Supporting Individuals with Photophobia in VR: A Case Study of *VR Shades*, an Accessible VR Application Feature Prototype

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ABSTRACT

Virtual reality (VR) is a predominantly visual medium, which can be challenging for individuals with visual disabilities. This is especially true for people with photophobia (i.e., light sensitivity), as brightness controls are mainly unavailable in VR applications. To address this inaccessibility, the authors developed *VR Shades*, a prototype VR application feature allowing users to modify visual light transmission (VLT) in VR applications. Huth participated in the case study; she has lattice degeneration, which led to dual retinal detachments. After surgical intervention, she experienced many permanent visual changes, including extreme photophobia. The study sought to understand if *VR Shades* could increase VR accessibility by providing VLT-level controls within the virtual environment. Results indicate that *VR Shades* can increase VR usage while decreasing recovery time. These findings contribute to the emerging field of accessible VR research, indicating that simple features can significantly impact people who find current VR technologies inaccessible.

Keywords: Virtual reality, VR, accessibility, visual disability, visual light transmission, VLT, light sensitivity, photophobia.

Index Terms: Human-centered computing → Accessibility → Accessibility technologies—Virtual Reality

1 INTRODUCTION

In 2016, Oculus released the first modern commercially available virtual reality (VR) system. Since that time, VR technology and usage have experienced significant growth while also revolutionizing entertainment [7, 8, 10], socialization [1, 4, 15], and the workplace [5, 20, 21]. However, due to VR being primarily a visual technology, it can be inaccessible to individuals with visual disabilities who may find the technology challenging or impossible to use [26]. While research into VR for people with visual disabilities exists, it is primarily focused on individuals who are blind [6, 14, 27] or individuals with low vision [2, 11, 28]. In contrast, studies exploring VR accessibility for individuals with photophobia (extreme light sensitivity) are virtually nonexistent, and VR researchers typically used photophobia as an exclusionary criterion [12] due to the potential complications.

Photophobia is a commonly diagnosed symptom of many medical conditions (e.g., migraines, dry eye, post-concussion syndrome, ADHD, fibromyalgia, meningitis) [18, 19]. Individuals with photophobia can experience multiple symptoms caused by visual light exposure, including eye pain, eye fatigue, migraines, nausea, and dizziness [18, 19]. As a result of the minimal support for modifying the brightness in VR applications, individuals with photophobia may be unable to experience VR fully. This potential inability to use VR is problematic for many reasons, including socializing, working, exploring, learning, and accessing health care [26], which can affect a person's quality of life. However, the authors argue that employment is the highest concern due to the increased usage of VR in the workplace [3, 9, 17] and the historical underemployment of people with disabilities [13].

This knowledge gap and need were highlighted when the authors of this study met while participating in a panel discussing an accessible Metaverse [23]. Huth, who has lattice degeneration that led to dual retinal detachments, described her inability to use VR for any significant time due to her extreme photophobia. For Huth, using VR applications or even completing the initial setup of the Meta Quest 2 VR system, which takes approximately 20 minutes, could lead to hours of experiencing photophobia symptoms: nausea, dizziness, eye pain, and eye fatigue [18, 19]. The longer Huth spends in a single VR session, the greater the probability and severity of experiencing symptoms, potentially requiring staying in dark environments with limited movement for the rest of the day.

After discussing the impact of photophobia on human health and its corresponding limitations with VR, the authors agreed that more customizable options in virtual environments were needed to better support disabled users. Combining Gluck's VR development and research background with Huth's personal experience as a user with extreme photophobia, we began co-designing a solution.

2 METHOD

The authors employed Google's Start with One, Invent for Many [24] methodology for developing and evaluating the *VR Shades* accessible VR application feature prototype.

2.1 VR Application Feature Design and Development

2.1.1 Design

During the "define phase" of the Start with One process, it was clear that the solution needed to be designed to support usage within any VR application rather than just creating one VR application that accommodated individuals with photophobia. Additionally, this solution needed to modify the visual light transmission (VLT) and needed to support a range of users with photophobia by allowing for customization of VLT levels within the VR head-mounted display (HMD). Considering these conditions, the authors designed the *VR Shades* accessible VR application feature to be a standalone asset that developers can add to any VR application. *VR Shades* provides 11 different levels of simulated digital VLT lenses (Figure 1), supporting the needs of all users by providing VLT levels ranging from letting all light through to nearly opaque.

2.1.2 Development

Gluck developed *VR Shades* in Unity 2022 [25] and built for the Meta Quest VR platform [16]. Coding was written using C#. The asset was developed to modify the opacity levels (alpha level) of a game object, using a black transparent material, placed in front of the user's virtual point of view, which changes the VR application's VLT levels. As precise VLT levels were unobtainable during development, initial opacity levels were selected to create a flow of diminishing light intensity ranging from 0% (transparent) to 99.8% (nearly opaque) (Figure 1, 2). Users can decrease the VLT (increasing *VR Shades* level) by holding the right controller to the

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HMD and pressing the right Touch trigger. Holding the left controller to the HMD and pressing the left Touch trigger increases VLT (decreasing *VR Shades* level). The shade level was developed to resemble wearing and swapping sunglasses with differing tints to increase or reduce light transmission.

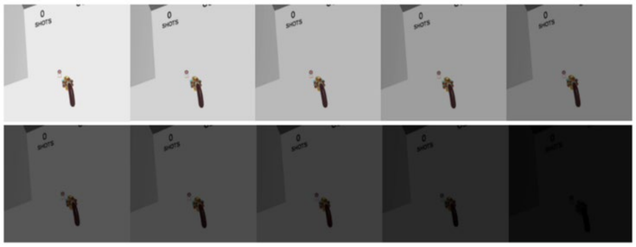

Figure 1. *VR Shades* shade levels 1 to 10

Due to *VR Shades*' development as a standalone asset, a separate VR application was designed and developed to incorporate the *VR Shades* feature, provide a virtual testing environment, and record application data. A simple VR shooting gallery environment was developed where the user shoots at a virtual target. When the target is hit, it deactivates, then moves to a random location and reactivates. The application contains a timer, the score, and the total shots fired (Figure 2).

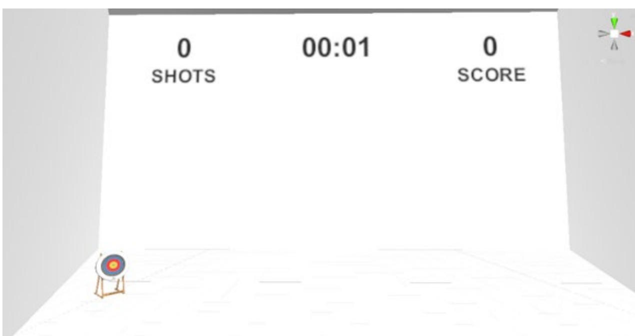

Figure 2. Virtual shooting gallery environment. Shade level 0.

2.2 Participant Background

2.2.1 Visual Background

In December 2009, Huth was diagnosed with lattice degeneration in both eyes, resulting in both retinas detaching. The detachments led to a series of four surgeries that included scleral buckling and a vitrectomy. She experiences permanent visual complications, including reduced visual acuity in the right eye, extreme light sensitivity (photophobia), double vision, and reduced peripheral vision. In addition, she experiences ongoing visual flashes and continuous vitreous opacities (floaters).

2.2.2 VR and Vision Loss Background

As part of her work, Huth needs to use VR technology. While testing the HMD, she noticed she could not be in an immersive environment for more than a few minutes due to light intensity and nausea. The virtual environments were all bright, cluttered, and difficult for her to navigate. She often missed critical information, such as navigation menus and objects that were placed outside her visual field, without in-application indications that they existed.

2.3 Testing Setting

Huth conducted the sessions in her apartment in the mornings. Mornings were selected as this is when she feels her vision is strongest.

2.4 Apparatus

Huth used the Meta Quest 2 VR system to conduct the case study. The VR shooting gallery application with the *VR Shades* accessible VR application feature was installed via SideQuest [22].

2.5 Data Collection

Data from the trials, one for each *VR Shades* level, were collected in two ways: in the VR shooting gallery application and via a journal-style spreadsheet. The application recorded the date, start time, total play time, *VR Shades* level, total score, and total shots fired for each session in a text file. In the journal-style spreadsheet, Huth recorded the date, music in the background, *VR Shades* level, recovery time, photophobia symptoms, and overall session notes.

3 Findings

Two data types were collected during this case study: objective and subjective. The VR shooting gallery-style application collected objective data, including the date, start time, total play time, *VR Shades* level, total score, and total shots fired. Additionally, Huth recorded the date, *VR Shades* level, music playing in the background, and recovery time in the journal- style spreadsheet. Huth also recorded subjective data in the form of photophobia symptoms and additional notes describing experiences from the session. Table 1 presents the recorded objective data related to the overall session. (Some sessions were duplicated due to a lack of visual or auditory information regarding which *VR Shades* level was selected. Table 1 only presents the data collected from the first session for each *VR Shades* level.)

Table 1. Non-game interaction objective data collected via VR application and recorded by Huth.

Date	Start Time	Time in VR (seconds)	*VR Shades* Level	Opacity %	Recovery Time (minutes)
3/23/2023	8:21 am	172.9	0	0.0%	10
3/25/2023	10:12 am	222.2	1	17.5%	7
3/28/2023	8:38 am	449.6	2	35.0%	< 1
3/29/2023	9:05 am	263.4	3	50.0%	7
3/30/2023	8:56 am	591.3	4	65.0%	0
3/31/2023	11:19 am	684.8	5	80.0%	0
4/3/2023	8:45 am	568	6	90.0%	0
4/4/2023	9:43 am	497.7	7	92.5%	0
4/5/2023	9:56 am	258.7	8	95.0%	0
4/6/2023	9:56 am	210.5	9	97.5%	0
4/7/2023	8:57 am	408.7	10	99.8%	< 1

Based on the overall session information, glancing at the amount of time in VR per session data resembles a bell curve. The resulting bar graph of VR session usage is presented in Figure 3. Time in VR (excluding the two outliers) has a median of 684.8 seconds and is negatively skewed ($M = 393.4$, $SD = 177.6$).

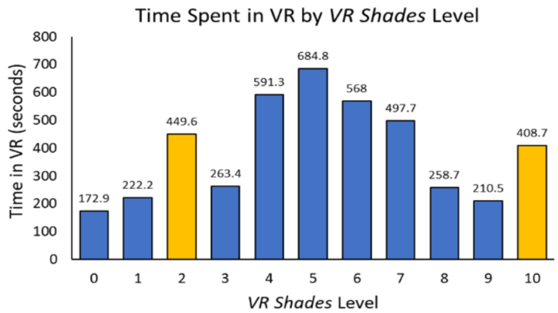

Figure 3. Bar graph of the time, in seconds, Huth spent in VR for each shade level. (Outliers denoted in yellow.)

The remainder of the objective data collected relates to interactions within the VR shooting gallery application. This data includes the total score and shots fired while playing the VR application. This data was used to calculate overall accuracy at each *VR Shades* level by dividing Total Score by Total Shots (Table 2).

Table 2. Game interaction objective data captured by application.

Date	*VR Shades* Level	Total Score	Total Shots	Accuracy % (calculated)
3/23/2023	0	17	56	30.36%
3/25/2023	1	37	67	55.22%
3/28/2023	2	81	131	61.83%
3/29/2023	3	53	67	79.10%
3/30/2023	4	114	153	74.51%
3/31/2023	5	146	172	84.88%
4/3/2023	6	120	153	78.43%
4/4/2023	7	102	134	76.12%
4/5/2023	8	50	73	68.49%
4/6/2023	9	37	65	56.92%
4/7/2023	10	64	117	54.70%

As with the time in each session, shooting accuracy data seems to resemble a bell curve. The shooting accuracy bar graph by *VR Shades* level is presented in Figure 4. Shooting accuracy has a median of 84.88% and is negatively skewed (M = 65.51%, SD = 15.73%).

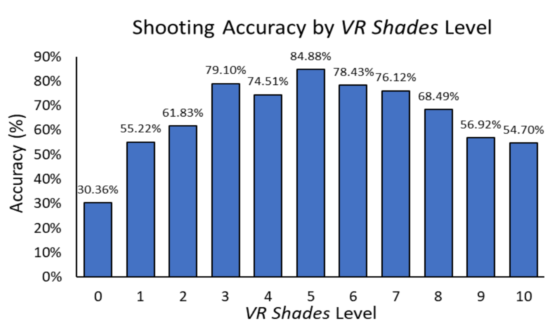

Figure 4. Bar graph of the shooting accuracy, in percentages, recorded by the application for each shade level.

In addition to the objective data collected and recorded, Huth recorded subjective data at the conclusion of each session. This data provided detailed information about how the session for a given *VR Shades* level affected photophobia symptoms and overall notes regarding the session. The subjective data is presented in Table 3.

Table 3. Subjective data recorded by Huth after each session.

Date	*VR Shades* Level	PS	Notes
3/23/2023	0	Nausea	• Nausea came from looking for the target. • Harder to hit target with right gun. • Stuffy nose may have contributed to feelings of nausea.
3/25/2023	1	Nausea	---
3/28/2023	2	Nausea	• Discovered it's hard to stay stationary and hit targets in certain zones. I need to move my body.
3/29/2023	3	Nausea	• Got into the game so I moved more. • Eyes didn't hurt because brightness nausea started.
3/30/2023	4	Eye Fatigue	• Harder to be accurate – target hitting was easy, but hitting center was harder/less discernible.
3/31/2023	5	Eye Fatigue	• Left eye tired from being in game.
4/3/2023	6	None	• I left because eyes squinting, but otherwise fine.
4/4/2023	7	None	• Too dark. • Saw all lights in head. • Bright halo where old target was, and double vision happened.
4/5/2023	8	None	• Too dark. • Too much double vision!
4/6/2023	9	None	• Too dark. • Accuracy awful and double vision/halo very bad.
4/7/2023	10	Nausea	• Too dark, but double vision/halo went away. • Had to move around so much to find target I got nauseous. • Could play if accuracy wasn't a factor.

(PS – Photophobia Symptom)

4 Discussion

4.1 Huth's VR Experience pre-*VR Shades*

Huth began using VR in 2022 to enhance her understanding of the accessibility features present in HMDs and to learn if the technology could support remote work. Her initial attempts led to extended periods of nausea and hesitancy to return to VR environments due to painful and lengthy recovery times. Despite this, Huth's experience using an art application inspired her to continue trying to find ways she could use the technology. She found the art application's features allowed her to immerse herself in customized digital content and sparked creativity that led her to want to use VR again.

4.2 Implications from the Case Study

The findings based on Huth's experience using the *VR Shades* accessible VR application feature during this case study anecdotally show that *VR Shades* can positively impact VR usage by a person with extreme photophobia. Except for two outliers (*VR Shades* levels 2 and 10), the data demonstrates that Huth experienced an increase in how long she could spend in the VR shooting gallery application and increased accuracy until *VR*

Shades level 5, where time and accuracy began to decrease (see Tables 1 and 2). Thus, based on the collected data, Huth should play the application using shade level 5 for optimal time and accuracy in VR. Additionally, *VR Shades* level 5 did not result in the photophobia symptom of nausea, resulting in no time required to recover from her VR session.

Regarding recovery time, *VR Shades* levels 4 to 9 provided Huth with no recovery time, and levels 6 to 9 resulted in her experiencing no photophobia symptoms. Additionally, nausea reported at levels 3 and 10 could have resulted from VR sickness (i.e., cybersickness), which can result from movement within a virtual environment. Huth reported more movement in her notes at these levels.

These anecdotal findings suggest that individuals with photophobia using VR may benefit from being able to select from a series of virtual VLT lenses to create an optimal visual VR environment. Setting granular VLT levels via the simple shade level selection method allows the user to constantly modify the VLT levels as needed throughout the VR experience. These aspects of the *VR Shades* VR application feature have the potential to increase time spent in VR while decreasing symptoms for individuals with photophobia.

4.3 Huth's VR Experience Using *VR Shades*

Early in the testing phase, Huth found it difficult to want to enter the VR environment due to the symptoms she experienced. She found that she was hesitant to move too much to avoid triggering nausea, as had been an issue in prior attempts to use experience-based VR applications.

After completing the brightest levels of the *VR Shades* application, Huth began to enjoy the experience. As the brightness matched her visual comfort level and photophobia symptoms reduced, she could focus on hitting the target accurately. This enjoyment and focus dissipated once the darker shades enhanced the light flashes and halo effect she often experiences when navigating dim environments.

4.4 Limitations and Future Work

4.4.1 Limitations

The authors understand that the major limitation of this case study is having a single participant who is also a co-designer of the VR application feature. Google's Start with One, Invent for Many [24] methodology is explicitly designed to work in this format. Additionally, the case study would have benefitted from a better design of the journal-style spreadsheet in which subjective findings were recorded. A journal with specific questions and selections would have resulted in better, more consistent subjective data. Finally, the modification of VLT via the shade levels was based on differing opacity levels rather than actual VLT levels. This method may have resulted in a non-linear progression of the percentage of visual light being transmitted to the user.

4.4.2 Future Work

The research team plans on continuing our work on the *VR Shades* accessible VR application feature and will build upon the anecdotal results from this initial case study. A subsequent study aims to recruit participants with and without photophobia to establish an empirical relationship between VR usage time, *VR Shades* level, and eye pain, eye fatigue, migraines, nausea, and recovery time. A third study will then explore how individuals with photophobia are affected by or benefit from other VR visual accessibility features, such as those explored by Microsoft Research for individuals with low vision [28].

Additionally, Gluck will design an Arduino system project using a light-intensity illumination module to measure and record VLT levels accurately while using different *VR Shades* levels within the HMD. This information will be used to create a linear progression of the percentage of visual light being transmitted to the user through the *VR Shades* accessible VR application feature's 11 levels of simulated digital VLT lenses.

The authors anticipate finding that using *VR Shades* will increase VR usage with reduced photophobia symptoms and shortened recovery periods from these symptoms for individuals with photophobia and that users of *VR Shades* will report less eye strain and fatigue.

5 Conclusion

This case study describes the design, development, and initial evaluation of the *VR Shades* accessible VR application feature. Using Google's Start with One, Invent for Many [24] process, the authors co-designed the feature, which is intended to provide in-VR accommodation for individuals with photophobia. Anecdotal evidence from an evaluation of the different shade levels suggests that *VR Shades* can increase time spent in VR and virtual interaction accuracy while decreasing photophobia symptoms and recovery time for individuals with photophobia.

The authors believe that VR accommodations for people with disabilities are essential, primarily due to VR's increasing usage in the workplace. While additional research is necessary, the authors believe that those with and without photophobia could benefit from having access to customizing the visual light transmission levels of VR applications.

Acknowledgments

The authors wish to acknowledge Cadmus, Dr. Shikha Mehta, Dr. Hannah Solini, Elizabeth Kagan, and Martina Fongyen. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of Cadmus, Dr. Mehta, or Dr. Solini.

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