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The Effects of Environmental Lighting on Human Emotions

GEO 511 Master's Thesis

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31.10.2021
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Abstract

Public places are often avoided during nighttime mainly because people don’t feel safe as soon as it gets dark. While this is a problem all over the world, it gets worse during wintertime when the nights are even longer in the northern hemisphere. However, research has shown that the problem is more a psychological problem than it is physical one, as the chance of something happening, is usually not as high as people believe. Nevertheless, pedestrians are still scared, and fear should be taken seriously.

Some European countries like Poland, Sweden or Iceland tried to counter this negative effect by trying out new ways of colorful accent lighting to accentuate roads, parks and squares. While first feedbacks seem to be positive, the research about the topic is still sparse.

This thesis likes to dig deeper into this topic, and it does so by conducting its own online experiment. For this experiment a virtual park was created with the help of Unreal Engine 4. 32 participants were sent through two different lighting scenarios within the park. One had white lights and one had blue lighting. The online experiment required participants to have their webcam enabled as a facial recognition software from iMotions was running to collect data about participants emotions and their intensity. At the end of the experiment, participants were asked to give their own opinion about the lighting conditions.

The results showed that the group who had the blue scenario felt calmer than the group having the white scenario. This was true for the automated facial recognition software and participants self-assessment.

Acknowledgments

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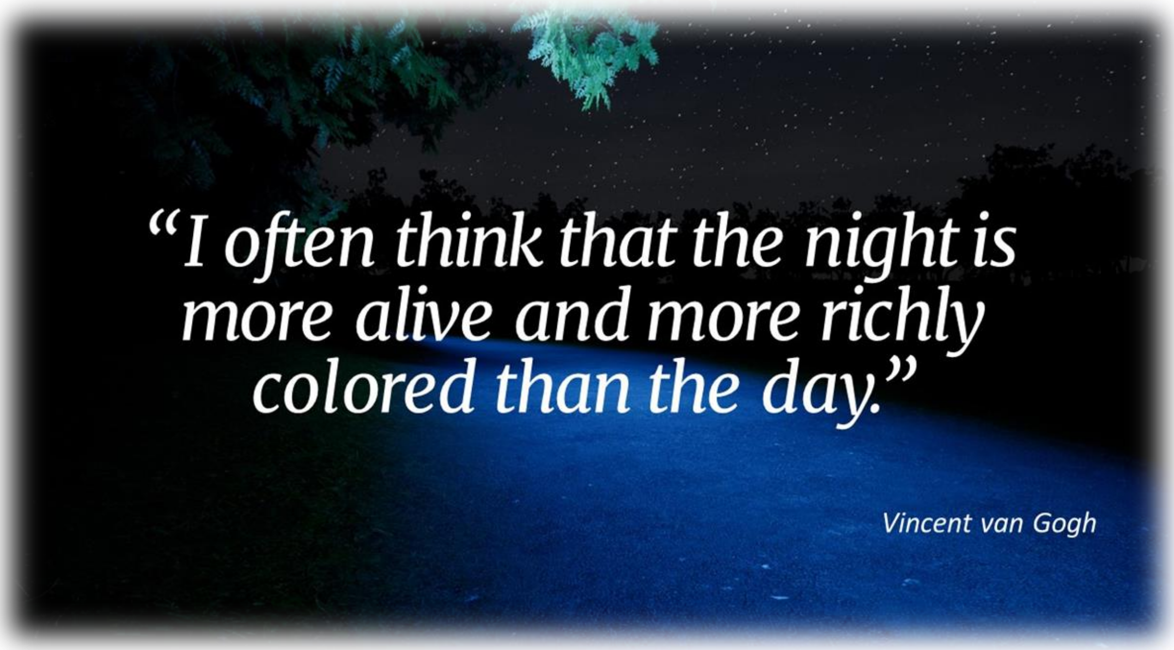
List of Abbreviations

2D	Two-dimensional Space
3D	Three-dimensional Space
ATP	Adenosine triphosphate
EDA	Electrodermal Activity
ECG	Electrocardiogram
EEG	Electroencephalogram
ESO	European Southern Observatory
GPU	Graphics Processing Unit
GSR	Galvanic Skin Response
H	Hypothesis
I.e.	Id est
LED	Light-emitting Diode
LAI	Leaf Area Index
NDVI	Normalized Difference Vegetation Index
RGB	Red, Green, Blue
RQ	Research Question
TV	Television
UI	User Interface
VLC	VideoLAN Client
VR	Virtual Reality
µS/s	Micro siemens per second

1. Introduction – An Illuminated World



It has been known for a long time that different lighting has an effect on human emotions and their behavior. It can be strongly assumed that the sensibility to different light has its origin in the day and night cycle of planet earth where many species, including humans, are significantly more active during daytime. However, the invention of fire, light bulbs and most recently computer screens have blurred the line between day and night.

Although it is clear, that light has an effect on many species on this planet, it becomes much more complex when we look at the fact that light is a certain spectrum of electromagnetic waves. As an example: Blue light has a shorter wavelength than red light and a study on pepper plants found out that samples that were exposed to red and blue light grew significantly more biomass then samples that were exposed to red light alone (Brown et al., 1995). Different color has an effect on humans too, and there is even a slight gap between the genders. Cowan et al. (2000) found out that human males react stronger to blue light than human females do. On the other hand no significant difference between the genders was found regarding red light (Cowan et al., 2000). Our natural lighting environment is dominated by the sun and earth's rotation. As humans we have little control over the sky and therefore its lighting. However, during nighttime this changes completely. While the sun is not shining, people use various forms of illumination to be able to work, study and interact with each other. In Nordic countries the daylight time is extremely short during the winter season. This makes artificial light sources even more important not just because of safety reasons (Jensen, 1999), but also for the well-being of people. Shortwave light suppresses the production of melatonin, which is an hormone that makes the organism sleepy (Thapan et al., 2001).

Since Nordic countries have more to deal with this issue than southern countries, they have proposed several ideas to counteract the darkness and its downsides.

Figure 1: Town Square in Akranes, Iceland (Akraneskaupstaður, 2015).

One of the strategies they use, is to fill the environment with colorful accent lighting. This lighting is meant to encourage people to spend time outside, even though it's dark. Another example is Tegnérparken in Uppsala, Sweden.

Figure 2: Tegnérparken, Uppsala Sweden (Wang, 2018).

The park there is near a school and many children go to play in the park during daylight hours. However, as soon as the sun went down, the children went home as well. Phillips placed several colorful LED lights inside the park and the result was that children suddenly spent 37 % more time outside in the park and 15 % less time inside watching TV or playing video games. Furthermore, 38 % of the children's parents joined them while spending time in the park (Wang, 2018). Assuming the higher exposure to this colorful accent lighting is the cause of the increased time spent outside, this could encourage more park or public place owners to change their lighting. If used systematically, citizens could benefit from having more enjoyable leisure time with more positive emotions, which could lead to people being happier in general.

1.1. Motivation and Problem Statement

Most people on this world don't live in a Nordic country and therefore they don't need to deal with endless nights or entire seasons where the sun doesn't shine for weeks. However, darkness is the same everywhere and many people are afraid of the dark. One of the reasons they are scared is perceived lack of safety in a public place during nighttime (Nalla & Ceccato, 2020). If this fear is justified or not is one thing but even if a certain place would be totally safe it's enough for people to stay away from it. The government of a country can take steps to reduce crime although they will most likely never be able to eliminate it entirely (Grabosky, 1995). According to empirical research the perceived safety plays one of the main factors if people are to visit a certain space or not (Costamagna et al., 2019).

While there have been numerous studies about the effect of lighting on the human psyche, the specific research about colorful accent lighting is relatively thin. In all the examples of colorful accent lighting, the creators of these art pieces or park decorations claim to enhance people's experience when inside these places. When we look at the numbers of people who actually spend time there, these claims are not necessarily false (Wang, 2018). However, it is still unknown what causes people to spend more time in these places. What we do know however, is that people tend to spend more time in places when they associate positive emotions with these places (Gartner, 2012). This can lead to situations where people prefer to take the longer route to a certain place because they might like something on that specific route, or they want to avoid some parts of the shorter route. Especially women have strong feelings of fear in public places, even though research states that most attacks on women happen in private places like their homes (Valentine, 1990).

Lighting has an effect on humans' psyche and their emotions. While studies have shown over and over again that certain light patterns and colors can influence one's mood and well-being, those studies focused mainly on room illumination with lighting that is on the Kelvin scale, meaning warmer yellowish light and colder blueish light. This thesis would like to evaluate if additional blue ascent lighting could help humans to get positive emotions from lighting. The idea comes from various north European countries where parks were enhanced with these colorful lights. Videos will be used to simulate such a scenario for several test subjects. The results are expected to show differences in participants' emotions (physiological reactions and self-reports) across the test conditions, i.e., between regular lighting and blue ascent lighting.

1.2. Research Goal and Research Questions

Based on the problems presented in the previous section, this work is intended to contribute to the research on the effects of accent light on human emotions.
In order to achieve this research goal, an online user study was conducted to assess if participants do react differently in an environment with blue light compared to an environment with white light
Participants have been divided into two groups One group was sent through a virtual park with blue accent lighting, while the other group had regular/typical white lighting. To measure participants' emotions, their faces were tracked with a facial recognition software called iMotions through their webcam.

The following research questions were addressed to determine what influence color accent lighting has on human emotions:
RQ1: *How does blue accent lighting affect human emotions? More specifically, does blue accent lighting have a greater calming effect on a human's emotions compared to typical white color lighting?*
RQ2: *How accurate is participants' subjective judgments of their current emotional state (i.e., conceptualized along two dimensions: valence and arousal) correlate with automated facial coding metrics?*

2. Literature Review

In order to answer those research questions, we need to take a deeper look into the literature in those areas of science that play an important role for this thesis. These include electromagnetic waves, colors, biology, psychology, and others. At the end of this chapter, we can state some hypotheses.

2.1. How Light Works

Even though light is in our everyday life there is still much about it that we don't understand. Since the beginning of time light has played a major role in human society but as advanced as we are today, there are still many things we don't know. Even Albert Einstein stated at the end of his life that he still couldn't figure out light quanta in its entirety (Roychoudhuri et al., 2017). The term "light quanta" is not used as much anymore, instead the modern description of it today is "photons"(Glauber, 2006). The introduction of light quanta or photons happened due to the fact that even though it was known that light carried energy inside it, it was unclear how much it really was. Photons were introduced as some sort of unit as the energy inside light would need to be discrete and therefore meaning not endless (Roychoudhuri et al., 2017). Today a photon is calculated as follows:

`E = h * c / λ = h * f`

Where:

- `E` is the energy of a photon
- `h` is the Planck constant,
- `c` is the speed of light,
- `λ` is the wavelength of a photon,
- `f` is the frequency of a photon.

(Panfil, 2020)

Furthermore, light is the visible part of the electromagnetic spectrum which has a wavelength of 380 – 700 nm (National Aeronautics and Space Administration, 2010b).

2.1.1. Electromagnetic Waves

There are two major sorts of waves which can be distinguished from one another. These are mechanical waves and electromagnetic waves. Mechanical waves transport energy through matter such as waves in the water or soundwaves in the air. They require a medium to travel and if that medium is not there, they simply couldn't exist. Electromagnetic waves on the other hand don't require a medium to travel and therefore they can even travel through the vacuum of space (National Aeronautics and Space Administration, 2010a). In the 19th century a German physicist called Heinrich Hertz found out that radio waves and light travel at the same speed and therefore a connection was likely (Edwards, 2012).

Electromagnetic waves are two combined waves that are perpendicular to each other. They consist of the electric field and the magnetic field. The spectrum of electromagnetic waves is actually very big ranging from 0.0001 nm for gamma rays up to hundreds of meters for radio waves.

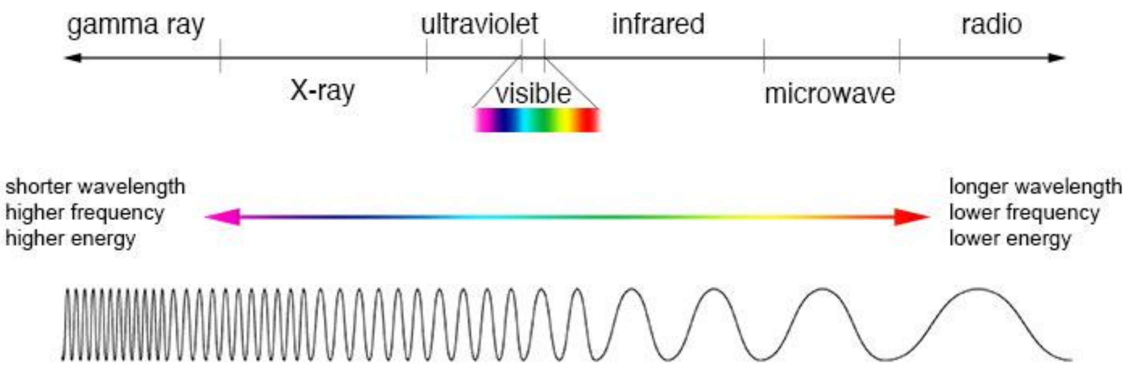


Figure 3: The spectrum of visible light inside the EM-waves spectrum (NASA, 2010).

As the picture shows there are other forms of electromagnetic waves that also sound familiar and are used in our everyday life. Even though we are not able to see them we can still use them for different purposes. X-Rays are used to pictures bones inside a human body. Ultraviolet light, especially UV-B which has a wavelength of 280 – 315 nm, is responsible for sunburns people experience when they spend too much time in the sun without protection (Moore et al., 2013). Infrared wavelengths are often used in remote sensing to assess surface temperatures (Weng, 2009) although there are many other uses for it.

2.1.2. Natural Light Sources

As we now know light carries energy and therefore is created through energy. The biggest sources of light energy we know of, are stars and the one we know best is of course our own sun. The sun creates energy by a thermonuclear fusion reaction (Allam et al., 2018). It emits energy in many different wavelengths, but the biggest amount is in the range of visible light.

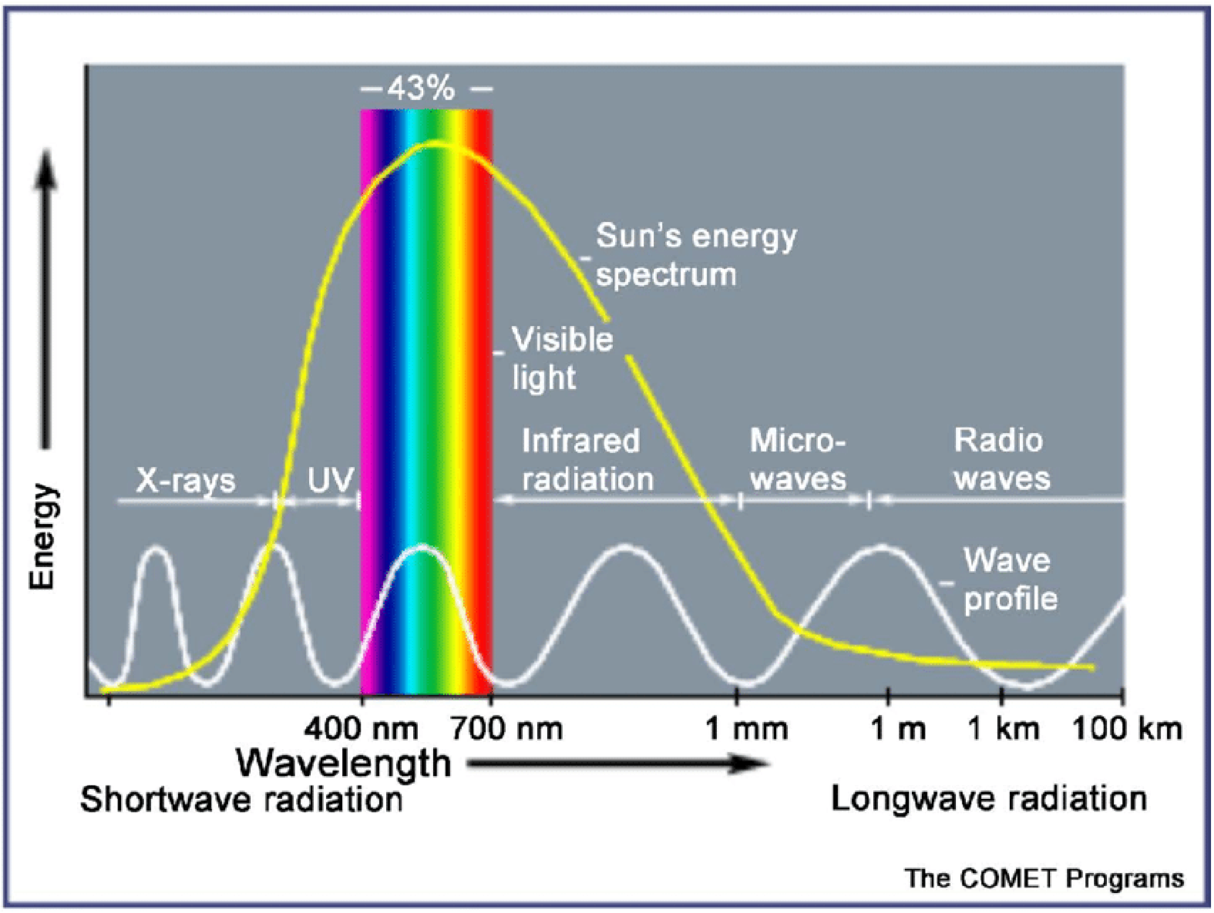


Figure 4: The yellow line indicates the range our sun emits its energy (Allam et al., 2018).

As we can see in the figure above, the peak of the yellow line is in the blue slightly greenish part of the visible spectrum. Since blue light has a shorter wavelength than green light it carries more energy. This together with the thickness of our atmosphere is the reason our sky appears blue and not green. Violet has an even shorter wavelength than blue but the amount of violet light our sun emits, is lower than the amount of blue light, hence our sky is not violet.

Another natural source of light is bioluminescence which means the production of light through biochemical reactions. The most common example of bioluminescence are fireflies. They create cold light with the help of luciferin, ATP and oxygen (Seliger & McElroy, 1964). Fireflies are not the only form of life that are capable of emitting light. Bioluminescence is also prevalent in plants. In fact scientists are trying to create plants that maybe one day, can replace some of our lamps (Kwak et al., 2017). Another example of bioluminescence life are dinoflagellates which are single-celled eukaryotes living in the water. They start to glow blue as a defense mechanism (Lindström et al., 2017).

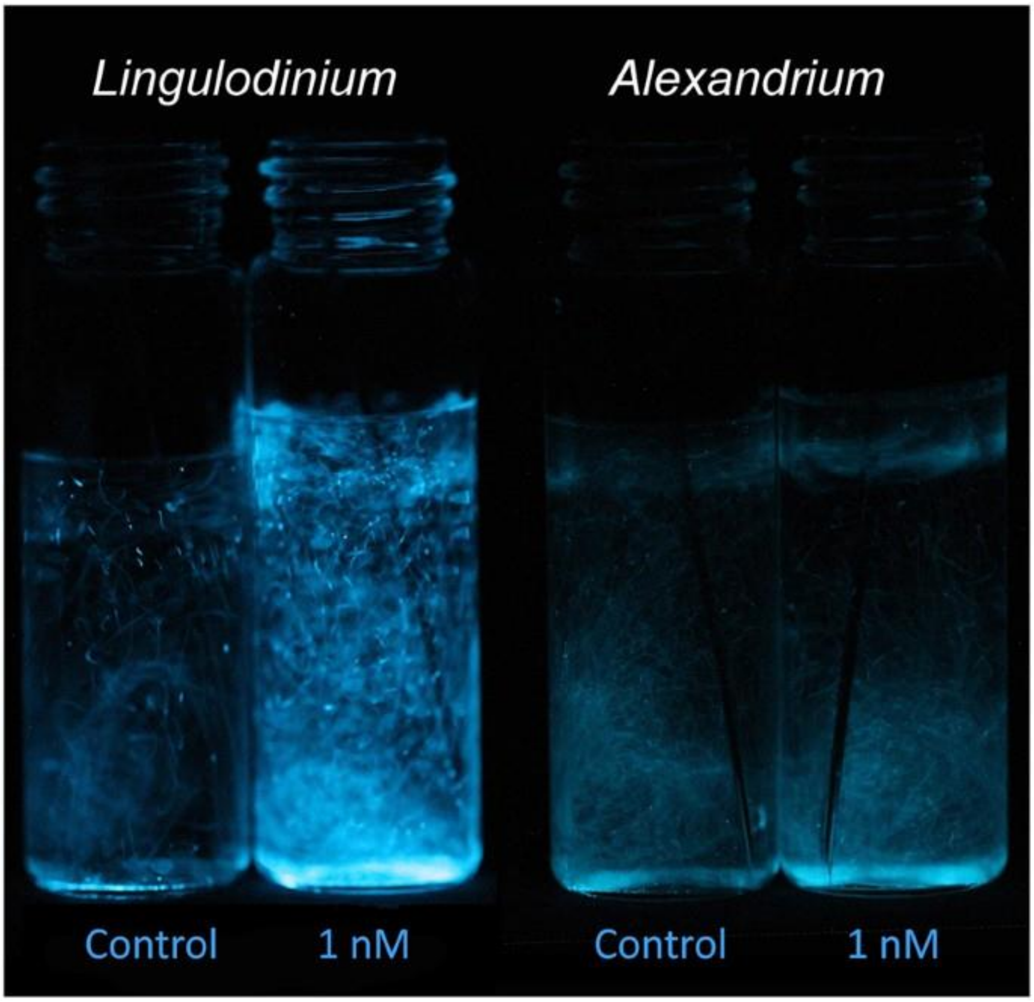


Figure 5: Two species of dinoflagellate in water. It is believed that they glow as a defense mechanism. (Lindström et al., 2017).

The defense mechanism is trigger by mechanical stimulation (Lindström et al., 2017). Dinoflagellates natural enemies are copepods. The theory is that due to the mechanical stimulation when copepods arrive, dinoflagellates start to glow which in return attracts bigger predators that hunt copepods (Lindström et al., 2017).

2.2. Colors

When the visible part of light is split into different color ranges, we can also explain why certain objects here on earth appear in different colors.

Figure 6: North America from space (NASA's Earth Observatory, 2002).

When we look at Earth from space three colors are most prevalent: Blue, green, and white.
Let's start with white. Both clouds and the arctic ice shield on the figure above are white because both have a very high albedo, which means they reflect a very high percent of incoming shortwave energy (Stapf et al., 2020). Furthermore, they reflect the whole visible spectrum equally. Since clouds and ice are not completely flat like a mirror, they reflect light in all sorts of directions, which makes them appear white to us. In clouds this effect is called Mie-Scattering (Leith, 2018).

Most plants appear green to us and fortunately there are so many plants on earth that we can even see the green color from space on our landmasses. This allowed us to create indexes such as NDVI or LAI to measure the amount of vegetation on the surface area of the planet (Carlson & Ripley, 1997). The reason they appear green is that plants use a reaction called photosynthesis as their primary source of food. With photosynthesis plants are literally able to harvest the energy of the visible spectrum of light (Ke, 2001). However, they only harvest in the blue spectrum and the red spectrum. This makes them appear green, since green is not absorbed and therefore gets reflected.

The color with the biggest area on the figure above is blue which of course are the oceans. This is interesting because when we look at water in a glass it appears colorless. Then why do oceans appear blue? The reason is that water absorbs dominantly longer wavelengths such as red light. However, this effect is only visible when there is a huge amount of water present. A small glass of water simply doesn't have the quantity to make the effect visible (Braun & Smirnov, 1993).

2.3. Evolution

Earth has a natural day and night cycle (Figueiro et al., 2017). Every species that evolved on the surface of this planet had to adapt to this cycle. Research has shown that humans have an "inner clock" which is called "circadian rhythm". One cycle is slightly longer than 24 hours and it is most likely a result of Earth's 24-hour day and night cycle (Figueiro et al., 2017). The circadian system is also connected to light exposure. To distinguish between day and night many species evolved to have eyes (Fernald, 1997). At some point eyes became more than just that and also helped in navigating. This is true even for eyes that are not as complex as ours. Starfish belonging to the species "Linckia laevigata" for example have very low spatial resolution and are color blind but a study has shown that they, too, use their limited eyesight for navigation (Garm & Nilsson, 2014). While using eyes to navigate can be a huge advantage it also comes with a downside. Eyes need light to navigate and are therefore depended on light sources. During daytime there is no problem of having enough light on the planet's surface but during nighttime it becomes a problem to only rely on eyes, especially during a phase when there is no moon. Many species, including humans, are therefore mostly active during daytime and sleep at night. However, humans have found ways to create artificial lights with the help of fire or electricity. Tests have shown that humans gradually lose their sensitivity to see shortwave light as they age (Sample et al., 1988).

When humans see something, the light of the environment travels at the back of the human eyeball where the retina is. The retina is a tissue, which is considered a part of the brain (Kolb, 2013).

2.4. Light Pollution and its Impact on Wildlife

While humans are used to streetlamps during the night, animals quite often have a harder time adapting to light pollution (Eisenbeis & Hänel, 2009). The family of species that suffer the tremendously from light pollution are believed to be insects (Owens et al., 2020). The issue is that artificial light disrupts the natural day and night cycle of animals. This is true not only for simple street light and therefore meaning local sources of light, it's also true for diffuse skyglow which appears on the distant horizon from a city nearby (Owens et al., 2020). The disruption of the day and night cycle is not the only problem for the wildlife. Many insects are attracted to light sources and they chase after them. This is especially recognizable during summertime when people sit outside in the evening. The issue is that insects near a light source also expose themselves for insectivores (Owens et al., 2020). Not all animals are attracted by the same wavelength of light. Many are able to see ultra-violet light but are blind the long-wave light such as red or orange. However, not only insects suffer from artificial light as birds can also get disoriented by larger light sources (Eisenbeis & Hänel, 2009).

2.5. Key Terms

In order to get a good understanding of the matter, I'd like to introduce a few key terms. These terms are important for the rest of thesis, especially the results section.

2.5.1. Definition of Blue

There are several definitions of blue. Dictionary.com describes it as *"the pure color of a clear sky; the primary color between green and violet in the visible spectrum, an effect of light with a wavelength between 450 and 500 nanometers"*(Dictionary.com, n.d.-a). However, this gives us a wide variety of possible blueish hues. Fortunately, there are several color models that have been invented to specify different colors more clearly in order to use them. One of the most famous one is the RGB model where RGB stands for "Red, Green and Blue" (Süsstrunk et al., 1999). It is an additive color model which means that the individual red, green or blue values are added together to then result in the desired color. The values normally range from 0 to 255 which is exactly the size of 8-bit or 1 byte. This can of course be expanded on as wider range of values also ensure a wider range of possible colors. There are multiple variants of RGB color spaces and there is no best or worst variant as it all depends on the specific situation (Süsstrunk et al., 1999). However, in many cases values from 0 to 255 are enough were black is represented with three values of zero and white is represented with three values of 255.

If we take the RGB model as a template to answer our research question then we would represent white as 255, 255, 255 and blue on the other hand as 0,0,255 because that would be the purest form of blue in this model.

2.5.2. Definition of Valence

Throughout this thesis we will come across the term “Valence” several times. As this term is widely used today in a chemical context it’s important to note that the word valence has a totally different meaning when it comes to psychology. The word was first used by German American psychologist Kurt Lewin in the 20th century. He describes positive valence as something a person is drawn or attracted to it. On the opposite, something a person is repelled at is said to have a negative valence (Price et al., 1951). With this definition we can essentially view valence as some sort of emotional scale where a positive valence leads to positive emotions and a negative valence leads to negative emotions.

2.5.3. Definition of Calm

If we look up the word “calm” in the dictionary it says the following *“free from excitement or passion”*(Dictionary.com, n.d.-b). While the dictionary tells us what calm is not, it unfortunately doesn’t give us a clear indicator what it is and how we would measure it. To give us a better understanding of what calm could be we can take a look at the Geneva wheel of emotions (Scherer, 2005) which serves as a framework to better define different states.

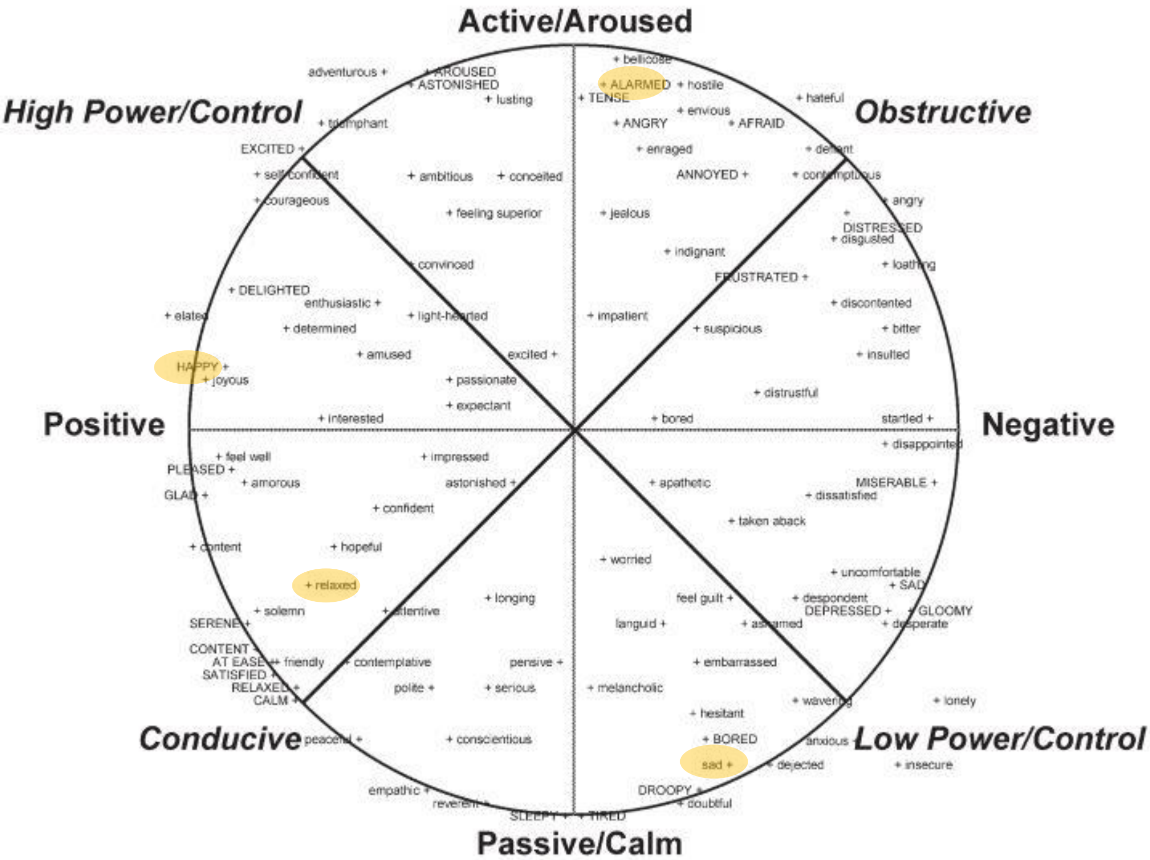


Figure 7: Geneva Wheel of Emotions from Scherrer (2005). Highlighted are the four emotions that are most important for my experiment: Alarmed, happy, relaxed and sad.

The Geneva wheel of emotions gives us a wide range of emotions, but they are all based on the two main axis which are "Arousal" for the vertical axis and "Valence" for the horizontal axis. This means if we have a high amount of valence and a high amount of arousal, we get emotions like "excited" or "adventurous". On the other hand, when we have a low amount of valence and arousal, we get emotions like "embarrassed" or "bored". Nevertheless, the definition of "calm" would therefore mean having a low amount of arousal and if we try to measure calmness in an experiment it would require having a difference in arousal between two measured values.

2.6. Expectations

Based on the previous chapters we can have several anticipations, which then lead to some hypotheses.

2.6.1. Reasons leading to Hypotheses

Studies suggest that colors can have a big influence on human emotions. While some are learned through culture, for example that red is associated with love, others are less obvious (Calvillo

Cortés & Falcón Morales, 2016). Furthermore they might also differ when they are used as terms in a written form compared to when they are shown as colors themselves (Jonauskaite et al., 2020). Some colors like red can have positive and negative meanings as red is also the color of blood and is therefore often associated with war. Blue on the other hand is one of the few colors that have mostly positive associations (Jonauskaite et al., 2020). A 2012 study from Japan suggested to install blue lights on railway stations in order to prevent people to commit suicide. According to their research, the installation of blue lights led to a decrease of 84 % in number of suicides (Ueda et al., 2012). If this worked, it would provide a tremendous help in preventing suicides while at the same time being a low-cost solution. Unfortunately it seemed that preventing suicides is maybe not that easy as a later study, also from Japan, suggested that even if the blue light could help to prevent suicides, the effect would probably be significantly smaller than it was suggested previously (Ichikawa et al., 2014).

Figure 8: This bikepath is near Lidzbark Warmiński in Poland. It contains phosphors that are charged with sunlight during the day and then glow during the night (TPA Sp. Z oo, 2016).

Another example of blue light is in the city of Lidzbark Warminski in Poland. The Company TPA built a 100-meter-long bicycle road which is painted with blue phosphorus road paint. The sun charges the road paint during the day which then glows blue for up to ten hours during the night (Tan, 2016). The constructers hope to calm pedestrians and bicyclists down and prevent accidents during the night. While no additional energy is needed to make the illumination work, the road costs twice as much as a regular road would (Finger, 2017).

As we can see, the examples above all suggest that blue light might have a calming effect on humans.

2.6.2. Hypotheses

Based on the literature presented in the previous chapter, I thus hypothesized that:

H1: *The addition of blue accent light will calm participants more than white light only.*

H2: *If blue light will calm participants more than white light, then this should be reflected in their self-assessment as well as through their facial expression.*

3. Material and Methods

A good way to measure someone's reaction to certain circumstances is usually simply to put them into those very circumstances. While simulations can cover a lot of aspects, they are not able to cover everything (United States. Congress. Office of Technology Assessment., 1994). While this statement dates back to 1994 it still holds value today. In many cases putting people in a real-life training simulation is not possible due to various reasons, which could include dangerous situations, time constrains or simply monetary limits. For this thesis the limits are simply a lack of places that have colorful accent lighting, meaning there is no place nearby where it would be possible to test several participants under various conditions. The second-best option therefore was, to conduct an experiment in a virtual reality context.

An immersive way to experience a virtual environment is with specialized equipment that is specifically designed for it. The most common way to use VR these days is with a VR headset and its controllers, one for each hand. There are several companies that built several devices for it in various price categories. Some of them are Sony, Samsung, Oculus and HTC (McCaffrey, 2017). Numerous occasions have proven that a virtual reality setting can tremendously help in decision making. One of these experiments was conducted by Lee and Lee (2021). They reconstructed a plaza in the city of Seoul with the existing lighting conditions. In a second attempt they change the lighting according to a new plan and then they compared the two by using VR technology. They found the new lighting to be superior but it also showed that VR can be very helpful by comparing lighting scenarios (Lee & Lee, 2021).

Unfortunately, there are also downsides to VR. The first one is simply the high cost of hardware the is necessary to run VR content (Zelle & Figura, 2004). The 3D effect that comes with modern VR content is mostly achieved with stereoscopic 3D these days. The technique generates two different pictures which are slightly different to mimic the position of both human eyes. In humans both eyes get information from their surroundings, but they are slightly different because the eyes are not on the exact same position. Our brain then processes them to the real-world surroundings we are used to. Stereoscopic 3D is trying to imitate this by showing slightly different pictures per eyes, multiple times a second. As one eye sees about 30 frames per second the scenery appears fluent to the human eye and the combination of both eyes make it look very realistic.

3.1. Choosing an Engine

To create an artificial scenario that could be visited virtually, and maybe even with VR glasses, I first had to choose a suitable game engine. Basically a game engine provides a framework for developers to create a videogame (Ward, 2008). There were two contenders for it: Unity and Unreal Engine 4. When I looked up the internet on information, which engine I should use, I found many subjective opinions on the topic and basically everyone seemed to have a different opinion then the next person. Furthermore, the development of both engines is so rapid that some features of an engine might change entirely over a few months. In 2015 Unity was said to be more intuitive and easier to grasp while Unreal Engine 4 has a very easy to understand user interface (UI) (Pachoulakis & Pontikakis, 2015). Based on this assessment I started working with Unity as it seemed the easier choice at this time.

Figure 9: An early test scenario I created with Unity to see how an illuminated tree would look like during nighttime.

The reason I made green glowing plants is because of the inspiration from Kwak et al. (2017) where scientist try to create plants that use their ATP to glow all night long. Although the idea and the research for this topic is very interesting, I later decided to not include the green glowing plants in my scenario as I only wanted to focus on one color. I also thought about implementing dinoflagellates which glow blue due to mechanical intervention (Lindström et al., 2017), but the technical aspect would have been more challenging. The implementation from a narrative point of view would have been even more challenging as dinoflagellates are mainly marine creature (Gomez, 2012).

Figure 10: Almost the same scenario as the previous figure but without fog and a stronger illuminated moon.

After some days of testing out unity engine I wanted to create a bigger scenario that would look like something I originally had in mind, namely a park. This was when I realized the limitations of the engine or rather the limiting availability of 3D assets. While both Unity and Unreal engine are free to use, they only come with a limited number of free 3D assets such as trees, furniture, modular houses etc. While it is always possible to buy new assets the cost can increase drastically as these assets are usually made from different people all over the world and there exists a real market for this (Korbel et al., 2019). While different formats of 3D assets exist, they can usually be converted into other formats quite easily. This makes it possible to use certain 3D assets for totally different purposes. Some assets might be created for a videogame and then sold on the internet. The next company that buys those assets can use them for architectural visualization or everything else they want. The advantage that Unreal Engine has over Unity is that the engine comes with a lot of free assets and materials right off the box, meaning that new users don't need to buy extra assets if they don't want to spend too much money. This was my main reason to switch to Unreal engine later on as they already provided some very good assets I could use, especially assets like park benches, foliage and playground assets.

3.2. 3D Objects and Assets

Whenever we work in virtual 3D spaces, we essentially come across polygon meshes and textures, because they are the bread and butter of 3D objects and are essential if the environment needs to be believable (Harrison, 2003).

3.2.1. Polygon Meshes

Polygon meshes commonly referred as "meshes", consist of vertices, edges, and faces. These components are used to create 3D geometric models or objects (Shirley et al., 2009). As the meshes become more and more complex they also use more storage space (Alliez, 2005). An old but still common technique to counter this is by using "normal maps" which simulate shadows and therefore allow for less complex meshes by adding another texture layer (Blinn, 1978).

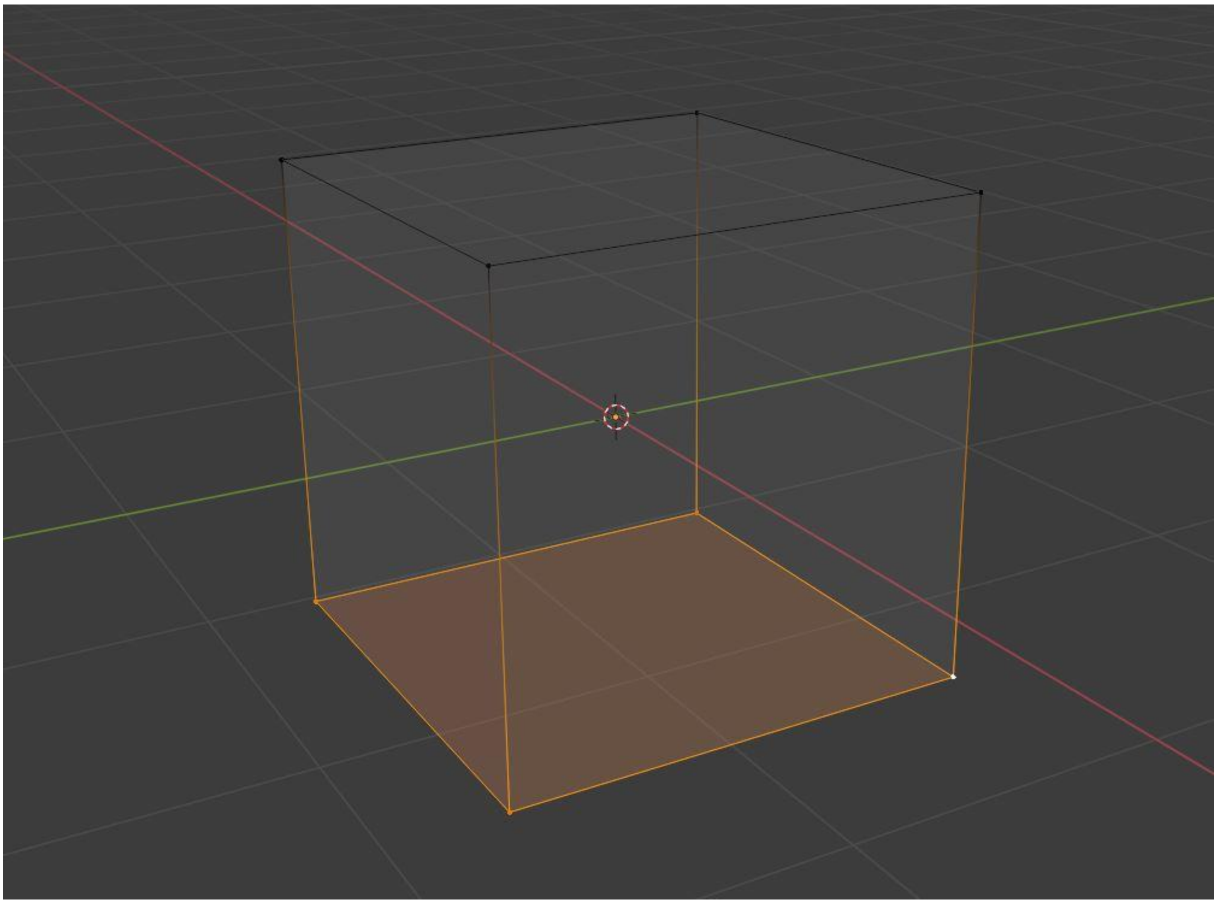


Figure 11: This image is from Blender and shows the simplest form of a polygon mesh, which is a cube. It consists of eight vertices. The lower four vertices are selected, therefore they appear orange. Since they are connected to each other they also appear as the bottom face of the cube.

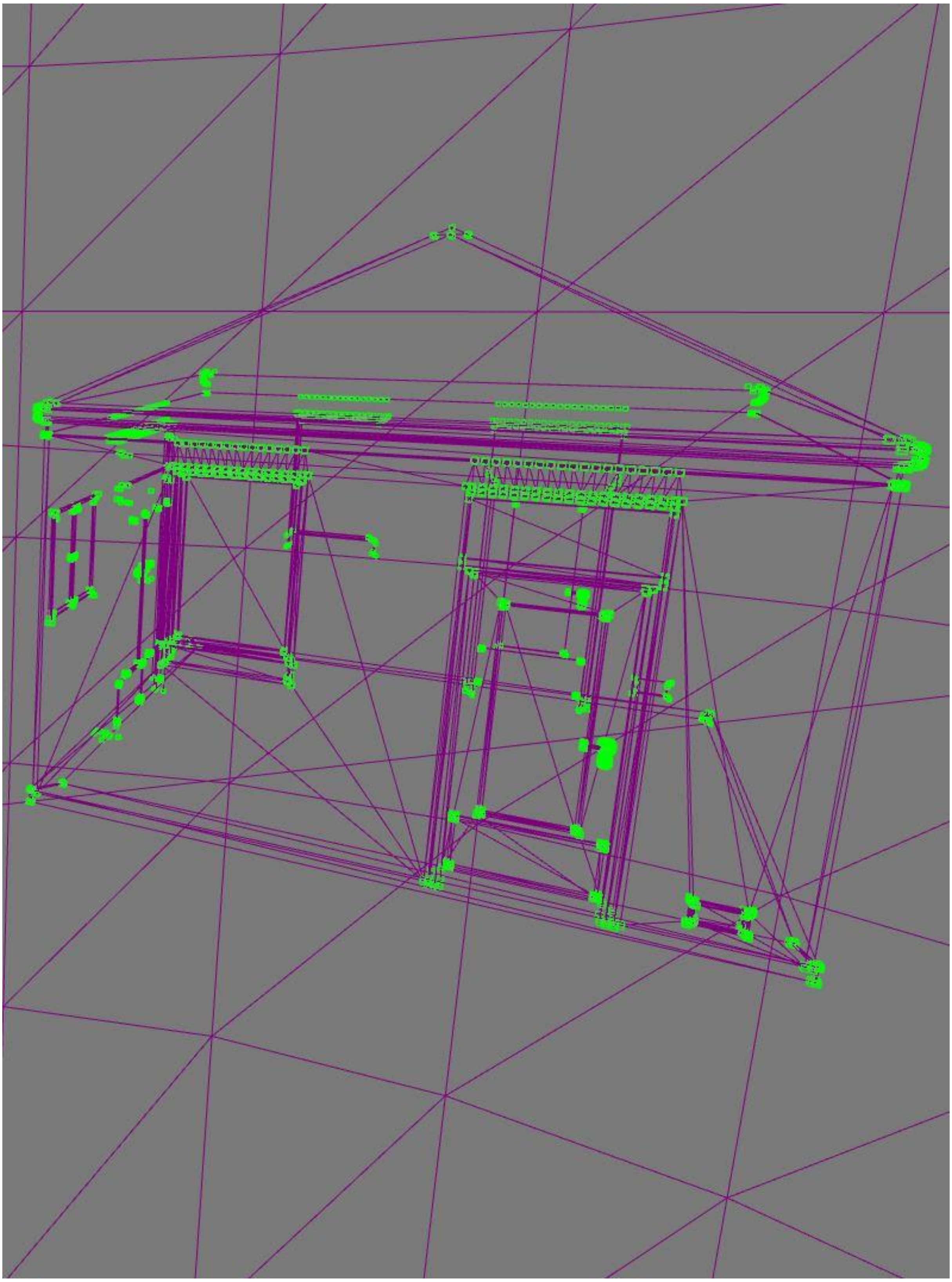


Figure 12: This is a wireframe of the first building in my scenario right at the park entrance. The vertices are highlighted green.

3.2.2. Textures

Textures are 2D images that are placed on the meshes to give them a believable appearance. They provide the mesh with color information, and as an example, a woodgrain texture around a fitting mesh would make the object look like a piece of wood (Mcreynolds, 1999).
To match the textures on to the meshes they need to be mapped which is called UV-Mapping.

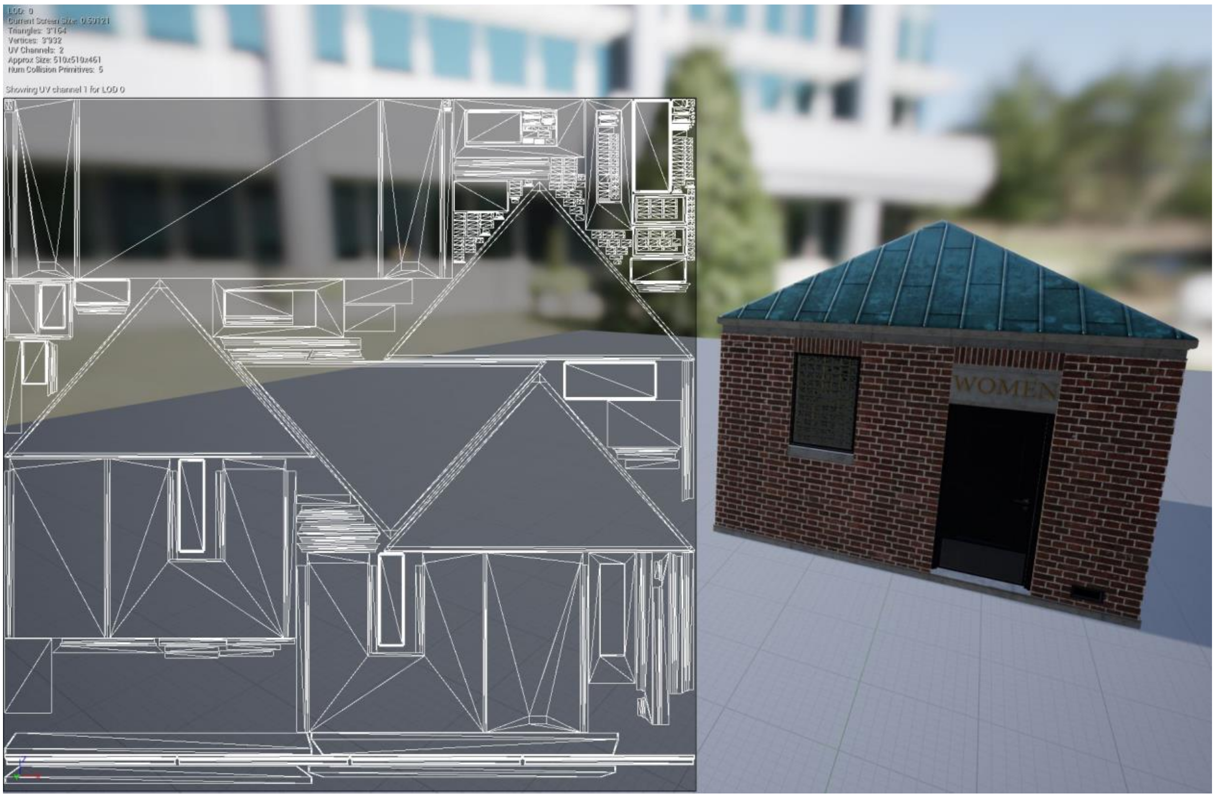


Figure 13: On the right-hand side is again the first building from my scenario but this time with the full texture. On the left-hand side is the UV-Mapping for the building.

3.2.3. Blender

As mentioned in the previous chapter, 3D assets are crucial when creating a virtual world. If the desired scenario would need to look realistic a lot of different 3D assets would need to be used. Fortunately, Unreal Engine already provided some good assets but to get certain models specifically designed for my own purpose I knew I would need to create some assets myself.
Creating a 3D object from scratch is called “modeling”. It deals with the form, shape and appearance properties and the possibility to store them on a computer (Shirley et al., 2009).
Blender is an open-source 3D modeling tool and is similar to Autodesk’s Maya or 3D Max, which are two of the most used 3D software today. The advantage of blender, beside it’s being free, is that is has a tool for basically everything and is considered the “Swiss Army knife” of 3D modeling (Flavell, 2010).

Figure 14: A house I created in Blender. While the house never fully made it into the final scenario, I was still able to use some parts of it.

However, I only used Blender as sparingly as I could since 3D modeling takes a lot of time and especially with complexes geometry can become tricky very fast.

3.3. Unreal Engine

Unreal Engine is a videogame engine that was developed by Tim Sweeney, the founder of Epic Games. The engine was first shown in 1998 in the videogame “Unreal”, which was a first-person shooter (Sweeney, 2005). In 2021 Unreal Engine released its fifth generation for early access by the name Unreal Engine 5. While Unreal Engine 5 comes with a completely new user interface and several new features, it still shares a lot with its predecessor Unreal Engine 4.
While It’s primarily an engine to create videogames, it’s also used for promotional purposes. For example, Audi uses it to show their cars to customers (Wenz, 2021). The engine is also widely used for Architectural visualizations (Basauli, 2021).

3.3.1. Technical Aspect

There are multiple approaches when it comes to implementing lighting systems in videogames. In addition to that every approach also has multiple techniques. As technology develops, so do these techniques and with every new generation of videogame engines, these lighting techniques become more and more sophisticated.
Two of the most basic approaches in lighting are dynamic lighting and baked lighting. For the end-user, there is usually no visible difference in the lighting condition as both methods can

look very gorgeous. However, for the computer it is key to implement the right techniques for the right situation, otherwise precious computer power is wasted.

Dynamic lighting is rendered in real-time by an end-user's GPU (Bitterli et al., 2020). This has the advantage of reacting to every change of lighting condition. For example, the lights of a moving car can be calculated immediately and can therefore be shown in a realistic manner. The same goes for shadows during daytime scenarios. The downside of dynamic lighting however lies in the required processing power. The computer needs to maintain this light at all time during the scenery, even if it is not moving. This can cause a lot of stress for the GPU, especially on weaker computers.

Baked lighting on the other hand takes a different approach. As the name suggests, something has been "baked", like a bread in the oven. In simple terms, virtual 3D environments are made with meshes and textures. While dynamic lighting constantly calculates the light and shadows onto these textures, baked lighting pre-computes the light and literally "burns" the lighting into theses textures. In fact, the scenery is almost painted as if there were light. The downside of this is that precomputing takes a lot of time, especially for larger scenes. Furthermore, this precomputing time almost eliminates the possibility of making changes during runtime as it would take too long and for the user it would feel like a slideshow. However, the benefit of baked lighting is that it almost comes resource free and doesn't need much computing power during runtime, as everything is already pre-calculated.

3.3.2. Park Design

The park design seemed a crucial part in my experiment since this would be the place people visit. Whatever the atmosphere of this park would be, it would most likely have an impact on the experiment.

At first, I wanted to create three different scenarios. One of them would be an urban area in a city, another would be a small path in the middle of a forest and the last one would be a park environment. To get some references I looked at existing environments because that is what game designers usually do when they create videogames (Álvarez & Duarte, 2018). My first plan was to create the city and the forest environment from scratch without any real-life references but maybe some inspirations from them as the environments would need to be believable after all.

Figure 15: This was my first attempt on creating a city. The highway glows blue and leads into the dark on purpose.

The first city I created had a highway in the middle with several lanes and two train tracks on the outside. I originally wanted to show glowing road paint as this is something that research is trying to implement in the near future. The new road paint, on a phosphorus base could also emit some light during the night and therefore help visibility in the dark (Nance & Sparks, 2020). However, I had to focus on one issue instead of several issues in order to get proper results and therefore, this scenario was scrapped and assets I could use were taken for the final scenario later.

For the park environment I wanted to go a different route and recreate the Irchel park in Zurich as some of the experiment's participants would probably know the park, since its right next to the university campus.

Figure 16: My recreation of Irchel park in Zurich with Milchbuck Tramway-station in the lower part of the picture.

However, it later turned out that recreating the Irchel park would not be a good idea because some people might already know the place. The problem was that some participants could have certain feelings and emotions already attached to it, which could bias the whole experiment. Also, worth mentioning is that the whole scenario would take place during nighttime as the reaction to artificial light is the main purpose of this thesis. The reason this picture looks like it is during daytime is simply due to better visibility I preferred working in a daytime scenario. Many details get lost when the scenario is too dark.

Figure 17: An earlier version of the park. The main way is already there, and the blue road is also visible from the bird's perspective.

Since I wanted participants to get a feel of the park, I decided to create an outer circle of park road where people would move around. Therefore, the park road was the first thing I built, and it also works as some sort of “park border”. To smooth out the park road, I implemented them as splines, which is a feature Unreal Engine provides specifically for the creation of roads and streets. It helps the user to form the roads in synergy with the landscape, otherwise the environment would most likely look unnatural.
As soon as the basic structure was done the next step would be the background.

3.3.3. Creating a City

As I decided to create only one scenario instead of three different scenarios, which was my original idea, I thought I could integrate some aspects from the other scenarios. That’s why I wanted to create a city background since the park should feel like it is in the middle of a medium sized city. One of the main obstacles in creating an artificial city is that there is a wide range of diverse buildings while at the same time there are groups of buildings that look almost the same because they are made by the same architect or company. That means I would somehow consider both aspects in order to make the city look believable. While placing the same 3D object multiple times is not a problem it’s also not very realistic because in reality even neighborhoods which were designed by the same company have small differences in almost every building, which was revealed in a study that compared energy consumption between sister buildings (Juodis et al., 2009). Furthermore, the people that live inside these appartements have different lighting conditions. In order to address that, I had to photoshop multiple textures. Most importantly I had to diversify the color conditions of the appartement’s lights which were visible from outside.

Figure 18: Different people use different lighting conditions for their appartements.

Due to performance reasons the buildings nearby use textures that are of a much higher quality then those buildings far in the background. Fortunately, the engine helps a little with downsizing the textures when they are far-away, unfortunately this process doesn't always work as intended and therefore it's usually beneficial to at least take a look at it, if corrections need to be made.

As this was always going to be a nighttime scenario, I knew that the sky would also play an important role in it. During the testing phase with the Unity engine, I experimented with the moon a little bit but later I found the risk of distraction to be too high. Therefore, I decided the scenario should be without a moon and without clouds but with a tiny bit of fog to make it a little brighter. Unreal engine comes with a default sky and some options for customization. While they do look good and would certainly work in an actual video game, I wasn't really satisfied with it. That's why I went on and created my own sky sphere. A skybox or in my case a sky sphere, is the illusion of seeing the horizon or objects miles away, because all those things from far away cannot be generated without draining performance too much (Harrison, 2003).

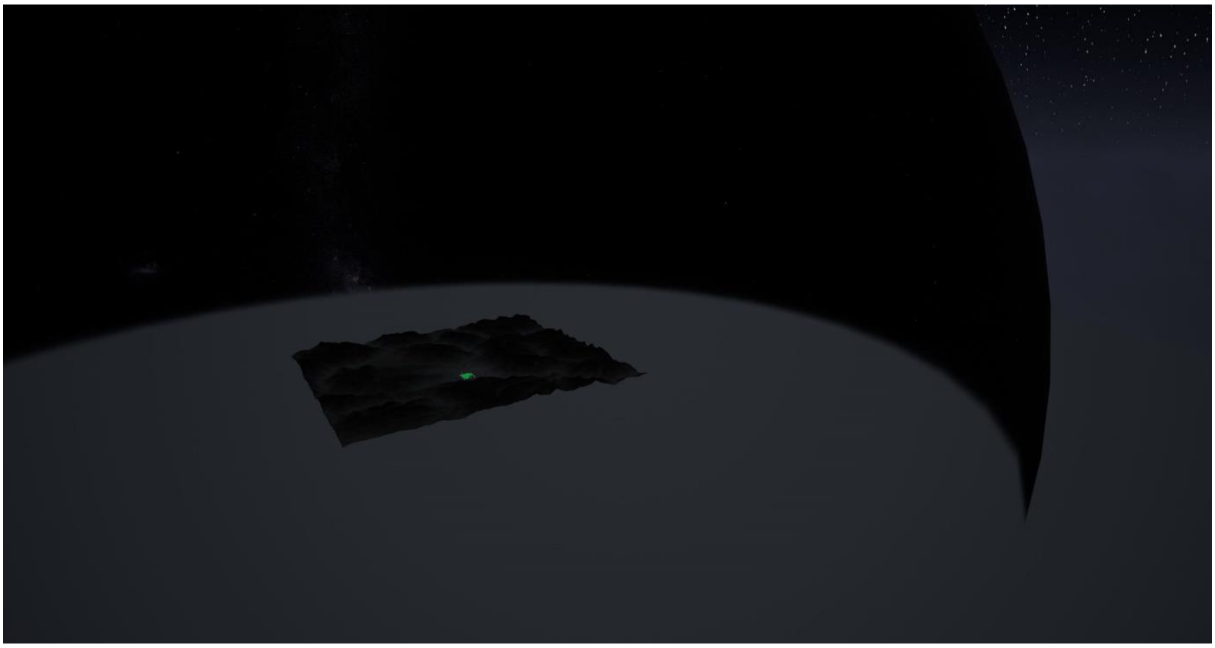


Figure 19: The green dot in the middle is the park with its city. The sphere outside is the custom sky sphere I created because I didn't want to use the default sky Unreal Engine provides.

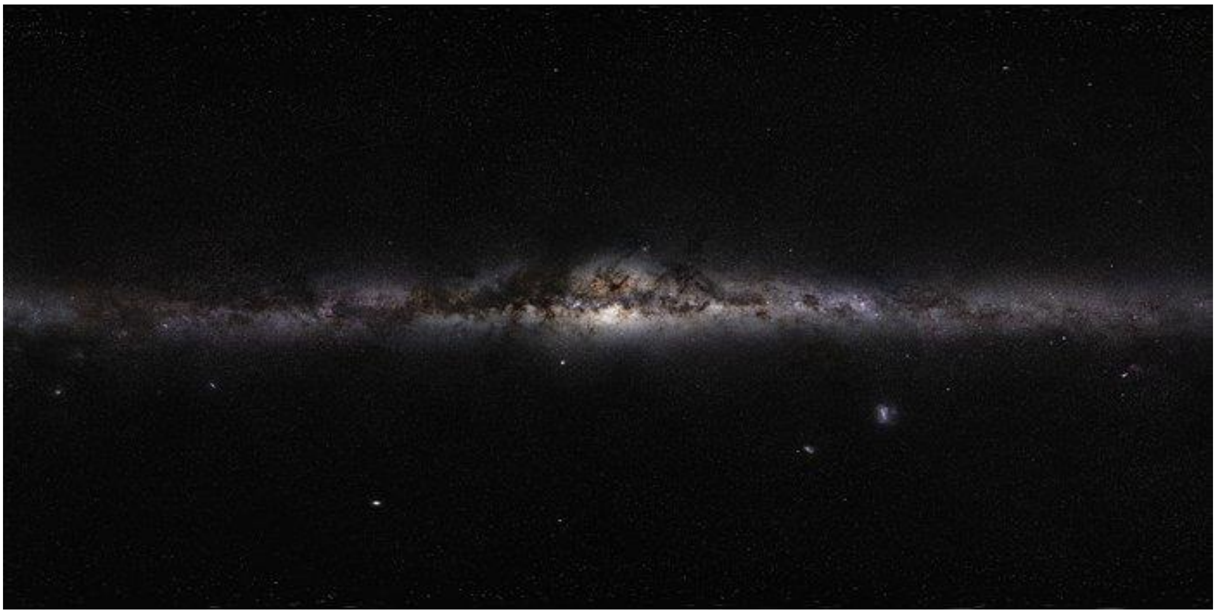


Figure 20: Picture from the Milky way galaxy which I used as a skybox (European Southern Observatory, 2009).

The picture I used as a skybox was made by ESO (European Southern Observatory, 2009). As this image was created by a large modern high-tech telescope the image quality is stunningly beautiful. Unfortunately, and this may sound counterintuitive, but the high quality of the image made it unrealistic at the same time because humans on the ground would never see the sky or the milky way this clear. To counter that, I purposely had to darken and blur the image to make it look more realistic. For this, I used photoshop as well.

Figure 21: Bird perspective of the whole city with the park in the middle. The surroundings lack details as everything uses performance and those parts outside of the park wouldn't be visible from inside the park.

The whole city is set in a valley surrounded by mountains. As the park is right in the middle of the city, I used low polygon assets for far away objects to save GPU performance. The trees outside the city aren't really trees in a geometrical sense. They are billboards which are two-dimensional images placed on a vertex (Harrison, 2003). This two-dimensional simplification also allowed me to save performance. Since those trees are far away, they are not recognizable as 2D objects and the darkness of the scenery also helps. I'd like to reiterate that there was no scenario which showed the park in daylight. The picture in Figure 21 was made to show the whole extension of the city and it was easier for me to work with daylight conditions. However, switching between day and night is not as trivial as one might think because in close distance on the ground some shadows would look unnatural if the light wouldn't specifically match the scenery. During the creation of the landscape, realistic shadows was not important for me, therefore I sometimes placed several directional lights, which would all act as suns. The advantage is that there are fewer dark spots because there were less shadows in the scenery. Obviously, this would make no sense in a final level since our solar system only has one sun.

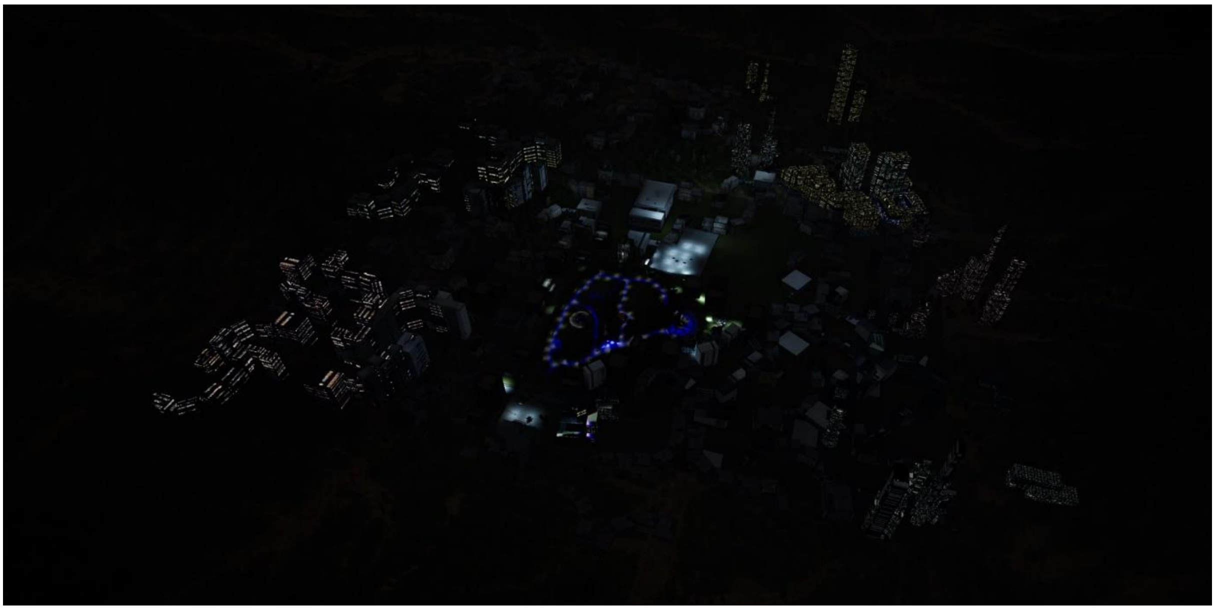


Figure 22: Same perspective as the figure above but during night-time. Some areas lack light because they wouldn't be visible from the park and light costs computer performance as well.

Whenever I placed a group of objects, I had to switch to nighttime to see how it would look like in the final version. I had several issues where objects looked very good under daylight conditions but were barely visible in the night. The solution was to carefully place every single light.

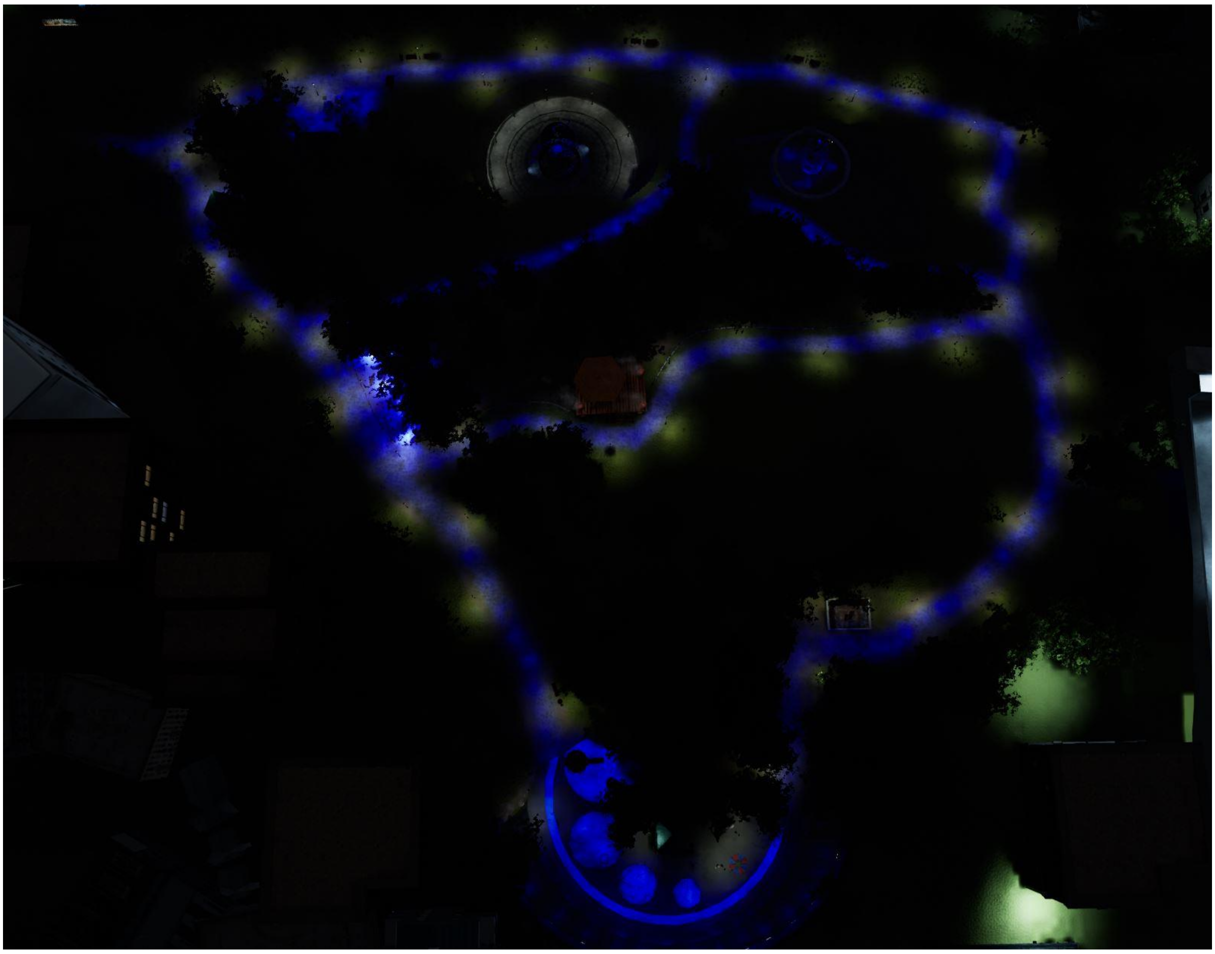


Figure 23: Bird perspective of the final park. Especially visible the additional roads and lights.

As mentioned previously the park was meant as a circle where participants would start at the entrance, walk the outside route and then return to the entrance. However, I felt like the park would feel empty like this and there would need to be objects in between to make it look more realistic. That’s why I built some connection roads inside the park. They are shortcuts between points of interests like the illuminated garden (Checkpoint 1), the lake and the little hut in the middle of the park.

Since the beginning of the project, it was clear for me that I wanted to provide sight protection between certain areas of the park. To some extend this is provided by the topography but it was also important to place some trees between the areas. The reason for the sight protection was the element of surprise. I didn’t want participants to see all checkpoints and points of interests to be seen right at the entrance. I think I managed to do that in a reasonable manner as too many sight protections could lead to an unnatural labyrinth-like look.

3.3.4. Attention to Detail

For me it was always clear that I wanted to make the scenario as realistic as possible. The reason of this experiment has always been to elaborate how humans would react to this kind of environment in a real-life situation. To get as close as possible to a real-life situation, the attention to detail in my scenario would play a key role to make it believable.

Figure 24: I also placed some fireflies near the entrance of the park. They were subtle, just like in real-life, but some people were still able to spot them.

At first I though about adding some animals to the park. I had assets for wolves, crows and some others. Later I decided to remove them again as I didn't want to risk scaring people, which would alter the experiment. Furthermore, most of those animals were not typical nocturnal creatures and therefore it didn't make a lot of sense to include them. However, I did include one species of insects, namely fireflies. Their addition is really subtle and I don't think they scared anyone. It's possible that some participants didn't even see them but those that did, said they would like it.

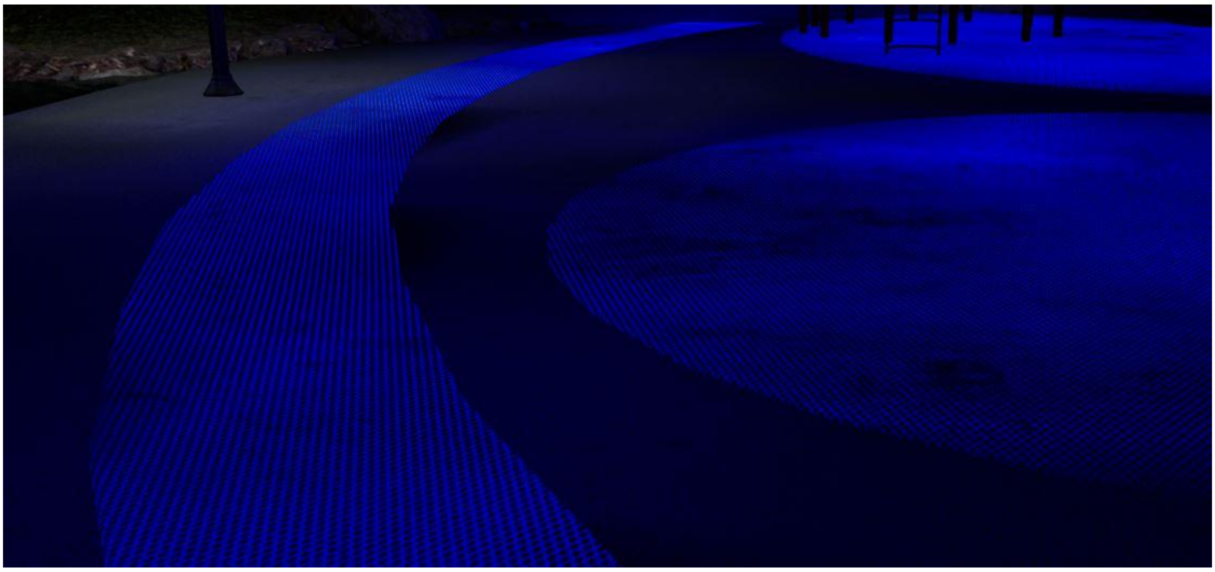


Figure 25: Playgrounds are usually not cleaned every day, therefore they often have dirt on the ground.

To simulate dirt, I placed some decals on the ground. These decals are exactly as the name suggests. They are placed on objects to make them look a certain way. I placed several decals in the whole park and they are not just dirt decals. Others are cracks in the asphalt or damage to buildings. They simulate worn out walls or roads who got cracks due to their age or the weather. I thought it would look more real if the road and the buildings have some signs of aging.

Figure 26: I tried to make the transition between road and lawn as smooth as possible.

In my earlier works the transition between multiple landscape textures were too harsh and they looked unnatural. For this scenario I tried to make a smooth transition that looked more realistic.

3.3.5. Checkpoints

Since the scenario is about experiencing the environment, I didn't want the participants to just move around the park until they were at the entrance again. Therefore, I implemented four checkpoints where the walking would go slower, and the camera would move to certain areas in order to show them to the participant. It was meant as some sort of sightseeing.

Figure 27: This is the entrance of the park in the blue scenario.

Figure 28: The park entrance in the white scenario.

Apart from the lighting conditions the levels are exactly the same. I wanted the entrance of the park to feel like visitors have a choice in where they want to go. In the scenario itself, participants don't have a choice on where to go, since the whole process is automated. However, in a real-life situation park-visitors would have a choice and in order to make the park believable it should feel like they have a choice.

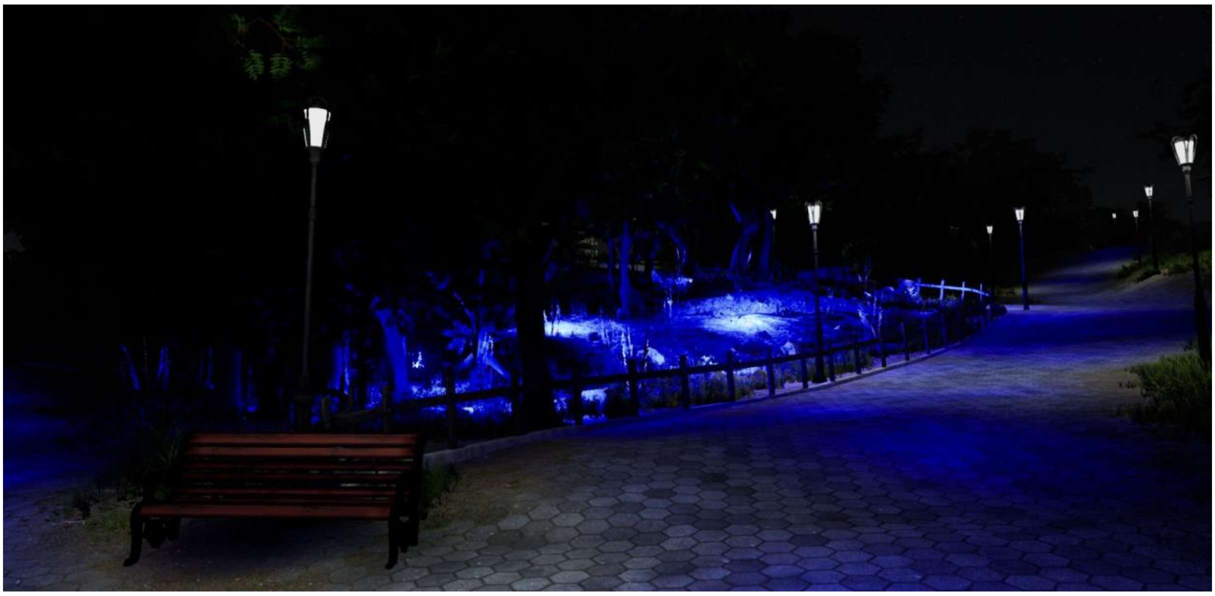


Figure 29: The first checkpoint is a part of the wood, which is illuminated on the ground.

The first checkpoint was inspired by Descanso Gardens which is a botanical garden in southern California. It features a wide range of different plants including fruit plants but also many different trees. It is operated by a nonprofit organization and is funded by memberships, gifts and the county of Los Angeles (Descanso Gardens, 2021).

Figure 30: Descanso Gardens in California (Kolb, 2016).

I chose Descanso Gardens as an inspiration because they have an area where they illuminate the trees exactly the way I originally intended to (Descanso Gardens, 2021).

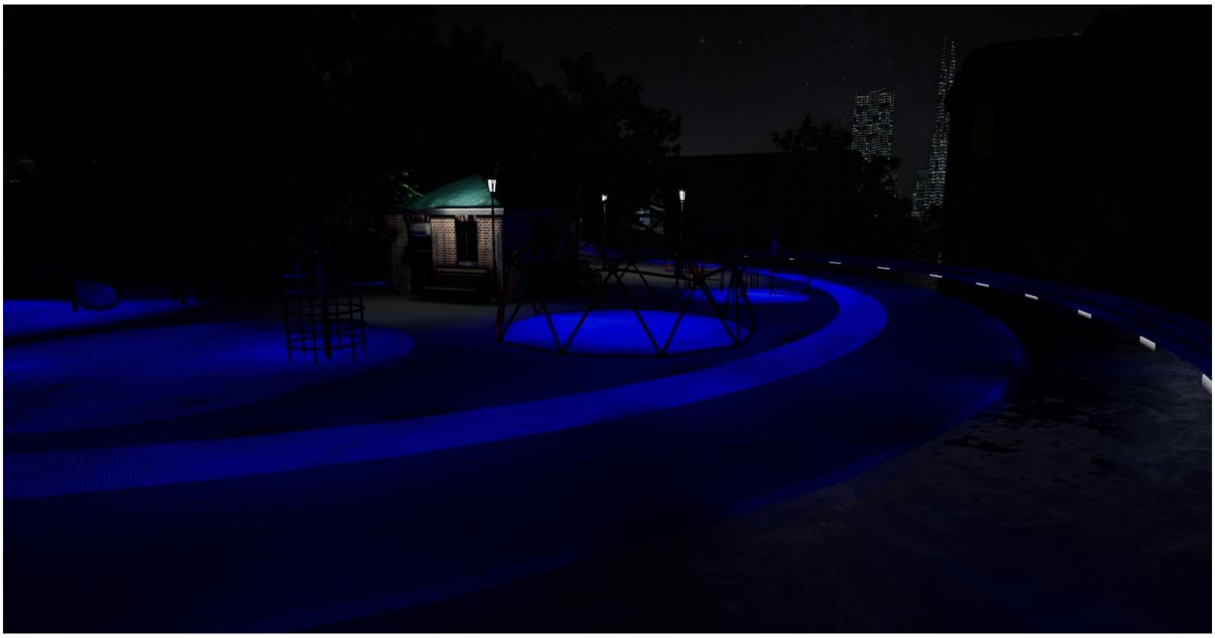


Figure 31: The second checkpoint is a playground on a plateau with a stunning view over the city's skyline.

Contrary to the rest of the park where the road emits blue light, I decided to do it a little bit different on the playground plateau. The playground plateau has an asphalt floor as well but there is also a net on the ground. I though, it would look better if I make the net glow instead of the asphalt.

Figure 32: The third checkpoint is an illuminated fountain inside a small lake.

The fountain inside the middle of the small lake was my first checkpoint idea. The moving water is generated due to a particle effect. Particle effects are similar to special effects for video games. These particles are generated with the help of a particle emitter, then they move their way and disappear at the end of their way. Essentially they have a life cycle which includes “produce”, “activity” and “death” (Zhang & Hu, 2017).

Figure 33: The fourth and last checkpoint is a small restaurant at the end of the park near the entrance.

In an earlier version of the park, I had some crows on the ground and on the tables. However, crows are not active during the nighttime and apart from being there they didn't add any value to the scenario, that's why I deleted them again.

3.3.6. Lighting Conditions inside the Park

The differences between the blue and the white are very small from a technical point of view. The idea was to keep everything exactly the same except for the illumination. The white scenario only had streetlamps with a pure white light. For the light colors I used the RGB scale as it allowed me to get pure colors. For the white light I used an RGB value of 255, 255, 255 and for the blue light on the ground I used 0, 0, 255 which is a pure blue. I wanted to have "pure" colors as the saturation level in colored light could also play a role in a participant's emotional state (Rajae-Joordens & Hanique, 2012). The intensity of the streetlamps was the same in both levels. There were differences in illumination due to the environment. While the blue accent lighting on the ground in combination with the streetlamps would make the scenery more illuminated compared to the streetlamps alone, the situation was inversed at the checkpoints because in the white scenario the checkpoints were illuminated with white light and therefore brighter. It did this because of two reasons: First I wanted to make it look realistic and I had the example from Poland in my mind. Second, I wanted to compensate the difference in brightness between the white and the blue light because people feel already uneasy during nighttime and I didn't want the pure brightness of the illumination to be a deciding factor for people's decision.

3.3.7. Limitations

While the graphics look good it is still a 2D video and cannot compete with a Virtual Reality scenario, let alone a real-life experience. If I knew from the start that the scenario would have been shown as a 2D video instead of a VR environment, which was originally planned, I would have built the park slightly different because in a 2D video I could use a lot more graphical resources and more demanding effects like raytracing. Nevertheless, even in a VR experiment there are limits. For example, there is no smell in a computer-generated scenario. While I could have implemented sound to make it more realistic, I decided against it because I could distract participants. Depending on the sound some people could get scared. As an example: A fitting sound for this park would be the sound of crickets. However, some participants might have an insect phobia which could lead to a biased experiment.

Another limiting factor was the video itself and its file size. The video would need to run smoothly even on computers with a bad internet connection. To achieve that, I was limited by file size and couldn't make the videos with the amount of quality I wanted to.

3.4. iMotions

iMotions is a platform that aims to analyze human behaviors. There are multiple tools available such as: Eye Tracking, EDA/GSR, EEG, ECG and Facial Expression Analysis (iMotions, 2021).

3.4.1. Technical Aspect

The algorithm of iMotions facial recognition software works by detecting several facial movements. These movements are given a value to calculate the amount of movement in order to interpret these values.

Brow Furrow	Brow Raise	Cheek Raise	Chin Raise	Dimpler	Eye Closure	Eye Widen
5.57E-05	6.08E-07	6.49E-12	0.08028196	0.00771463	8.10E-10	47.0921936
1.98E-05	2.30E-07	2.07E-12	0.03982691	0.00433094	6.09E-10	35.491806
8.08E-06	1.20E-07	7.78E-13	0.03764477	0.00393177	4.74E-10	30.100174
5.93E-06	8.43E-08	8.22E-13	0.02835236	0.00315217	1.91E-10	16.5243168
7.66E-06	8.14E-08	1.04E-12	0.02267995	0.00234035	1.61E-10	12.5105953

Table 1: Some of the movements that iMotions detects to interpret emotions.

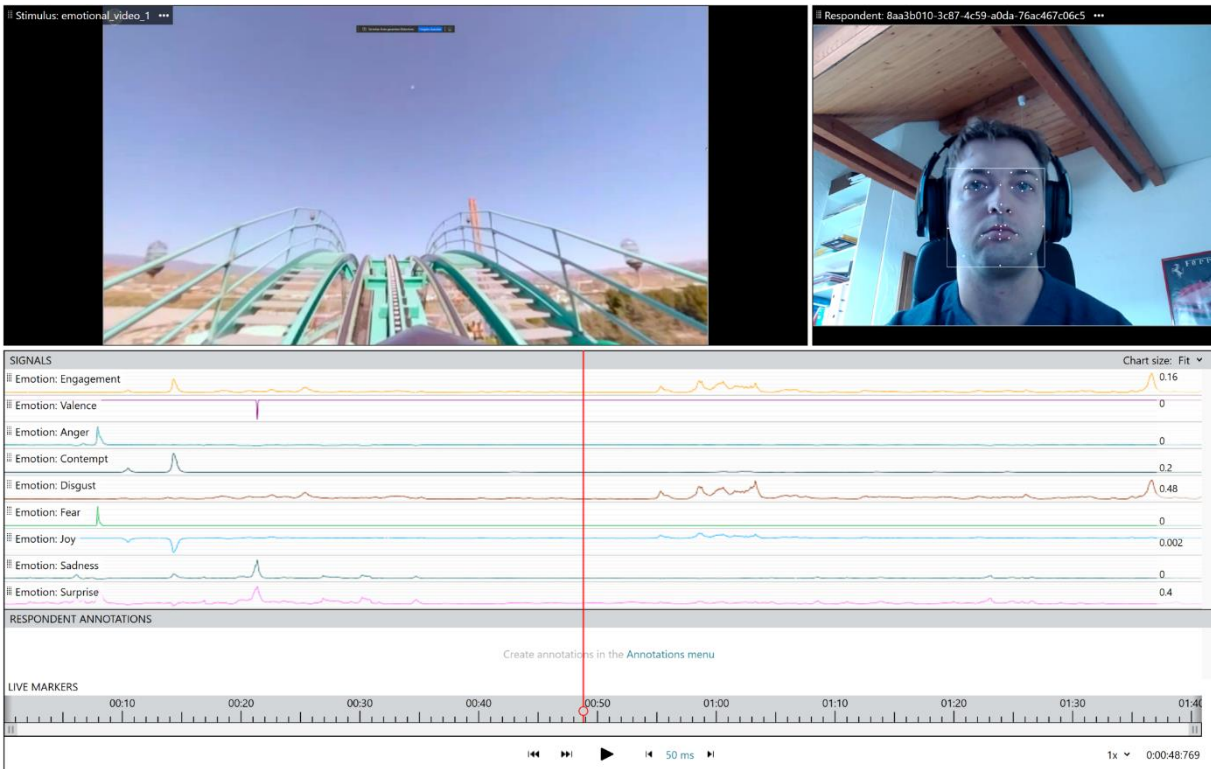


Figure 34: iMotions Affectiva baseline video. The rollercoaster was used to excite participants in order to calculate an emotional baseline for everyone. This scene was at the start of the video right before the coaster goes downhill for the first time.

Facial recognitions are recorded in a timeline. This makes it possible to see the exact facial values at any given time. In the top left of figure 34 we see the video and in the top right we see the facial expression the participants make at that specific time. The mask on the participants face has dots which works as reference points for the software. In the lower half of the picture, we see several graphs. These graphs signal the emotions that are calculated from values shown in table 1. There are seven emotion: Anger, contempt, disgust, fear, joy, sadness and surprise. The upper two graphs are valence and engagement. For this thesis I use the term engagement as just another expression for arousal or intensity, as depending on the software they have different names.

The situation in Figure 32 is interesting because in the video we can see that the roller coaster car is about to hit the peak of the track right before it goes downhill. The participants face on the right-hand side looks bored as climbing the track on a rollercoaster is not very exciting. When we look at the lower panels, we see the red line, which signals the current point on the timeline. If we look at the top graph, which is engagement, we see that a little bit further down the timeline, the engagement starts to increase and then flattens again. This is when the roller coaster car goes downhill. From this example we can learn that the technology works and that the video does have an impact on the person watching the video.

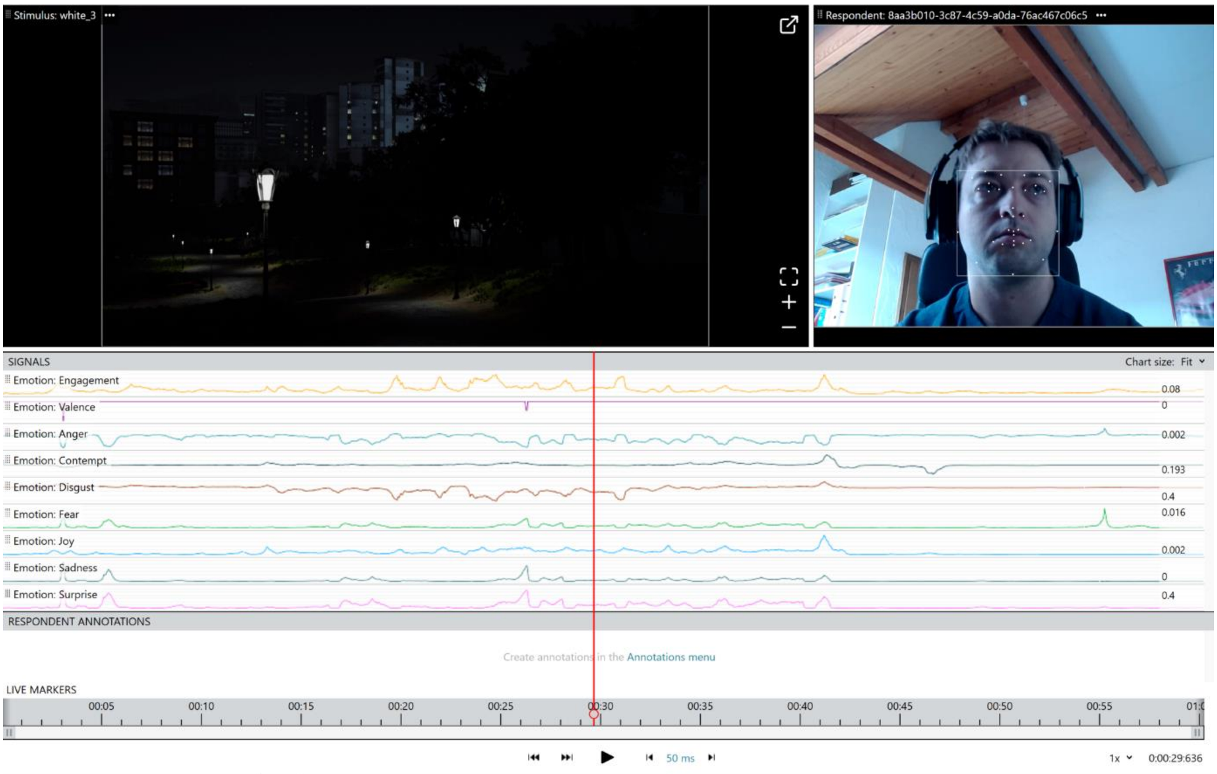


Figure 35: Creator's face during the white scenario 29 seconds in the third video.

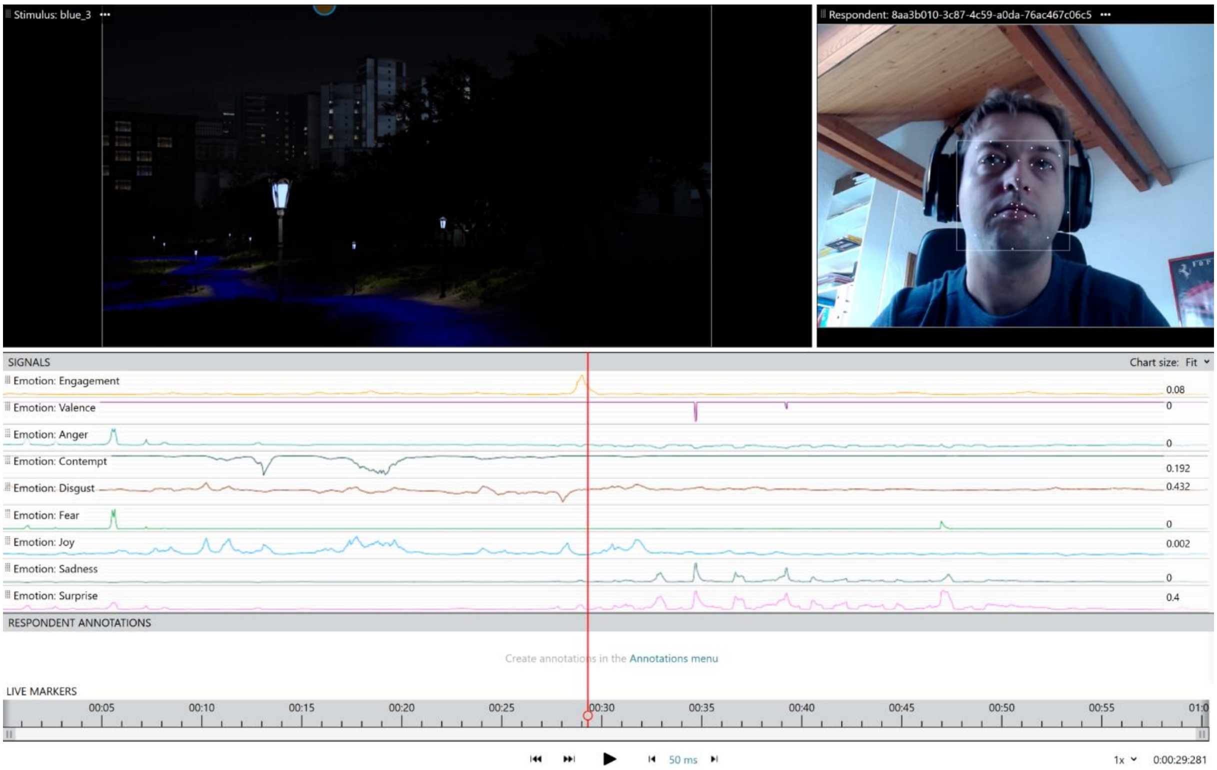


Figure 36: Creator's face during the blue scenario 29 seconds in the third video.

Figures 35 and 36 show the same spot on the timeline in the white and the blue scenario. We can already see on the graphs that there is a difference in engagement between the two situations even though it's the same location, just a different lighting scenario. To be fair, this situation is not relevant and was not used in the results as this was just a test run from me and since I'm the creator of the scenario, my emotions are obviously biased.

Row	Timestamp	Source-Stimu-liName	Event-Source	Samp-leNum-ber	Contempt	Engagement
1	0	intro_1				
2	2	intro_1	1	0	0.19218781590461731	0.081290058791637421
3	33	intro_1	1	1	0.19232660531997681	0.082538649439811707
4	65	intro_1	1	2	0.19223491847515106	0.080994881689548492
5	98	intro_1	1	3	0.19228562712669373	0.082204520702362061
6	130	intro_1	1	4	0.19224885106086731	0.080668412148952484
7	161	intro_1	1	5	0.19228148460388184	0.080789722502231598
8	193	intro_1	1	6	0.19226813316345215	0.080594919621944427
9	225	intro_1	1	7	0.19228450953960419	0.080487169325351715
10	257	intro_1	1	8	0.19230291247367859	0.08054640144109726
11	289	intro_1	1	9	0.19231216609477997	0.080524876713752747
12	321	intro_1	1	10	0.1922772079706192	0.080378144979476929
13	353	intro_1	1	11	0.19228735566139221	0.080313026905059814
14	401	intro_1	1	12	0.19228415191173553	0.080439358949661255
15	433	intro_1	1	13	0.19229514896869659	0.080311916768550873
16	465	intro_1	1	14	0.19231051206588745	0.080273017287254333
17	497	intro_1	1	15	0.1923123300075531	0.080350309610366821

Table 2: Part of a log file that iMotions gives to analyze the data. The log files are much bigger, this is just a tiny part.

To analyze the data iMotions gives detailed log files in *.csv format. In my case the log files have a file size of about 20 MB per participant. Their information includes all tracked emotions, valence, engagement, detailed facial movements, and very important timestamps in milliseconds. The timestamps were essential for me because iMotions doesn't have a questionnaire tool in its current version. This is why I had to use www.onlineumfrage.com to ask specific questions. The timestamps helped me to match participants with specific questions that were answered. Unfortunately, that only worked for a few participants as some people were doing the experiment at the exact same time which made it impossible to distinguish those answers.

Figure 37: Screenshot from Biopac's Acqknowledge software (Version 4.3 www.biopac.com, accessed 27.10.2021) showing arousal and valence of one participant.

To process the facial expression data, I used Biopac’s Acqknowledge software from www.biopac.com. Emotional arousal is directly related to the excitement, which in iMotions is called engagement, that participant express during their virtual walk in the park in either the blue or white scenario. Raw data of participants' facial expressions were exported from iMotions, and then imported and processed in Biopac. I first divided the signal into five temporal segments corresponding to the five videos (rollercoaster video, video 1 to video 4). For arousal, I calculated the area under the curve (Figner & Murphy, 2011) in other words I used the integral between the first and the last point of each segment, and after that I normalized it by the trial duration of those segments as the trial duration is not equal across the four videos (the measurement unit of arousal is then µS/s). Lastly, the arousal values for all participants have been normalized again.

For valence I used the mean value of each segment and then I normalized the data according to the formula below.

The purpose of the rollercoaster video was to get everyone excited. From this excitement every participant was given a value which I then called “emotional-baseline”. From this baseline every reaction was a derivative. This means they are relative values when we compare participants. The calculation works as follows:

-for Video 1: [Arousal(baseline) - Arousal(Video1)] / Arousal(baseline)
-for Video 2: [Arousal(baseline) - Arousal(Video2)] / Arousal(baseline)
And this went on for all remaining videos, which then resulted in a baseline correction of all participants. The baseline correction allowed me to compare participants to each other.

3.4.2. Limitations

The software is only as good as the camera that records the data. Sometimes the facial expression is very subtle and in case the lighting and the camera are also bad, the data might be inaccurate. Furthermore, it requires participants to always look directly into the camera for the eye tracking to work. Fortunately, there is a warning if people get distracted too much and look away.

3.5. Experiment Setup

To design an experiment, I have to consider which variables I want in order to assess our results. Results alone are meaningless if I don't have a clear vision on what I am trying to find. According to David W. Martin there are two major variables: Independent and dependent variables (Martin, 2008). The independent variable is what the experiment creator, is changing in order to find what he or she is looking for. In my case the independent variable is the lighting condition. The range of the independent variable is also important as it defines the possibilities of outcomes (Martin, 2008). Too many possibilities are hard to measure and generally require more participants. For my experiment the range was simply either blue lighting or white lighting. Originally, I wanted to use more colors than just blue. As my first attempts of level building in Unity shows, I wanted to have green glowing trees as well (Figures 9 and 10). The downside of this would have been the assessment of the results. With multiple color changes in my scenarios, I couldn't know which color would make the difference. Therefore, I decided to take blue as the only color that would change between the scenarios. The reason for this was that according to a study blue and cyan maybe universally liked because blue skies and clean water are universally appealing to humans (Palmer & Schloss, 2010). However, I experimented with different colors in the early stages when I switched from Unity to Unreal Engine 4. These pictures can be seen in the appendix.
Dependent variables are the things we want to measure (Martin, 2008). In my case the dependent variables are mainly "Valence" and "Arousal/Intensity", since these variables determine if my research questions can be answered or not. Although "Valence" and "Arousal/Intensity"

appear as single dependent variables, one could also argue that they are composite dependent variables (Martin, 2008) because iMotions uses its own algorithm to calculate these variables out of several emotions which again are calculated out of facial muscle movement. However, if I'd only look at my own post-experiment-questionnaire they would rather appear as single dependent variables. Physiological measurements such as iMotions facial recognition technique are also called indirect measures as participants don't necessarily react consciously to the environment (Martin, 2008).

According to David W. Martin (2008) there are two ways to conduct an experiment with participants. The first one is an "in between subject" approach where two groups of people have a different experiment and then those two groups are compared to each other (Martin, 2008). In my case this would mean that there is a group doing a virtual walk through the park in the blue scenario and another group doing the walk in the white scenario. The advantage of this method is that those groups are totally independent of each other and therefore cannot be biased. The disadvantage is that it generally needs a certain number of people, because doing this is essentially splitting the participants into two independent groups. The other way of conduction an experiment is the "within subject" approach where every participant goes through all circumstances or in my case all videos, white and blue. Originally, I wanted to do a "within subject" approach because I feared that I wouldn't get enough people for a VR experiment if I tried a "between subject" approach. Maybe this could have been true but when I switched to a fully automated online-experiment I thought that I could get enough participants for a "between subject" approach. In retro perspective I think this was a good choice because if I had to send participants into eight videos instead of four, there was a good chance that they get bored. Furthermore, the experiment itself would have been longer for at least ten minutes, maybe even more because I would have needed to ask additional question like: *"How would you compare the two scenarios?"*

Deciding which scenario would be first was also a question because whatever choice I would make, people would be biased for the second scenario which would look very similar to the first one, and people would already know what to expect. However, there is another disadvantage to a "between subject" approach, which could have played a role in my experiment, but I assume it didn't. With 32 participants there is a small chance for add pairings. As an example, the blue and the white scenario were assigned randomly but in theory there is a slight possibility that a majority of the blue group just doesn't like the color blue and therefore they would feel worse when compared to the white group. Obviously, the opposite could also be true. In a “within subject” approach this could not happen as everyone gets to see all the videos (Martin, 2008).

Three of the four videos were exactly one minute long, and the fourth video was one minute and forty seconds long. Originally, I wanted to make all four videos the same length, but this led to the last video feeling odd and rushed because the walking speed was too high compared to the other videos. Furthermore, there was also an illuminated statue at the end of the fourth video and I wanted participants to have enough time to take a look at it. Whenever people see something the body needs a little bit of time to emotionally react to the environment. In a study on emotional responses to map aesthetics, participants were given ten seconds to look at a specific map (Fabrikant et al., 2012). According to that, I chose to give participants at least the same amount of time for every major object in the scenario I wanted them to see.

The experiment was split into several parts which were also hosted on different servers. Every participant was provided a link. The link itself was the same for everyone because we wanted people to be able to give the link to their friends, hoping we could get more participants. As soon as they clicked the link, they were randomly assigned either the blue or the white scenario. The only difference between those scenarios were the four videos. From a technical point the scenario split happened right after someone clicked the link, but participants wouldn’t notice this because apart from the videos the experiments were identical, which is shown in the flowchart below.
After clicking the link, participants were met with an introduction to the experiment and a consent form they had to fill in if they were keen to participate. This was followed by a webcam calibration which was needed to record facial expressions. The calibration had two parts, first the participants head needed to be in the right position and his or her eyes would need to look directly at the screen. If these conditions were not met, the participant couldn’t continue the experiment. The second part were nine slides where the participant had to follow the white dot on the otherwise black screen. This was used to calibrate the eye-tracking system.

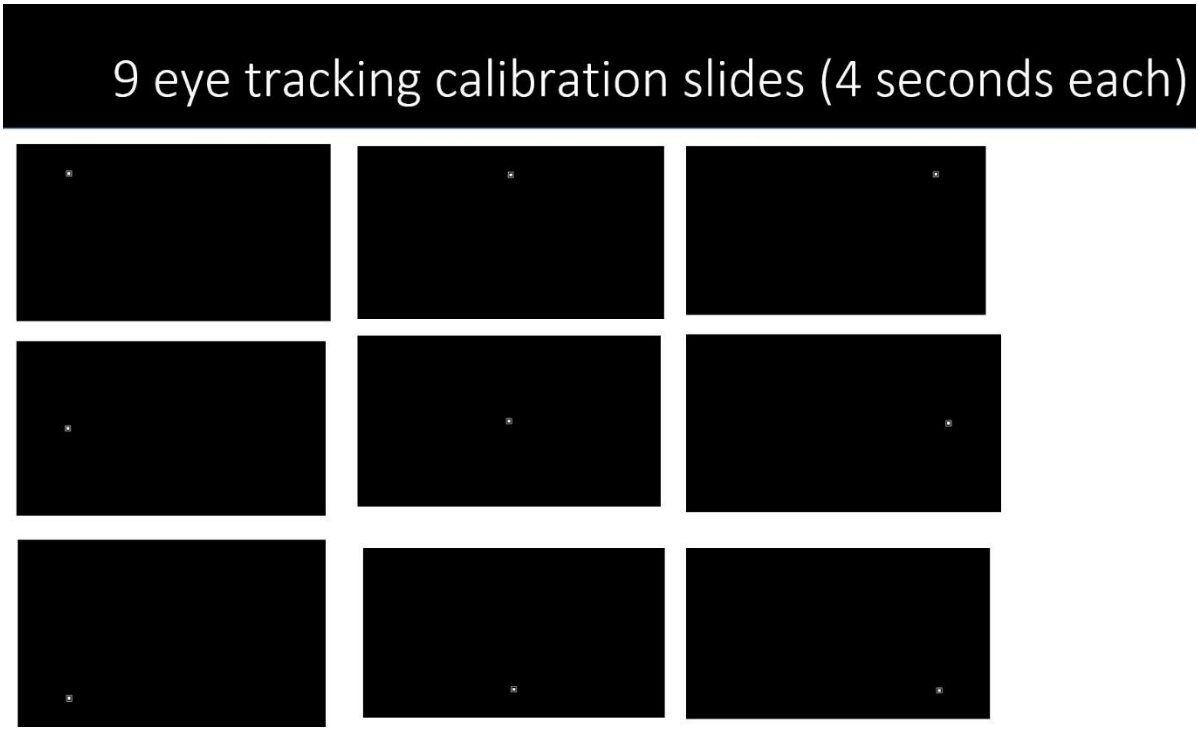


Figure 38: This is a compilation of nine slides that were used to calibrate the eye-tracker. These slides were played in succession of each other.

The next step was the introduction of my response wheel. I created my own response wheel where we took inspiration from Scherrer's Geneva Wheel of Emotions (2005) which was shown as figure 7 in this thesis. I had multiple reasons for the modifications I made. The first was simplification. If I had kept every emotion there was on the original Geneva wheel there would have been a good chance that 32 participants would have chosen a lot of different emotions. In a case like this, the evaluation at the end would have been hard to interpret because there were not enough participants to give an indication on which emotions were chosen preferably. Another reason for simplification was speed. My responsive wheel was made to give a quick answer after a short video where people had certain emotions as a response to the video. I wanted participants to answer in a fast way, when they still had that emotion. If I would have taken the original wheel (Scherer, 2005) instead there would have been a good chance that participants were searching the wheel for minutes just to find the exact emotion they would have wanted to choose. The third modification I though was necessary was the explicit intensity scale. In the original wheel (Scherer, 2005) the intensity was implied by the placement of the emotions. However, there was not an exact scale. Therefore, I equipped our wheel with a scale from 1 to 5 where people could click the emotion and intensity they felt. The button they clicked on would get a green cross to signal where they clicked in case they miss clicked and wanted to change it. In total participants could choose between 21 different choices per wheel, as the "no emotion" choice could also be made.

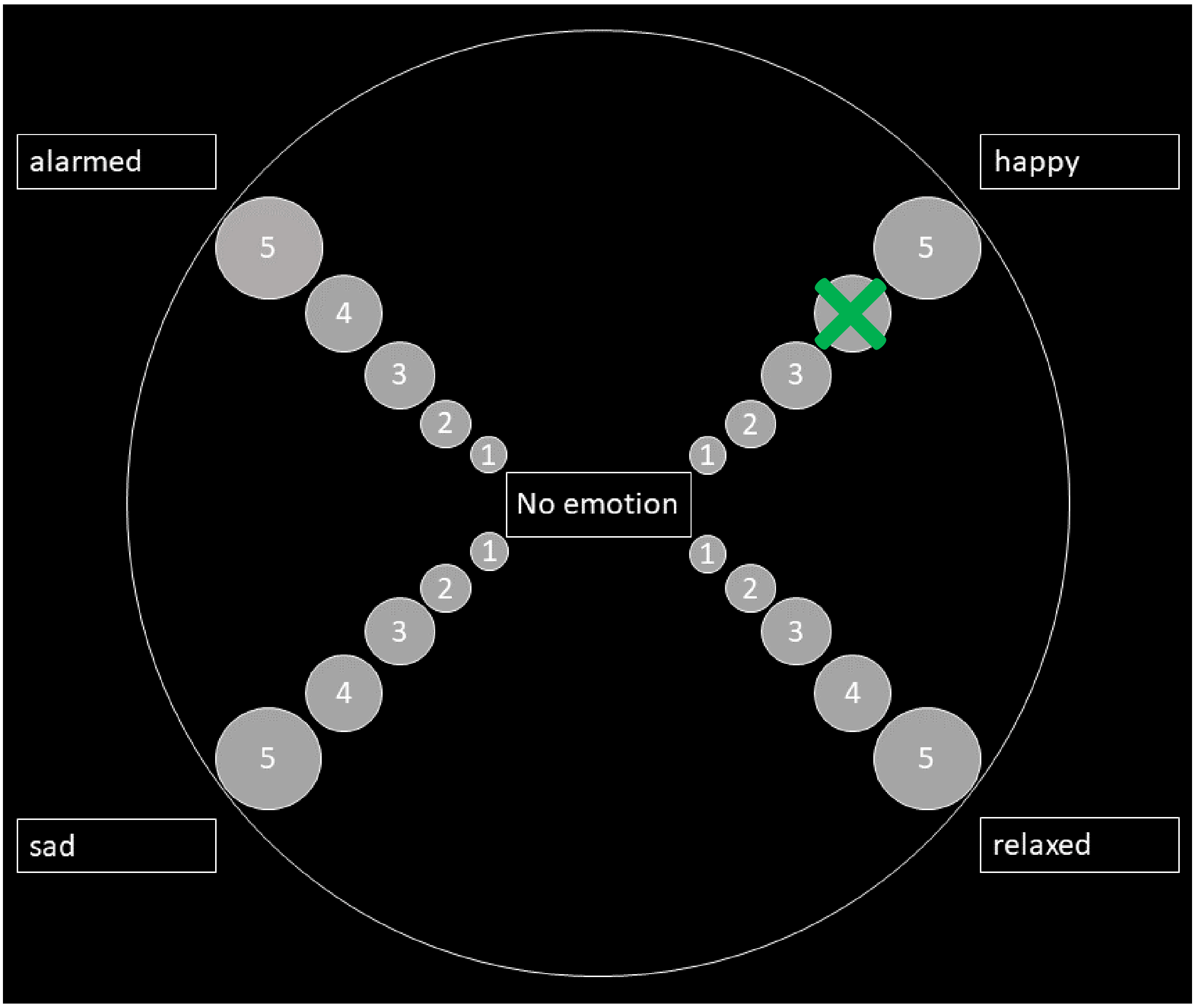


Figure 39: The response wheel as it was used in the experiment. It was inspired by Scherrer's Geneva wheel of emotions but features only four emotions. On the other hand, it also has five intensity levels per emotion.

Since my scenario simulates nighttime, I made the response wheel with a dark background and grey bubbles. The reason for this was to not disturb the viewer by changing the lighting conditions on the user's screen. There are five occasions where the response wheel appears, and they are either right before a video or right after. Depending on the size of the screen this could have been hard on participants' eyes and I feared it could have altered the results. Another reason for this decision had safety in mind as with a bit of input lag the screen could start flashing between white and dark which could trigger epilepsy in certain individuals. One out of 4000 humans suffer from photosensitive epilepsy and we wanted to prevent this (Harding & Harding, 2010). The next step in the experiment was the rollercoaster video. It was a 360° video provided by Discovery and sponsored by Gillette (Discovery, 2016). I chose the rollercoaster video because we wanted to excite participants before the park videos since the purpose of the park videos was to compare how much participants would calm down under different lighting circumstances.

Unfortunately, 360° videos have their downsides. One of them is the lack of support by many standard video players such as VLC or Windows Media Player. YouTube for example, has support for 360° videos which enables users to use their mouse in order to change the view.

Figure 40: Interactive wheel on YouTube which enables users to change their view during a 360° video (YouTube, n.d.).

If someone tries to watch a 360° video in a regular player, the image appears very weird because the video has image material from different angles at the same time. The player cannot properly process these angles because a standard camera would only record from one angle.

Figure 41: The beginning of the rollercoaster 360° video as seen in VLC media player. The image data is all over the place (Discovery, 2016).

For the testing of the experiment, it was fine to watch the video on YouTube, but this was never an option for the final experiment. There are too many distractions on YouTube, such as comments or advertisements which didn't matter for the experiment. The ability to freely change the viewpoint of the video wasn't necessary either for my purpose. I basically only had two choices, to change the video entirely or trying to cut it into a 2D movie. I decided to try the latter which I was able to achieve with the help of "Adobe Premiere" a video editing software. The downside of cutting the video was that I had to remove a lot of image data and the remaining video data was in a low resolution because I had to zoom in more than I wanted to. Otherwise, ugly edges would appear that look unnatural. Furthermore, some beta testers reported small lags during the video. This forced me to reduce the size, and therefore the video quality, even more. In the end I cut the video to about one and a half minutes. After the rollercoaster video the first response wheel was shown, and participants were asked to answer how they felt.

The next step was the beginning of the actual experiment which I started with a story to give the participant a little bit of context on why he or she would visit this park. The story was:

"Imagine you are visiting a city you have never been before. It is slowly getting dark outside. As the day has already been rather exciting you would like to relax a bit before getting back to the hotel. One of the locals tells you about a nice neighborhood park, just a few blocks down the road from your hotel. You decide to visit this place at the end of the day.

You will be virtually walking through this park. ***You do NOT need to move on your own****. Just enjoy your walk. Each video will have four stops with different views where we will ask you how you feel, using the response wheel you have seen earlier."*

Following the introduction story, the first video would play where participants would find themselves at the entrance of the park. As mentioned above, there was a 50 % percent chance of which park, the blue or the white one, a participant would get. After every video, which had a length between 1 and 2 minutes, participants were shown the response wheel again and asked about how they felt. Important to note is that at the end of every video participants would come to a checkpoint, shown in chapter 3.3.5. These checkpoints were meant as highlights of the respective videos, since I felt that just following the park road could bore participants. It also gave me a reason to alter the camera speed every now and then. Since the park needed to be believable it was necessary it had a realistic size, but a certain size would also require a certain travel speed. The implementation of checkpoints where the camera would slow down allowed me to get participants to look at the scenery at checkpoints while still going around the park in a reasonable speed.

The last part of the experiment was the post-test-questionnaire. They allowed the participants to give their own opinion about the experiment. It was a series of fifteen question. Some of them were simple tick questions, others required small answers in text form. These questions were hosted by www.onlineumfragen.com. The exact questions in detail are shown in the appendix.

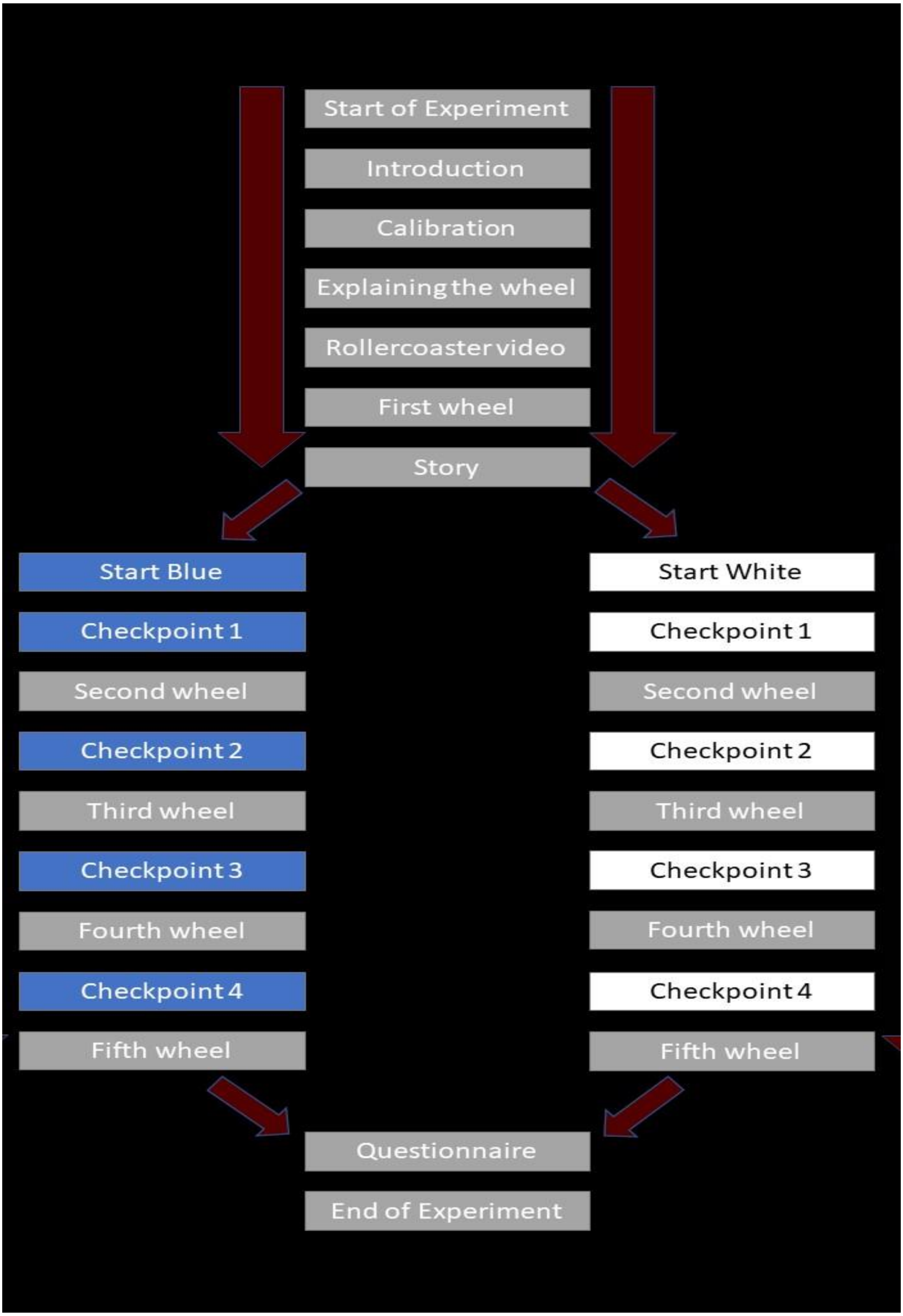


Figure 42: Flowchart showing the steps of our experiment. There is a random split before the videos as some users would experience the blue, others the white scenario. All images regarding the checkpoints are found in the appendix.

4. Results

The results are split into two different parts. The first part is the result of the facial recognition and eye tracking software called iMotions. These results are to a large part unconscious results. Although the participants are able to move their eyes and facial muscles at will, they don't really know how the software algorithm works. This means they might be able to alter the result, but they are not able to change the results at will. Furthermore, participants shouldn't have any motives to alter their results. The second part of the results are the answers from the questionnaires. These answers are conscious results where the participants are able to express themselves on how they felt during the experiment. The combination of unconscious and conscious results should give us a believable representation on how participants felt during the experiment. It should also show me if there is a difference between the two scenarios and if there is one, on how big that difference might be.

4.1. Results from Facial Recognition

Although iMotions detect several emotions such as anger, joy or sadness I focused only on arousal/intensity and valence as these two values are already some sort of summary containing several emotions. However, every person is different, and they start the experiment with a totally different emotional state depending on their current well-being or what they might have experienced just prior to the experiment. In order to get everyone to a similar level I started the experiment with a rollercoaster video, which was explained in the chapters 3.4 and 3.5.

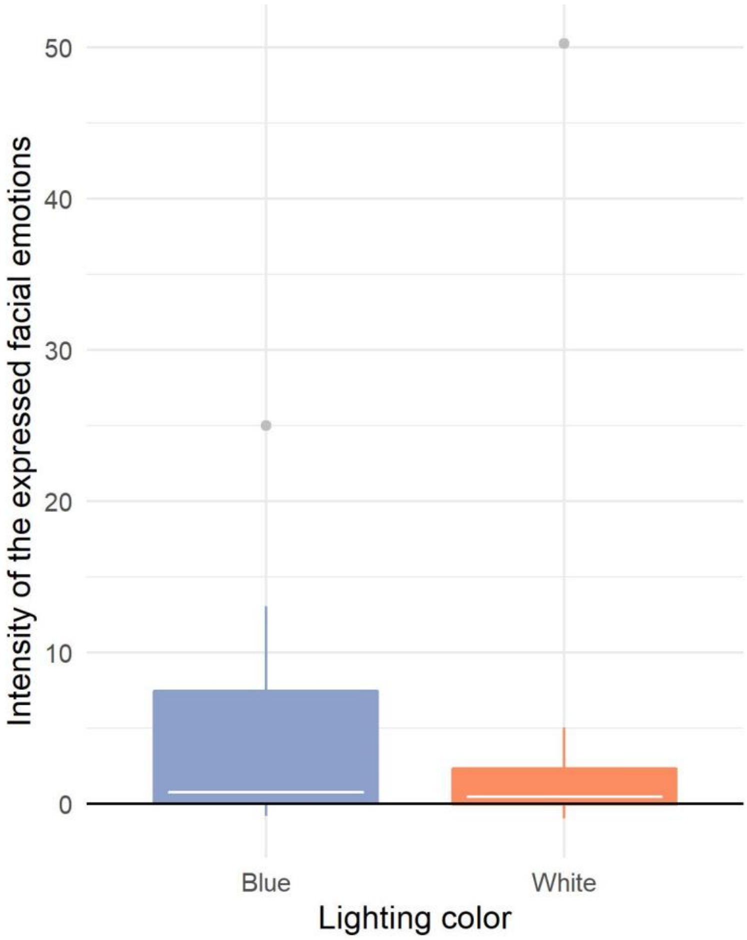


Figure 43: While there is a difference in arousal between the two scenarios (in micro-Siemens per second, μS/s), the difference is too small to be significant.

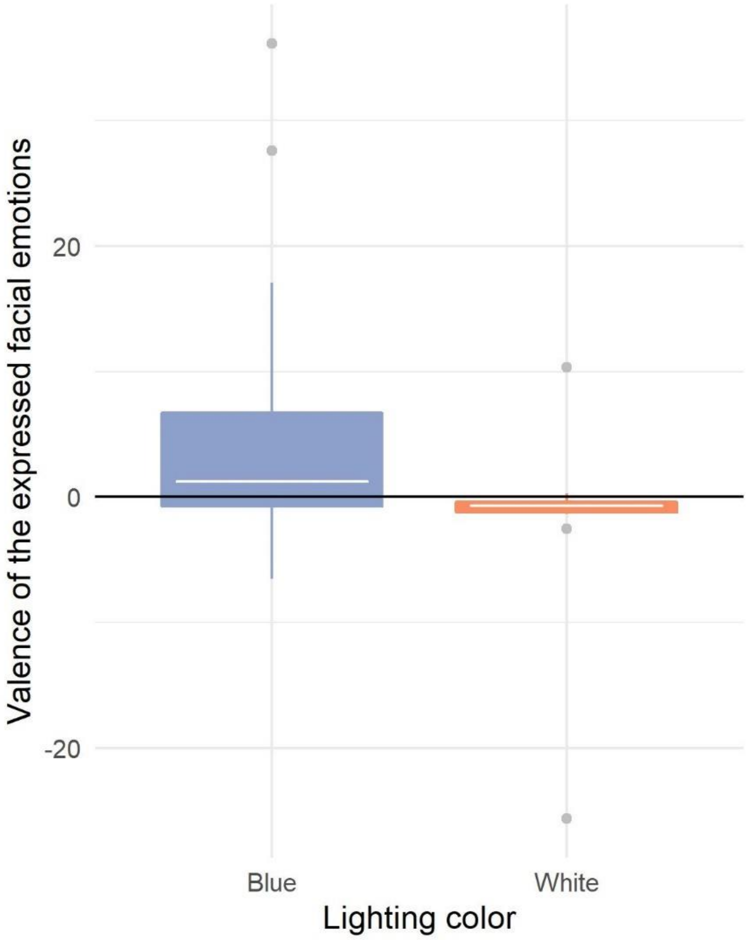


Figure 44: The averaged valence of the expressed facial emotion (in percentage, %) between the two lighting scenarios is large enough to be significant.

In order to measure the differences, I performed a multilevel linear regression model on the data to assess whether there was an influence of lighting color on participants' emotions, especially meaning arousal and valence of expressed facial emotions, while watching the four park-walk videos.

Results show that participants who viewed the videos with blue lighting showed a higher and more positive valence than those in the white condition (β = 2.10, ***p* = 0.045**, 95% CI = [0.17, 15.43]). In contrast, we found no significant difference between arousal values between the two lighting conditions (β = 0.38, *p* = 0.71, 95% CI = [-5.60, 8.13]).

4.2. Results from Self-Assessment

The results from the questionnaires are more subjective in nature. Sometimes people can’t accurately tell how they feel which makes is harder to interpret their emotions. Nevertheless, subjective information can still hold a lot of value as people are able to express themselves directly with words and not just numbers.

4.2.1. Results Arousal / Intensity

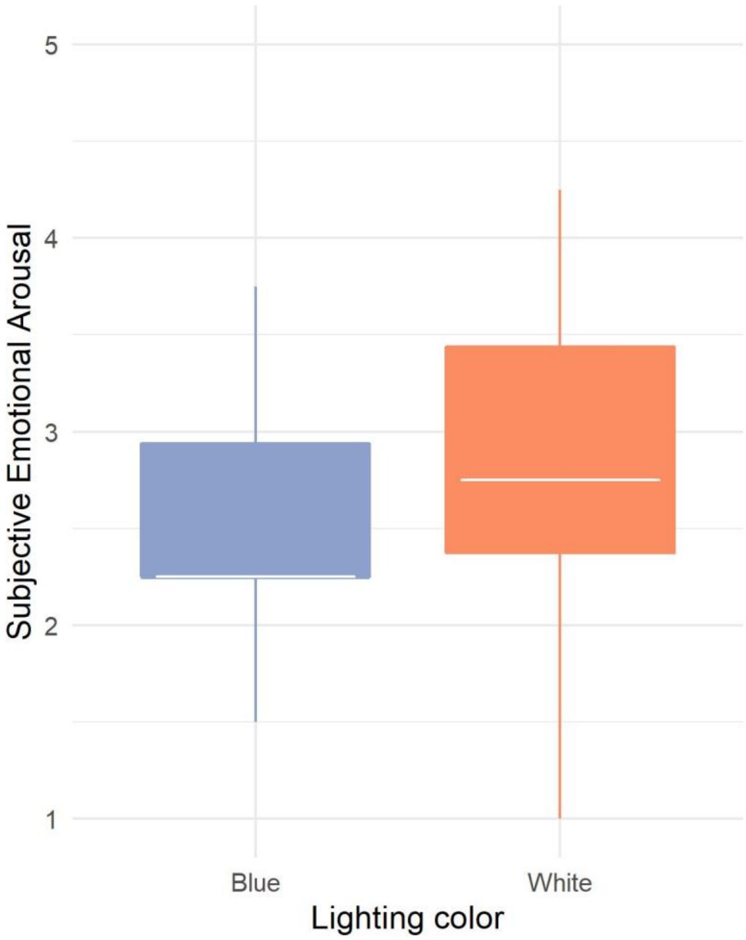


Figure 45: Subjective intensity/arousal mean level for both scenarios and during the whole experiment.

The figure above shows that the arousal level is higher on average in participants who had the white scenario in comparison with participants who had the blue scenario. However, we can also see that the range of intensity is wider within the white scenario.

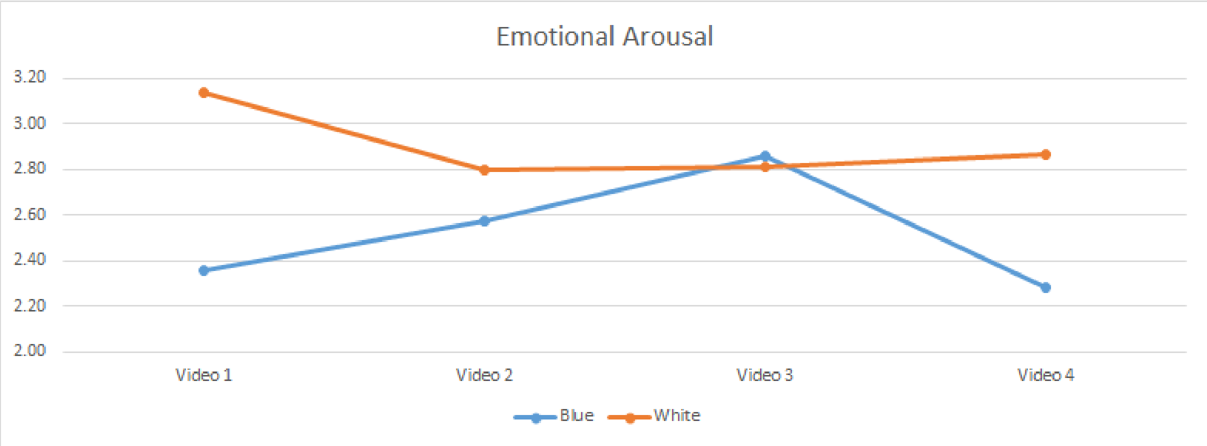


Figure 46: Subjective intensity/arousal participants had during the experiment, categorized per video.

When I look at the arousal per video, I can clearly see that participants who had the blue scenario almost constantly reported a lower intensity of emotions when compared to participants who had the white scenario. There is one small exception at video three where they are almost at the same point.

4.2.2. Results Valence

My response wheel, explained in chapter 3.5., gives participants the choice to choose from four different emotions: Alarmed, happy, sad and relaxed. There is also a fifth choice, which is completely neutral.

Valence	*Lighting color*	*Video 1*	*Video 2*	*Video 3*	*Video 4*
	Blue	36% relaxed and 64% alarmed	43% relaxed, 14% happy and 43% alarmed	71% relaxed, 7% neutral (no emotion) and 21% alarmed	71% relaxed, 7% happy, 7% neutral (no emotion) and 14% alarmed
	White	13% relaxed, 5% happy and 82% alarmed	20% relaxed, 5% neutral (no emotion), 5% sad and 70% alarmed	24% relaxed, 5% happy, 5% neutral (no emotion), 10% sad and 57% alarmed	41% relaxed, 5% neutral (no emotion) and 55% alarmed

Table 3: Subjective assessment of participants which shows the percentage of chosen emotions. Relaxed are highlighted blue, while alarmed are highlighted red as those are the two most important emotions.

Table 3 shows that the emotion "relaxed" was chosen more often by people who had the blue scenario when I compare them with the white scenario for each video. In a similar way the emotion "alarmed" showed up more in people's assessment who had the white scenario. Emotion "sad" never showed up for any blue video but twice for video 2 and 3 for the white scenario.

“Happy” was chosen by both white and blue participants but slightly more by blue scenario participants. Neutral was chosen almost equally rare by both participant groups. Based on the chosen emotions, both groups show an increase for “relaxed” while a decrease for “alarmed”, which means there seems to be a trend of positive emotions during the experiment.

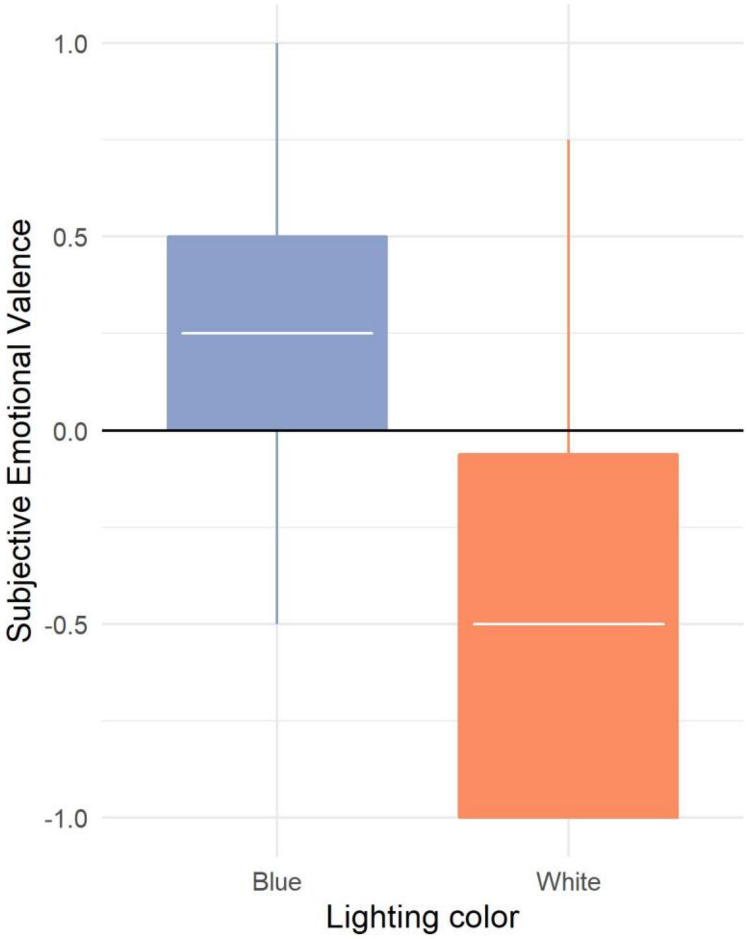


Figure 47: Mean subjective participant valence for both groups which shows a higher valence for the blue group on average.

I can categorize all four emotions into two groups. While relaxed and happy increase valence, sad and alarmed decrease valence. Neutral can be considered as 0. When I look at the mean values over all four videos, I can clearly see that the blue group has chosen significantly more emotions that increase valence when compared to the white group. For the blue group both upper and lower quartiles are above the mark 0, which would be neutral. The opposite is true for the white group where both quartiles are below the mark 0.

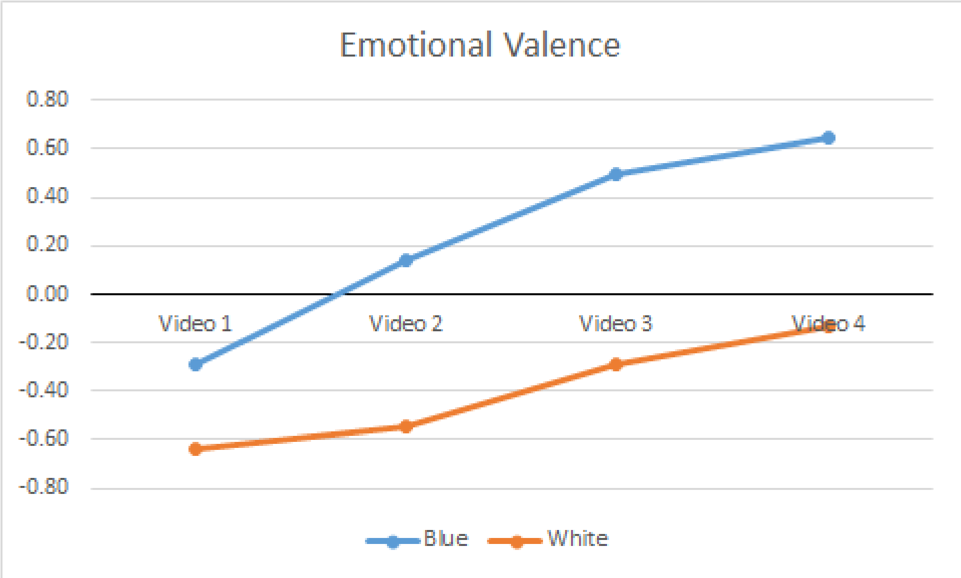


Figure 48: Subjective valence over time for both groups. Both groups have an increasing valence curve but the blue curve rises steeper. The units are shown in percent, which means 0.8 means 80 %.

What we can see in figure 48 is that the valence continues to rise over the course of all four videos. This is true for both scenarios but the difference between the white scenario and the blue one increases and is higher at the end of the fourth video. The valence for the blue group is only negative in the first video while the valence for the white group is negative in all four videos.

4.2.3. Results Post-Test-Questionnaire

After the videos, participants were able to answer multiple post-test-questions and give their own opinion in text-form if they chose to do so. The first question was:

How relaxing did you find this environment?

Answers were:

1. Very Relaxing
2. Somewhat relaxing
3. Neutral
4. Not much
5. Not at all relaxing

Answers showed that there is a significant difference between the blue and the white group when it came to answering this question. A Mann-Whitney-U-Test revealed that participants in the blue lighting condition (M=2.8, SD=1.27) found the park environment statistically significantly more relaxing than those in the white condition (M=3.7, SD=1.11; ***U* = 76, *p* = 0.045**)"

The one-sample Wilcoxon test, which compares both median values with the value 3 (neutral), shows that only the white group deviates significantly from value 3 (***t*(17) = 77.5, *p* = 0.021**), meaning that only the white group finds the scenario less relaxing then the average.

Further questions revealed that out of 32 participants 21 were female, while 11 were males. None of them claimed to have a color deficiency when asked. To preserve privacy participant were not directly asked about their age but rather in which group they belong. These groups were:

1. Under 20
2. Between 20 and 30
3. Between 31 and 40
4. Over 40

Three participants chose group 1 and another three participants chose group 3. The rest of the 26 participants chose group 2 which means that most participant are between 20 and 30 years old.

Participants were also given the chance to give their own remark about things they may have liked or not. Most stated that the setting itself made them a little scared as they would not want to walk around alone in a park during nighttime. This was especially true for the white group but also the blue group stated to have felt some fear. Some clearly said that the park itself would seem very nice and relaxing during daytime but the issue comes with darkness. When asked about revisiting the park almost all said they would only return during daytime.

Another question was if participants were satisfied with the color of the lights. Both groups answered almost equally close that they were satisfied with the color of their scenario. However, what needs to be kept in mind is that both groups haven't seen the other scenario, meaning the white group has never seen the blue illumination and vise-versa. Two participants answered they would like to have more yellow lighting and one person wished for purple and green lighting. Interesting is that nine out of fifteen participants in the blue group specifically made positive remarks about the blue illumination such as the blue light would make them feel more relaxed or calmed them down.

5. Discussion

To assess what my results mean and how I should interpret them we should take a look at our research questions and hypotheses again:

RQ1: *How does blue accent lighting affect human emotions? More specifically, does blue accent lighting have a greater calming effect on a human's emotions compared to typical white color lighting?*
RQ2: *How accurate is participants' subjective judgments of their current emotional state (i.e., conceptualized along two dimensions: valence and arousal) correlate with automated facial coding metrics?*

H1: *The addition of blue accent light will calm participants more than white light only.*
H2: *If blue light will calm participants more than white light, then this should be reflected in their self-assessment as well as through their facial expression.*

5.1. Answering the Research Questions

The results of my own experiment definitely indicate that participants who experienced the blue scenario seemed to be calmer when compared to those participants that experienced the white scenario. While the facial recognition techniques from iMotions couldn't detect a significant difference in emotional intensity, the difference in valence was significant. This already answers the second part of the first research question since the blue lighting condition did have a greater calming effect compared to the typical white lighting. To answer the first part of the first research question we can look at participants self-assessment, specifically which emotions they chose in the response wheel. In videos 1 to 3 the emotion "relaxed" was chosen over twice as much by the blue group when compared to the white group. In video four the difference was smaller but still thirty percent more in the blue group. At a similar rate the emotion alarmed was chosen more by the white group. I can therefore conclude that not only does it calm participants down more but the emotions they experience seem to be different for both groups as the blue group states to experience more positive emotions than the white group. Therefore, I was able to confirm my working Hypothesis.

The second research question revolved around participants being able to accurately assess their own emotions. As it has been stated before, some people have trouble expressing their own emotions or on other occasions might not be able to know what they feel. This was one of the main reasons why I split our experiment into a facial recognition test where unconscious expressions where detected and a self-assessment part with a post-test-questionnaire. The results indicate that for valence both conscious and unconscious tests show a more positive value in the blue group than the white group. As valence is an indicator for positive emotions (Price et al., 1951) we can argue that the participants were able to accurately tell what emotions they felt. Regarding the intensity of emotions however, there seems to be a contrast between facial recognition and participants self-assessment. While participants in the blue group reported a lower arousal then participants in the white group for three out of four videos, the facial recognition test showed a slightly higher arousal for the blue group in general. Nevertheless, the difference in arousal for the facial recognition test is so small that it is not significant, and the same thing could be argued is true for the self-assessment as well. This makes answering the second research question a little bit tricky as one part of the question is true. For valence we can say that the participants were able to tell how they felt but regarding their intensity of emotions they were wrong, even though the difference is very small. This means my hypothesis is not completely wrong but also only partially true, as I was not able to confirm if participants were able to accurately assess their intensity of emotions.

5.2. Comparing the Results with Literature

A majority of our participants stated that although they liked the park overall, they would only revisit that location during daytime. This makes sense as in real-life concerns about safety is one of the main reasons to avoid public places during nighttime (Nalla & Ceccato, 2020). This means emotions were likely already worse when compared to a daytime scenario. We know that women's fear of public places is stronger when compared to males (Valentine, 1990), however in this thesis the number of participants was too small to give any reasonable indication if women reacted stronger to the park as men did. Furthermore, the number of men and women wasn't equal in this experiment, since we had 21 women and 11 men. This ratio also doesn't allow us to give any indication about the lighting scenario, since men are said to react stronger to blue light compared to women (Cowan et al., 2000). Many participants of both genders stated that they would not go to the park during nighttime. This was true for both scenarios but the participants in the blue group reported less issues with the illumination. This finding agrees with a Danish study which indicates that road illumination is a key point of pedestrian safety (Jensen, 1999). We also know that not safety alone but also perceived safety is important for people being in public places (Costamagna et al., 2019).

Another interesting point is the study from Tegnérparken in Uppsala, Sweden where children stayed in the park longer after the new illumination was built and were even joined by their parents (Wang, 2018). Those findings came to the same result as I did, however it's important to note that the children still preferred playing during daytime when the sun was still there. This means that the colorful accent lighting cannot replace daylight but it seems to be a better option when compared to standard white-yellowish light which was installed at the park previously (Wang, 2018). In my experiment I didn't really touch the topic of light intensity as both scenarios had the same light intensity with just different colors. However, high intensity and focused lighting are more related to emotions the involve action, where low intensity and diffuse lighting are more related to emotions like fear or affection (Calvillo Cortés & Falcón Morales, 2016). This can be positive and negative.

5.3. Limitations

The experiment was meant to be conducted in a VR setting which I had hoped would bring even clearer results. Unfortunately, with the Covid situation it became clear that I would not be able to do a VR experiment because of restrictions and most likely lack of willing participants. At that time, spring and early summer 2021, many people were not even vaccinated and therefore it seemed difficult to find enough participants. This forced me to find an alternative to an on-site VR test, which I found in iMotions, with the help of my Supervisor and Professor. Even though the technology of iMotions is very interesting it also comes with downsides compared to an on-site VR experiment. Participants have a less immersive experience with an online test and the video on a computer screen are just not comparable with seeing these scenarios in a VR environment, for which they were originally built. Another limitation of online tests is the lack of interaction between the creator of the experiment and the participants. They might have had questions or weren't sure what to do on some occasions, there are many possibilities. Feedback like this also helps to improve for future experiments. On the bright side I have to admit that the online test was easier to run as soon as it was done. In a VR experiment there would always need to be a supervisor in the same room.

Speaking of the results there is always a change that statistics speak only half the truth. Experiments with low numbers of participants are especially prone to this. Qualitative analysis, which focuses on participants own remarks, can be very subjective and with only 32 participants there is no guarantee that they are representative for a larger group. This is especially true since most of my participants were between 20 and 30 years old.

6. Conclusion

This conclusion is split into two parts, a summary that reiterates key points from the discussion chapter and a short outlook what could be done in the future to help further research.

6.1. Summary

This thesis aimed at the question whether blue accent lighting could help in calming down people in public places. Furthermore, the thesis looked for evidence if people's own perceptive of emotions matched the measured emotions from facial coding metrics. The results indicated that people are able to recognize their emotions well, but they have trouble in assessing the intensity of emotions as the experiments showed differences between participants self-assessment and automated facial coding metrics. The findings do match with previous found literature, however it needs to be said that experiments such as this are hard to find if they have ever been done before. The only literature that was found, was about the effects of different lighting conditions in a general sense. Furthermore, previous research focused either on the color of light specifically, such as blue light or they focused on accent lighting in general.

6.2. Future Work

As this research is relatively new there are many things that could be done. The first thing I'd suggest is conducting an actual VR experiment in a similar way I wanted to do originally. There are too many limits of a 2D screen and an online test. Furthermore, there is a lot of data that was acquired during this thesis that wasn't used due to several reasons, such as time restrictions. This data could further enhance our perspective on the topic and give us a better understanding about the effects of accent lighting on human emotions.

Although it doesn't strictly belong to this topic it is still worth mentioning that similar applications like the glowing street paint to enhance road visibility as well as the research about bioluminescence, which could one day lead to a more sustainable illumination technique, are also fields of research that are worth pursuing. Similar experiments to mine, VR or 2D, could help in acquiring data.

Another interesting approach would be to conduct experiments on places that already exist, such as the blue road in Lidzbark Warmiński, however it is clear that traveling there and setting up a research station with high-tech equipment is very expensive. Assuming future work on this topic comes to similar results, the question arises where the implementation of real-world applications makes sense. As the example in Lidzbark Warmiński shows, the price of the blue road is twice as much as a regular asphalt road would cost. This would mean that only some roads could be converted to new blue glowing roads.

Figure References

Figure 1: Akraneskaupstaður. (2015). FJÁRHAGSÁÆTLUN AKRANESKAUPSTAÐAR ÁRIÐ 2016. https://www.akranes.is/is/frettir/fjarhagsaaetlun-akraneskaupstadar-arid-2016

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Figure 3: National Aeronautics and Space Administration. (2010a). *Anatomy of an Electromagnetic Wave | Science Mission Directorate*. NASA Science. https://science.nasa.gov/ems/02_anatomy

Figure 4: National Aeronautics and Space Administration. (2010b). *Visible Light | Science Mission Directorate*. NASA Science. https://science.nasa.gov/ems/09_visiblelight

Figure 5: Lindström, J., Grebner, W., Rigby, K., & Selander, E. (2017). Effects of predator lipids on dinoflagellate defence mechanisms - Increased bioluminescence capacity. *Scientific Reports*, *7*(1), 1–9. https://doi.org/10.1038/s41598-017-13293-4

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Figure 41: Discovery. (2016). *Mega Coaster: Get Ready for the Drop (360 Video) - YouTube*. https://www.youtube.com/watch?v=-xNN-bJQ4vI

All other figures and tables in this thesis are my own creations.

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Appendix

1. Consent Form
2. Response Wheel Introduction at the Start of the Experiment
3. Questions from Post-Test-Questionnaire
4. Entrance and Checkpoints Blue Scenario
5. Entrance and Checkpoints White Scenario
6. Early-Stage Pictures
7. Additional Images
8. Personal Declaration

Consent Form

Welcome!

You have been invited to participate in a study, which is described below. Please read all the information before continuing.

Thank you for participating in the **study on the effects of accent lighting on human emotions** carried out by Martin Lanz (martin.lanz@uzh.ch) for his Master's thesis at the Geography Department of the University of Zurich (UZH), in Zurich, Switzerland. The project is supervised by Prof. Dr. Sara Irina Fabrikant (+41 44 6355150, sara.fabrikant@geo.uzh.ch) and Dr. Sara Lanini-Maggi (+41 44 6355255, sara.maggi@geo.uzh.ch).

The study will be conducted entirely online. The online session will take about **35 minutes** of your uninterrupted time. This entails watching four videos and answering questions about them, followed by a background questionnaire.

We will record your face with your webcam throughout the session. **To get a clean recording we ask you to please keep your body and face as still as possible throughout the study.** The study does not involve any risks for you.

Your participation in the study is entirely voluntary. You may withdraw your consent to participate in the study at any time without providing notice or reason.

Inclusion and exclusion criteria: Any healthy adult may participate in the experiment. The exclusion criteria listed below ensure that our statements are derived from a healthy population who can comfortably complete the experiment.

- Inclusion criteria: Healthy adult.
- Exclusion criteria: Under any medication or drug that may influence the nervous system, such as anti-depressants, aspirin, painkillers, or Ritalin.

Obligations of the participant: You will be expected to carefully pay attention to the instructions.

Benefits to the participant: The study offers no direct benefit to the participant.

Risks to the participant: The study is carried out in an online environment and there is no physical or other effects to participants' health. However, **we suggest that participants choose a quiet environment and at least a 35 minutes time frame without any expectations to be interrupted or disturbed**.

Changes to information provided: Any changes in the study that may affect the safety of your participation or your privacy we shall inform you in writing.

Data confidentiality: The study involves recording your personal information. In accordance with the General Data Protection Regulation (GDPR, EU data protection law), all data are coded by replacing the names with a code and are made **anonymous**. Furthermore, **your name or video will never be used in any of our reports and publications**. All collected data will be kept encrypted and stored on secure media protected by a password only known to researchers listed above. The personal information provided here is stored for a period of 10 years due to a legal obligation. A local ethics committee may examine the information during this period. All of the information is stored in a locked laboratory space and on a highly secure server at the Department of Geography in the University of Zurich.

Costs: The entire study will not incur any direct costs to the volunteer.

Termination of participation: Your participation will be cancelled:

- If you are unable to understand or adhere to the instructions of the experimenters.
- If you choose to withdraw from our study. Should you wish to withdraw from the study, your records will be deleted.

Damages: This is a low risk study, and we are not insured for any damage that may occur to you during the experiment. However, if you wish to attribute any form of physical or mental annoyance to the study, please contact us immediately. We shall assist you the best we can and provide you with a clinical consultation if necessary.

Contact persons: If anything is unclear or worrisome, or in case of emergencies that may occur during or after the study, you may contact one of the following persons:

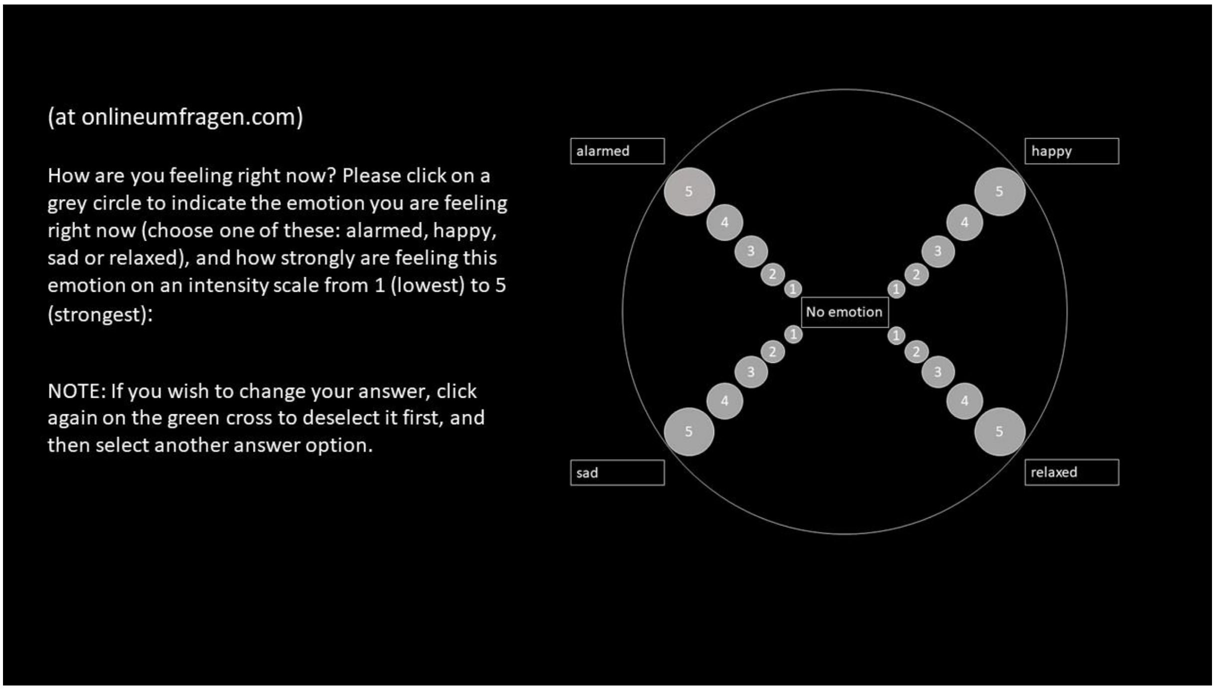
- Martin Lanz (martin.lanz@uzh.ch)
- Prof. Dr. Sara Irina Fabrikant (044 63 55150, sara@geo.uzh.ch)
- Dr. Sara Lanini-Maggi (044 63 55255, sara.maggi@geo.uzh.ch)

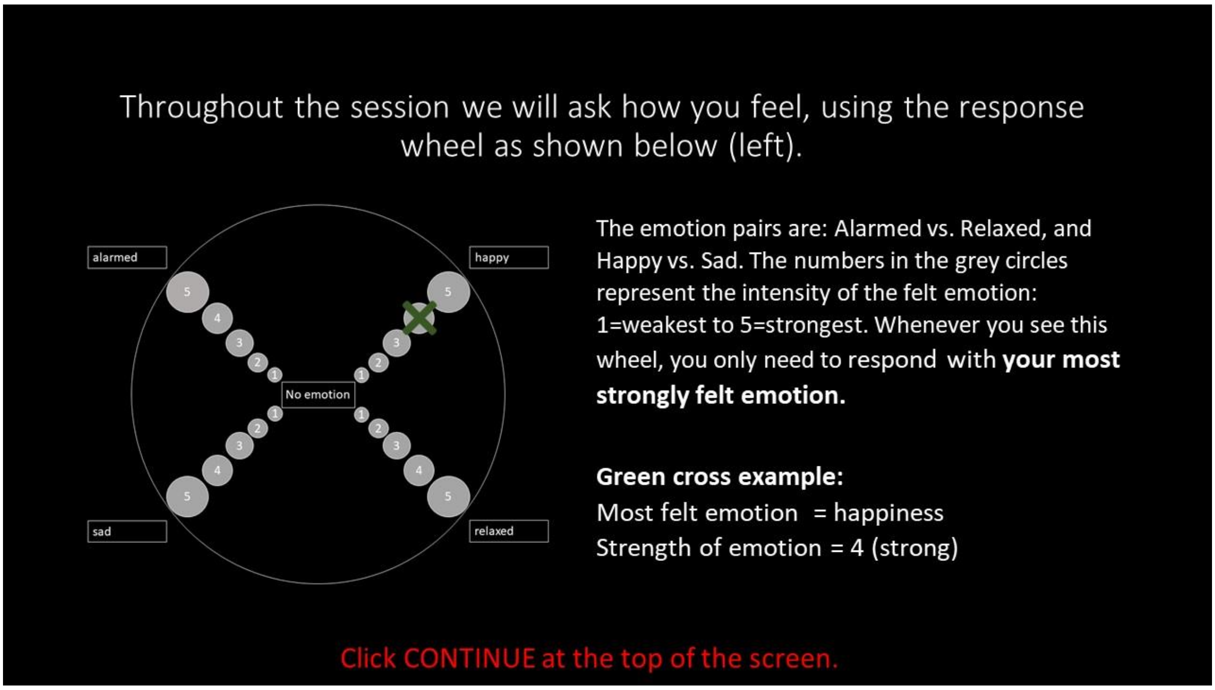
INFORMED CONSENT

1. I have been given enough time to read the information sheet on the experiment.
2. I understood the requirements of the experiment and agree to participate in the study.
3. My participation is voluntary and I have not been forced to participate in any way.
4. I understand that I can withdraw my consent to participate at any time during the study.
5. I understand that my data in their anonymized form will be used towards research only and may be publicly reported.
6. I understand that a local ethics committee may examine my personal details to check the activities of this research study.
7. I understand that under all circumstances my personal information shall be treated confidentially.
8. I understand that the study leaders in the interest of the study may cancel my participation at any time.
9. I understand that I must adhere to the instructions of the experimenter and fulfill the requirements outlined in the information sheet.

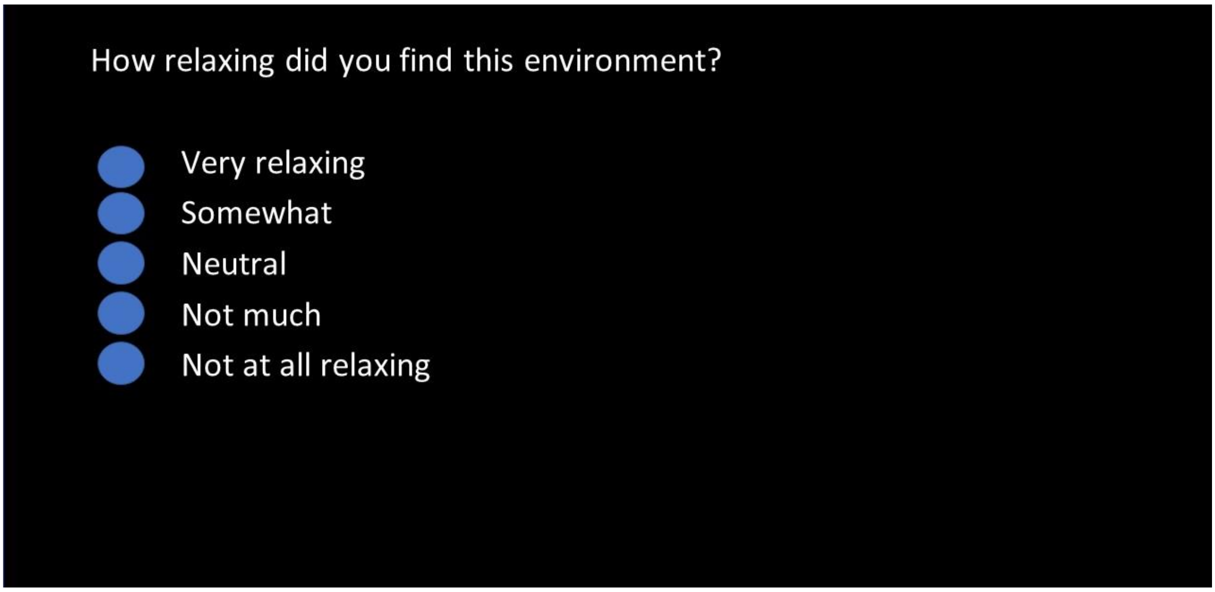
IMOTIONS

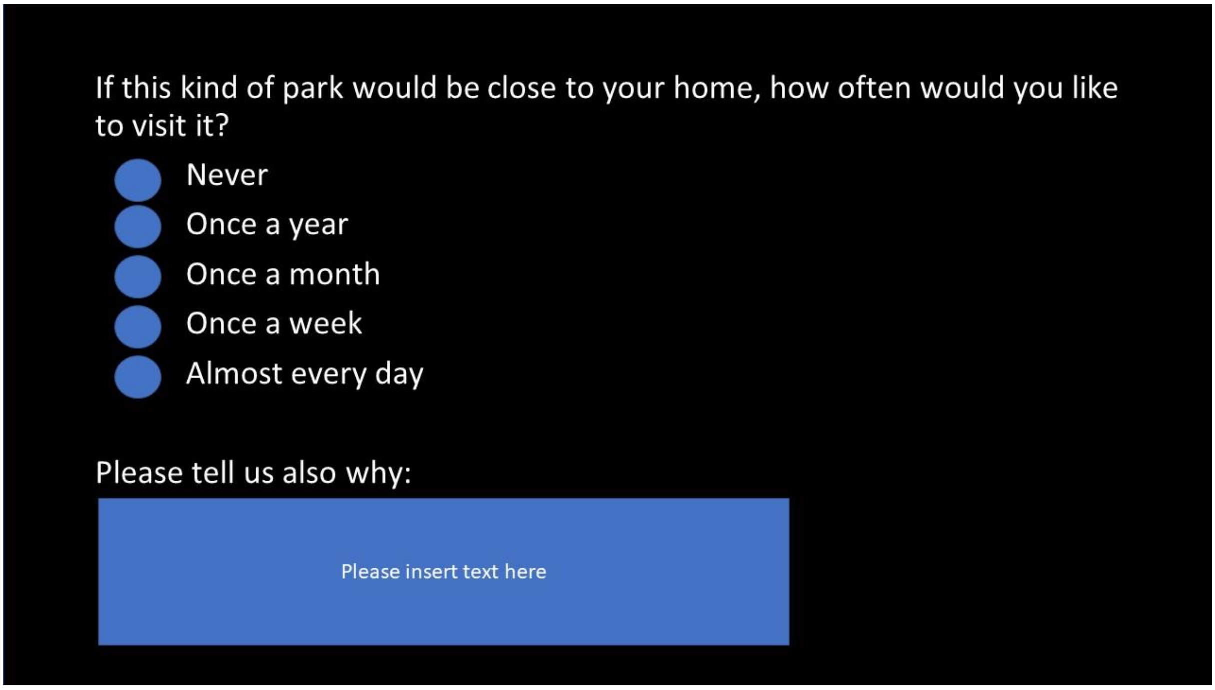
Response Wheel Introduction at the Start of the Experiment

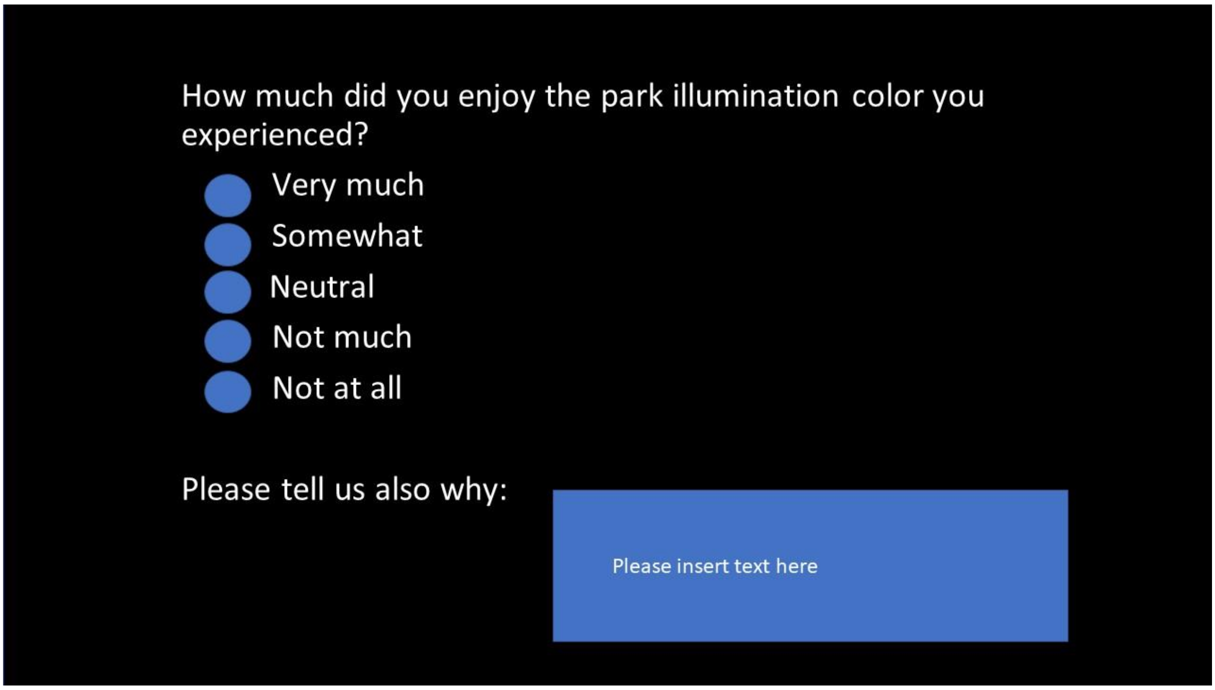


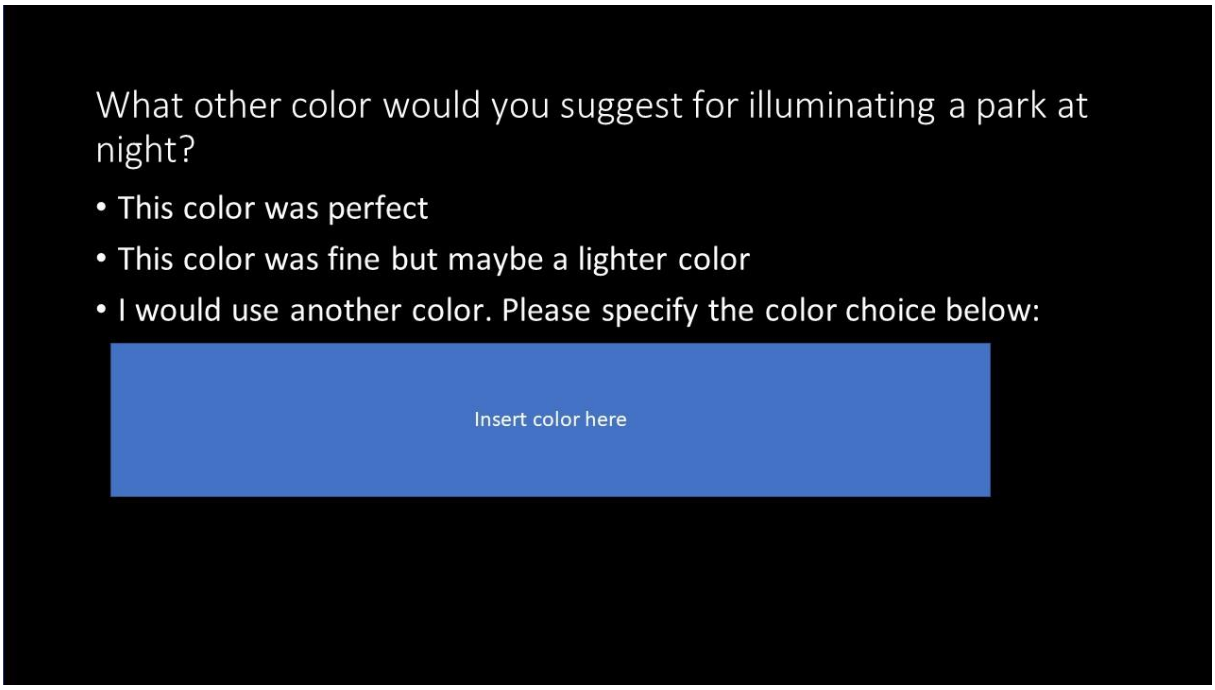


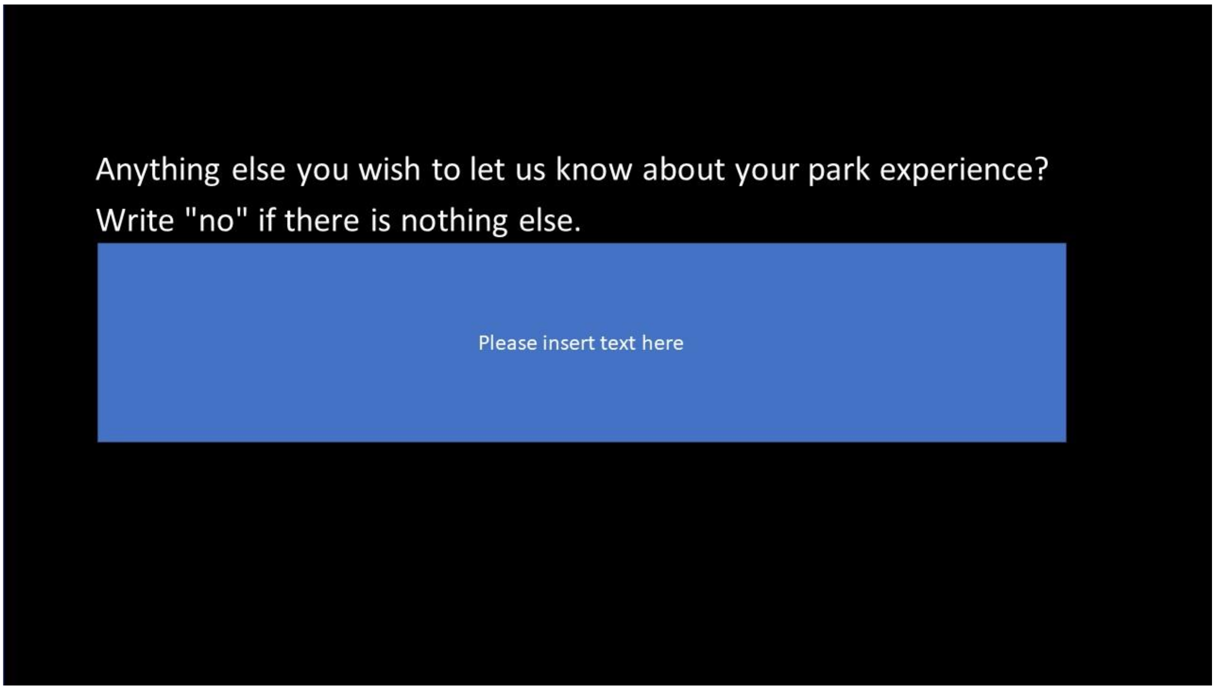
Questions from Post-Test-Questionnaire

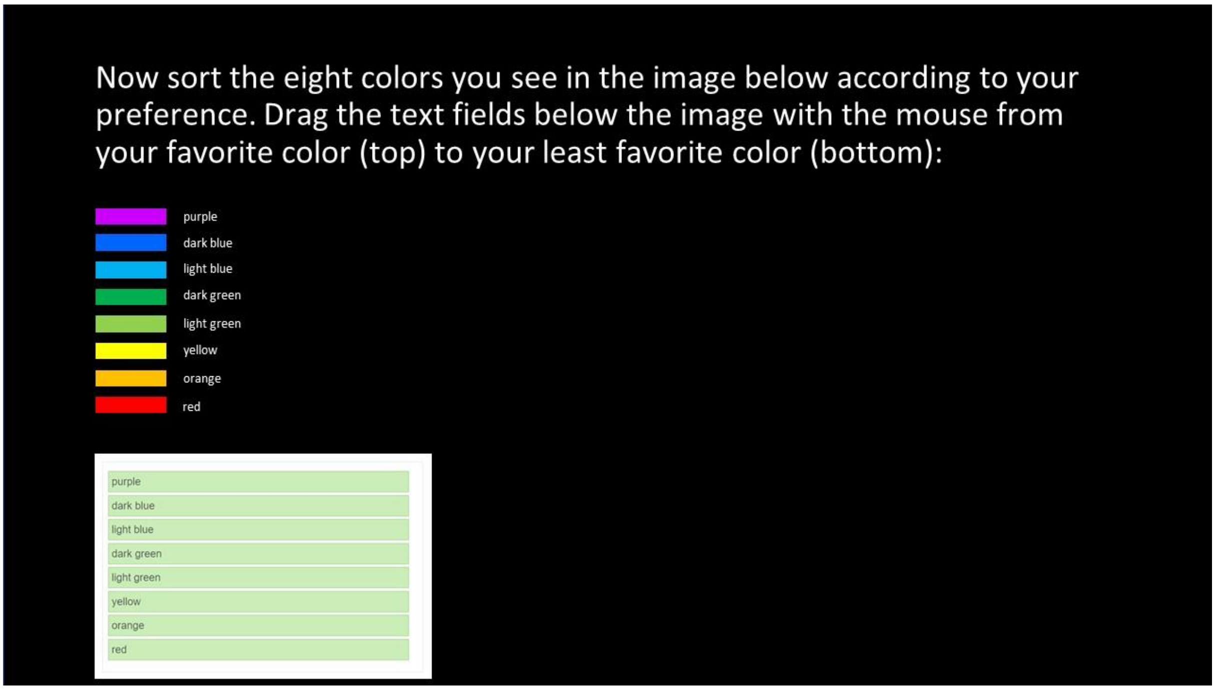


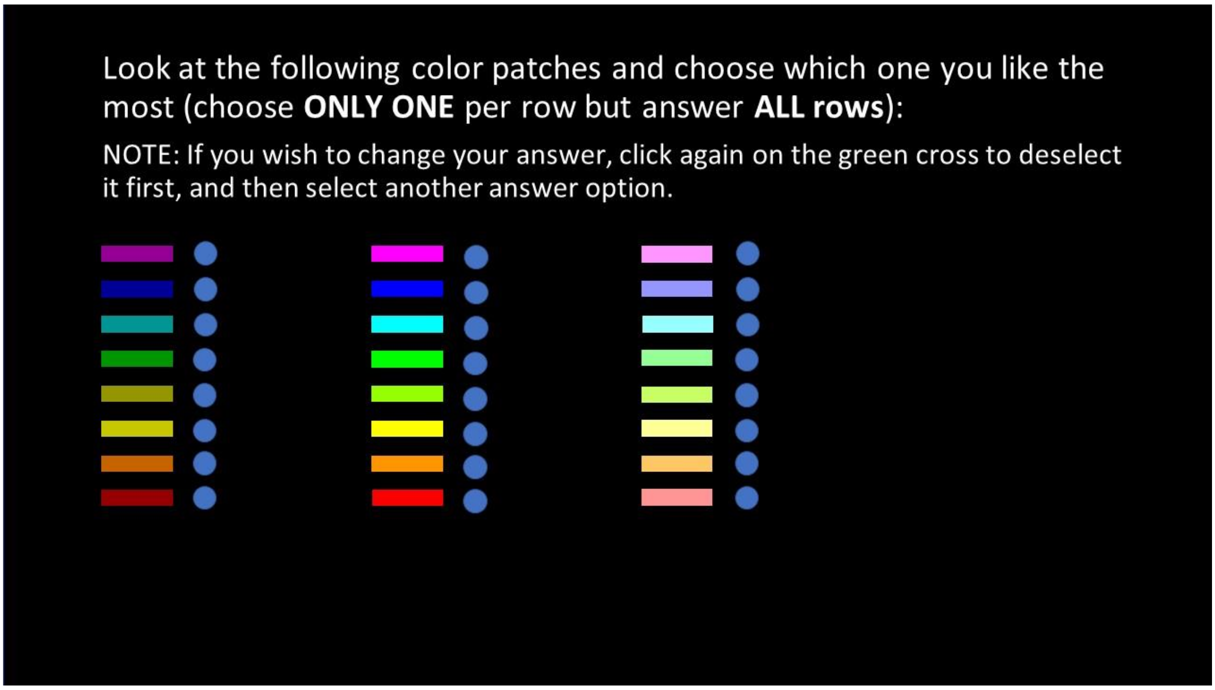


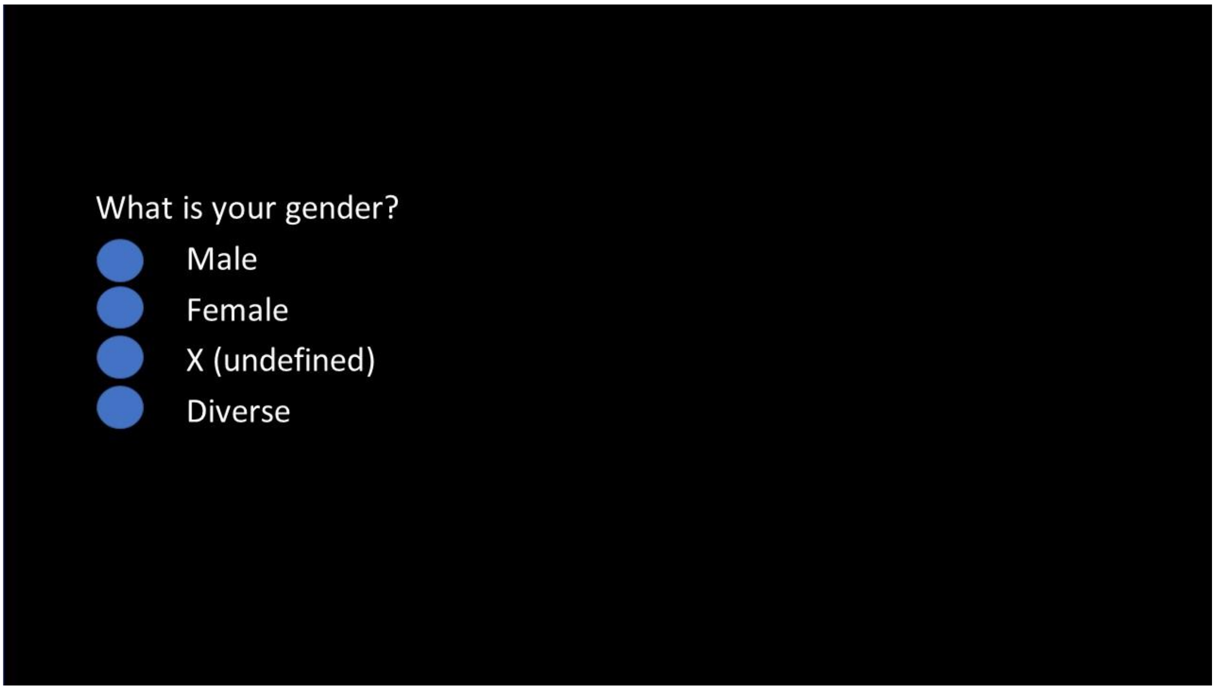

How much did you enjoy the park illumination color you experienced?
Very much
Somewhat
Neutral
Not much
Not at all
Please tell us also why:
Please insert text here

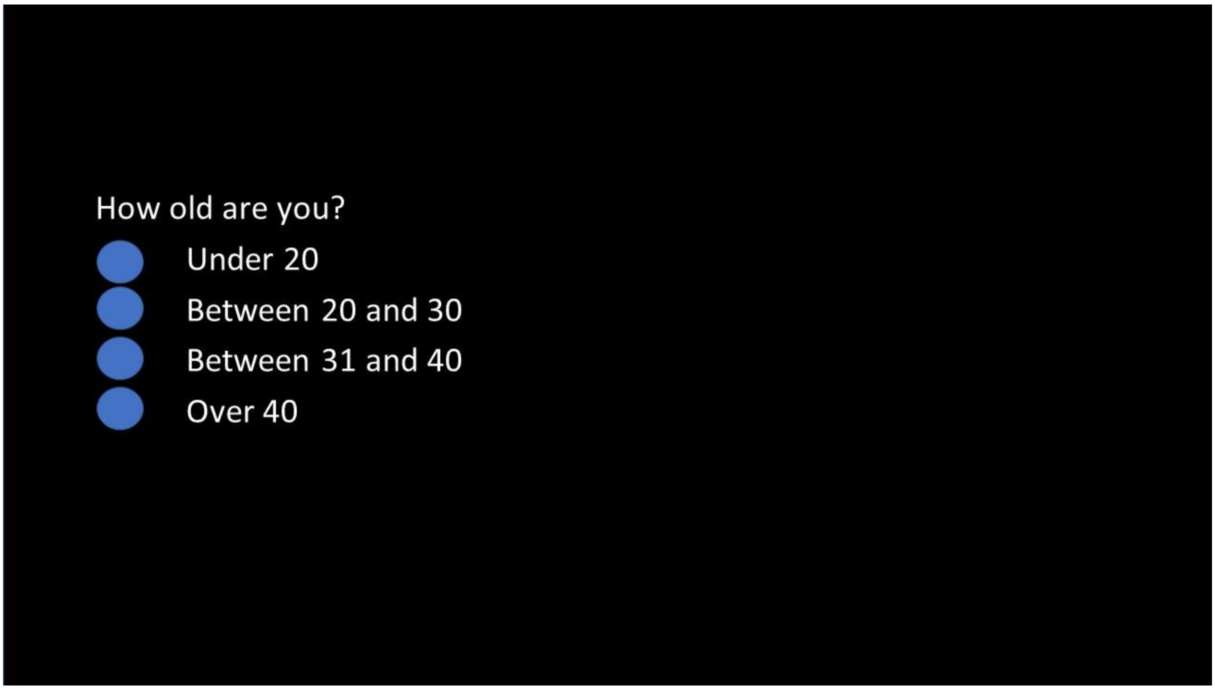

What other color would you suggest for illuminating a park at night?
• This color was perfect
• This color was fine but maybe a lighter color
• I would use another color. Please specify the color choice below:
Insert color here

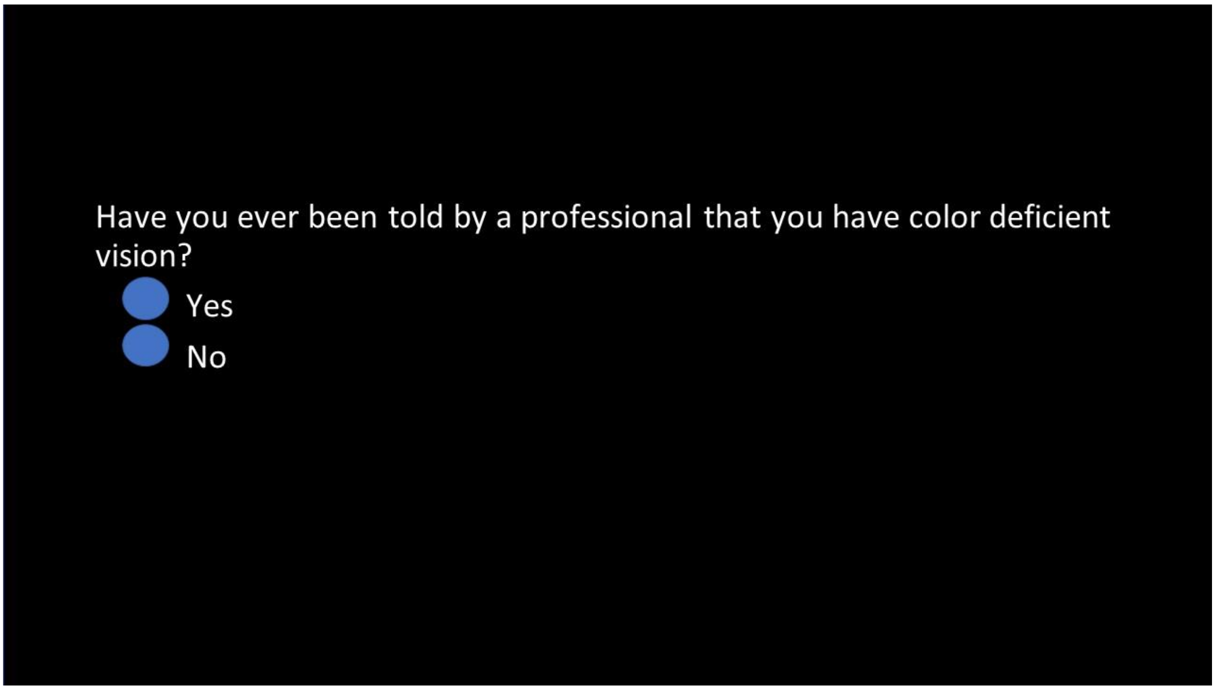

Anything else you wish to let us know about your park experience?
Write "no" if there is nothing else.
Please insert text here


Now sort the eight colors you see in the image below according to your preference. Drag the text fields below the image with the mouse from your favorite color (top) to your least favorite color (bottom):
purple
dark blue
light blue
dark green
light green
yellow
orange
red
purple
dark blue
light blue
dark green
light green
yellow
orange
red


Look at the following color patches and choose which one you like the most (choose **ONLY ONE** per row but answer **ALL rows**):
NOTE: If you wish to change your answer, click again on the green cross to deselect it first, and then select another answer option.


What is your gender?
Male
Female
X (undefined)
Diverse


How old are you?
Under 20
Between 20 and 30
Between 31 and 40
Over 40


Have you ever been told by a professional that you have color deficient vision?
Yes
No

On average, how often do you go for a walk in your leisure time?

- Never **(skip the next two questions)**
- Once a year
- Once a month
- Once a week
- Almost every day

If you do go for a walk, where do you usually go?

If you answered "never" to the previous question, click "No answer".

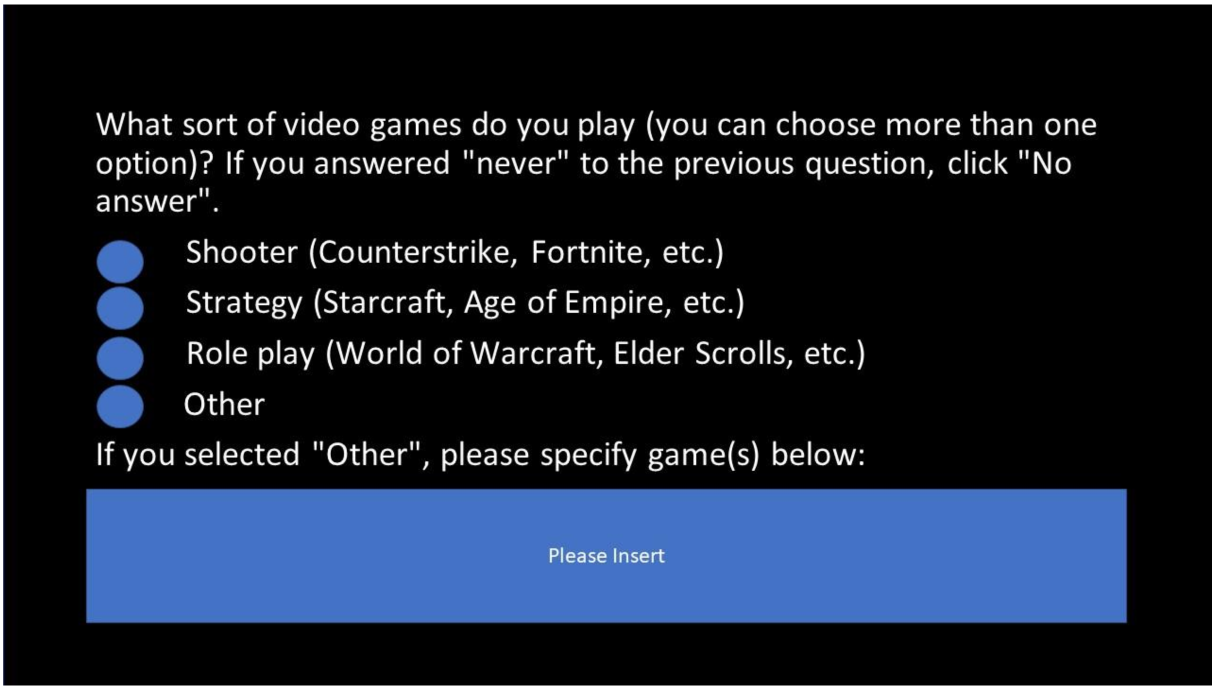
- All sorts of places, never the same
- Park
- Forest
- Around the neighborhood
- Downtown / city center
- No answer

If you go for a walk, when is your **preferred** time?
If you answered "never" to the previous question, click "No answer".

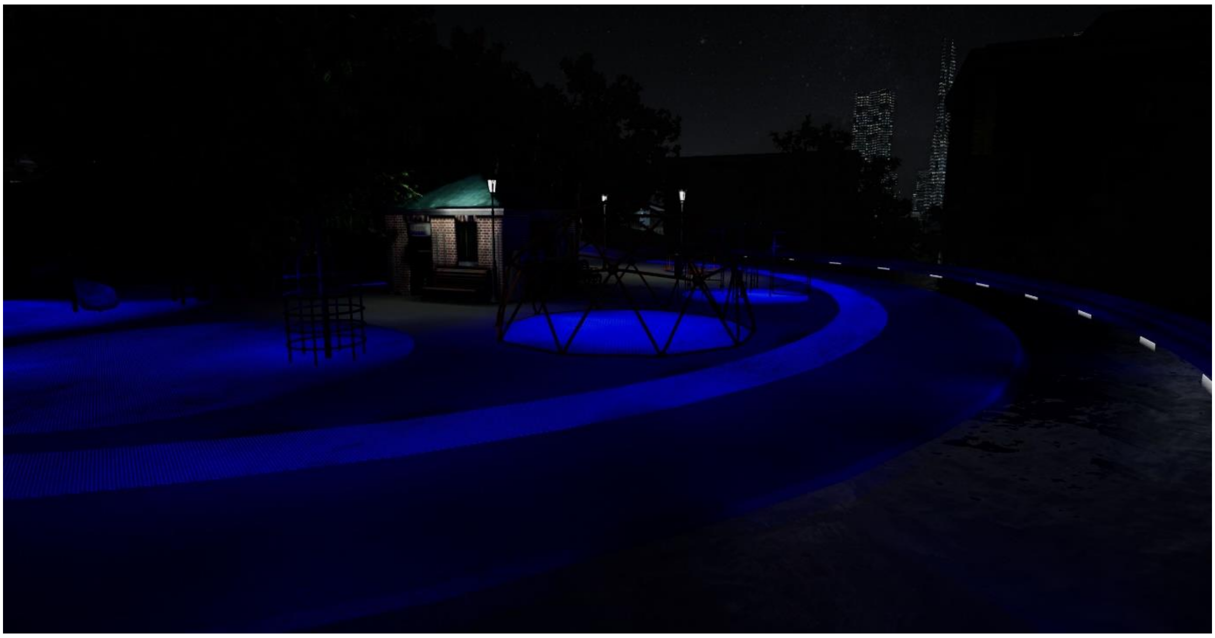
- Early in the morning
- During the day
- In the evening
- At night, when it is already dark outside
- No answer

How often do you play video games?

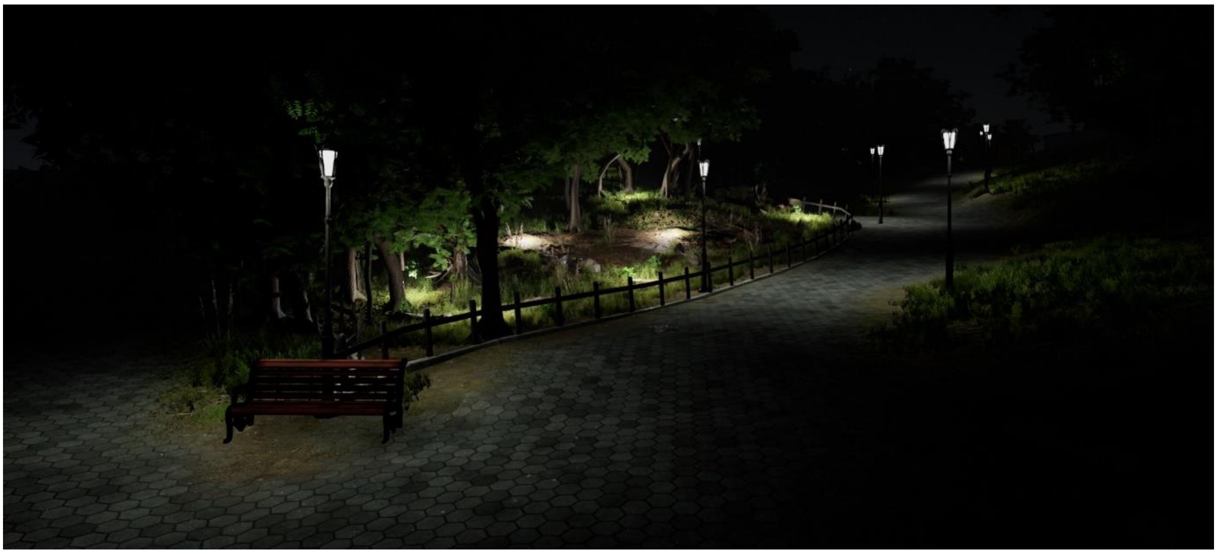
- Never (skip the next question)
- Once a year
- Once a month
- Once a week
- Almost every day

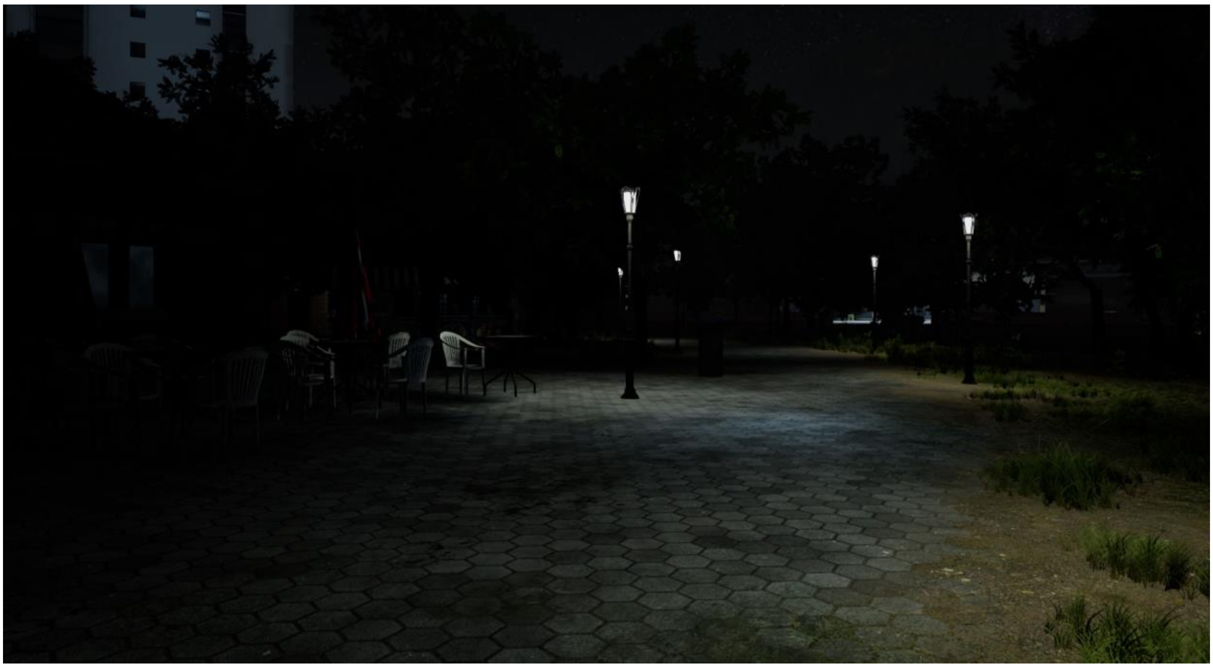


Entrance and Checkpoints Blue Scenario



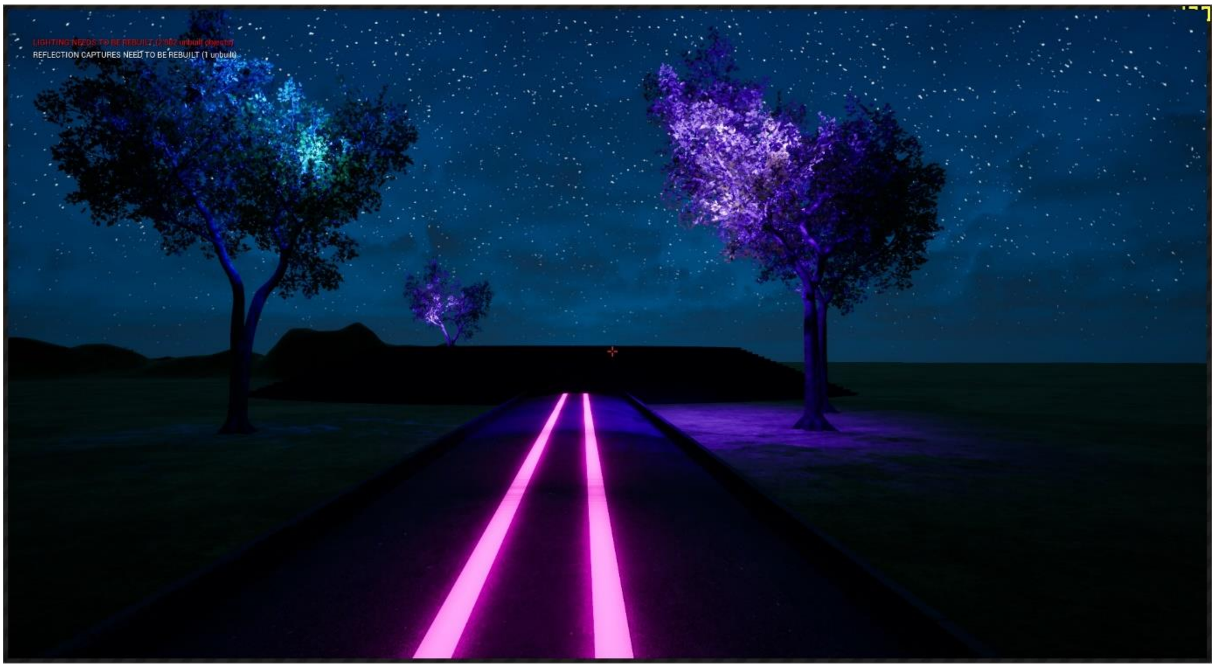
Entrance and Checkpoints White Scenario





Early-Stage Pictures

Testing different lighting conditions within Unreal Engine 4 during early stages.



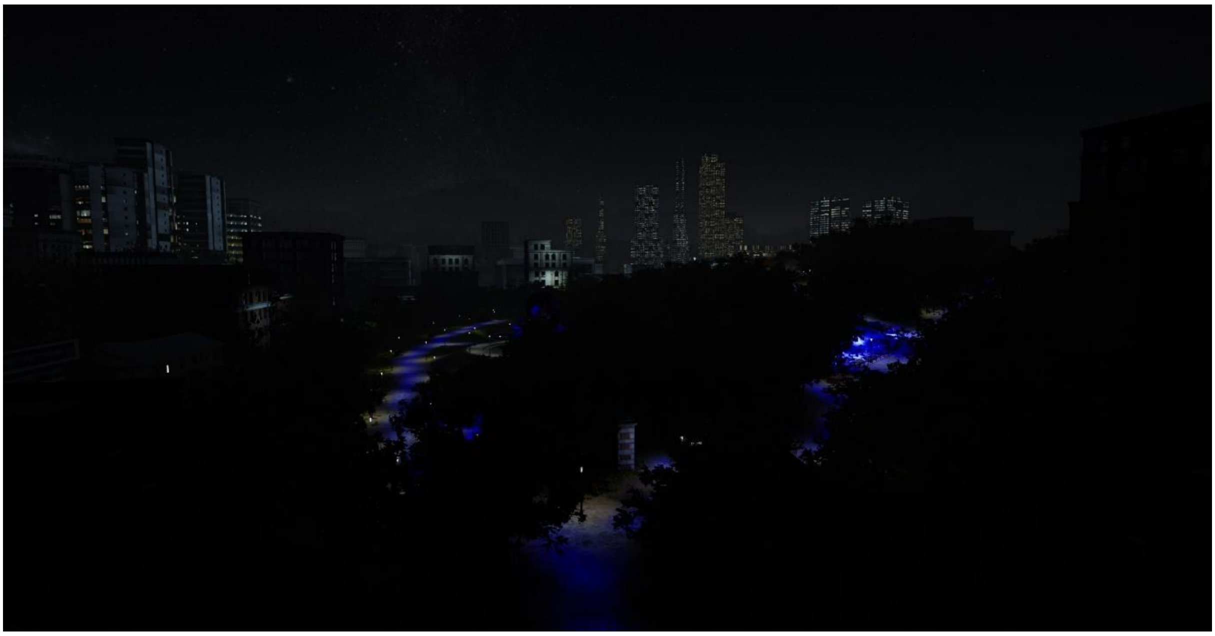

Shift+F1 for Mouse Cursor
REFLECTION CAPTURES NEED TO BE REBUILT (1 unbuilt)


REFLECTION CAPTURES NEED TO BE


LIGHTING NEEDS TO BE REBUILT (1'610 unbuilt objects)
REFLECTION CAPTURES NEED TO BE REBUILT (1 unbuilt)


LIGHTING NEEDS TO BE REBUILT (1'615 unbuilt objects)
REFLECTION CAPTURES NEED TO BE REBUILT (1 unbuilt)

Additional Images from the Scenarios



31.10.2021

Personal Declaration

I hereby declare that the submitted thesis is the result of my own, independent work. All external sources are explicitly acknowledged in the thesis.

Zurich, 31st of October 2021

Martin Lanz