Assessing the Impact of Design Elements on VR User's Comfort Level

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Abstract. The current state of virtual reality head mounted displays (VR/HMD) suffers from several issues that prevent wider adaptation. A key hurdle facing VR is user discomfort in the form of visual fatigue, eye strain, and related sensations. Methods for mitigating visual discomfort have been developed and implemented, however there is much to be desired. This paper explores the impact of the brightness and temperature of lighting in a VR environment. Through assessing user responses to manipulated lighting variables, this experiment will demonstrate which aspects of lighting cause a user less visual discomfort. Optimizing the temperature of lighting will reduce user discomfort, improving the overall user experience of VR.

Additional Key Words and Phrases: Human Computer Interactions, Computer Graphics, Virtual reality, User comfort, Human centered computing.

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1 INTRODUCTION

HCI researchers aim to improve the user experience of a particular device or system. When it comes to daily use or wearable devices, a prerequisite for a good user experience is the comfortability of the device. As technology has improved, devices have had more room to design with comfort in mind. As displays became more advanced, more opportunities to increase the user experience arose. As a direct result of HCI research, it was concluded that offering users an option for "Darkmode" or "Lightmode" increased the users level of comfort, and subsequently the overall experience [1]. When it comes to VR, there are some inherent limitations in terms of replicating a 3D immersive experience with a 2D display. Discomfort tends to be one of the main issues in terms of user experience in a stereoscopic 3D visual environment. Researchers have been developing methods to reduce such discomfort for years, currently many techniques for mitigating discomfort exist [10].

People tend to receive around 80 percent of information through a visual medium, making visual comfort a pivotal aspect of the user experience [[10], [20]]. Darkmode assesses the impact of grayscale lighting on a user's visual comfort in a 2D setting. The same idea has also been applied to head mounted displays and maintains validity [[1], [10]]. Applying the same logic as Darkmode to different scales, such as color temperature and brightness creates further opportunities to improve the user experience. Brightness of lighting has a direct impact on user comfortability. The effect of brightness can be seen easily in the context of reading, if the lighting is too dim, a user must strain to read the characters causing discomfort [6]. Another property of color is temperature, which refers to the specific orange/blue hue of the lighting. Blue is referred to as colder, and orange as warmer. Color temperature has less obvious effects on a user, however, the most noticeable tends to be thermal comfort. Thermal comfort is the perceived comfort of an individual in terms of warmth or coldness. Color temperature, especially in an immersive setting can affect an individual's thermal comfort, regardless of any physical changes [4]. Color temperature has a psychological effect that manifests in the real world and via display technology. Given the immersive nature of VR, color temperature has an enhanced impact when compared to a 2D display [[11], [19]].

The impact of ambient lighting has been studied since before the advent of VR. Many intuitively understand that some lighting is better than others. If given a choice between buzzing, flickering office lights and natural lighting, most people would choose the latter. Not only do people prefer natural light, but it has a positive impact on the wellbeing of an individual [15]. Interestingly, running parallel instances of a lighting experiment, one in VR and one in a physical office setting yield very similar results. An experiment conducted on wall color and how it impacts thermal comfort of occupants was replicated in an identical office space modeled in VR. The fact that both of these experiments produced very similar results validates VR as a useful tool for conducting such research [[11], [2]]. Following this logic, lighting in a stereoscopic 3D environment retains similar interactions with an individual as it does in the material world. Understanding this idea opens up countless avenues to improve lighting in VR environments. Research regarding color temperature and brightness will also apply in the context of a VR head mounted display.

The goal of this paper is to explore the impact of color temperature and brightness on a VR user's comfort levels. Color temperature is the level of perceived warmth in the hue and brightness is the intensity of the light [13]. Building off of previous research regarding lighting and applying it to a stereoscopic 3D environment will provide insight into what makes a user comfortable. Building an understanding of how these specific design elements impact a user allows for further refinement of VR environments. With an improved ability to understand how to design the ideal environment, the potential for discomfort in users is reduced, improving the overall experience.

2 RELATED WORKS

2.1 Visual Perception

When it comes to human perception, or our ability to make cognitive contact with the of the material world, eyesight is by far the most used and subsequently the most important sense. Research has demonstrated that about 80 percent of perceptual information is received by the visual cortex [[20], [5]]. VR aims to replicate a 3D environment with solely vision. One of the main hindering factors of creating quality VR is making sure that nothing interferes with the user's eyes' ability to focus and their line of sight to converge on a point [7]. Understanding how specific design elements involving lighting impact the visual perception of the user is necessary in order to reduce discomfort. Although methods currently exist for reducing visual discomfort in VR, there is always room for improvement, especially given the commonality of user discomfort in VR [10]. Visual perception is complex and in the current state of VR not enough emphasis is placed on optimization. Prioritizing visual comfort is a key component of creating a better overall VR experience.

2.2 Darkmode

When using a display to interact with a device, a baseline expectation is that using said display does not cause the user discomfort. The concept of darkmode exemplifies this idea well in the context of HCI. Over time it was observed that users complained about eye strain or fatigue when it came to looking at a bright white screen all day, especially in a low light setting. Developers addressed this issue by beginning to implement an alternative mode in which the text and background color were reversed. This mode has become colloquially referred to as "dark mode" and exists in most software nowadays [9]. Dark Mode focuses on grayscale lighting and how to optimize the lighting based on the setting in order to reduce eye strain and fatigue. Although the development and inception of dark mode was in a 2D context, it can be effectively applied in a 3D context as well. Dark mode or more specifically the manipulation of grayscale lighting values in a 3D stereoscopic head mounted display can effectively be used to reduce visual fatigue and eye strain [1]. Extrapolating on this idea presents the opportunity to optimize other properties of lighting in VR to reduce visual discomfort and improve the overall VR experience.

2.3 Brightness' Effect on Stress

The amount of light changes the way people perceive an environment. Brightness in an environment has been shown to have an effect on comfort and stress levels of people. The more light the safer people tend to feel. This is thought to be because the amount of light increases the user's perceived awareness of their surroundings. This has been shown by measuring both physiological data as well as using questionnaires about their experience in virtual reality [3]. It is pertinent to understand if different aspects of light, such as temperature, affect stress and their feeling of safety as well to gain a full understanding of how light affects comfort.

2.4 Light Temperature Effect in the Real World

Light temperature is considered an important aspect of design when using LED lights in real world environments. It has been shown that lower levels of light temperature are considered more comfortable for relaxation while higher levels are considered more comfortable for working conditions. This was shown even through the cultural differences between Asia and Europe/America showing this is not just a cultural convention [17]. It would be valuable to translate these findings into a virtual environment in order to optimize that medium's sense of comfort. This is further supported by a study by Tomoaki Kozaki that after studying the effects of light on melatonin production found that light intensity had a significant effect [14]. Showing how changes in light can have physiological effects on the body.

2.5 Measuring Comfort Within VR

Previous research has used surveys to measure comfort [[12], [18]]. This has been the case in many studies of a variety of topics both within and outside of VR [[12], [16]]. Critics of this method point out it is subjective and while this is true, it has been shown that there are physiological signs of discomfort that match reported discomfort [[12], [8]]. Since we do not have a large amount of resources it is preferable to use a survey to measure comfort as it is easy with very little loss in accuracy. Surveys about comfort within VR often include questions pertaining to visual fatigue, vertigo and headaches as well as general questions about comfort [6].

3 METHODOLOGY

3.1 Participants

Participants were recruited from the general population. A total of 20 participants were selected for this experiment. The participants were informed about the experiment, its purpose, and the VR technology involved. They were asked to sign a consent form and given an initial survey to collect demographic data before starting the experiment.

Figure 3.1: The Meta Quest 2 headset used to run the VR experiment

Candle Light	Incandescent bulb	Sunset	Morning/afternoon light	Daylight at noon	Full Sun	Overcast sky
1500	2680	3200	4200	5500	6500	7500

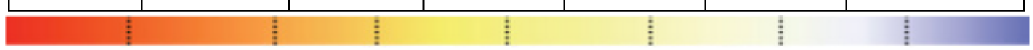

Figure 3.2: Table showing day to day color temperature range

3.2 Setup and Equipment

The VR headset used for the experiment was an Oculus Meta Quest 2. The VR environment was developed in Unity, and the application was run on a laptop. An initial VR room was designed and subsequently altered into 6 total environments, each with altered lighting temperature values.

3.3 Procedure

The experiment was conducted in a quiet room with a comfortable chair and adequate lighting. The participant was seated in the chair, and the VR headset was adjusted for comfort (reference figure 3.3). The participant then spent 60 seconds in six simple VR rooms with different light source temperature values (2000, 3000, 4000, 6000, 8000, and 10000 Kelvin). Each room will be randomized to avoid order effects. A general overview of experiment procedures is as follows:

1. Participant fills out consent form
2. Participant fills out initial survey

Figure 3.3: Experiment Setup

3. Participant puts on headset and adjusts until comfortable
4. Participant is informed of how the experiment will run
5. Participant is tasked with reading the chart on the wall
6. Participant is asked survey questions
7. Participant is asked to move to the next room
8. Repeat steps 5 - 7 for the rest of the rooms
9. Participant takes the post-experiment survey

3.4 Measurements

During the experiment, the following measurements were collected:

- General Discomfort
- Fullness of Head/Pressure
- Difficulty Focusing
- Eyestrain
- Fatigue
- Blurriness

Figure 3.4 - 3.9: This figure shows the 6 VR room variations with the color temperatures range of (2000, 3000, 4000, 6000, 8000, and 10000 Kelvin). The lower the Kelvin temperature the warmer (more orange) color white produced. (Refer to section 3.3)

For each room the participants were asked to rate the above variables on a scale of 1-5, with 1 being experienced very little to none of the variable in question and 5 being experienced very much of the variable.

3.5 Survey

After the participant completed all six VR rooms, they were asked to complete a short survey. The survey consists of the following questions:

1. How would you rate your overall comfort level during the VR experience?
2. Did you experience any visual discomfort or eye strain during the VR experience?
3. Did you notice any differences in your comfort level based on the lighting temperature in the VR rooms?
4. Considering your experience, which rooms lighting temperature did you find most comfortable?
5. Do you have any additional comments or suggestions for improving the VR experience in terms of lighting conditions?

For questions 2 and 3 participants that answered yes were also asked to elaborate on their experiences.

3.6 Data Analysis

The data collected during the experiment was analyzed using descriptive statistics (mean, standard deviation, etc.) and inferential statistics (ANOVA) to identify any significant effects of the light source temperature on and the measured variables. Blurriness was left out of the analysis as many users had vision impairments and were not allowed to use visual correction tools which would add unnecessary confounding variables.

3.7 Ethical Considerations

Participants' privacy and anonymity was ensured. The data collected during the experiment was used only for research purposes and was not shared with any third parties. Possible effects of participating in the experiment were disclosed in the consent form provided as well. Participants were informed about their right to withdraw from the study at any time without any penalty.

4 RESULTS

4.1 Descriptives and ANOVA

Table 1. Mean ratings of various types of discomfort with respect to each room

	General Discomfort	Fatigue	Eye Strain	Difficulty Focusing	Head Pressure
Room 1	1.8	1.5	1.7	1.5	1.4
Room 2	2.0	1.7	1.9	1.6	1.6
Room 3	1.7	1.4	1.6	1.4	1.4
Room 4	1.6	1.5	1.9	1.9	1.6
Room 5	2.0	1.5	2.3	1.7	2.0
Room 6	2.0	1.9	2.2	1.9	1.5

Table 2. Standard deviations of various types of discomfort with respect to each room

	General Discomfort	Fatigue	Eye Strain	Difficulty Focusing	Head Pressure
Room 1	1.398	1.080	1.252	0.972	0.516
Room 2	1.633	1.059	1.101	0.966	1.265
Room 3	1.494	1.265	1.265	0.966	0.843
Room 4	1.265	1.269	1.287	1.663	1.265
Room 5	1.247	0.707	0.823	1.160	0.707
Room 6	1.414	1.101	1.033	1.101	0.707

The results of the experiment suggest that lighting temperature has a limited effect on user discomfort in a VR environment. The one-way ANOVA revealed non-significant differences between lighting temperatures and the measured variables of Fullness of Head/Pressure, Difficulty Focusing, Eyestrain, Fatigue, and General Discomfort. However, the survey results showed that the majority of participants (80%) preferred warmer lighting temperatures, with a smaller number of participants indicating no preference or preferring cooler, bluer lighting. Further analysis revealed that the preferred lighting temperatures were in the range of 2000 to 4000 Kelvin, with rooms 1-3 being the most preferred.

Table 3. One-way ANOVA results on participants ratings of various types of discomfort split by lighting temperature

Discomfort Type	F	df1	df2	p
Fullness/Pressure	0.089	5	24.827	0.993
Difficulty Focusing	0.299	5	25.110	0.909
Eyestrain	0.618	5	25.072	0.688
Fatigue	0.253	5	24.963	0.934
General Discomfort	0.153	5	25.167	0.977

One possible explanation for these results is that the effects of lighting temperature on user comfort in VR may be overshadowed by other factors, such as display resolution, field of view, or the amount of time spent in the virtual environment. Additionally, the limited sample size of 10 participants may have contributed to the lack of significant findings. Future research with larger sample sizes could provide more insight into the impact of lighting temperature on user comfort in VR. There is a large reason to believe that our surveying is insufficient to produce statistically significant results. 80% of our participants preferred the color temperature range of 2000 to 4000 K which aligns with data from another study surveying preferred color temperature ranges [17]. Therefore it is possible that our survey was not optimized to gather data comprehensive measures on how the variables affect comfort levels. Further improving the survey could shed more light on how color temperature interacts with our tested variables. Overall the mean and standard deviation numbers looked quite normal. The mean numbers were all within 1 - 2 with no outliers. The standard deviation numbers were all with in 0.5 - 1.5 with no outliers. The ANOVA results support these outcomes with no statistically significant p values below 0.05. The post-experiment survey results show that the participants overwhelmingly reported some level of visual discomfort or eye strain during the experiment. There was also a preference for the warmer rooms as stated earlier.

5 CONCLUSION

In conclusion, the findings of this study suggest that lighting temperature has a limited effect on user discomfort in a VR environment. However, the majority of participants preferred warmer lighting temperatures, which may have implications for the design of VR environments. Specifically, designers may want to consider using lighting temperatures in the range of 2000 to 4000 Kelvin and focusing on other design factors, such as display resolution and field of view, to improve user comfort in VR. This is consistent with other research as Arianna Latini reported that participants will have a preference of wall color while reporting no significant changes in comfort [11].

One observation aside from the intention of this experiment included physical discomfort from the headset itself. One participant complained about how the headset was too tight despite the straps being as loose as they could be. Factors such as these were not taken into consideration in the design of the experiment. Given another chance to conduct the trials we would ensure that the headset was either high enough quality to not cause any discomfort, or ensure the participants would be able to comfortably wear the headset before conducting the experiment. To make sure of this we would include a try-on session in the initial survey to guarantee the headset fits properly. Doing this would potentially eliminate any confounding variables related to the physical discomfort of using a VR headset.

It is important to note that this study has limitations, including a small sample size and the possibility of other factors influencing user discomfort in VR. Future research with larger sample sizes and more comprehensive measures of user discomfort may provide a more nuanced understanding of the impact of lighting temperature on user comfort in VR.

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