review a complex animation frame by frame. In complex animations. Since we are doing basic animations on basic 2D objects we do not need the Pause and Step buttons as all the animations are already done in Unity itself.

As a matter of fact, Unity is very good with physics since a lot of 3D and 2D physics animations and behaviour is already premade in the engine itself. In case you want to use physics, Unity has got you covered with that. No need to draw and process basic shading and physical behaviour and you can focus on creating the best games you can. [44]

Now we need to add two objects where the user would have to look and what would be registered by the system as the fact of gazing. This is done in the GameObject menu. Since Unity treats these objects as GameObject they are located in a separate menu. Unity provides different objects that can be rendered ranging from spheres and cubes to custom objects. We have decided that the game should indicate and guide the user with eye exercises. This will be done by rotating the objects that the user is looking at. Since the sphere is a circle in a 2D environment we cannot use it. Instead we would use a capsule. The capsule has got rounded corners so it does not irritate our eyes with edges. To add a capsule, we go to GameObject -> 3D Object -> Capsule. We do it twice so the game adds two capsules to the scene. We place them on opposite sides of the scene so the user could look at them and they would register the gaze.

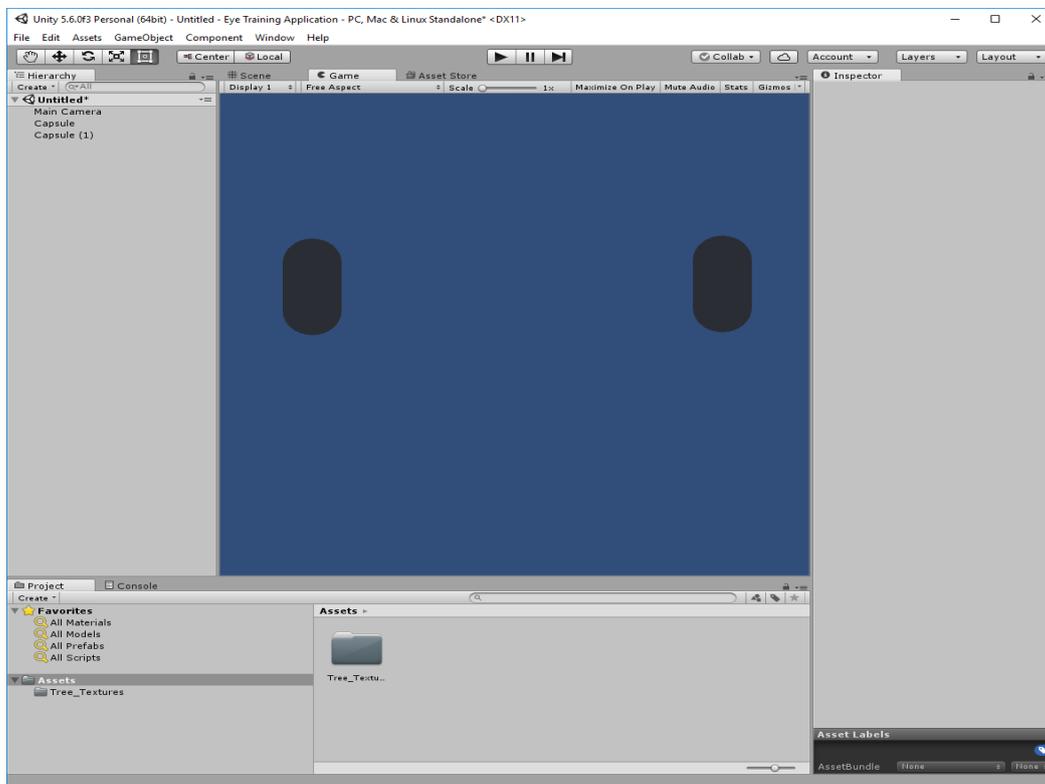


Figure 18 First application screenshot

After the objects are added we need to add behaviour to them. This is done in the Inspector Tab. Firstly, we need to make them gaze-aware i.e. Unity needs to know what objects should be looked for when the game registers eye gaze.

This is done by using the Tobii SDK for Unity. After downloading the folder contains all the needed files to make an application “gaze friendly”. After importing the package to our project, we can add the ability to monitor eye gaze on objects. This is done by in the

Add Component section. To every object, we add a component named GazeAware. This component is provided in the Tobii SDK and is necessary for the eye tracking to work. Next, we need to add some code elements to give them additional behaviour. Currently they do not do anything even if the user looks at them. To add rotation to the capsules we need to add a Script component. This is also done in the Add Component menu. But first we need to rename the capsules to LeftCapsule and RightCapsule respectively. I named my scripts RotateLeftOnGaze and RotateOnGaze respectively. I chose C# as the scripting language since I am more familiar with it.

```

using UnityEngine;
using Tobii.EyeTracking;

[RequireComponent(typeof(GazeAware))]

public class RotateLeftOnGaze : MonoBehaviour {
    private GazeAware _gazeAware;
    void Start()
    {
        _gazeAware = GetComponent<GazeAware>();
    }
    void Update()
    {
        if (_gazeAware.HasGazeFocus)
        {
            transform.Rotate(Vector3.forward); //rotate capsule
            GetComponent<Renderer>().material.color = new Color32(47, 214, 54, 150);
            Invoke("turnOffLeftCapsule", 2); //delay of 2 seconds
            Invoke("turnOnRightCapsule", 2); //delay of 2 seconds
        }
        else
        {
            GetComponent<Renderer>().material.color = new Color32(255, 208, 52, 50);
        }
    }
    // show right capsule
    void turnOnRightCapsule()
    {
        GameObject.Find("RightCapsule").transform.localScale = new Vector3(1.3f, 1,
1);
    }
    //hide left capsule
    void turnOffLeftCapsule()
    {
        GameObject.Find("LeftCapsule").transform.localScale = new Vector3(0, 0, 0);
    }
}

```

Figure 19 Code for the left capsule of the first application

```

using UnityEngine;
using Tobii.EyeTracking;

[RequireComponent(typeof(GazeAware))]
public class RotateOnGaze : MonoBehaviour{
    private GazeAware _gazeAware;
    void Start()
    {
        _gazeAware = GetComponent<GazeAware>();
        GameObject.Find("LeftCapsule").transform.localScale = new Vector3(0, 0, 0);
    }

    void Update()
    {
        if (_gazeAware.HasGazeFocus)
        {
            transform.Rotate(Vector3.forward); //rotate capsule
            GetComponent<Renderer>().material.color = new Color32(47, 214, 54, 150);
            Invoke("turnOffRightCapsule", 2); //delay of 2 seconds
            Invoke("turnOnLeftCapsule",2); //delay of 2 seconds
        }
        else
        {
            GetComponent<Renderer>().material.color = new Color32(255, 208, 52,50);
        }
    }
    //turn off left capsule
    void turnOnLeftCapsule()
    {
        GameObject.Find("LeftCapsule").transform.localScale = new Vector3(1.3f, 1,
1);
    }
    //turn of right capsule
    void turnOffRightCapsule()
    {
        GameObject.Find("RightCapsule").transform.localScale = new Vector3(0, 0, 0);
    }
}

```

Figure 20 Code for the right capsule in the first application

The result is that both capsules rotate when the user looks at them. Not only that, but they change colour as well. When the capsule is static it is brown and when it is rotating the colour changes to green. When the user looks at one of the capsules the other is not shown to make it easier for users to determine where to look. After the user has looked at the capsule it disappears after two seconds and the opposite one appears waiting to be gazed. A little notice to the user on what to do was placed on the screen. Unity has a whole set of different UI elements. We needed a simple textbox that would tell what to do with the capsules. To add a textbox to our project we need to go to GameObject tab, select UI and add Text. A sample textbox appears on the screen. We add info that user should look at the capsules turn by turn. The advisable period is that the capsule turns 180 degrees or half of the circle.

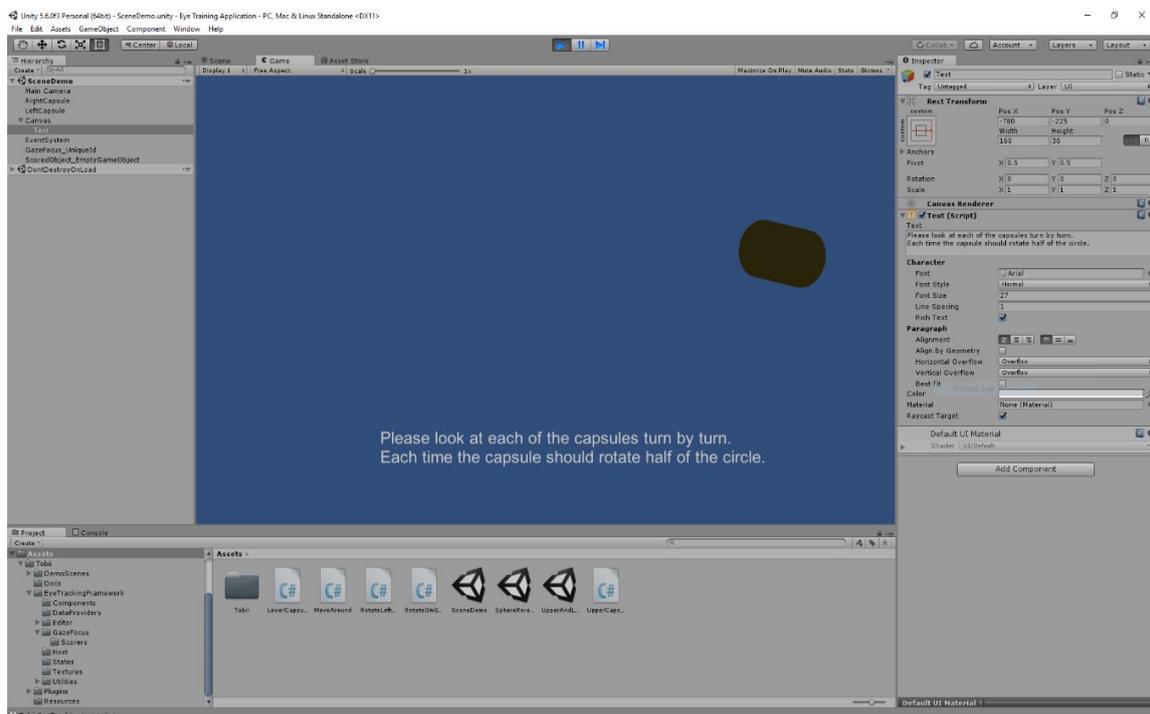


Figure 21 First application in action

Only end points of the screen need to be checked whether eyes have reached this area or not. When the eyes have indeed reached the selected area, the system checks whether the eyes are on the spot which is far right and far left of the screen. The number of tries is unlimited. However, it is advisable to do around 30 eye movements i.e. each of the capsules should be looked at 15 times. It should be sufficient for the user as he/she will be able to train his/her eyes without getting them tired or stressed.

The area between these points is out of the scope of our program, however with further additions some further checking could be done to make the program more precise. For instance, there may be control to check whether eyes move exactly horizontally and how fast they can change directions.

4.8.2 Second application creation

For creating the second application we should take the next exercise from the list above. This means that the user should move his/her eyes vertically. Another project should not be created as Unity provides the ability to create multiple scenes within a single project.

We create a new scene by clicking File and then New Scene. Unity opens a blank scene with the same controls but with no elements on the grid. Since our users will need look up and down we create two capsules. It is the same process as before. We go to the GameObject tab, choose that we want to add a 3D Object and then select Capsule from the list. We do it two times since we need one capsule at both ends. We place the capsules on top and bottom of the scene and increase their sizes so users could easily focus on them and the system would easily distinguish gaze on them. Next, we add the ability for the eye tracker to know that these objects are the ones that may be gazed upon. This is done though the Add Component menu by adding the Gaze Aware component.

When the preparation is ready we need to add behaviour to our objects. This is done through a script in C#. The script rotates the capsule and changes the colour of the capsule when the user gazes on it and starts a timer. The timer lasts for two seconds and when it ends the capsule disappears and the opposite one appears. A similar script is done for the second capsule only the names are vice versa.

The capsules are named UpperCapsule and LowerCapsule respectively.

Their behaviour is similar to those that were used in the previous scene. That means that we can use a similar script to make them rotate and change colour.

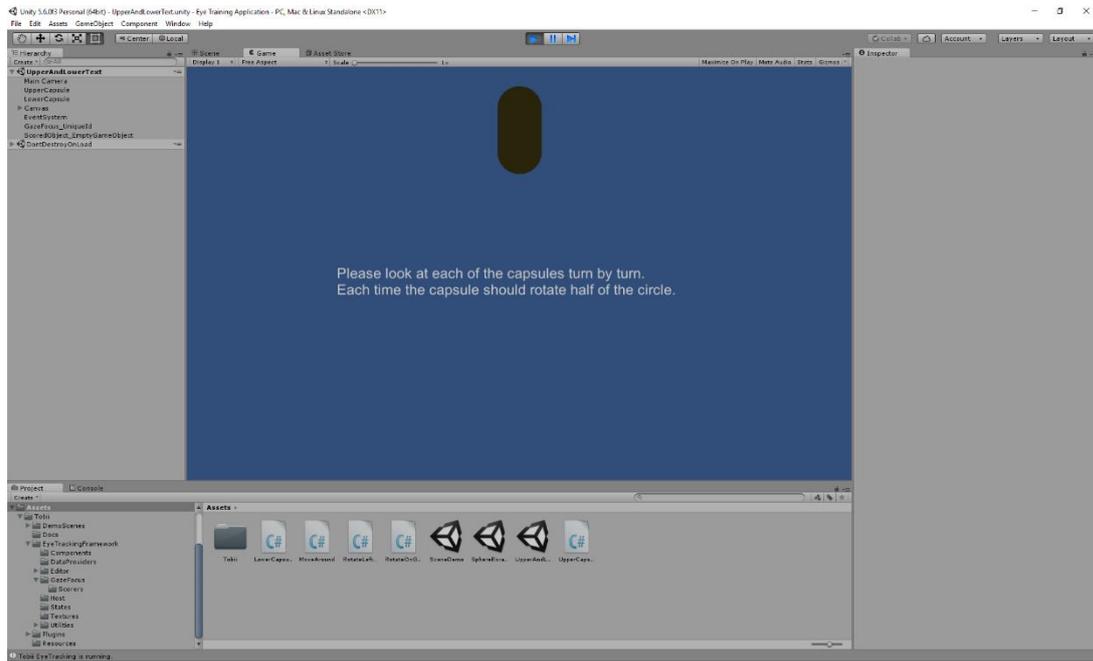


Figure 22 Screenshot of the second application

```

using UnityEngine;
using Tobii.EyeTracking;

[RequireComponent(typeof(GazeAware))]
public class UpperCapsuleRotate : MonoBehaviour {
    private GazeAware _gazeAware;
    void Start()
    {
        _gazeAware = GetComponent<GazeAware>();
        GameObject.Find("LowerCapsule").transform.localScale = new Vector3(0, 0, 0);
    }
    void Update()
    {
        if (_gazeAware.HasGazeFocus)
        {
            transform.Rotate(Vector3.forward);
            GetComponent<Renderer>().material.color = new Color32(47, 214, 54, 150);
            Invoke("turnOffUpperCapsule", 2);
            Invoke("turnOnLowerCapsule", 2);
        }
        else
        {
            GetComponent<Renderer>().material.color = new Color32(255, 208, 52, 50);
        }
    }
    void turnOnLowerCapsule()
    {
        GameObject.Find("LowerCapsule").transform.localScale = new Vector3(1.3f, 1,
1);
    }
    void turnOffUpperCapsule()
    {
        GameObject.Find("UpperCapsule").transform.localScale = new Vector3(0, 0, 0);
    }
}

```

Figure 23 The script for the upper capsule for the second application

```

using UnityEngine;
using Tobii.EyeTracking;

[RequireComponent(typeof(GazeAware))]

public class LowerCapsuleRotate : MonoBehaviour {
    private GazeAware _gazeAware;
    void Start()
    {
        _gazeAware = GetComponent<GazeAware>();
    }
    void Update()
    {
        if (_gazeAware.HasGazeFocus)
        {
            transform.Rotate(Vector3.forward);
            GetComponent<Renderer>().material.color = new Color32(47, 214, 54, 150);
            Invoke("turnOffLowerCapsule", 2);
            Invoke("turnOnUpperCapsule", 2);
        }
        else
        {
            GetComponent<Renderer>().material.color = new Color32(255, 208, 52, 50);
        }
    }
    void turnOnUpperCapsule()
    {
        GameObject.Find("UpperCapsule").transform.localScale = new Vector3(1.3f, 1,
1);
    }
    void turnOffLowerCapsule()
    {
        GameObject.Find("LowerCapsule").transform.localScale = new Vector3(0, 0, 0);
    }
}

```

Figure 24 The script for the lower capsule for the second application

4.8.3 Third application creation

The third application would involve moving our eyes in a circular pattern. It is described in the fourth exercise. In order to create the new scenario, we need to create a new scene. We go to File and select New Scene.

A blank canvas appears in front of us with standard Unity controls. Next, we need to select an object that will be moving in the scene and what would control our viewing. In previous applications, we used capsules as the object was not moving but only rotating. Now we specifically need the object to move and do not care whether it rotates or not. A good shape to select in this case would be a sphere.

Since, we are still using our 2D project with a flat environment then our sphere will look like a ball. Adding the sphere to our game is very easy. We go to the GameObject menu and in the submenu named 3D Objects we select Sphere. A sphere appears in our scene on the board.

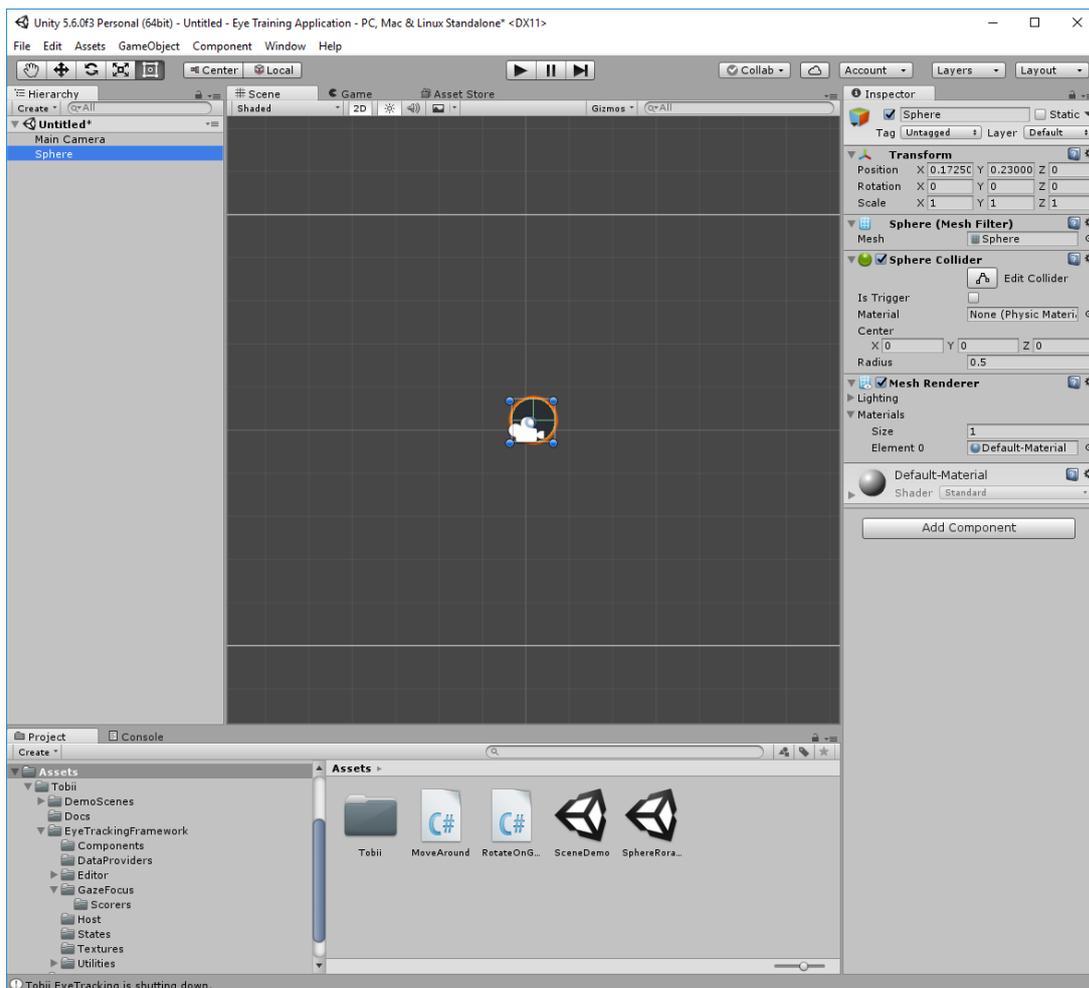


Figure 25 Screenshot of the third application

To make viewing it easier for the user and the controller we make it larger by holding Shift and dragging one of the corners. Now that we have an object to focus on we need to add properties to it. This is done by using the Add Component button. First of all, we need to make the object gaze-aware. This means that Unity and Tobii will keep track of this object and if the user looks at it then Unity will know that maybe some action should be performed. This action should be added via a script. Since the script also belongs to the object we press Add Component button and add a new script with the name Movearound. It will be written in C#.

We need to determine how the object will be moved. One option is that it will move on its own and the program will indicate when it is registering a gaze on it. The second one is moving the sphere by gazing on it. This is a more difficult task. Our eyes are used to following objects. If we make the sphere gaze-movable then every time we blink it will stop and will continue moving as soon as we open our eyes. This creates stutters and is not very pleasant for the eye. Moreover, when the user realizes that the controller cannot read eyes when they are closed he/she will try not blinking at all. This in its turn will create more eye strain and tiredness.

We want to help people relax and not create more stress. The first option is then more suitable in our case. The game will move the sphere in a circular pattern and when it registers a gaze on the sphere it will change the colour of the object.

The sphere should be constantly moving. Every frame it should move a little bit. We use cosines and sines to get the right circle and we multiply them by three so that the radius of the rotation would increase. The radius can anything we want, but I found that three provides us with the best result. Next, we add the ability to change colour when the object is being looked at and it changes colour back if nobody is gazing.

```

using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using Tobii.EyeTracking;

[RequireComponent(typeof(GazeAware))]
public class MoveAround : MonoBehaviour {

    float timeVar = 0;
    private GazeAware _gazeAware;
    // Initialization
    void Start () {
        _gazeAware = GetComponent<GazeAware>();
    }

    // Update is called once per frame
    void Update() {

        if (_gazeAware.HasGazeFocus)
        {
            GetComponent<Renderer>().material.color = new Color32(255, 208, 52,
50);
        }
        else
        {
            GetComponent<Renderer>().material.color = new Color32(47, 214, 54,
150);
        }

        timeVar += Time.deltaTime;
        float x = Mathf.Cos(timeVar) * 3;
        float y = Mathf.Sin(timeVar) * 3;

        transform.position = new Vector2(x, y);
    }
}

```

Figure 26 Code for the third application

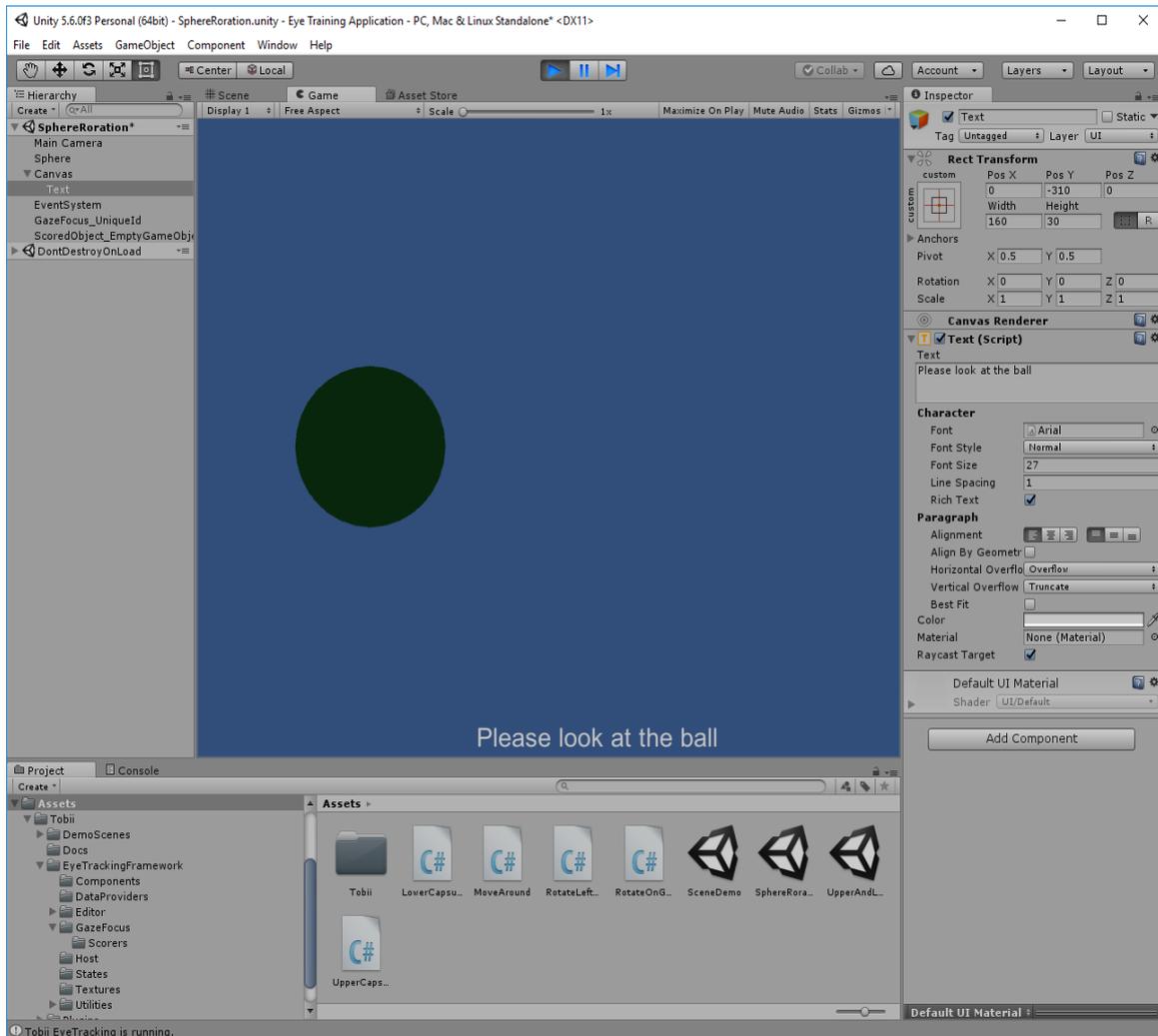


Figure 27 Third application in action

Since color change happens slower than we blink it means a seamless movement and the colour stays the same even when blinking which adds comfort to the user.

The final touch is the addition of a small textbox mentioning that the user must look at the ball to train eyes. This is done through the GameObject menu by going to UI and adding a textbox.

5 Analysing the system

After the application has been created, it should be evaluated on people to determine what are their opinions on it. How good it is, what are the advantages and drawbacks of using an eye tracker for doing eye exercises. It is important to know the usability of the application since people who will be using it are probably not very tech-savvy and a clean and simple app that will be easy to use and guide them on what to do and how. There are a lot of different techniques for evaluating an application. Some focus on the overall user experience, some prefer the usability of the app and how well newcomers can get to know it. Since Unity is a game engine and its primary role is to create games this application is also considered a game. It is just controlled with eyes and not with a typical controller. All the other parts are the same as in a game. In order to evaluate this game a method should be selected that would evaluate this application from different perspectives. For the ease of user understanding all three applications will be considered as one with different parts. The basic principle of them is similar and they differ only in the direction eyes need to choose in order to achieve the desired result.

5.1 Choosing a method

A good user experience website named <http://www.allaboutux.org> suggested three questionnaires that could be well suited for this application. Let us see what are the advantages and disadvantages of these methods.

5.1.1 AttrakDiff

One option could be using AttrakDiff questionnaires. It is a very easy to use and simple tool for evaluating web services, PC software, mobile software as well as hardware designs. It is very easy to construct and takes around 10 minutes to start. There is a free version as well as a paid one. The premium version allows to conduct researches on more people at a time. It is possible get a graph representation of the result as well as demographic who participated in the studies. It consists of 10 questions and there are seven options to answer based on your opinion. You must fill in whether you think the subject is more positive or negative in different qualities such as design, price and ease of use. However, it is more designed for products that have been on the market for longer periods of time. Yes, you can answer that you have used the product less than a month

but 30 days is quite a large period in terms of product evaluation. Moreover, the number of questions is very small. Only 10 and they just cover the basics. Furthermore, not more than 20 people can participate in these studies.

5.1.2 ServUX

Another option could be the ServUX questionnaire. It is a modular questionnaire for evaluating service user experience. That is where it gets its name from. Since it is a modular system, it contains different modules for addressing different aspects of service user experience. The benefits of using ServUX are that it is very quick and lightweight so it can be adjusted to different systems. It can be used online or remotely and is easy to use. On the other hand, since it is a light system it needs additional data to get in-depth to fully understanding the system. Moreover, it is not very suitable for computer software.

5.1.3 Game Experience Questionnaire (GEQ)

A good option could be the Game experience questionnaire or GEQ. Developed by IJsselsteijn, W.A.; de Kort, Y.A.W.; Poels, K. from the Eindhoven University of Technology this questionnaire helps evaluate the experience of people who played any kind of game. The advantages are that it is mainly meant for functional prototypes which is exactly what we have with our systems. It is also meant for testing products that are already on the market.

It is a questionnaire type of research which consists of different modules. The first one is the core module which takes into account actual experiences that happens during gameplay. Players are being asked questions while they are playing the game and they should answer how much do they agree or disagree with the statement. After answering the questions the game continues.

The second module is the social presence module which addresses the social aspect of the game. It is only used if the game has got social interactions with players of non-player characters.

The last module is the post-game module. It mainly focuses on the experience that players had after the game has ended. Since our opinion can change over time it is also possible to apply the questionnaire multiple times to see how has the opinion on the game changed over time.

Since it has a point system this means that we can measure what changes in the user experience when we apply changes to the game. There are however, drawbacks to this

system as well. Some games are created for single player mode only. There is no social part in them. This means that one part of the questionnaire cannot be evaluated since there is nothing to evaluate. The other drawback is that the in-game part that needs to be done while playing the game is quite large. There are 33 questions that need to be answered and doing this during a game is not the easiest of tasks. It may interrupt the player a bit, but the questions are relatively short and answers are even shorter. The answers are numbers from zero to four where zero is the lowest score a question can get and four being the maximum meaning that the player extremely agrees with the question.

I have contacted the Game Experience Lab at the University of Technology of Eindhoven and they provided me with a set of measurement tools that would be needed to use the Game Experience Questionnaire. The same can be done via the link <http://www.gameexplab.nl/index.php?page=contact> and they send you the tools and descriptions via email.

The Game Experience Questionnaire will be used to evaluate our applications.

5.2 Conducting the tests

Testing was conducted at my home. I have bought a new Tobii EyeX controller from Sweden and installed all the necessary drivers and software onto my system. The tracker is placed at the bottom chin of the monitor which is a Dell U2415H. Several people were invited home to evaluate the applications created.

Among them was a man who is a gamer at heart. He is 25 years old just like I am and loves playing games. He has never used an eye tracking controller before and was very eager to try it out. He owns a gaming computer as well as a couple of consoles and every day spends at least two hours playing games.

The second person who tested the application was a woman. She is 58 years old and does not play computer games. In fact, she does not even have a computer because she does not need it. She has never heard anything about eye tracking but knows that you should always do eye exercises. She is not afraid of new technology. She is a perfect candidate to test usability of the system since she has never used a lot of modern technology and how fast she can master a new device or an application can speak about the easiness of it

The third person who volunteered to try something new in her life was a teenager. She is 15 years old. She spends most of her day with a smartphone in her hands and she cannot

imagine how people lived without them. She is not very good with technology but she loves new things and is a very fast learner.

I did not participate in the experiment since I am the creator of this application, I know how it works and what is needed from me to successfully pass all the tests. Moreover, I am potentially biased to the application as it is my creation and for me it is very easy, comfortable and fun. However, other people who see this for the first time in their lives might have different views on this. Especially important are those people who have never used eye tracking before. This is a completely new world to them as they experience a way of controlling a game on a personal computer without the use of mouse or keyboard. To be precise, only specific applications have a 100 per cent hands-free mode where you do not have to press any buttons at all. Most of the applications rely on a keyboard press as a confirmation of the action.

People with different background, age and experience with technology tested the application on how user-friendly it is. They were instructed that they need to play a special game. One by one they sat down in front of the computer and we calibrated the controller to their eyes. After calibration, we tested that the 3D eye model is correct by testing calibration with the built-in tool provided by Tobii in the Tobii Eyetracking application. After insuring that the tracker was correctly calibrated they were shown the eye training application and without introducing them to it they had to figure out how to use it themselves. This test the usability of the program and how easy it is to master it when the person has never used eye tracking before.

Ten seconds into the game they were asked the first part of questions that are meant for the in-game portion of the user experience questionnaire.

The first reaction to the tracker was smiling and amazement that objects move and change colour just by looking at them. People who are used to physical things start immediately searching for something to click or press. However, when they realize that all this is not needed and that they can just look at an object and everything will start to move and come to life. After five minutes of testing games were shut down and players were immediately presented with the second part of the game experience questionnaire. Now they answered based not only on the first impressions but on the experience of playing all three games. The games got mostly positive feedback and the main interest after the experiment was if they can try this again and what else exists for these types of controllers.

The questions as well as possible answers are presented below.

The Core Module consists of 33 questions. Each question should be answered with one of five different feeling descriptors.

They are: 0 – **Not at all**, 1 – **Slightly**, 2 – **Moderately**, 3 – **Fairly**, 4 – **Extremely**.

Each question could be answered only once and the participant should describe his/her opinion on the question during the gameplay with a number ranging from zero to four. Zero being the lowest score and four being the highest. All the questions are connected with how the person feels during the game.

1 I felt content

2 I felt skilful

3 I was interested in the game's story

4 I thought it was fun

5 I was fully occupied with the game

6 I felt happy

7 It gave me a bad mood

8 I thought about other things

9 I found it tiresome

10 I felt competent

11 I thought it was hard

12 It was aesthetically pleasing

13 I forgot everything around me

14 I felt good

15 I was good at it

16 I felt bored

17 I felt successful

18 I felt imaginative

19 I felt that I could explore things

- 20 I enjoyed it
- 21 I was fast at reaching the game's targets
- 22 I felt annoyed
- 23 I felt pressured
- 24 I felt irritable
- 25 I lost track of time
- 26 I felt challenged
- 27 I found it impressive
- 28 I was deeply concentrated in the game
- 29 I felt frustrated
- 30 It felt like a rich experience
- 31 I lost connection with the outside world
- 32 I felt time pressure
- 33 I had to put a lot of effort into it

Since there is no social part in this game as the user plays solo and there are no non-player characters we should not include the Social Presence module. The third module however must be included as it assesses the feelings that happen right after the game has been finished. It is important to know the opinion that comes after the task has been completed. It is more based on the experience that was achieved and not on the first impressions like it was in the first module.

The post-game module has the following questions that need to be answered as soon as the game ends. It has a total of 17 questions and the answers are the same as in the first module.

As with the first module users need to choose only one of those answers.

They are: 0 – **Not at all**, 1 – **Slightly**, 2 – **Moderately**, 3 – **Fairly**, 4 – **Extremely**.

Each answer can give a maximum of 4 points. The answers range from zero to four. Zero being the lowest answer. And four being the highest.

1 I felt revived

10 I felt exhausted

2 I felt bad

11 I felt that I could have done more useful things

3 I found it hard to get back to reality

12 I felt powerful

4 I felt guilty

13 I felt weary

5 It felt like a victory

14 I felt regret

6 I found it a waste of time

15 I felt ashamed

7 I felt energized

16 I felt proud

8 I felt satisfied

17 I had a sense that I had returned from a journey

9 I felt disoriented

5.3 Criteria for analysis

After the Core GEQ Module questions have been answered they need to be analyzed based on criteria that would group the answers into seven components. The list can be found below. These components are the ones that show how good or bad the program is according to those who participated. This can give clues as to what is bothering people and what should be improved. It also shows the first reaction to the program as the questionnaire is being answered during the gameplay itself.

Component scores are computed as the average value of its items.

Competence: Items 2, 10, 15, 17, and 21.

Sensory and Imaginative Immersion: Items 3, 12, 18, 19, 27, and 30.

Flow: Items 5, 13, 25, 28, and 31.

Tension/Annoyance: Items 22, 24, and 29.

Challenge: Items 11, 23, 26, 32, and 33

Negative affect: Items 7, 8, 9, and 16.

Positive affect: Items 1, 4, 6, 14, and 20.

After the GEQ Post-Game Module questions have been answered they need to be analyzed based on criteria that would group the answers into four components. The list can be found below.

Since this module is done after the game the answers are mostly based on the experience with the game and not on first impressions as it is with the first module. If you do questionnaires at every iteration then it is possible to see what the progress for this application is. Developers can find out what changes to the system provided the most and the least positive or negative effects. It means that this is also a form of feedback.

Component scores are computed as the average value of its items.

Positive Experience: Items 1, 5, 7, 8, 12, 16.

Negative experience: Items 2, 4, 6, 11, 14, 15.

Tiredness: Items 10, 13.

Returning to Reality: Items 3, 9, and 17

Now the answers of our participants will be analyzed.

5.4 Analyzing the results

5.4.1 First volunteer

The first participant is a 25-year-old male who played the game for the first time in his life. He has never done or seen anything connected with eye tracking technology. He is a gamer but mostly plays games on console.

The answers are the following:

For the Core GEQ questions:

Table 1 First volunteer GEQ answers

Question	Answer
1	4
2	4
3	2
4	4
5	4
6	3
7	0
8	1
9	0
10	3
11	0
12	3
13	2
14	3
15	4
16	0
17	2
18	2
19	1
20	3
21	2
22	0
23	0
24	0

25	3
26	1
27	2
28	3
29	0
30	3
31	4
32	0
33	0

The **competence** scores were: 4, 3, 4, 2, 2 and the total average was **3**

The **sensory and imaginative** immersion scores were: 2, 3, 2, 1, 2, 3 and the total average was **2.2**

The **flow** scores were: 4, 2, 3, 3, 4 and the total average was **3.2**

The **tension / annoyance** scores were 0, 0, 0 and the total average was **0**

The **challenge** scores were 0, 0, 1, 0, 0 and the total average was **0.2**

The **negative** affect scores were 0, 1, 0, 0 and the total average was **0.25**

The **positive** affect scores were 4, 4, 3, 3, 3 and the total average was **3.4**

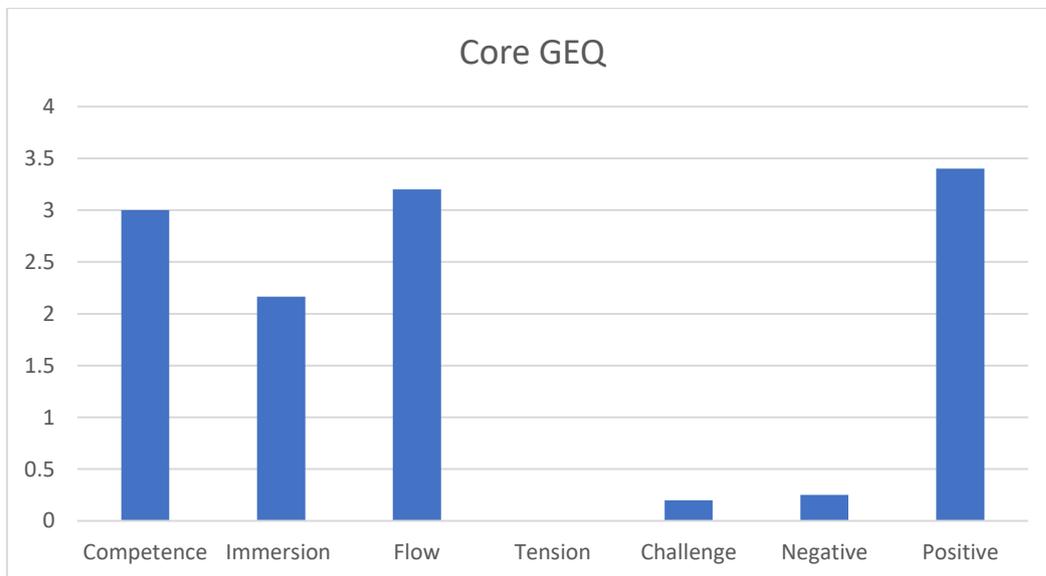


Figure 28 Summary of the first volunteer's GEQ answers

The results show that the game was easy to master, gives highly positive feelings and is easy to follow. He felt that the game was overall easy and fun. The gameplay is smooth. The interviewee said that he would like to play more games that could be controlled with eyes. On the other hand, the immersion score is a bit low and could be fixed by adding more animations to the game and making it more pleasant to the eye with different shapes and textures.

For the post-game module, the answers were following:

Table 2 Post-Game answers of the first volunteer

Question	Answer
1	1
2	0
3	0
4	1
5	3
6	0
7	4
8	3

9	0
10	1
11	0
12	2
13	0
14	0
15	0
16	2
17	1

The **positive** experience scores are 1, 3, 4, 3, 2, 2 and the total score was **2.5**

The **negative** experience scores are 0, 1, 0, 0, 0, 0 and the total score was **0.17**

The **tiredness** experience scores are 1, 0 and the total score was **0.5**

The **returning to reality** experience scores are 0, 0, 1 and the total score was **0.33**

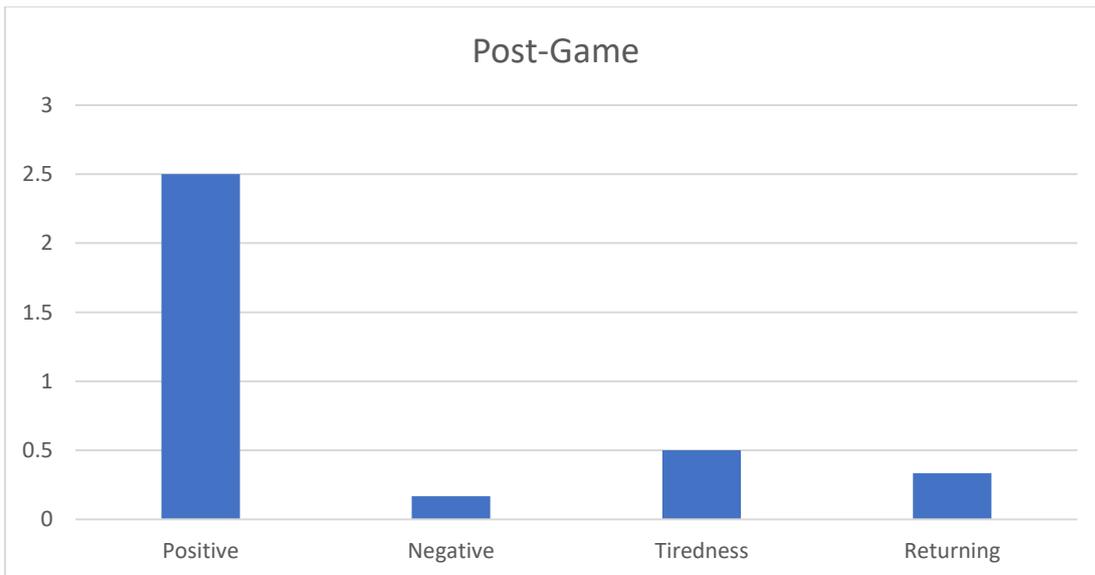


Figure 29 Post-Game answer summary of the first volunteer

The game provided mostly positive experience with a good score of 2.5 points out of possible 4. It was interesting to play and something new to the participant. The negative effects are mostly missing and it is very easy to return to reality after this game although after concentrating too much a little bit of tiredness can be felt in the neck. Overall it was an enjoyable experience and he would like to try something similar in the future. He even asked where these types of controllers are being sold and if other games can be controlled with eyes.

5.4.2 Second volunteer

The second participant is a 58-year-old woman. She does not play games nor use a computer so this is a completely new technology to her. She has never heard of eye trackers. She has to learn everything herself. Everything she finds out is completely done herself.

The answers are the following:

For the Core GEQ questions:

Table 3 GEQ answers of the second volunteer

Question	Answer
1	3
2	2
3	0
4	3
5	4
6	1
7	0
8	0
9	0
10	3
11	0
12	2
13	0
14	3
15	4
16	1

17	0
18	0
19	4
20	4
21	3
22	0
23	0
24	0
25	0
26	0
27	4
28	4
29	0
30	4
31	0
32	0
33	1

The **competence** scores were: 2, 3, 4, 0, 3 and the total average was **2.4**

The **sensory and imaginative immersion** scores were: 0, 2, 0, 4, 4, 4 and the total average was **2.3**

The **flow** scores were: 4, 0, 0, 4, 0 and the total average was **1.6**

The **tension / annoyance** scores were 0, 0, 0 and the total average was **0**

The **challenge** scores were 0, 0, 0, 0, 1 and the total average was **0.2**

The **negative** affect scores were 0, 0, 0, 1 and the total average was **0.25**

The **positive** affect scores were 3, 3, 1, 3, 4 and the total average was **2.8**

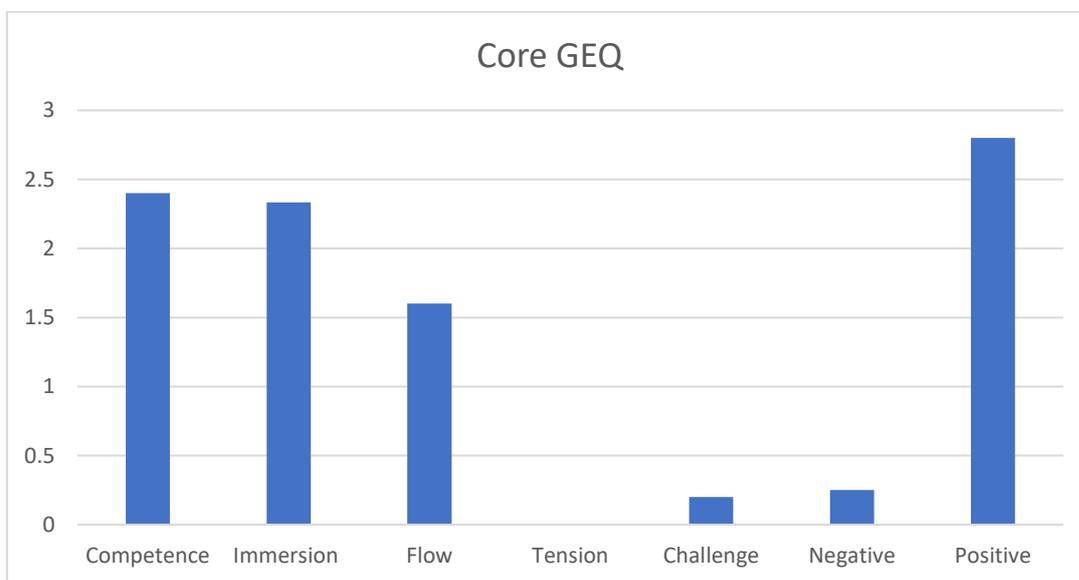


Figure 30 Summary of the second volunteer's GEQ answers

The game was very easy to master. There was no need for explaining anything apart from the requirement to sit straight and keep the head straight. Since the game does not have any distracting elements it is easy to focus on the task. It was quite easy to follow the game and understand what is needed as the game provides hints. The flow is good and the game provides positive emotions.

For the post-game module, the answers were following:

Table 4 Post-Game answers of the second volunteer

Question	Answer
1	2
2	0
3	0
4	0
5	1
6	1
7	3
8	4

9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	3
17	4

The **positive** experience scores are 2, 1, 3, 4, 0, 3 and the total score was **2.2**

The **negative** experience scores are 0, 0, 1, 0, 0, 0 and the total score was **0.17**

The **tiredness** experience scores are 0, 1 and the total score was **0.5**

The **returning to reality** experience scores are 0, 0, 4 and the total score was **1.33**

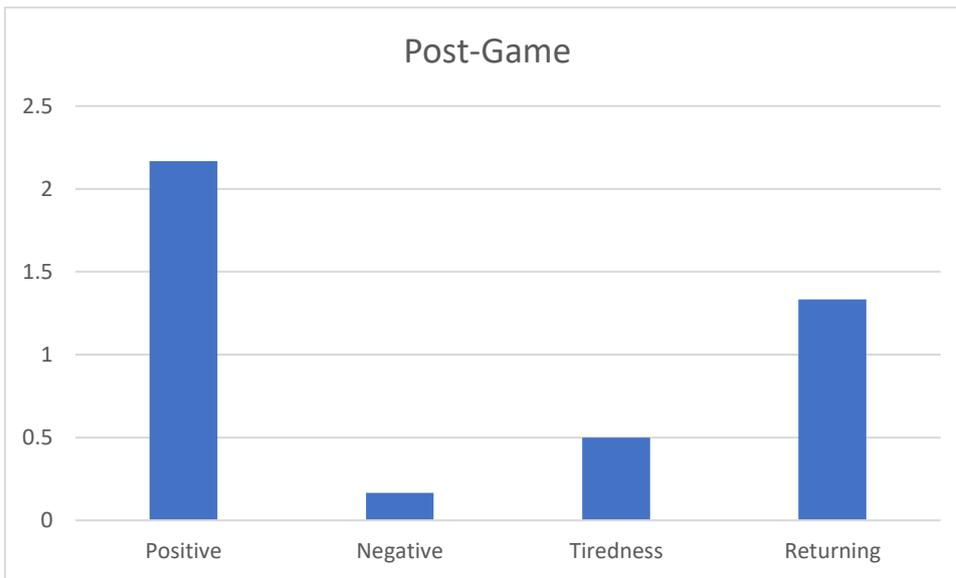


Figure 31 Post-Game answer summary of the second volunteer

The post-game questionnaire shows that the game was enjoyable and immersive. The participant said that she would like for the games to last longer as they are very fun. She discovered something new what she has not seen before and was very pleased with the technology. Doing these exercises did not feel like a chore at all and was something new and refreshing. She did not feel tired at all and wanted to continue even when the test was over. The only problem was an urge to move the head to the object that was on the screen instead of only shifting eyes. The controller works better if the head position does not

change and only eyes move. This is a thing that players need to get used to but it usually does not take long.

5.4.3 Third volunteer

The third participant is a 15-year-old girl who uses a smartphone every day. Technology was around her for her whole life. She is not very tech savvy and has not heard of eye tracking and what it is. She is a fast learner and loves discovering new things.

The answers are the following:

For the Core GEQ questions:

Table 5 GEQ answers of the third volunteer

Question	Answer
1	4
2	4
3	0
4	4
5	4
6	4
7	0
8	0
9	0
10	4
11	0
12	2
13	1
14	4
15	4
16	0
17	4
18	0
19	0
20	4
21	2

22	0
23	1
24	0
25	1
26	1
27	2
28	1
29	0
30	1
31	0
32	0
33	0

The **competence** scores were: 4, 4, 4, 4, 2 and the total average was **3.6**

The **sensory and imaginative immersion** scores were: 0, 2, 0, 0, 2, 1 and the total average was **0.8**

The **flow** scores were: 4, 1, 1, 1, 0 and the total average was **1.4**

The **tension / annoyance** scores were 0, 0, 0 and the total average was **0**

The **challenge** scores were 0,1, 1, 0, 0 and the total average was **0.4**

The **negative** affect scores were 0, 0, 0, 0 and the total average was **0**

The **positive** affect scores were 4, 4, 4, 4, 4 and the total average was **4**

The competence score is very high as she feels that she mastered all the exercises brilliantly. They were very easy to follow and easy to understand. There were no difficulties with understanding how the game works and what is needed to complete it. She did not feel immersed in the game as she believes there should be more animations. The flow is a half of

the maximum. The participant noted that it would be nicer if the games changed themselves or if there would be some kind of a way to change them with eye gaze. She liked the game a lot and this was a whole new experience to her as she has never tried anything similar. There was no negative feeling during the test. She also did not feel challenged because the game was very easy and did not require any skills from the player.

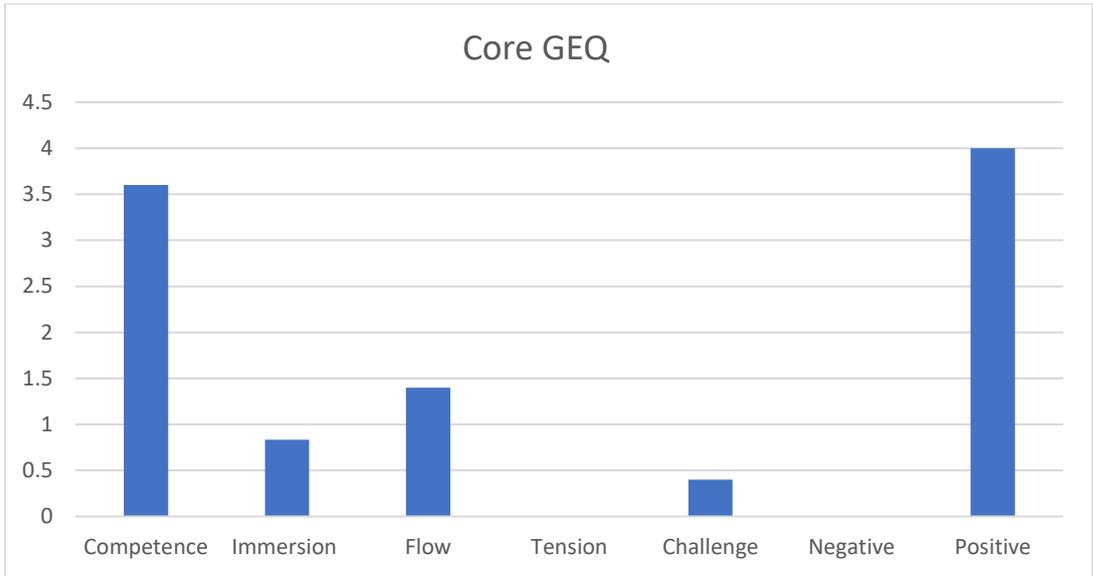


Figure 32 Summary of the third volunteer’s GEQ answers

For the post-game module, the answers were following:

Table 6 Post-Game answers of the third volunteer

Question	Answer
1	0
2	0
3	0
4	0
5	2
6	0
7	4

8	4
9	1
10	0
11	0
12	3
13	0
14	0
15	0
16	1
17	3

The **positive** experience scores are 0, 2, 4, 4, 3, 1 and the total score was **2.3**

The **negative** experience scores are 0, 0, 0, 0, 0, 0 and the total score was **0**

The **tiredness** experience scores are 0, 0 and the total score was **0**

The **returning** to reality experience scores are 0, 1, 3 and the total score was **1.33**



Figure 33 Post-Game answer summary of the third volunteer

After the game has ended the positive experience dropped as the participant expected more out of the game. Nothing negative emerged but comparing to the results that were taken while she was playing the game it can be noted that the lack of animations made the whole experience somewhat less enjoyable than it could be. The participant also noted that she did not feel tired at all and that the games could last longer. Returning to reality was easy although she noted that at first, she forgot that she can now move her head.

6 Related works

There has been a lot of research in the field of eye tracking. Some are meant to help disabled people, others use eye tracking for marketing and behavioural studies. Companies are trying to improve the eye tracking itself. For instance, Tobii who produce the EyeX controller that was used in this thesis add more and more features to their consumer products, so that ordinary people could also benefit from all the innovations that were done in this area.

Since we get so much information with our eyes they can potentially give information back as well. As an example, there is a research by the Mélodie Vidala, Jayson Turnera, Andreas Bullinga and Hans Gellersena, that focuses on monitoring mental health with wearable eye trackers. This could potentially warn the doctors of the changing health condition of their patient and they could start treating an illness before it has any effect on the patient. [45] [46]

There have been attempts of creating games from scratch with eye tracking as a joystick controller. It was made primarily for user's eye motion disability rehabilitation and was successfully tested and verified that it indeed provided rehabilitation effects for the user's visual movement. [47]

Some researchers study the effects of eye training on health and what benefits can it provide to our eyesight and health in general. [48]

This thesis connects the ideas of creating computer games that use an eye controller as a source of input and doing eye gymnastics to keep our eyes healthy and our vision sharp.

7 Summary

The goal of this thesis was to create and analyze an eye tracking application that would encourage users to use it as a matter of doing eye exercises.

Eye structure and how we see things were discussed and analyzed. Three applications have been created using the Unity 5 game engine as well as Tobii EyeX eye tracker as a source of input. After that they were tested and evaluated by volunteers who gave their feedback on what were their feelings regarding these applications, how easy it was to use them and did they like it or not.

These applications provide a new experience to the users who may want to enter the world of eye tracking or just simply do eye gymnastics. The total reviews from the questionnaire seem to indicate that the applications provide mostly positive feelings with easy to master tasks as well as very good game flow. Volunteers wanted to continue using these applications as well as try out more. There was almost none negative feedback as the application and the way it is controlled was something new for the volunteers and they mastered it with ease. This could potentially increase the number of people who use eye tracking in their lives. Not only for gaming purposes, but for improving health or doing researches as well.

Continuing research in this area more applications could be added to the project and different animations could be added to make the games more entertaining. Moreover, a good idea would be to make the whole experience hands free where the entire application would be controlled by eyes from the game selection to performing eye training. Further studies could be conducted on how using eye tracking technology could benefit eyesight and eye health in general. Moreover, applications could be made more interactive and tested on a much larger scale and for a longer period of time to determine the long-term effect of doing eye exercises with an eye tracker.

References

- [1] M. M. Farouk Radwan, "Color psychology, the effect of colors," 06 05 2017. [Online]. Available: https://www.2knowmyself.com/miscellaneous/Color_psychology.
- [2] Enki Village, "Body Language Examples," 06 05 2017. [Online]. Available: <https://www.enkivillage.org/body-language-examples.html>.
- [3] M. Brian S. Boxer Wachler, "LASIK Risks And Complications," 25 04 2017. [Online]. Available: http://www.allaboutvision.com/visionsurgery/lasik_complication_1.htm.
- [4] M. Brian S. Boxer Wachler, "Eye Exercises," January 2017. [Online]. Available: <http://www.webmd.com/eye-health/eye-exercises>.
- [5] "What Percentage of the Population Wears Glasses?," [Online]. Available: <http://glassesrafter.com/information/percentage-population-wears-glasses.html>.
- [6] M. Theodore Leng, "wikiHow to Exercise Your Eyes," 2016. [Online]. Available: <http://www.wikihow.com/Exercise-Your-Eyes>.
- [7] w. u. b. M. H. a. G. H. O. By Rob Murphy, "The See Clearly Method and Other Programs: Do Eye Exercises Improve Vision?," May 2014. [Online]. Available: http://www.allaboutvision.com/buysmart/see_clearly.htm.
- [8] E. Wargo, "How Many Seconds to a First Impression?," 2006. [Online]. Available: <http://www.psychologicalscience.org/index.php/publications/observer/2006/july-06/how-many-seconds-to-a-first-impression.html>.
- [9] L. Segre and G. Heiting, "Low Vision Aids For Reading," February 2017. [Online]. Available: <http://www.allaboutvision.com/lowvision/reading.htm>.
- [10] L. Hardesty, "Finger-mounted reading device for the blind," 10 March 2015. [Online]. Available: <http://news.mit.edu/2015/finger-mounted-reading-device-blind-0310>.
- [11] Discovery Eye Foundation, "20 Facts About the Amazing Eye," October 2014. [Online]. Available: <http://discoveryeye.org/20-facts-about-the-amazing-eye/>.
- [12] American Association for Pediatric Ophthalmology and Strabismus, "Anatomy of the Eye," March 2017. [Online]. Available: <http://www.aapos.org/terms/conditions/22>.
- [13] M. Garin, "Eye Anatomy: How Do Our Eyes Work?," September 2015. [Online]. Available: <http://www.eyehalthweb.com/eye-anatomy/>.
- [14] H. Kolb, "Facts and Figures concerning the human retina," 2012. [Online]. Available: <http://webvision.med.utah.edu/book/part-xiii-facts-and-figures-concerning-the-human-retina/>.
- [15] D. Georgiev, "What is the maximum human field of vision?," January 2016. [Online]. Available: <https://www.quora.com/What-is-the-maximum-human-field-of-vision>.
- [16] Science Learning Hub, "Depth perception," April 2012. [Online]. Available: <https://www.sciencelearn.org.nz/resources/51-depth-perception>.

- [17] Master muscle list, “Levator Palpebrae Superioris,” 2017. [Online]. Available: <http://www.lumen.luc.edu/lumen/meded/grossanatomy/dissector/mml/lps.htm>.
- [18] J. Garrity, “Structure and Function of the Eyes,” 2017. [Online]. Available: <http://www.msmanuals.com/home/eye-disorders/biology-of-the-eyes/structure-and-function-of-the-eyes>.
- [19] L. Segre, “Eye Anatomy: Parts Of The Eye,” August 2016. [Online]. Available: <http://www.allaboutvision.com/resources/anatomy.htm>.
- [20] Moorfields, “Anatomy of the eye,” May 2017. [Online]. Available: <http://www.moorfields.nhs.uk/content/anatomy-eye>.
- [21] K. Than, “How the Human Eye Works,” May 2016. [Online]. Available: <http://www.livescience.com/3919-human-eye-works.html>.
- [22] krazycos, “What is digital eye strain?,” [Online]. Available: <https://gunnar.com/what-is-digital-eye-strain/>.
- [23] M. Oaklander, “Here’s What Happens To Your Eyes When You Look at Multiple Screens,” January 2016. [Online]. Available: <http://time.com/4171966/digital-device-eye-strain-screens/>.
- [24] “How LEDs Produce White Light,” [Online]. Available: http://www.photonstartechnology.com/learn/how_leds_produce_white_light.
- [25] G. Morrison, “LED LCD backlights explained,” March 2013. [Online]. Available: <https://www.cnet.com/news/led-lcd-backlights-explained/>.
- [26] National Eye Institute, “Statistics on the number of people with low vision,” 2010. [Online]. Available: <https://nei.nih.gov/eyedata/lowvision#5>.
- [27] Tobii dunavox, “How eye tracking works,” 2017. [Online]. Available: <https://www.tobiidynavox.com/about/about-us/how-eye-tracking-works/>.
- [28] “About Tobii AB,” 2017. [Online]. Available: <https://www.tobii.com/group/>.
- [29] Imotions, “What is eye tracking and how does it work?,” January 2016. [Online]. Available: <https://imotions.com/blog/eye-tracking-work/>.
- [30] Tobii AB, “How do Tobii Eye Trackers work?,” 2017. [Online]. Available: <http://www.tobii.com/learn-and-support/learn/eye-tracking-essentials/how-do-tobii-eye-trackers-work/>.
- [31] Advanced instruments, “What is calibration?,” 2017. [Online]. Available: <http://www.aicompanies.com/education/calibration/what-is-calibration>.
- [32] Tobii AB, “How eye tracking works,” 2017. [Online]. Available: <https://www.tobiidynavox.com/about/about-us/how-eye-tracking-works/>.
- [33] T. Hume, “Eye Tracker Reviews: Pupil Labs, Tobii, Eye Tribe, XLabs,” 2016. [Online]. Available: <http://thume.ca/2016/03/24/eye-tracker-reviews-pupil-labs-tobii-eyex-eye-tribe-tobii-x2-30/>.
- [34] Tobii, “Tobii EyeX,” 2017. [Online]. Available: <https://tobiigaming.com/product/tobii-eyex/>.
- [35] Tobii Pro, “Tobii Pro Studio,” April 2017. [Online]. Available: <https://www.tobii.com/product-listing/tobii-pro-studio/>.
- [36] Tobii Gaming, “Tobii Tracker 4C,” May 2017. [Online]. Available: <https://tobiigaming.com/eye-tracker-4c/>.
- [37] Tobii Developer Zone, “Differences between Tobii Gaze SDK and Tobii EyeX SDK,” 23 June 2014. [Online]. Available: <http://developer.tobii.com/differences-between-tobii-gaze-sdk-and-tobii-eyex-sdk>.

- [38] Tobii Developer Zone, “An introduction to Tobii EyeX,” January 2014. [Online]. Available: <http://developer.tobii.com/an-introduction-to-the-tobii-eyex-sdk/>.
- [39] Tobii Gaming, “Tobii 4C specifications,” May 2017. [Online]. Available: <https://help.tobii.com/hc/en-us/articles/213414285-4C-Specifications>.
- [40] Hammond Opticians, “Eye Exercises,” May 2017. [Online]. Available: <http://www.hammondopticians.co.uk/eye-exercises/>.
- [41] Remedy Tip, “Important Tips on Eye Gymnastics for the Improvement of Vision,” May 2017. [Online]. Available: <http://remedytip.com/important-tips-on-eye-gymnastics-for-the-improvement-of-vision/>.
- [42] Unity, “Unity 3D,” May 2017. [Online]. Available: <https://unity3d.com/unity>.
- [43] ___Petr___, “Does the "Step" button in Unity Editor actually steps 1 frame?,” December 2014. [Online]. Available: <http://answers.unity3d.com/questions/862240/does-the-step-button-in-unity-editor-actually-step.html>.
- [44] Unity, “3D Physics Reference,” May 2017. [Online]. Available: <https://docs.unity3d.com/Manual/Physics3DReference.html>.
- [45] A. B. H. G. Mélodie Vidala. Jayson Turnera, “Wearable eye tracking for mental health monitoring,” November 2011. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S0140366411003549>.
- [46] P. Richard S. E. Keefe, P. Jeremy M. Silverman and P. Richard C. Mohs, “Eye Tracking, Attention, and Schizotypal Symptoms in Nonpsychotic Relatives of Patients With Schizophrenia,” pp. <http://jamanetwork.com/journals/jamapsychiatry/article-abstract/497754>, February 1997.
- [47] C.-S. Lina, C.-C. Huan, C.-N. Chan, M.-S. Yeh and C.-C. Chiu, “Design of a computer game using an eye-tracking device for eye's activity rehabilitation,” October 2002. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S0143816603000757>.
- [48] J. A. M. Rawstron, C. D. B. M. Burley and M. J. M. F. Elder, “A Systematic Review of the Applicability and Efficacy of Eye Exercises,” April 2005. [Online]. Available: <http://search.proquest.com/openview/3f2e659081cb11d82ddd359ced29f3ec/1?pq-origsite=gscholar&cbl=35531>.
- [49] “Statistics of Low Vision in the US,” 06 05 2017. [Online]. Available: <https://nei.nih.gov/eyedata/lowvision#5>.
- [50] “Statistics on number of blind people in the US,” 06 05 2017. [Online]. Available: <https://nei.nih.gov/eyedata/blind>.
- [51] R. T. L. Mr. Robert A. Zuraw, Perfect Eyesight: The Art of Improving Vision Naturally, Taoist Publishers, 2011.
- [52] A. Poole and L. J. Ball, “Eye Tracking in HCI and Usability Research,” in *Encyclopedia of Human Computer Interaction*, 2005, p. 729.