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EMPATHY AND IDEA GENERATION FOR COLOR VISION DEFICIENCY IN VIRTUAL REALITY

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ABSTRACT

Virtual reality allows immersive experiences of life and the activities of others in an unprecedented way. Immersed in such experiences, operators can understand and empathize with the life challenges of others. Such empathy and understanding can be pivotal for generating ideas on how to create products that improve the lives of people with specific needs. In this project, the effect of a virtual reality experience on empathy and the generation of ideas was investigated. We experimentally examined operators' experiences of color vision deficiencies with their own eyes in a game. We evaluated if the immersive virtual reality experience will allow the operator to gain a deeper understanding and establish empathy with color vision deficiency users. Through this, we will identify the needs of color vision deficiency users. We further investigated should such experience lead the operators to generate better design ideas. We examined two virtual environments representing commonly experienced real-life places, a grocery store and a library. They were interacted with as games. The experiment was conducted in two sessions: a virtual environment on a computer screen and a virtual reality experience of the same environment using a head-mounted display. We measured if the experiences deepened the understanding and empathy with a color vision deficiency experience in the same game. The empathy of the 23 participants was tested with questionnaires after each of the experiences, on a computer screen and in virtual reality. We also inquired about lists of the five most common issues color vision deficiency users perceived by the operators on three occasions, before the experiment, between the two sessions and at the end. At the end of the experiment, the operators were asked to generate as many as possible ideas for tangible products that might help people with color vision deficiencies. The results show that the virtual reality experience helped participants deepen their understanding of the needs of people with color vision deficiencies. The idea generation was not found to be statistically significantly affected by the VR experience. Future work is needed to measure the difference between traditional virtual environments and virtual reality on humans understanding and empathy.

Keywords: empathic experiences, VR, ideation, everyday environment, Leuven Embedded Figures Test, Task Load Index

Häyrynen E., Pitkänen S. (2022) Empatia ja Ideoiden Tuottaminen värisokeudesta virtuaalisessa todellisuudessa. Oulun yliopisto, Tietotekniikan tutkinto-ohjelma, 44 s.

TIIVISTELMÄ

Virtuaalinen todellisuus mahdollistaa mukaansatempaavia elämänkokemuksia ja muiden aktiviteettien kokemisia ennenkuulemattomalla tavalla. Tällaisiin kokemuksiin upottautuminen mahdollistaa ymmärrystä ja empatian tunnetta toisten haasteista. Tällainen empatia ja ymmärtäminen voi olla keskeistä kun halutaan kehittää ideoita, joilla voidaan parantaa erityistarpeisten ihmisten elämää. Tässä projektissa tutkittiin virtuaalisen todellisuuden kokemuksen vaikutusta empatiaan ja ideoiden kehittämiseen. Kokeellisesti tutkimme pelissä tutkittavien värisokeus-kokemuksia heidän omilla silmillään. Me arvioimme pystyykö mukaansatempaava virtuaalisen todellisuuden kokemus syventämään kokelaiden ymmärrystä ja lisäämään heidän empatiaa värisokeita ihmisiä kohtaan. Tämän avulla havaitsemme värisokeiden ihmisten tarpeet. Tämän kokemuksen avulla tutkimme lisäksi pystyykö kokelaat kehittämään parempia suunnitelmia värisokeille tällaisen kokemuksen jälkeen. Tutkimme kahta virtuaalista ympäristöä jotka kuvasivat yleisiä tosielämän paikkoja: ruokakauppaa ja kirjastoa. Ympäristöjä käytettiin ja koettiin peleinä. Kokelaiden kokemus sisälsi kaksi osaa: virtuaalinen ympäristö tietokoneen näytöllä ja tämän jälkeen sama virtuaalinen ympäristö virtuaalisessa todellisuudessa käyttäen virtuaalilaseja. Mittasimme syventyikö kokelaitten ymmärrys ja empatia värisokeita ihmisiä kohtaan tässä pelissä. Kaikkien 23:en kokelaan empatia testattiin kyselyillä tietokonenäytön ja virtuaalisen todellisuuden kokemusten jälkeen. Kokelailta myöskin pyydettiin listaamaan kolmessa eri kohdassa viisi tärkeintä ongelmaa värisokeiden ihmisten elämässä. Tämä kysymys kysyttiin ennen kokemuksia, kahden kokemuksen välissä ja kokemusten jälkeen. Koko tutkimuksen lopuksi kokelaita pyydettiin tuottamaan mahdollisimman monta aineellista ideaa tuotteista, joilla voitaisiin auttaa värisokeita ihmisiä. Tuloksena huomattiin että kokemus virtuaalisessa todellisuudessa syvensi kokelaitten ymmärrystä värisokeiden ihmisten tarpeisiin. Tämä kokemus virtuaalisessa todellisuudessa ei tilastollisesti merkittävästi vaikuttanut ideoiden tuotantoon. Jatkotyötä tarvitaan mittaamaan ymmärryksen ja empatian eroa perinteisten virtuaalisten ympäristöjen ja virtuaalisen todellisuuden välillä.

Avainsanat: kandidaatintyö, empaattiset kokemukset, virtuaalinen todellisuus, ideointi, jokapäiväinen ympäristö, Leuven Embedded Figures Test, Task Load Index

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LIST OF ABBREVIATIONS AND SYMBOLS

CSE	Computer Science and Engineering
VR	virtual reality
HMD	head mounted display
VE	virtual environment
CVD	colour vision deficiency
PC	personal computer

1. INTRODUCTION

A large part of our world is designed around color: we know when to cross the road based on the color of a traffic light or when a toilet is vacant based on a green or red-colored sign on the door. Statistics and other user interfaces convey information using different colors. Humans with different color vision deficiencies get less information about the world around them in these situations and in everyday life. Designers are aware of these problems, but it can be hard to grasp all the limitations color vision deficiency causes. There are UIs that don't take color vision deficient people into consideration. To design for color vision deficient people, a designer must understand how the world looks through their eyes and what design choices affect their lives. Empathetic feelings towards humans with color vision deficiency can motivate a designer to design the world with CVD in mind.

Color vision deficiency is estimated to affect up to 8% of males and 0.5% of females.That means about x suffer of the whole population suffers from CVD [1]. CVD includes many different types, which will be discussed in related works.

Empathy plays a big role in understanding other people, their emotions, and actions. If you feel for the other person, that means you have at least a small understanding of their condition. Therefore, a greater amount of empathy can push people like developers to produce a more suitable world for everyone struggling with conditions.

Virtual reality is a technology that has huge possibilities but which some have not yet made possible. VR allows people to experience life in ways they never have before.VR is usually experienced on a head mounted device that brings you so close to the content on the display that you almost feel like it is real. VR and a HMD combined make for an immersive experience that can evoke emotions better than any TV or mobile device. It is important for this project to generate strong emotions on the subjects, and VR is a great tool for that.

A virtual environment will be created for our test subjects to experience. The VE will be interactive to evoke more empathy for the subject. The aim is to produce a virtual environment for developers and designers that can make them realise what it means to be color blind. The VE will demonstrate a day-to-day life struggle color blind people face, and the goal is that non-color-blind people will gain empathy towards people suffering from CVDs.

The virtual environment will be tested on human subjects. The subjects will be placed in the virtual environment and their levels of empathy and understanding toward color vision deficient people will be examined before and after the experience.

2. RELATED WORK

2.1. Color Vision Deficiency

The human eye has receptors located in the retina that allow humans to see color. There are three different receptors, one for each primary color. Blue receptors are short-wavelength sensitive, red receptors are sensitive to long-wavelengths, and green receptors are to medium-wavelengths (sometimes these receptor groups are shortened to L-, M-, and S-cones for convenience sake) [1, 2, 3]. These receptors (also known as cones or cone receptors) allow humans to see the three main colors and their combinations [1, 2].

Color blindness is a widely used term and it covers a wide range of vision-related disorders. A more specific term would be color vision deficiency or impaired color vision, but color blindness is still widely used [2]. There are many different congenital color vision deficiencies, and these deficiencies can be categorized by severity. These deficiencies are caused by gene mutations that affect the aforementioned cone receptors [1, 4]. In anomalous trichromacy color vision is near normal (there is a variance from case to case) but one of the cones has an altered sensitivity, which leads to weaker color discrimination [1]. In dichromacy, one of the cones is completely missing or one of three cone groups is defective. Missing one of these three groups results in different types of color vision deficiencies: tritanopia (missing blue light receptors), deuteranopia (missing green cones), and protanopia (missing red cones). Different anomalous trichromacy cases can also be categorized the same way by the affected receptor group; protanomaly for red cones, deuteranomaly for green cones, and tritanomaly for blue cones [1, 2, 3]. In monochromacy, two of three cone groups are defective or missing, which leads to black and white vision and a total lack of color discrimination [2, 1].

Color vision deficiencies can affect many aspects of life. It affects everyday situations such as cooking, choosing clothes, and the enjoyment of different hobbies. Even career paths are affected by CVDs [3]. Driving a car is one major part of everyday life where the ability to see and recognize colors is important. A lot of information is shared with the driver through colors; the car in front will turn their red rear lights on when breaking, and traffic lights use color to indicate safe passage over the road. Subjects with CVDs may prefer driving at night because they have had some difficulties detecting rear lights and reflectors on the road [3, 5].

2.2. Empathy

Understanding empathy is important before trying to evoke empathy in subjects. Empathy, like multiple other psychological terms, has been found to be a hard word to define [6, 7]. Empathy is often thought of as an emotion that occurs when one sees others in pain or struggling based on their behavior and expressions. The scientific definitions and views used for empathy have been based on multiple phenomena in human emotions [6, 8]. By reading multiple definitions, one can understand the whole idea of the term. Empathy can be understood as recognizing and feeling others' mental states and emotions and feeling concerned for other people. Someone who feels empathy can also visualize placing themselves in another's body. In this project, the focus is on thinking about how it would feel to be the one with CVD. According to Gleichgerrcht E. and Decety J. in [8] and Decety J. in [9] Batson C. D. determines empathy in [10] as to when one is almost feeling similar to the other person and the line between self and other is blurring [7, 9, 11, 8, 10]. As these definitions are considerably contrasting, it is difficult to comprehend how empathy is felt from person to person. There are obvious cultural differences that affect how empathy is felt and perceived. For example, it was found in a study that Finnish people are not that empathic [12]. The extensive study compared over 100000 people from 63 different countries around the world and ranked them by their levels of empathy. Finland placed 61st, meaning that Finland was the third least empathic country in the study [12].

Empathy is an important interpersonal human emotion for regular life but also for lines such as medicine, for patient satisfaction. Institutions want medical students to learn empathy since better empathy leads to better healthcare [8, 9]. Additionally, Bratek and Al's study shows that empathy levels decline throughout medical school [13]. Medical students taught about empathy during their studies reached higher empathy levels by the end of their respective studies [14]. Therefore, it is important that medical students are taught about empathy during their studies. It is apparent that teaching about empathy serves a considerable function in society. Empathy is generally a good trait to have since it helps professionalism in business. Everyday experience and Stern S. T. [15] indicates that teamwork and leading in business can be better with empathy. People being concerned about others and people taking care of others should furthermore have a projection on our environment.

An important question is whether subjects will be able to empathize more or less with people suffering from CVD after our experience. In the project, it will be examined whether the subjects experience a shift in their respective levels of empathy. In this project, there are subjects that have different levels of empathy, and the change in empathy levels caused by our experience will be examined. The subjects are placed with others who are suffering from color vision deficiency. This blurs the line between self and other, comparable to the way Gleichgerrcht and Decety describe empathy [8]. Color vision deficiency, being a physical impediment that can be visualized, can affect our subjects' ability to feel stronger emotions and have more radical shifts in their empathy levels.

2.3. Virtual Reality Possibilities

Virtual reality is a versatile tool. VR has seen a surge of new applications in different fields. Many scientific fields benefit from VR, e.g., in medicine, VR is used for medical rehabilitation [16]. It can also be used in gaming, learning, and even flying real drones. VR has additionally proven to be a technology that can evoke empathy [17]. VR is so immersive it is the best technology available for evoking emotions and specifically empathy. Games can evoke empathy towards color blindness better than a more traditional style of studying [18]. Serious games give enormous possibilities to learning [19]. Games usually consist of virtual environments that are interactive and immersive.

2.3.1. Virtual Reality and Empathy

Virtual reality has BEEN shown to be a possible technology for enhancing empathy. Putting people in others' place can have an immense effect on a human being. Chris Milk made a 360-degree film in Syria about a young girl who had been suffering in the war [20]. The film was shown in VR for people in Europe, and the viewers were affected by it. The realism brought the viewers closer to humanity, and the viewers got to empathise with her. He, like others, thinks that this technology can be used to enhance empathy in a massive way [20].

Having perspective on others' lives is a major tool in enhancing empathy in a person. Diseases are difficult to understand from a book, but when one can see with their own eyes how other people are suffering, experiencing empathy is easier. Jeremy Bailenson has comprehensive studies of empathy in VR [21]. These studies show that putting people inside other people or even animals with VR can have a big effect on people. In his book he has examples of how NFL executives were put in VR into the place of the quarterback in a american football game to better understand the game and the feelings of the player. Also people being placed as cows in a cattle farm, the participants realised how cruel the conditions of cattle can be, and after the experience, the people felt more empathic towards cows.

In his book, Bailenson also presents "loose guidelines" for making VR content [21]. The first guideline asks readers to make sure that VR is necessary for their project. VR has its strong and weak points like any other medium, so readers should think carefully if their use case is best in VR. His second guideline warns readers about making the users sick. Simulator sickness is at best uncomfortable and at worst can cause some accidents in real life if user gets dizzy some time after getting simulator sickness. Last guideline tells readers to be safe. Using VR requires movement in real space, and when using VR, the user can easily forget their location in real space, which can lead to some accidents [21].

2.3.2. Empathic Experiences of Protanopia in VR

In a similar study by S. J. Ahn et al. [22], VR proved to be a worthy tool in raising empathy in color vision deficient people.This study included 3 different experiments. 44 participants were part of the first experiment. First, before arriving, the participants filled out pretests about empathy etc. After arrival, they received short explanations about CVD before the VR experience. The participants were split in half. The first half experienced a CVD filtered environment, which made it hard to differentiate between red and green colors, and the other half just imagined having a CVD. The participants experiencing the CVD filter were unable to separate red and green objects. Experiment also included a same-sex confederate, who posed as a colorblind student, training to differentiate red and green. Participants were asked to guide this confederate verbally in the task of putting different colored screws into different colored holes, after which participants were informed that the study had ended. A confederate student asked each participant to stay and help him/her with the training after the experiment was over. Participants could decide if they helped and how long they helped the confederate student. Experiments 2 and 3 modified the task and had bigger sample sizesm but they measured the same things in each experiment [22].

The ones who experienced the CVD filter felt more colorblind than the ones imagining it. After the experiment, the participants who were less empathic towards CVD people from the beginning were the ones whose empathy got most enhanced. Generally, the experiment provoked more positive attitudes toward all of the CVD population [22].

Ahn et al.'s study is promising for this project. Their results support our hypotheses and are an example of how you can raise empathy towards CVDs using VR. VR technology has rapidly advanced since the year their study was conducted. For comparison, the HMD they used had a resolution of 640 x 480 pixels compared to the HTC VIVEs 2160 x 1200 pixels (HTC VIVE is the HMD used in this research)[23]. Advanced technology should lead to more immersive virtual environments and better results [22, 23].

References	Subjects	Comparison	Description	Platforms	Measures	Results
Latini et al. (2021)	23 participants	Comparison was how the subjects would react to the colour of the wall between real and virtual environments, with different coloured walls, with different temperatures	Subjects were put into a virtual room and a real room tasked with watching a coloured wall and a set temperature 17-22' the subjects filled proofreading tasks next to the coloured wall and after getting out of the rooms they filled quizes on motion sickness .	VIVE pro eye headset Unity3D	Productivity and termal and visual comfort in real life compared to VR	VR was found to be a great tool for measuring productivity and comfort in a coloured room
Lewis et al. (2011)	21 participants, students	Understanding and awareness of visual impairements before and after	Subjects performed simple tasks in virtual environment while trying out different visual impairements. They were questioned before and after the experiment about visual impairements.	Unreal engine 3	Understanding of visual impairements and problems associated with it	Students saw a increase in understanding of the visual impairements and problems associated with it
Cheah et al. (2019)	11 participants, university students	Amount of food taken in real life buffet and VR buffet. Neurophysiological states and difference in real life buffet versus VR buffet.	Subjects filled a online questionnaire then subjects were equipped with different sensors measuring different neurophysiological measurements. They went through a virtual buffee taking as much food as they would in real situation. After that they went through a real buffee doing the same thing while still wearing the sensors.	OCTAMON 8-channel fNIRS Shimmer wearable sensors Microsoft band VR setting	Amount of food taken in the virtual environment compared to food taken in the real life environment. Nutritional contents and calories in each situation. How neuropshysiological states differ in each situation.	Subjects had similar neurophysiological responses and the nutriotional contents of subjects' food were similar in each environment.
Cwierz et al. (2021)	20 participants	Comparison between real life CVD test and virtual reality CVD test	Subjects performed close to identical FM 100 tests in both virtual environment in VR and in real life. The test can distinguish between normal colour vision and a colour vision with deficiencies	Unity3D HTC Vive	Understanding whether VR is a cabaple platform in producing correct results from CVD tests	VR is a valid technology for testing colour vision

Figure 1. Comparisons between studies focused on color vision using VR [24, 25, 26, 27].

2.3.3. VR in Productivity and Comfort

This experiment by Latini, A. and others first mentioned in 1 measured how three wall colors and different air temperatures affected participants' productivity and thermal and visual sensations. The three wall colors were red, blue, and white. The air temperature was either 17°C or 22°C. Productivity was tested with a proofreading task and thermal and visual sensations with surveys [24]. The subjects first experienced the real environments first with 17°C and then with 22°C with different colored walls.

After that, the subjects experienced the same experience in VR. The real and virtual environments were made as identical as possible, and test participants agreed that there were not any notable differences between the environments. None of the participants had any previous experience with virtual environments [24].

In the results, the participants agreed that the colored walls had an effect on their productivity, with the red-colored wall being the least pleasant. There were no significant variations between the virtual and real environments. Thermal sensation was affected by temperature changes. No differences between VE and real environment in visual sensations [24].

The fact that the virtual environment was condemned to be a viable option to experiment with productivity and sensations is a good sign for the CVD project. It is important that the virtual environment is accurate since it was suggested that an accurate virtual environment would increase a subject's reliability with VR [24]. Reliability with VR can give the subjects a deeper understanding of the ones suffering from CVD.

2.3.4. Using VR to Simulate Visual Impairments

Lewis and others conducted an experiment [26] where they simulated visual impairments in VR. They developed a 3D space in Unreal Engine 3 and used User Interface overlays and Post Processing to simulate different visual impairments. The simulated impairments were: glaucoma, macular degeneration, cataracts, hemianopia, myopia ,and hyperopia.

A group of 21 students was tested to see how effective the experiment was in enhancing their understanding of humans with visual impairments. Subjects were also asked about the realism of the 3D environment and visual impairments [26].Subjects thought that the simulator felt realistic and the impairments were simulated fairly well. Subjects reported better understanding of the diseases simulated and the daily difficulties people with these diseases encounter. Researchers were consulted by a visual impairment expert, and this expert thought that the simulator had some practical utility [26].

This research proves that visual impairments can be simulated successfully in VR and that experiments like this could enhance the understanding of visual diseases.

2.3.5. Neural Responses While Using VR

Cheah C. and others conducted an experiment [27], where they compared physiological activity between a real-life situation and a similar situation in VR. A group of 11 students first answered a questionnaire as a part of a larger study, after which they were put on real-life buffet or into a similar buffet in VR, while wearing sensors to measure a multitude of physical and neurological reactions. Subjects would be put in the other environment next week, so each subject would experience both buffets. These students were told in each situation to take as much food as they would normally. The researchers noted the amount of each food that was taken in each situation and compared the physiological and neurological reactions when the participants took high-density foods or low-density foods (they categorized every food with a density of 1,5 kcal/gram or higher as high-density, everything else was categorized as low-density). This research concluded that subjects showed similar neural reactions in both situations [27].

Even though this research suffers from a small sample size (n=11), it demonstrates how immersive VR can be. Finding similar patterns in neural reactions indicates that immersion in VR can go all the way to the neurological level.

2.3.6. Color Vision Deficiency Test in VR

This experiment by Cwierz H. and others tested the difference between color vision deficiency tests (FM 100) in a virtual environment and a real environment [25]. The objective was that both virtual and real-life tests would provide similar results. Some of the participants showed some level of CVD. The participants took the FM 100 test in real life and in a virtual environment, and afterward the results were compared. Cwierz and others also worked hard to get the virtual environment to be visually as close to the real test as possible. The colors were the most important in this project, and they needed to be correct [25].

The result was that the VE experience caused more errors in the test, possibly caused by the HMD image quality. The virtual test displayed that it could be a possible option when testing for CVD. Finally, the HMD technology was deemed viable in this task [25].

3. DESIGN

3.1. Hardware

The HTC VIVE VR headset was chosen on the basis of its easy formability and great compatibility compared to other devices. Each HMD has its own characteristics in color uniformity, just as every display ever made does. A high-end product was necessary for this project. Color is important in this project. The HTC VIVE device will be competent in this project even if the colors are not perfect. The displays in the HMD are AMOLED displays with deep blacks and great color. Additionally, the HMD has a high resolution of 2160 x 1200 pixels when the displays for each eye are combined, bringing the experience more to life [23]. The HMD used in the project can be seen in the 2.

Figure 2. HMD used in the research.

3.2. Software

The hardware and software need to work seamlessly in a project like this. There are multiple different platforms for developing a virtual environment, but Unity was chosen on the basis of preferences and ease of use. Some plugins simulating color vision deficiencies were found, which also was an argument for developing with Unity. Unity also allows its users to see the 3D environment in real-time while developing.

A user can see the changes affect the virtual environment immediately, which allows quicker testing and development. Unity uses C# as its main programming language.

3.3. Virtual Environment

A crucial part of this experiment is the virtual environment we are going to create utilizing Unity. The virtual environment is the space the subject will be placed in and where the experience happens. Unity allows you to create a realistic-looking 3D environment. The participants will be put in this environment to experience a situation from the eyes of a human with a CVD. The environments are constructed in such a way that they provoke an emotional response.

The first idea was to create a close-to-real-life situation where the effect of a CVD on daily life is apparent. It was decided that a grocery store scene would be the best approach. A grocery store should be a familiar environment for everybody, and they are usually filled with different colors. Therefore, the difference between perfect color vision and a deficient one should be apparent, and perhaps the participants will be taken aback by the lack of color in the environment. The environment is one long corridor with shelves full of products. The participant spawns into the corridor, and they are surrounded by a variety of colorful products. The participants can choose to move around the corridor, and some of the products on the store's shelves are going to be interactive, so the subject might grab them or move them. Interaction is important to make the effect of realism deeper.

A library is the second environment. The library is similar in design to the grocery store environment, but instead of groceries on the shelves, there are books. The same shelves are in use, and some of the books are again grabbable and interactive in that regard. The environments are similarly familiar to the participants, so conclusions are more definite. The participants are going to use the grocery store environment and the library environment in random order.

3.3.1. Experiment Controls

The participant will experience only one virtual environment. The participant will experience the environment on a computer, like most computer games, and another time in VR.

The participant uses a keyboard and mouse to move through the VE in the computer game. Inspiration was taken from first-person-shooter games where WASD-keys are used to move and the mouse is used to rotate the player. Extra controls included pressing E to pick up objects and Y to put on the CVD filter.

In VR, the participant was standing up and had controllers in their hands. The trigger button was used to grab objects, and the trackpad button was used to teleport. On the other hand, in VR, the controls were much more realistic in the sense that when the participant wanted to grab an object, they could do that by pressing the trigger which was quite similar to grabbing in real life. The CVD filter was on a virtual button in the environment that the participants pushed with a controller.

3.4. Experiment Design

Finding answers to the research questions requires knowledge of the participants' understanding of CVDs and empathy towards people with CVDs before and after the VR experience. That means that questionnaires play a major role in the experiment. The questions are based on the need to know how the participants feel about CVD beforehand and how the experience changes their perception. Another method used to gain information on the participants' understanding of the CVDs in this research is asking the participants to write down five different ways to make life easier for those suffering from CVDs. This requires participants to think from the perspective of the aforementioned humans, and thus participants display their understanding of the issue by writing these five things down.

The VR part of the experiment is essential to the experiment. This VR experience must simulate the chosen CVDs accurately. The virtual environment is designed to be a situation where having a CVD is noticeable and might cause difficulties. The participants will experience the VE in normal colors as well as in the CVD colors.

Protanopia was chosen as the CVD this project will demonstrate. This means that the subjects can't differentiate between red and green. Protanopia is one of the more common color vision deficiencies. The VE is designed in such a way that the objects that will be interactable will follow the color scheme of protanopia.

3.5. Experiment Procedure

The participants will be invited to a space provided by Oulu University where we have set up the experiment.

- The participant is seated and a short briefing of the experience is presented.
- Participants will first fill his personal information in age and sex, and also sign consent forms.
- Participants' color vision is be tested by using protanopia tests from Ishihara test. Their normal vision is also tested using a vision chart.
- Participant will write down 5 most important issues in the life of people suffering from CVDs.
- The computer game experience first with normal colors and after a few minutes a CVD filter is applied.
- A empathy questionnaire is filled by the participant. Participants also fill the same question that they answered before the computer game experience which is; write down 5 most important issues in the life of people suffering from CVDs. They can see their previous answers and they are advised that they may reorder, add or delete the earlier answers.
- The participant will fill the Leuven embedded figures test using maximum 5 minutes.
- Participant now experience in VR the same environment that they experienced on the computer playing with keyboard and mouse. Researchers help the participants to mount the HMD. The tasks and filters are same and the experience follows the same pattern as the computer game before did.

- After the time in the virtual environment the participants fill the same empathy questionnaire as well as the 5 things question for the third time and once again they may reorder, add or delete the previous results as they wish.
- Participants are asked to list as many as possible ideas for products that might help people with CVD in 5 minutes. Here the time limit was not set in stone meaning that if they had ideas coming and they were still sketching them at the 5 minutes mark, we would not stop them.
- The last questionnaire was the NASA task load index questionnaire and immediately after they finished that, they were handed their reward for the experience.

3.6. Data Collection and Correspondence

The data is collected in the questionnaires and quizzes before, in the middle, and after the experiences. The only personal information collected from the participants is age and sex. Other private information is not collected. The participants' answers in the same questionnaire from before and after experiences will be compared. The subjects' results will be compared against other participants as well.

The results from the surveys produce data that is used to answer the research questions. The comparison of the empathy questionnaires will answer the first research question (RQ1). The second research question (RQ2) will be answered when the participants list possible ideas that might help people suffering from CVD (before, in the middle, and after the two VE experiences). The third research question (RQ3) will be answered when the participants will write down the five most important issues in the lives of people suffering from CVD (after additional analysis of the generated ideas on quantity and variety).

3.7. Hypothesis and Research Questions

Our research questions come from aforementioned subjects and those research questions are:

1. Will the VR experience enhance empathy towards color vision deficiencies?
2. Will the VR experience deepen the understanding of participants towards users with different CVDs?
3. Will the VR experience improve the idea generation outcome?

These three questions in mind we will design our VR experience and setup.

H1: Immersive VR experience will allow the operator to gain deeper understanding and establish empathy with CVD users.
H2: The deepened understanding and empathy in VR should allow the operator to better identify the needs of CVD users.
H3: The deeper knowledge and better need identification in VR condition should lead the designers to generate better design ideas.

4. IMPLEMENTATION

4.1. Virtual Environments

For this research, two different virtual environments were made. These VEs were designed to have similar layouts as seen in the figures 10 and 3. These VEs also include tasks that the participants are asked to do after 5 minutes in the VE and after turning the protanopia filter on. Each VE uses the same movement system, same protanopia filter and same code to implement interactable objects. There are few differences, one of which is the way each uses color to share information to the user. The grocery store has differently colored apples (green and red) and the participants are tasked to pick specifically colored apples. The library uses colors to divide the bookshelves into different genres of books. The participants are asked to pick books from specific genre, so the participants will have to use the information given by these color coded bookshelves.

One of the most important parts of the VE for this research is the protanopia filter [28]. The filter is a post processing effect that gets applied to the environment by a button press. The filter is using protanopia which is the most common type of color vision deficiency and one of the more dramatic ones.

SteamVR Plugin [29] provides VR essentials for Unity developer, and were used for this research. Movement system, player controls and camera tracking were among the important functions used from the SteamVR Plugin. Also making items grabbable was efficient to make when using this plugin.

Movement in the VE happens mostly with teleporting with the aforementioned SteamVR Plugin [29]. The participant can point either controller and click the touchpad and move there. Also participants can take steps to move but this is limited to the size of the room space in the experiment. Major part of the experiment is grabbing and dropping objects. Grabbing happens simply by pressing the trigger button on either controller and releasing the trigger just drops off the item.

Little code was needed to be written since the SteamVR plugin already included most of the scripts needed and the CVD filter had its own code ready. The button that starts the CVD filter was one of the only ones that needed to be programmed by ourselves LINK TO CODE IN APPENDICES . A Youtube-tutorial was used in the development of the code for the button [30].

4.1.1. Grocery Store

The grocery store scene is as familiar an environment to everyone as anything. Inspiration was drawn from stores visited during the implementation. The store is kept uncomplicated to be easy to look at. The player first gets to experience the environment without the CVD filter. Closer to the entrance of the store, there is a sign that has tasks that the player can do while in the environment. The tasks include picking up a green apple and a red can. The task board can be seen in figure 6. These small items are easy to pick up. Then the player is supposed to drop off these items they picked up on the counter 5 on the other side of the store compared to the tasks-sign. The difficulty comes when the player is asked to press a button next to the task sign, also seen in figure 6 which turns the protanopia CVD filter on. The protanopia filter causes the player to not be able to see the red and green colors seen in figures 13 and 14. The effect is quite dramatic, and the difference betweem a normal colored VE is obvious. The apples are mixed with red and green apples on the same shelf. The original colors of red and green apples are gone and they are now shades of yellow and dark yellow. The same happens with the cans, the red and green cans are located next to each others. Every product on the shelves of this store has a sign under it that says what product it is, so the user does not necessarily need to know what an apple or a soda can looks like. These small tasks are implemented in the VE for the sake of participants' deeper understanding of how hard differentiating red and green must be for the people suffering from protanopia.

Multiple assets from the asset store were used to make the items on the selves of the store [31, 32, 33, 34, 35]. Also some of the other objects from the Unity asset store [36] were used [37, 38, 39].

Figure 3. Top down view of the VE.

In the figure 3 Only the middle aisle is accessible to the player. The surrounding aisles are there for visual purposes and without them the space felt a little claustrophobic. The space is bright like any grocery store would be.

Figure 4. The players spawn position.

In figure 4 spawn position where on the left there is the button to start the CVD filter and the task sign and then on the right is the counter where the players are asked to drop off the items they picked up.

Figure 5. The counter

Counter where players can drop items can be seen in figure 5, made to look like a supermarket counter with a place for the store clerk.

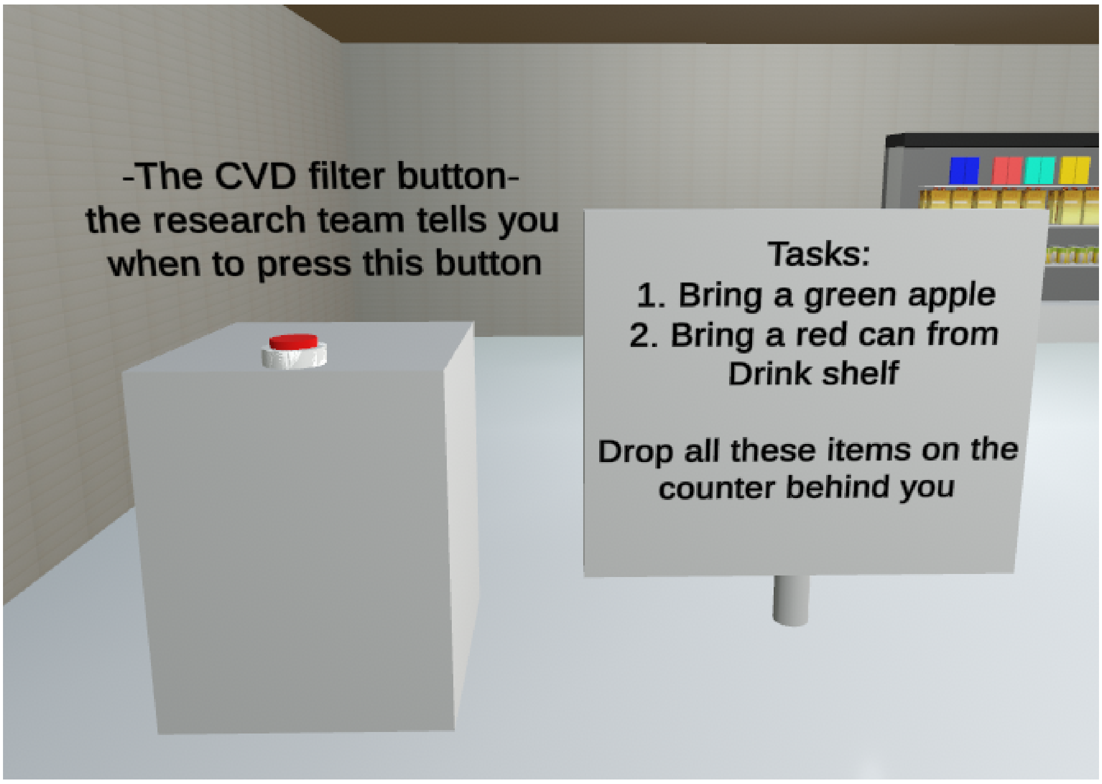

Figure 6. Button for CVD filter and task list

The button starts the protanopia CVD filter as seen in 6 and the task sign tells eloquently the player something to do in the VE. These tasks aren't mandatory they are

4.1.2. Library

The library was chosen as the second environment of the research. The library is a daily environment that is similar to a grocery store. Books in the library are colorful, and participants will see the difference in colors after the filter is applied. Book shelves are ordered by genres, and those genres are communicated through colors, as seen in the figures 7 and 8. This way of sharing information with the participants was chosen to demonstrate the way humans with CVDs miss information that normal humans will not miss. The library required a lot of different books, and QA books by QAtmo [40] were downloaded from the Unity Asset Store for this library. These books are situated on book shelves in their particular genre, as seen in the figure 9. Most of these books are interactable, and the user can grab, carry, and throw them. These books are affected by gravity. These books were made interactable so the participants could be tasked with bringing the books to a specific location.

There are a few posters in the library that give participants information. One of these posters lists all the genres available and which color means which genre, as seen in the figure 8. One of the posters is next to a stand with a button on it. Pressing this button will turn the protanopia filter on. The poster next to the button informs the participant to not press the button until asked to by one of the researchers. The last poster is the task poster. This poster has a few tasks on it and is next to a table. The tasks require the participant to use the genre colors to complete the tasks. There are three tasks, and each one requires the participant to bring a book of a specific genre to the table next to the table.

Multiple different assets from the Unity Asset Store were used for the library. These assets were used to make building the environment easier and to make the environment more immersive by looking more realistic. Building was made easier by using Snaps Prototype | School by Asset Store Originals [39] because this package includes a bunch of different prefabs for buildings. 15 Original Wood Texture by NevLext [41] made the library look more realistic and added to the immersion that way.

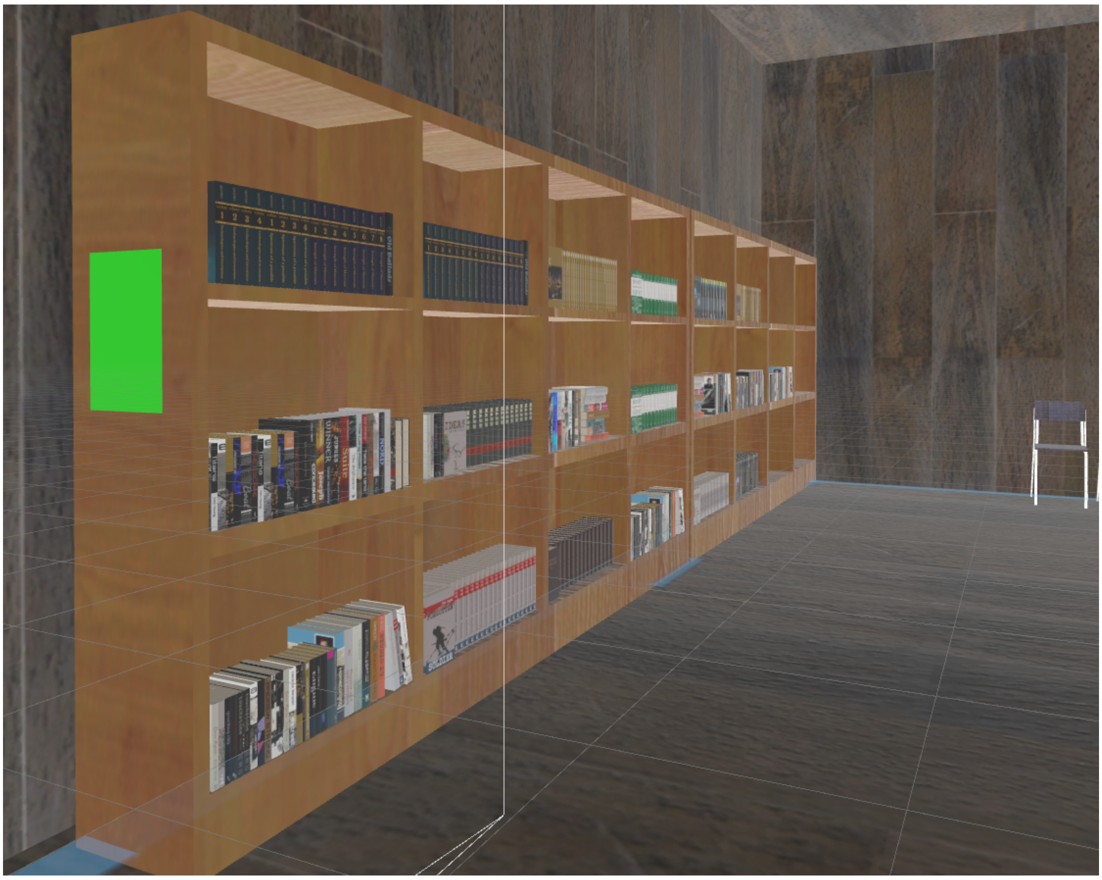

Figure 7. Non-fiction section of the library.

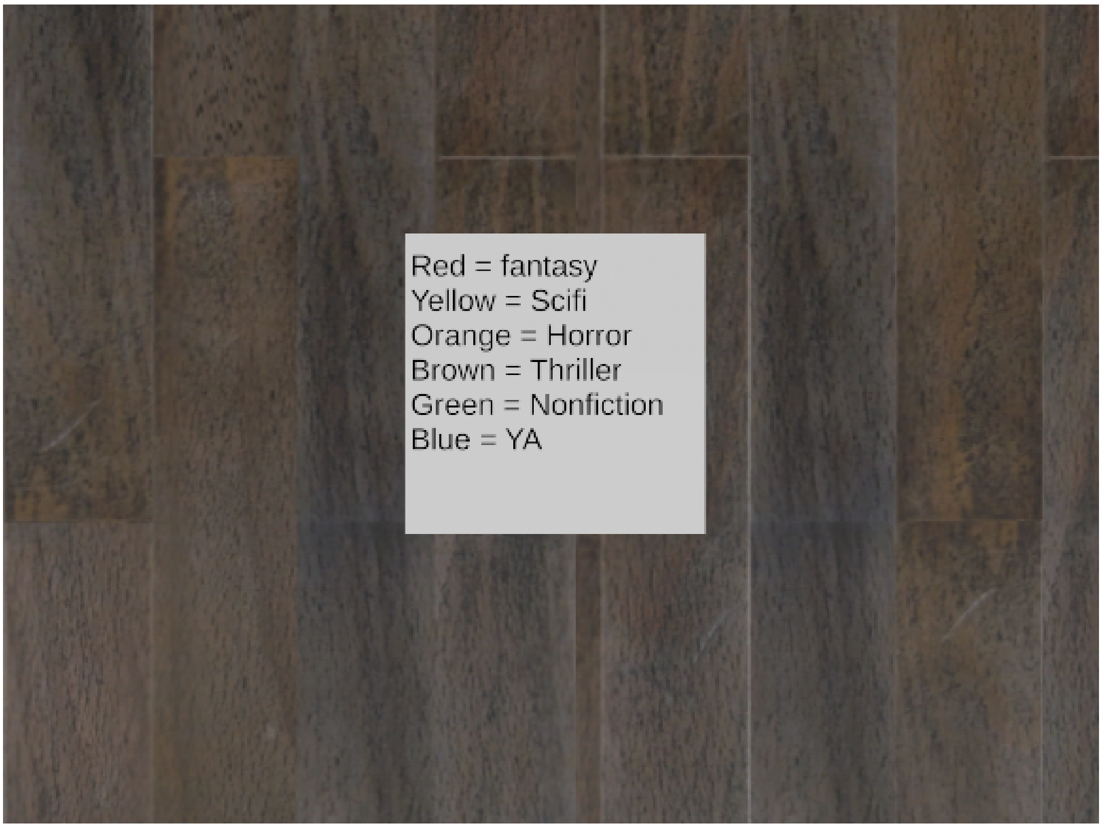

Figure 8. Poster on the wall of the library explaining the color coded bookshelves.

Figure 9. Color coded bookshelves in the library.

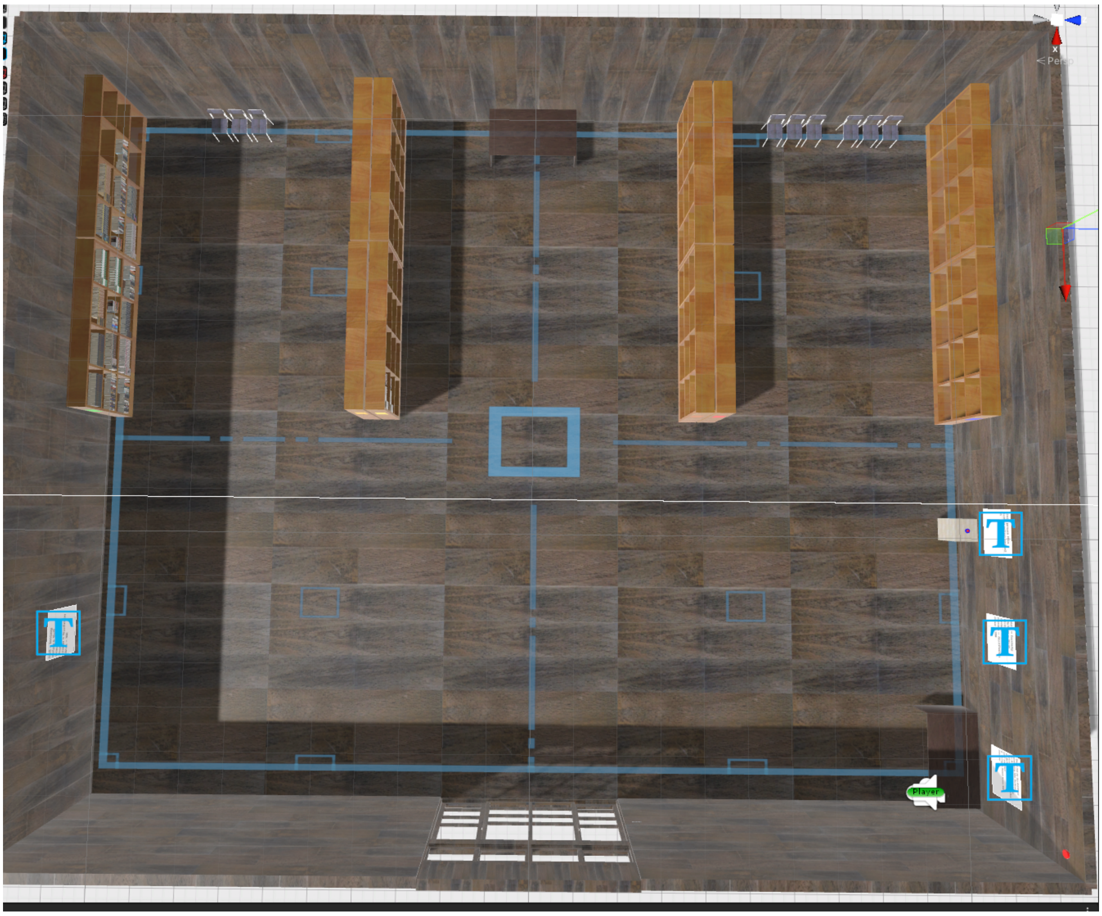

Figure 10. Library seen from the top.

4.2. Comparisons with CVD Filter Applied to the Two Environments

4.2.1. Grocery Store

Figure 11. Comparison of the store environment without the CVD filter(left) and with the filter(right).

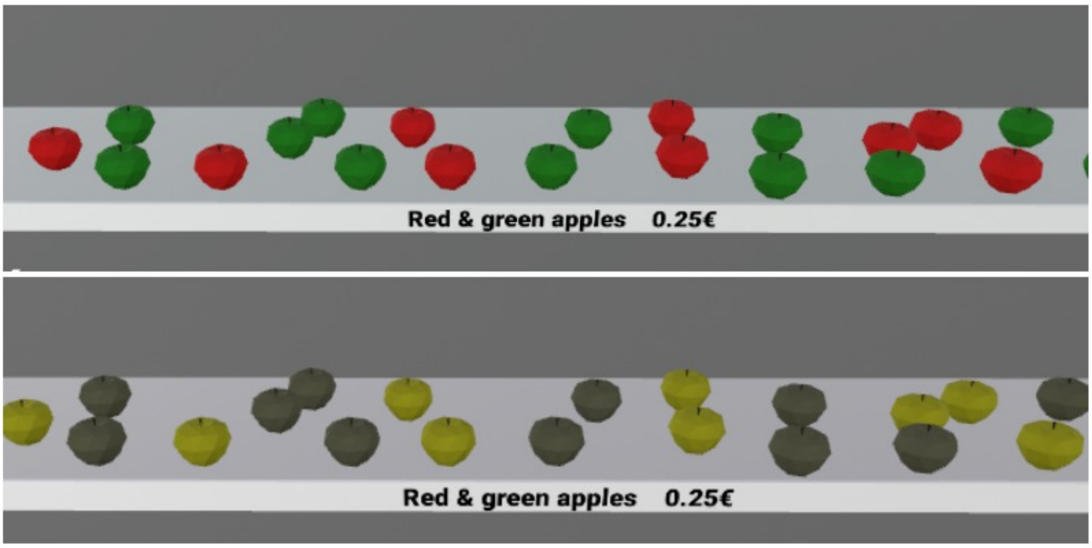

Figure 12. Comparison of the apples in the store environment without the CVD filter(higher) and with the filter(lower).

These pictures 11 and 12 visualise how much a CVD like protanopia makes life difficult.

4.2.2. Library

Protanopia clearly affects the daily situation in the library, as seen in the figures 13 and 14. The green tag indicating the section being a non-fiction section of the library can be hard to recognize with protanopia. Book designs look different and lose the design choices made by the publisher.

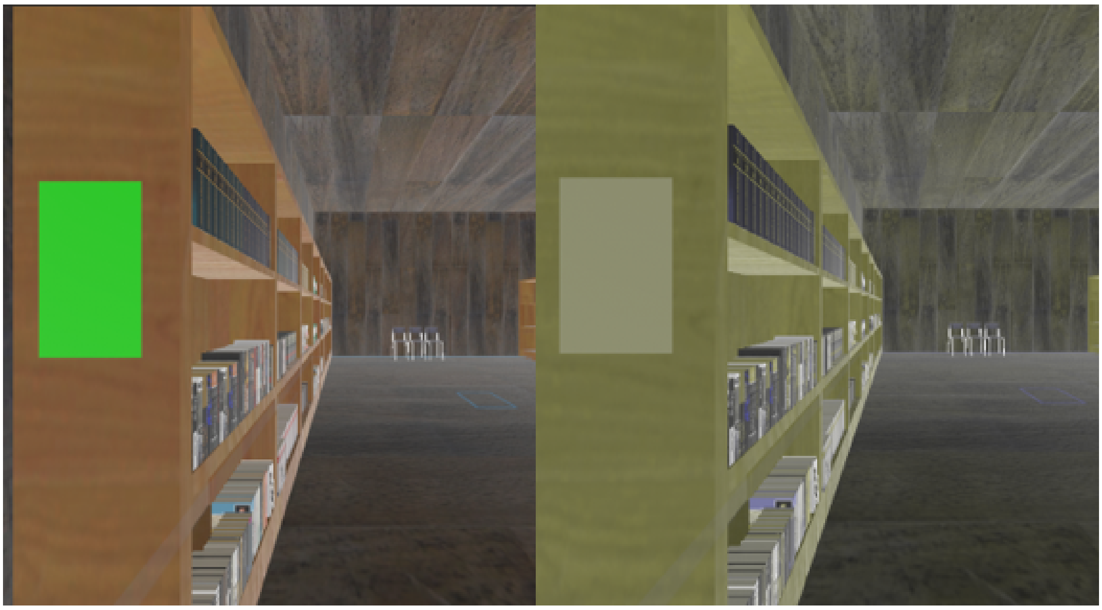

Figure 13. Comparison of the library environment without the CVD filter(left) and with the filter(right).

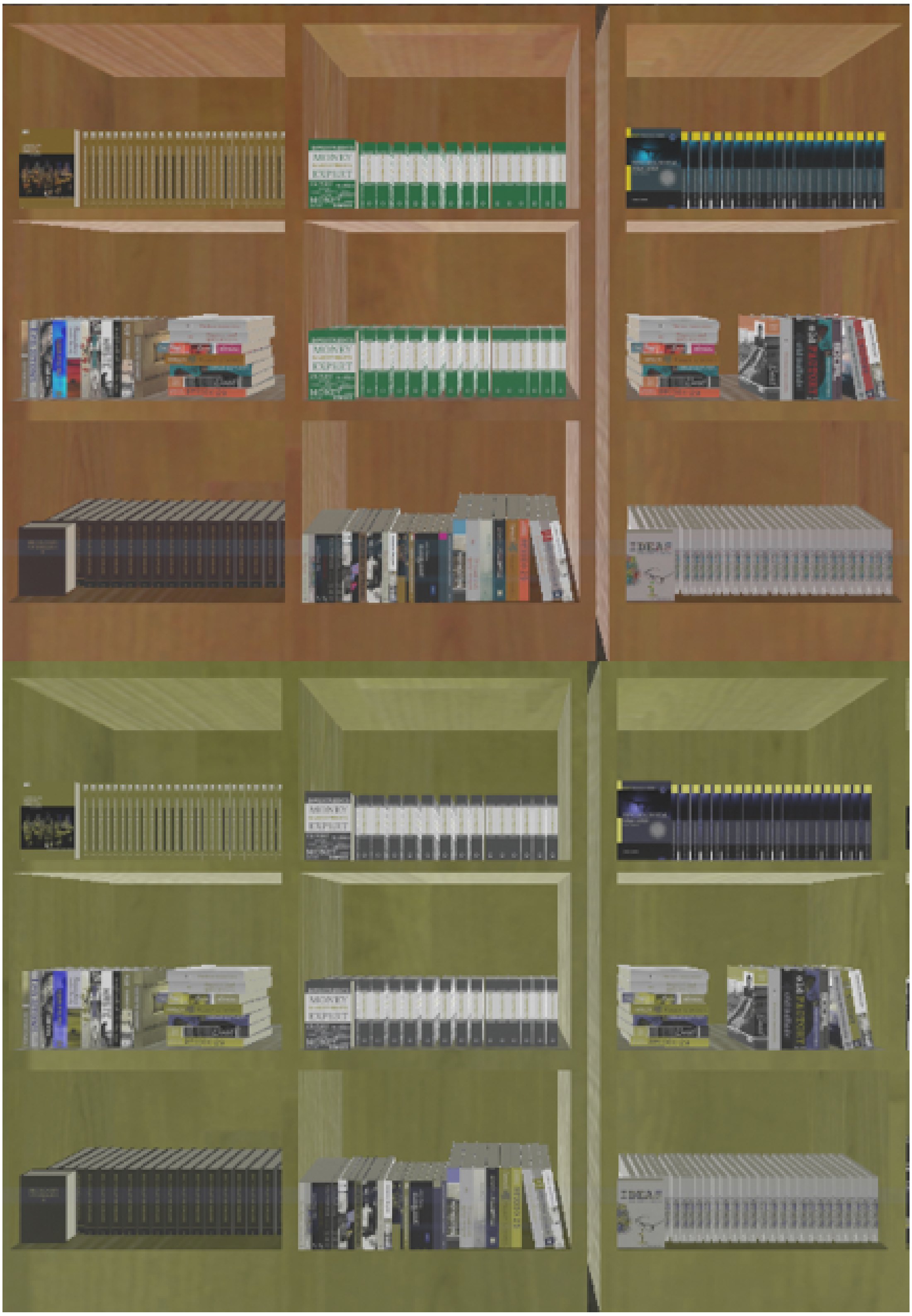

Figure 14. Comparison of the books in the library environment without the CVD filter(higher) and with the filter(lower).

4.3. Simulating Protanopia

This research requires the simulation of protanopia which is used in the VEs which can be done by manipulating the colors that the player sees. In this research, the CVD filter by Alan Zucconi [28] was used to simulate protanopia. This filter and many other applications and services uses the same method based on a research by Gary W. Meyer and Donald P. Meyer [42]. Alan Zucconi's CVD filter is based on "Color-Matrix", which is simplified a version of Thomas Wolfmaiers code, who based it on the aforementioned research [43]. This method is now considered inaccurate compared to more modern methods like presented in 'Computerized simulation of color appearance for dichromats' by Hans Brettel, Françoise Viénot, and John D. Mollon [44, 43]. Another notable modern solution is presented in 'A Physiologically-based Model for Simulation of Color Vision Deficiency' by Gustavo M. Machado, Manuel M. Oliveira;, and Leandro A. F. Fernandes [44]. Despite Color-Matrix algorithm being the oldest and most unaccurate method, it is still widely used. Only one CVD filter not using Color-Matrix algorithm was found and it was too old for unity versions used by the researchers. This led to this research using Color-Matrix based solution. This is not ideal for the accuracy of the protanopia simulation, but it was deemed serviceable.

4.4. Questionnaires

Questionnaires are asked of participants in three different parts. 1: before keyboard and mouse experience, 2: before VR experience, and 3: after VR experience The questionnaires can be found behind the link in the appendices.

- Demography question: age and sex.
- Ishihara charts CVD test [45]. According to Sydney eye hospital foundation, the Ishihara test is the best test for CVDs [46]. The full test would be too long and therefore only three charts were shown to the participants.
- A medical vision test [47]. All the participants had the same letters per eye so the test was equal.
- Empathy questionnaire The QCAE: a Questionnaire of Cognitive and Affective Empathy [48].
- NASA TLX, workload assessment tool for calculating the task load to understand what kind of an impact and toll the tasks had on the participant [49]. Tasks created by the research team:
- Write down 5 most important issues in the life of people suffering from CVD.
- Describe (sketch, annotate) as many as possible ideas for tangible products that might help people with color vision deficiencies in 5 minutes.

5. EVALUATION

5.1. Evaluation Plan

5.1.1. Experimental Setup

Figure 15. The experimental space

The space was quite small but spacious enough that participant had their own space, as seen in the 15.

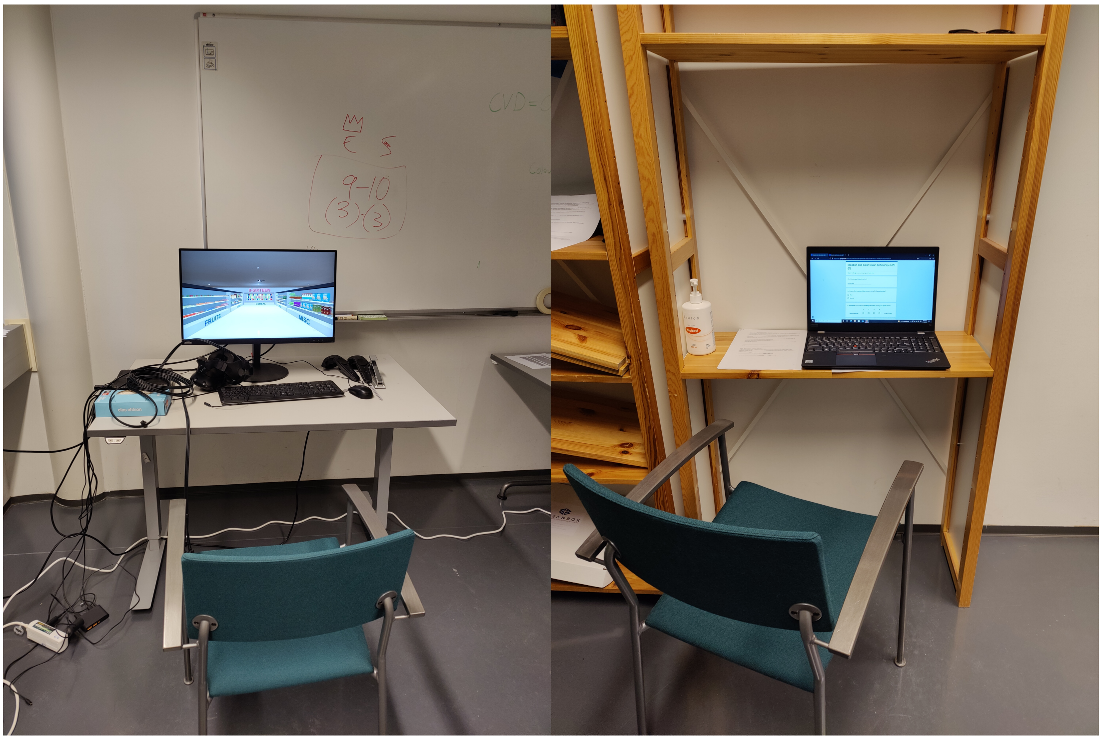

Figure 16. The computer used for the VR and on-screen experiences (left) and the computer used to the questionnaires (right)

The experimental setup includes a room with enough space for the VR experience, two tables, two computers, a chair for each table, and vision test paper on the wall. Here is the PC (left picture) where the participant played the computer game part. Here is also the laptop (right picture) where the participants filled out some questionnaires and they also sat on this bench when they filled out the tasks that were on paper.

For the vision test, the chair on the PC (left) was rotated 180-degrees to a set position 10 feet away from the wall where the test paper was attached at eye level. The room also included the required equipment for disinfecting the experiment equipment between participants.

5.2. Experimental Sequence

The experimental sequence was carefully designed, and all experiments followed it closely. This sequence can be seen in the 17.

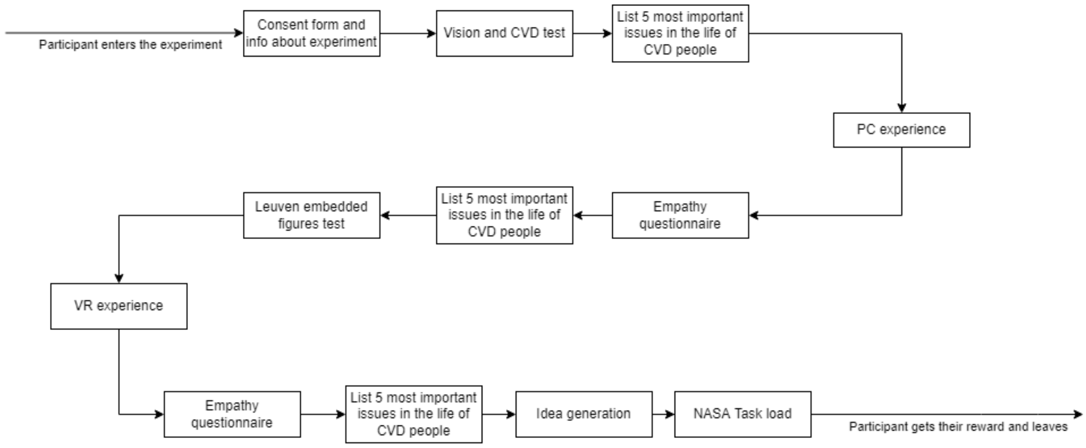

Figure 17. A diagram of the experiment procedure

5.2.1. Participants

The intended participants were university students who were not pregnant and did not have epilepsy. VR is not recommended for pregnant and epileptic people. Another subject to consider is that using the environments requires some skills to learn the simple controls. A university student that has grown up with mobile phones should be able to get to know these uncomplicated controls quickly, but not so much an older citizen. The project had 23 participants. Of the participants, 17 were male and 6 were female. Participants were good with the controls and sometimes asked questions regarding the movement and key bindings, but mostly the experimenters were simple enough so the participants understood the assignments.

5.2.2. Data Collection

This study requires a lot of data collection to answer the research questions. The only personal information gathered is the age and sex of the participants. These are gathered to see if age and sex affect the results. The data comes from the questionnaires given to the participants. The empathy questionnaire is filled out by the participants before and after the VR experience. This questionnaire gives data about the empathy level of the participants, and the effect of the experience on the empathy of the participants can be measured this way. Data about the participants' understanding of CVDs is also collected. Participants write down the five most important things people with CVDs suffer from before and after the experience. This produces data about the understanding of CVDs.

After the experience in VR, the participants write down as many product ideas as possible in five minutes. This gives data about the effect of the experience on idea generation and understanding of CVDs.

5.2.3. Empathy Questionnaire

Participants' results from empathy tests before and after will be compared. The empathy test QCEA (questionnaire of cognitive and affective empathy) includes 31 questions, and every question is answered on a 1-4 scale. The results from these questions will be added up to a cumulative sum. The sum of the two tests taken before and after the experiment can and will be unambiguously compared (RQ1). The difference will be counted by subtracting the after-experiment score from the before-experiment score, and the scores will be compared between participants.

Groups can be divided into those who were put into the grocery store VE and the library VE. The results of the different scenes can be compared to make sure the results aren't environment-based. Participants' sex will also be used to divide participants into data groups. Empathy test results before and after will be calculated for all these groups.

5.2.4. List of Identified Issues

More definitive answers on a wider variety of subjects. What the project is looking for is to get the participant inspired to come up with some good ideas for products. The written answers are more ambiguous. When a subject faces this question he starts to think what has colors and ends up with color-based interfaces like traffic lights and the toilets' vacancy sign. But they might not think that CVDs affect natural, simple things like choosing a colored can or an apple. A more common day-to-day life approach to this question after the experiment would imply a deeper understanding of CVDs caused by the experiment.

The library and the grocery store will affect the results. If the VEs are not immersive enough, the effect on empathy levels and understanding of CVDs could be minimal. These VEs are similar in layout, but use different materials and have different looks. These differences could lead to a situation where one of the VEs gives better results than the other VE. Each participant will only experience one of the environments, so the results can be compared between the VEs and it is possible to analyze the effect of each VE on the results.

5.2.5. VE Data

This research uses two different VEs, both with a screen and keyboard, as well as with VR. The participants were divided so that the same amount of male or female individuals experienced the environments. Otherwise, the VE the participant used was randomly selected. No further data was collected about the VR portion of the experiment. The researchers will take time to make sure every participant uses the same amount of time in the environment. The tasks are in the environment for deepening the understanding of CVDs of users. There is no need to collect results, whether the participant grabbed the right colored apple or a book from the right shelf.

5.3. Analysis Plan

The questionnaire of cognitive and affective empathy gives a numeric value of empathy for each participant before and after the experience in VR. The empathy value can also be divided into cognitive and affective empathies, which can be useful. The understanding of CVDs and idea generation parts can also be formatted into numeric values. The number of answers, reorderings, and additions to the "list 5 most important issues in the lives of people suffering from CVD"-question can be calculated. In the idea generation part, the number of ideas could be calculated as well as ranked by originality and practicality by the research team.

5.4. Results and Analysis

5.4.1. Research Question 1

Will the VR experience enhance empathy towards color vision deficiencies? The first VE experience on the keyboard and screen was found to be more effective than the VE experience in VR after that. Empathy levels decreased during the VR experience. The total value of empathy was calculated from affective empathy and cognitive empathy. Affective empathy decreased significantly whereas cognitive empathy did not decrease by a similar significance.

The total empathy level elicited a statistically significant decrease during the VR VE experience compared to computer screen, $M = -1.96$, 95% CI [-3.49, -0.43], $t(22) = -2.654$, $p = .014$.

Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
			Lower	Upper			
-1.957	3.535	0.737	-3.485	-0.428	-2.654	22	0.014

Figure 18. The first research question was answered by using a calculation on total empathy before and after VE experience in VR

5.4.2. Research Question 2

Will the VR experience deepen the understanding of participants towards users? The VR experience was found to deepen the participants' understanding of users with CVDs. The participants created new answers to the 5 things question and changed their previous answers after the VR experience 23 participants participated in a study to understand whether a CVD VE experience in VR would increase their understanding of struggles of people with CVDs. The VR experience elicited a statistically significant number of additions and reorderings to their original answers before the VE experience, $z = 2.54$. $p = .011$. 8 participants of the total 23 participants changed or added answers after the VR experience. All the other participants' answers stayed the same.

Total N	23
Test Statistic	36.000
Standard Error	7.089
Standardized Test Statistic	2.539
Asymptotic Sig.(2-sided test)	0.011

Figure 19. The second research question was answered by calculating the amount of reorderings and additions the participants performed after the VR experience to their original answers.

5.4.3. Research Question 3

Will the VR experience improve the idea generation outcome? Idea generation was not found to be statistically significantly affected by the VR experience.

A cumulative odds ordinal logistic regression with proportional odds was run to understand if idea generation was improved by the VR experience by the comparison of empathy before and after. Four different ordinal logistic regressions were performed, comparing either the practicality of ideas or the originality of ideas with empathy sum after VR experience or empathy sum before VR experience. This regression is done with empathy sum after VR experience and idea originality. There were proportional odds, as assessed by a full likelihood ratio test comparing the fitted model to a model with varying location parameters, $X^2(1) = 0.078$, $p = .780$. The deviance goodness-of-fit test indicated that the model was a good fit to the observed data, $X^2(55) = 49.153$, $p = .696$, but most cells were sparse with zero frequencies in 73.7% of cells. All four regressions generated similar results. The final models of all four regressions did not statistically significantly predict the dependent variable when reviewing significance values.

5.4.4. Hypotheses

Hypotheses	Test
H1: Immersive VR experience will allow the operator to gain deeper understanding and establish empathy with CVD users.	Paired-samples t-test
H2: The deepened understanding and empathy in VR should allow the operator to better identify the needs of CVD users.	Wilcoxon signed-rank test
H3: The deeper knowledge and better need identification in VR condition should lead the designers to generate better design ideas.	Ordinal logistic regression

Figure 20. The tests used for each hypothesis.

5.4.5. Additional Analysis

The participants all had good eyesight and good to great color vision. A NASA task load index-test was performed on each participant, and according to it, the participants were mentally challenged by the experiment. This was probably due to the many questionnaires and some of the interactions in the VEs. Also, the participants found that they were successful in the tasks but had to work quite hard to accomplish the level.

6. DISCUSSION

6.1. Project Findings Compared to Initial Target Setting

The project's findings did not confirm all the hypotheses. The second hypothesis was confirmed, which means that the participants were influenced by the experiments to better identify the needs of CVD users. The initial target and expectations were that the participants' empathy would increase during the VR experience, but the opposite happened. This could be because participants experienced the same VE just before on the keyboard and screen. Also, the empathy level used for the comparison was measured after the VE experience without VR. This first experience was found to significantly raise the understanding of the participants toward humans with CVDs, so it is likely that this first experience also raised the empathy levels from the baseline. The VR experience could have raised the empathy levels more from the baseline than the VE experience without VR if it was used as the first experience. The result of the second hypothesis was as expected initially. Both computer screen and VR experiences increased the participants' understanding of CVDs. The computer screen experience increased the understanding more, but this was to flatten the previous knowledge difference per participant. Therefore, the VR did not increase the knowledge as much is not that relevant. The third hypothesis was not confirmed. The first hypothesis, the empathy difference, was the biggest shock that empathy could decrease. Overall, the second hypothesis was a success, and the question that was asked three times from the participants was the correct solution. This project gained good data from that hypothesis even though some participants did not enjoy answering the same question three times.

6.2. Reflection on the Project Compared to Related Work

Chris Milk famously claimed that VR is the ultimate empathy machine [20]. Jeremy Bailenson and others came to similar conclusions [21]. The results of this project contradict their claims since the empathy levels decreased during the VR experience, even though the results are not conclusive. A computer screen seemed to be an immersive enough experience to affect empathy and understanding of CVDs. This project confirmed the effectiveness of the VR for deepening the understanding of CVDs and this could be used for different applications. The VR did not have the reported effect on the empathy of the participants, but because of how the research was structured, the results do not disprove the earlier theories about the effect of VR can have on empathy. If VR was experienced first by the participants, the participants' empathy could have been measured higher and the drop in empathy levels could have been steeper, though this is just speculation and future work is needed. The VR experience still increased the knowledge about CVDs. Therefore, this project confirms that VR is a capable tool. The related work focused on empathy, and it was the most important of the hypotheses. In some related studies, computer games were praised as a possible tool to teach and evoke emotions from the player[19]. The understanding increased a lot during the screen and keyboard game which would advocate the claims.

6.3. Future Work

Future work is needed to distinguish between the effect of a VE and the empathy difference in VR compared to a computer screen. An experiment in which participants are divided into two groups, one experiencing only the VR virtual environment and the other experiencing only the VE without VR, is required to determine whether VR has a greater impact on empathy than experiencing a VE through a traditional computer screen. The “5 most important issues in the lives of CVD people" task was filled three times by the participants. This was met with sounds of exhaustion from some of the participants, and they felt frustrated that they had to fill in the same question again. This might have been too much for the participants, and some just did not want to invent new objects to add to the list.

7. CONCLUSIONS

The project was developed to understand whether VR can be used to make people feel more empathic and understanding of color vision deficiencies when they are put in a situation where they see what the people suffering from CVDs see. The project created an experimental study to research this. Two virtual environments were created to make the simulation for the participants more realistic. Also, questionnaires were either made or established by using questionnaires from other sources. Then the results were transformed to an easily analyzable form and then analyzed with statistical computer algorithms to find whether the hypotheses were proven.

This project accomplished a successful, solid result. The positive outcome was a result of the combination of great research, planning, and execution. There were multiple related pieces the team found and studied. The virtual environments were developed accurately, and the participants could easily manage the tasks inside the VEs. Technology worked as it was meant to and the whole experiment concluded smoothly. The project had 23 good participants, which was a great turnout. Of the participants, 17 were male and 6 were female. Therefore, this project's results are inclined towards the male population, and the results do not represent the female population that well. The results were conclusive and answered every research question.

This project found that a computer screen and keyboard experience can be immersive enough to evoke a positive change in one's empathy. VR just is not effective enough to be a step above a normal computer screen experience in terms of visual simulation. Nevertheless, it was found that the VR experience increased the participants' understanding of CVD people. The understanding increased even further from the screen and keyboard experience and indicates that VR can definitely be used in an educational manner.

The initial target setting on the empathy difference was that the experience would positively add to the empathy of the participant. The related work claimed that VR would be a massive tool in enhancing empathy. This idea was refuted by the project, meaning that the empathy decreased. The team agreed that the biggest cause of this decrease was the computer screen experience.

Both experiences were expected to increase understanding, and this was confirmed. There have been suggestions in related works that computer-screen games can be excellent for teaching people about diseases. According to our findings, the VR experience improved understanding even more than the computer screen experience.

The results of idea creation refuted the hypothesis that idea generation would increase. For a large portion of the participants, idea generation did not increase significantly, and the results of this hypothesis were volatile.

In the future, the experiment could be executed by two different groups, where one group would only experience the screen and keyboard VE and be a control group, and the other group would experience only the virtual reality VE. This would create a straight comparison between a screen experience and a VR experience since the computer screen is a valid comparison point. Then the difference between a computer screen and VR could be compared when studying enhancing empathy. The questionnaires then would only have to be asked before and after the experience, so the participants might not become as exhausted by the questions.

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9. APPENDICES

9.1. Questionnaire and Contributions

https://github.com/eemelihayrynen/kandi.git

	Stage 1	
Student	**Hours**	**Contributions**
Eemeli Häyrynen	40	Project management, researching, writing, planning and communicating with the team
Severi Pitkänen	37	Setting up communications, planning, scheduling, writing and researching the subject.
	Stage 2	
Eemeli Häyrynen	80	Developing and designing store VE and writing implementation
Severi Pitkänen	80	Developing and designing library VE and writing implementation
	Stage 3	
Eemeli Häyrynen	55	Experiments, planning, writing and also communications with supervisor
Severi Pitkänen	54	Experiments and writing.
	Stage 4	
Eemeli Häyrynen	51	analyzing and discussing the results, writing and polishing the text
Severi Pitkänen	50	Analyzing the results, writing the text, and double-checking everything.
	Total	
Eemeli Häyrynen	224	
Severi Pitkänen	221	