What Do They See?: Simulating Visual Field Loss to Enhance Empathy and Facilitate Communication in Virtual Reality

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ABSTRACT

In this research, we aim to harness the capabilities of virtual reality (VR) technology to replicate visual field loss. The overarching goal of this endeavour is to foster increased empathy and to promote effective communication between individuals with and without vision impairments. To this end, we have engineered a multiplayer VR application that serves the purpose of emulating a range of visual impairments. This application can be leveraged for training, simulation, and the cultivation of empathy. In this paper, we provide a comprehensive account of the developmental trajectory, the iterative process, and the challenges encountered during the creation of the aforementioned VR application. Additionally, we offer the framework of a proposed study that aims to assess the user experience within the context of the developed system.

CCS CONCEPTS

• **Human-centered computing → Visualization systems and tools**; *Empirical studies in accessibility*; *Empirical studies in interaction design*; Interaction devices.

KEYWORDS

Visual Field Loss, Invisible Disabilities, Accessibility, Virtual Reality.

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1 INTRODUCTION

'Invisible Disabilities' are defined as disabilities that are not always readily apparent to others, such as prosthetic limbs or joints, chronic pain, internal health issues, and visual or auditory impairments. Invisible disabilities can interfere with day-to-day functioning but do not have a physical manifestation, resulting in communication problems or experiencing ableism in everyday life [12] [8]. Individuals with concealed disabilities may encounter communication difficulties due to the inconspicuous nature of their impairments.

Existing works often use tools such as 'The Help Mark' to address these problems. The Help Mark shown in Figure 1 is a symbol widely used by people who need assistance in public spaces in Japan [5]. The red background and the cross of the sign indicate 'help needed', and the heart symbol indicates 'willingness to help' [5].

The Help Mark was created by Akemi Yamaka, a member of the Tokyo Metropolitan Government in 2012. The main purpose of the symbol is to let others know the necessity of assistance for those who have 'Invisible Disabilities'. By carrying the Help Mark badge with the owner's belongings, individuals can naturally inform their conditions to strangers who are unfamiliar with their disabilities, making it easier for these strangers to offer assistance, such as providing a seat or other help. We take inspiration from the idea of Help Mark for this research.

Figure 1: The symbol of the Help Mark created by the Tokyo Metropolitan Government [5].

Although the Help Mark can provide the necessary assistance to others, it lacks detailed information about one's disability by itself. For instance, it could be hard to assist people who have vision impairments without understanding how they can see. However, in the virtual reality (VR) space, detailed information about vision impairments can be shared between users and they can even experience how a user with a specific vision impairment can see by simulating the vision impairment.

O'Sullivan et al. [13] pointed out that the use of VR allows people to immerse themselves within an environment and experience the environment similar to that of how people with disabilities may experience it, resulting in reducing or eliminating barriers to accessibility. Similarly, this research aims to utilise the benefits of VR space for vision impairments, especially for visual field loss, by creating novel interaction and visualisation to facilitate communication between users with and without visual field loss. We develop

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an online VR communication environment to investigate how the novel interaction and visualisation can **make invisible disabilities 'visible'** to everyone. Our aim in this research is twofold - i) Using this VR application, people with regular eyesight can simulate different types of visual field loss, thus can simulate a first-hand experience of this disability with the aim to enhance their empathy. ii) We develop a tool to facilitate interaction between a person with visual field loss with others in the virtual reality space.

2 DEVELOPMENT ENVIRONMENT

2.1 VR Development

The development of the VR application was carried out using Unity, a powerful game development engine widely used in the game industry. The VR device used for the development is the Meta Quest 2, a popular VR headset developed by Meta. The choice of Unity was motivated by its extensive community resources and packages, and robust VR support of the Meta Quest 2.

There are two choices of the VR framework: XR Interaction Toolkit[1] by Unity Technologies and Oculus Integration SDK[2] by Meta. There are pros and cons of each framework, and they will be described in the next section.

2.2 Multiplayer Functionality

The imperative requirement for the VR application under consideration is the capability to effectively synchronize users and various objects within the shared VR environment. This synchronization is of paramount importance, as it facilitates online interactions among users inhabiting the same VR space. This particular feature assumes a central role in the context of ongoing research endeavors, which are focused on the exploration of communication dynamics among individuals possessing varying degrees of visual impairments within the immersive VR space.

The research's VR development endeavors have strategically adopted the Photon Fusion [3], a networking plugin specifically designed to bolster Unity's multiplayer functionality. This decision was made in consideration of its inherent capacity to seamlessly integrate into the standard Unity workflow. Furthermore, Photon Fusion offers the advantage of a unified Application Programming Interface (API), allowing diverse users to engage in network-based communication within the virtual environment.

It is noteworthy that the administration and upkeep of network sessions are seamlessly orchestrated through a server system provided by the Photon Cloud. This server diligently manages all network sessions while remaining accessible to all users actively connected to it.

3 DISABILITY SIMULATION

According to Flower et al. [3], the concept of disability simulation pertains to an approach aimed at altering attitudes and perceptions concerning individuals with disabilities. This approach involves placing individuals without disabilities into specially designed situations, allowing them to gain firsthand experiential insights into the challenges and experiences associated with having a disability. We designed and developed the application through multiple iterations to improve the functionality of disability simulation.

3.1 Visual Field Loss

As depicted in Figure 2, various forms of visual field loss are evident, often exhibiting discrepancies between the affected areas of each eye. Notably, lesions occurring anterior to and encompassing the chiasm, often resulting from strokes or tumours, constitute the prevailing etiologies for such visual field impairments, as highlighted in Liu et al. [11]. Consequently, it is imperative that the VR application possesses the capability to simulate a diverse array of visual field losses.

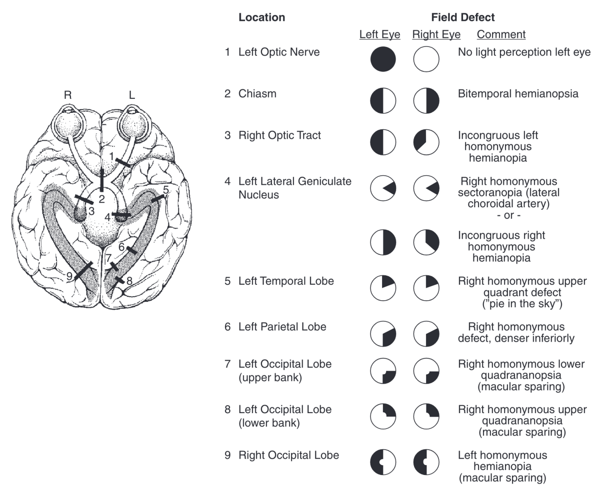

Figure 2: 'Classic' patterns of visual field loss and their anatomic localisation [10].

3.2 Using Cardboard as Physical Eye Patches

The initial concept behind disability simulation draws inspiration from Beis et al. [1], who sought to employ eye-patching as a treatment modality for patients with vision impairments. As depicted in Figure 3, our approach to disability simulation involves the use of two cardboard pieces shaped like semicircles, positioned on the displays for each eye of the VR headset. While this rudimentary method exhibited satisfactory performance, it was marred by challenges in adjusting the cardboard's position and frequent dislodgment. Moreover, this approach lacked the agility required to swiftly switch between simulating different types of visual impairments.

3.3 Using 3D Objects as Virtual Eye Patches

Our subsequent iteration entails a software-based solution that integrates the concept of employing eye-patching objects from the initial phase into the virtual reality (VR) environment. This implementation involves the deployment of non-reflective, black-colored 3D objects, designed to resemble virtual eye-patches. These virtual eye-patches are thoughtfully positioned in the line of sight at

[1]XR Interaction Toolkit - https://docs.unity3d.com/Packages/com.unity.xr.interaction.toolkit@2.5/manual/index.html
[2]Oculus Integration SDK - https://developer.oculus.com/downloads/package/unity-integration
[3]Photon Fusion - https://www.photonengine.com/fusion

Figure 3: Eye patching with cardboard to simulate left homonymous hemianopia (similar to No.9 in Figure 2).

precise distances, serving the purpose of obstructing and simulating visual field impairments within the VR space.

The implementation of virtual eye-patches necessitates a modification to the rendering process within the Unity project. In conventional VR applications, a single camera is employed to render the scene, catering to both eyes of the VR device. In contrast, the Oculus Integration SDK offers the capability to utilize two distinct cameras, one for the left eye and another for the right eye, by activating the "Use Per Eye Camera" option[4]. This functionality allows for the creation of a specialized rendering process that accommodates the virtual eye-patches within the VR environment.It's important to note that this particular option is exclusively accessible within Unity's older render pipeline, known as the built-in render pipeline. This feature may not be available in more recent render pipelines in Unity.

Figure 4 demonstrates how the virtual eye patches work in the setting.These virtual eye patches can be individually activated or deactivated, as showcased, including the four eye-patches for the top, bottom, left, and right sections. When manipulated independently, these eye-patches effectively obscure specific areas of the camera's field of vision, thereby enabling the simulation of visual field loss. In the rendering process, the left and right cameras are configured to exclude the right and left eye-patches, respectively, to ensure an accurate representation of the visual field.

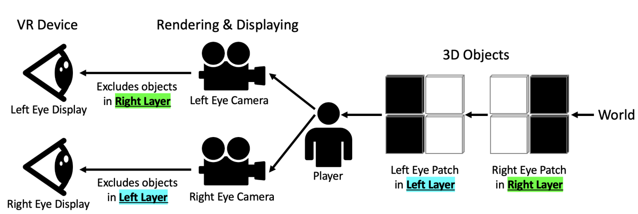

Figure 4: Virtual Eye-Patches of 3D Objects for bitemporal hemianopia (No.2 in Figure 2) with the Oculus Integration SDK and the Built-in Render Pipeline

3.4 Post-Processing Effects with Custom Shaders

The virtual eye-patches, implemented with 3D objects, effectively divide the visual field into quarters. However, this partitioning is insufficient for accurately simulating all the various types of visual field loss as depicted in Figure 2. In such scenarios, post-processing effects emerge as the more appropriate solution for simulating vision impairments.

Post-processing effects, often referred to as image effects, constitute a feature inherent in many rendering systems. They enable the application of additional processing steps to an image that has already been rendered by the camera. These steps serve to modify the appearance of the image, allowing for a more comprehensive and versatile simulation of various visual impairments [6].

By calculating two-dimensional screen coordinates provided by the rendering system, custom shaders have the capability to selectively render specific screen pixels as black, enabling the creation of customisable blind areas within the visual field. As demonstrated in Figure 5, each of these custom shaders is applied as a post-processing effect to individual eye cameras, collectively simulating bitemporal hemianopia and achieving the desired visual field impairment effect.

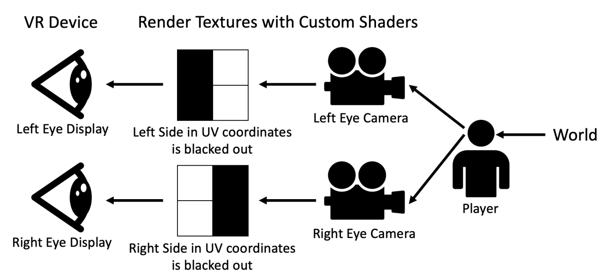

Figure 5: Virtual Eye-Patches of custom shaders for bitemporal hemianopia (No.2 in Figure 2) with the Oculus Integration SDK and the Built-in Render Pipeline

Previous examples of the virtual eye-patches are based on the built-in render pipeline. Another major render pipeline in Unity is the Universal Render Pipeline (URP). URP is a more 'lightweight' pipeline aimed at lower-end machines and cross-platform development. Unity intends to make URP the default pipeline for new projects in the future and an increasing proportion of learning resources will move away from the built-in pipeline and toward URP [7]. The XR Interaction Toolkit, one of the major VR frameworks in Unity, also uses URP for its rendering process. Therefore, it is preferable to use URP for the VR application of this research.

The problem of using URP is that 'Use Per Eye Camera' option of the Oculus Integration SDK is disabled and one camera renders the scene for each eye display of a VR device. Therefore, it is required to modify internal rendering process of dividing into left and right eye displays. In the shader graph of URP, Eye Index Node[5] can be used to apply post-processing effects to left and right eye displays

[4]OVRCameraRig Settings - https://developer.oculus.com/documentation/unity/unity-add-camera-rig/#configure-settings

[5]Eye Index Node - https://docs.unity3d.com/Packages/com.unity.shadergraph@17.0/manual/Eye-Index-Node.html

separately (Figure 6). We adopted this approach to simulate visual field loss in the VR prototype.

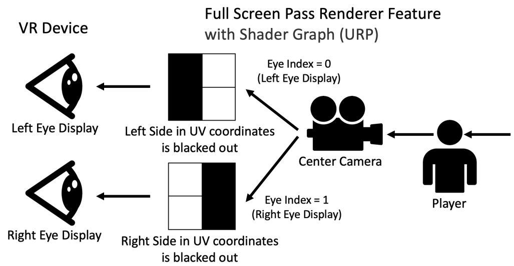

Figure 6: Virtual Eye-Patches of custom shaders for bitemporal hemianopia (No.2 in Figure 2) with the Universal Render Pipeline

4 STUDY DESIGN

4.1 Study Setting

There are two participants (User A and User B) involving the study. They are in the separate rooms and can talk using VR devices.

- **User A acts as a user with visual field loss** by simulating a specific visual field loss. The type of visual field loss changes randomly every task.
- **User B acts as a user without disabilities** and tries to help User A to complete tasks.

At the beginning of every task, User B has no information about User A's (simulated) visual field loss. The task is to bring an object to specified position and the time spent for the task will be measured in each attempt.

4.2 VR Prototype

There are two main scenes in the VR prototype: the tutorial scene and the task scene. After launching the application, both users join the tutorial scene to check thieir network connectivity and learn basic controls. They will be moved to the task scene afterwards and cooperate and complete tasks together there. Tasks will be done with two different supplementary features.

The first supplementary feature is a circle shadow to indicate that User A has some vision impairments and let other users know the necessity of assistance. The circle shadow is shown in Figure 7.

The second supplementary feature is a syncing action with disability simulation. During pushing a specific button of a controller, User B can simulate User A's visual field loss and sync the position and rotation, which means that **User B can see exactly what and how User A is seeing simultaneously**. Figure 7 demonstrates how User A sees with disability simulation of bitemporal hemianopia in the scene. Figure 8 also demonstrates disability simulation of more complicated visual field loss with macular sparing, which is the preserved vision in the center of the visual field.

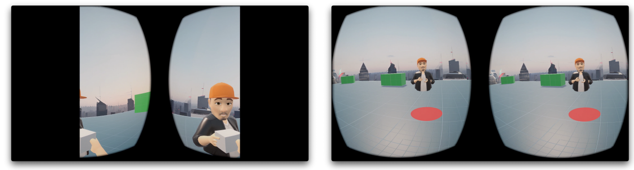

Figure 7: How user A (left) and user B (right) see in the scene of the VR prototype.

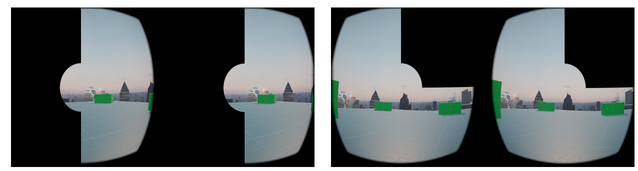

Figure 8: Disability simulation of other visual field loss with macular sparing (No.8 (left) and No.9 (right) in Figure 2).

4.3 Study Procedure

The duration of the full study is approximately 30 minutes.

(1) Before starting the study, both users are requested to complete a questionnaire Attitudes to Disability Scale (ADS) [14].
(2) Both users launch the application and learn how to control their characters in the VR scenes.
(3) After moving to the task scene, they are asked to complete a task that will require collaboration between both users.
(4) Both users are requested to complete NASA task load index (NASA TLX) [4], and User A is requested to complete Simulator Sickness Questionnaire (SSQ) to assess the degree of the sickness caused by the disability simulation [9].
(5) Both users restart tasks again with the second supplementary feature of a syncing action, as well as the circle shadow to indicate each others field of vision.
(6) Both users are requested to complete NASA TLX, ADS to check changes and Networked Minds Measure of Social Presence to assess the quality of communication [2].
(7) A shord semi-structured inteview is conducted at the end of the user study.

5 CONCLUSION

We have created a multiplayer VR application designed as an online communication platform. This application incorporates interactive features that promote communication between individuals, both with and without disabilities. Additionally, it includes a disability simulation component focused on simulating visual field loss with the aim of enhancing users' empathy. To achieve the most effective approach for VR applications, we conducted a comprehensive exploration and comparison of various methodologies tailored to the VR frameworks and Unity render pipelines. Our forthcoming research endeavors will involve evaluating the application to assess how effectively the interaction features facilitate communication and how the disability simulation enhances user empathy through user studies.

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