Seeing our Blind Spots: Smart Glasses-based Simulation to Increase Design Students' Awareness of Visual Impairment

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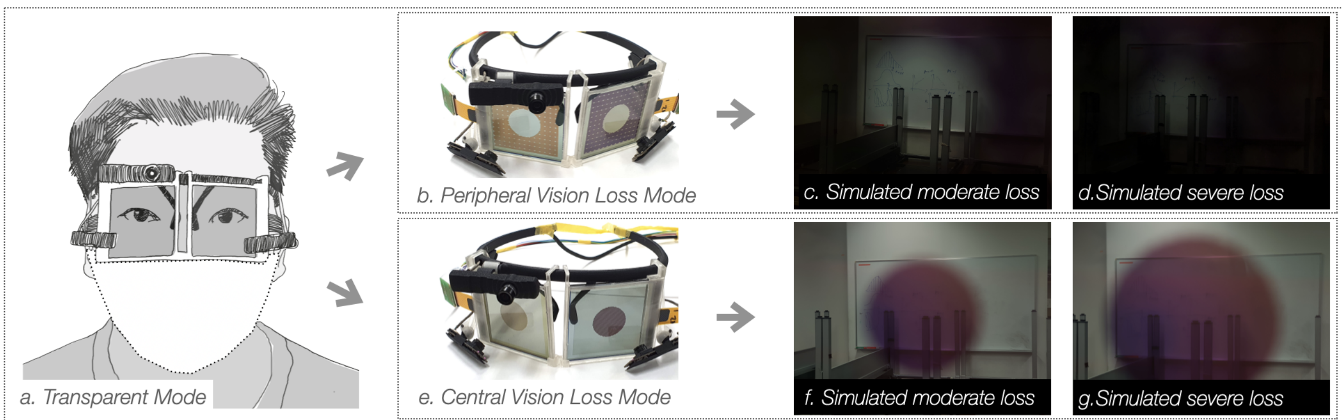

Figure 1: The optical see-through Visual Impairment Simulation Glasses Concept and Prototype. (a) supposes a normal vision user. (b) demonstrate the peripheral vision loss mode of our device. e) is the central vision loss mode. (c) & (d) are the simulated peripheral vision loss from moderate to severe. (f) & (g) are the simulated central vision loss from moderate to severe.

ABSTRACT

As the population ages, many will acquire visual impairments. To improve design for these users, it is essential to build awareness of their perspective during everyday routines, especially for design students.

Although several visual impairment simulation toolkits exist in both academia and as commercial products, analog, and static visual impairment simulation tools do not simulate effects concerning the user's eye movements. Meanwhile, VR and video see-through-based AR simulation methods are constrained by smaller fields of view when compared with the natural human visual field and also suffer from vergence-accommodation conflict (VAC) which correlates with visual fatigue, headache, and dizziness.

In this paper, we enable an on-the-go, VAC-free, visually impaired experience by leveraging our optical see-through glasses. The FOV of our glasses is approximately 160 degrees for horizontal and 140 degrees for vertical, and participants can experience both losses of central vision and loss of peripheral vision at different severities. Our evaluation (n =14) indicates that the glasses

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can significantly and effectively reduce visual acuity and visual field without causing typical motion sickness symptoms such as headaches and or visual fatigue. Questionnaires and qualitative feedback also showed how the glasses helped to increase participants' awareness of visual impairment.

CCS CONCEPTS

• **Human-centered computing** → *Interaction devices*; *Empirical studies in HCI*.

KEYWORDS

visual impairment, smart eyewear, eye-tracking, aging vision

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1 INTRODUCTION

As the global population progressively ages, the number of people with visual impairments will continue to grow. Individuals are likely to experience some degree of vision loss throughout their lives [10]. However, public facilities are designed assuming normal vision. To aid the understanding of visual impairments, several simulations have been created such as analog glasses [27], static display-based solutions [54], and video see-through AR glasses [48].

Despite the increasingly high prevalence of visual impairment and numerous calls about the importance of ensuring that existing and novel technologies are accessible to people with varying degrees of visual abilities, many designers remain unaware of the access barriers that they inadvertently introduce in the technologies they develop [15].

Enhancing design students' understanding of the barriers that users with visual impairment can serve to increase their general level of awareness, leading to a positive shift towards more inclusive practices [42]. The most effective way to promote a comprehensive understanding of how visually impaired individuals interact with technology and what their access needs are is to enable students to interact with them directly [7, 67, 70]. However, facilitating direct interactions between students and visually impaired people as part of educational programs for designers can be challenging for instructors and burdensome for individuals with visual impairments [45, 75].

To help designers gain some basic understanding of the access barriers, several simulators have been developed utilizing a number of different techniques [5, 38].

For simulations of visual impairment to be effective, they would need to be able to mimic a variety of different conditions and adapt to different situations and contexts [6, 22]. However, most existing tools either focus on 2D images-based simulations, screen filters or use normal glasses with tinted lenses or other non-electronic, static tools [3, 27, 49, 63, 79]. The fidelity at which these basic tools can simulate visual impairment is relatively low. The lack of adaptability to gaze movement limits their applicability for more complex tasks, and the inability to simulate different degrees of visual impairment could limit the user's understanding of the diversity between and within specific conditions [1, 11].

Some researchers have leveraged the use of Head Mounted Display (HMD) simulations, mostly limiting the usage to virtual reality [12, 38]. To develop a realistic simulation of cataract, Krosl et al. [48] took advantage of video-see through HMD with real-time eye tracking and involving ophthalmologists to create a more realistic simulation. However, using HMDs is still quite obtrusive due to their high profile and weight [35]. Moreover, their application is limited to a virtual environment, whereas visually impaired people perform their daily activities in the real world.

Particularly, accessing visual information through 2-dimensional images changes the way our eyes naturally focus during activities such as switching gaze from distant objects to closed ones and vice versa (e.g. depth perception and other visual properties are altered). This results in less realistic simulation and potential motion sickness symptoms [72]. Moreover, although high-end stereoscopic HMDs can simulate depth in a way that resembles the spatial properties of the real world, at least currently, they are not able to replicate how humans see and perceive depth under natural viewing conditions [72].

In this study, we focus on simulating (1) central vision loss and (2) peripheral vision loss, which are two typical symptoms of age-related macular degeneration (AMD) and open-angle glaucoma. To address the shortcomings of current simulation approaches we present a new set of low-profile smart glasses that combines optical see-through displays with real-time eye-tracking that map the simulation effect to correspond to the user's gaze, which enables a more intuitive and effective simulation of visual impairment.

Our contribution is as follows: our device is the first lightweight optical-see-through-based and real-time eye tracking integrated visual impairment simulation solution that enables users to experience different types of visual impairments in everyday activities in an unconstrained way, without significant obstructions to one's field of vision or the need for pre-defined virtual scenarios. Our user study confirmed that our device significantly reduced the users' peripheral vision and visual acuity respectively and increased their awareness of visual impairments without causing typical motion sickness symptoms such as visual fatigue and headache.

2 RELATED WORKS

2.1 Visual Impairment, Open-angle Glaucoma, and Age-related Macular Degeneration

According to the 2019 World Vision Report by the WHO, visual impairment occurs when one or more conditions of the eye affect the visual system [59]. As a result, visual impairment can be associated with a reduction in visual acuity, the field of vision, contrast sensitivity, or color vision [59]. Eye conditions that can cause visual impairment are remarkably common with many people expected to experience at least one of them throughout their life [59]. However, these conditions can vary in their severity and while some can be corrected through the use of surgical treatment or the use of assistive technologies, others lead to irreversible, and often increasing degrees of visual impairment [59].

Glaucoma is one of the leading causes of blindness [9, 21, 44, 74], and the number of people who suffer from glaucoma is increasing worldwide [62]. Compared with cataracts, blindness caused by glaucoma is irreversible [44]. In particular, one of the most common and severe types of glaucoma, open-angle glaucoma, is associated with the loss of peripheral vision as its main symptom, which can severely impact individuals' daily activities.

On the other hand, aging macular degeneration is a major cause of visual impairment in older adults [51]. As the average age of the population in many countries continues to increase, it is expected that more than 300 million individuals might be affected by this condition by 2040 [55]. Although AMD does not cause complete blindness, it is the most frequent cause of severe vision loss in older age groups and it is associated with high rates of disability and depression [64]. Aging macular degeneration causes losing central vision, which means people suffering from this disease tend to perceive visual information from the center of the field of vision at lower saturation and even with distortion.

Open-angle glaucoma and AMD manifest in significantly different ways but are both associated with difficulties in Independent Activities of Daily Living, in particular in regards to independent mobility [31]. The combination of high prevalence and significant impact on daily life makes open-angle glaucoma and AMD suitable for a simulation exercise for design students as it could help them to understand the different access needs that people experiencing these conditions might have [37].

2.2 Overview of visual impairment simulation strategies

Several researchers have explored the direct sharing of subjective experiences to communicate empathy, rational compassion, etc. and to provide intuitive assessment tools for people to understand each other better [49, 57, 58, 65, 66]. In the case of visual impairment simulation, there are three common approaches: analog tools, 2D images-based simulation, and Head-mounted-Display-based methods (VR and AR). Table 1 presents a brief comparison of the main characteristics of each type of simulator and our approach.

2.2.1 Analog visual impairment simulation tools. Analog tools (e.g. static glasses, contact lenses, or other filters) are designed to simulate a specific visual impairment [27, 65] through an overlay effect while preserving our original vision as an information resource.

Goodman et al. simulated different degrees of blurry vision, using layers of Cambridge Simulation Glasses, to assess the visual clarity of product features [28]. Juniat et al. gathered 254 medical students to complete three daily tasks while wearing Sim-specs, which simulate Age-related macular degeneration (AMD) and glaucoma [39]. Their goal was to enable students to learn about visual impairment. Kanzler et al. used "Produkt + Projekt" glasses as visual impairment simulators and analyzed participants' performance in a 40m obstacle walk to examine the influence of AMD on gait [40]. Czoski et al. use contact lenses to simulate AMD [16] with a similar goal to one of the other researchers.

To mimic a variety of visual impairments, there are commercial visual impairment simulators such as [19, 33, 61, 83]. In particular, Zimmerman Low Vision Simulation Kit [83] provides four goggles and several lenses which can simulate peripheral field loss, macular degeneration, cataract, scotoma, and hemianopsia.

However, eye conditions such as cataracts and aging-related macular degeneration, which lead to visual impairment happen in the eye itself. This means that the resulting altered visual representation impairments will move along with the eyeballs' movements. The visual impairment simulation-generated analog tools did not restore this attribute of our natural vision system, which inevitably leads to less realistic simulation.

2.2.2 2D image based Visual impairment simulation. Amongst the different types of software-based visual impairments simulators, EASE (Evaluating Accessibility through Simulation of User Experience) offers a blurring and red-green color blindness experience [54]. Wood et al. simulated cataracts using Vistech light scattering filters to investigate the impact of visual impairment on older adults' cognitive performance [77]. McAlpin et al. [53] developed a mobile device-based system simulating personalized CVD symptoms.

To emphasize the access needs of users who suffer from common vision or hearing impairments, [26] designed Windows-based software which has the ability to adjust the degree of impairment to different severity levels. Additionally, [17] presents a web page-based simulator that mimics Blurry Vision, Ghosting, Glare, Halos, Starbursting, Loss of Contrast, Visual Snow, Blue Field Phenomena, and Trails. Similarly, [34] built a smartphone application that can simulate several of the most common types of visual impairment associated with different eye conditions.

Although 2D images-based methods are relatively easy to build and low cost, their static simulation is simplified versions of the various visual impairments, which means they are not capable to replicate realistically the specific situation of a visually impaired person. Although the studies aforementioned enriched the toolbox of visual impairment simulation. They are limited to screen-based interactions, whereas there are many more visual activities that cover each essential aspect of our daily life. Finally, most types of visual impairment are associated with a number of different visual abnormalities. For example, in the case of age-related macular degeneration, four typical attributes have been identified: distortion, reduced saturation, reduced contrast, and darkened central vision; which means studies based on existing 2D simulation images are only able to provide simplified versions of visual impairments.

2.2.3 VR-based Visual impairment simulation. Ai et al. [2] created a VR-based visual impaired simulation system for glaucoma, diplopia, and aging-related macular degeneration. Their system provides computational graphic stereo vision and head movement tracking. Kim et al. presented Empath-D which is a VR-based visual impairment simulating a system with the goal of increasing empathy towards access needs in the context of App design [43]. Furthermore, Krosl et al. mimicked reduced visual acuity (VA) through blurring and had participants test the hypothetical effect of visual impairment in an emergency situation [47].

With the goal of educating and training ophthalmologists, physical therapists, and students, [36] had their participants navigate through a typical room in a virtual environment with simulated vision impairment. Wu et al. simulated a pedestrian street crossing scenario with aging-related macular degeneration [78]. However, all these existing virtual environment-based simulations are faced with a significant trade-off between low-resolution and accessibility of expensive equipment [48]. Moreover, VR simulations are limited to a particular scenario of application that has been previously created by the developer [38].

2.2.4 AR-based Visual Impairment Simulation. More recently, Krosl et al. took advantage of video see-through AR and collaborated with ophthalmology experts to create a more realistic cataract simulation experience [48]. This helped to address the simulation accuracy evaluation problem by having actual patients involved and their system was also equipped with real-time eye tracking. However, even though the work ultimately targets augmented reality, the prototype and experiments are conducted in Virtual Reality using pre-recorded 360-degree videos. The objective of their study was to quantify the influence of visual impairment on recognition distances of escape-route signs.

To simulate various visual impairments, Ates et al. used video-see-through HMD to generate the typical visual impairment effects such as Macular Degeneration, Diabetic Retinopathy, Glaucoma, Cataracts, Colorblindness, and Diplopia [6]. Shen et al. [66] simulated common symptoms of dementia.

Nevertheless, even the latest high-quality stereoscopic video see-through method or the virtual environment generally offers 2-dimensional visual information with no natural depth clues on the flat displays, which leads to unnatural conflicts in visual processing that significantly differ from our actual visual perception [72]. Further, this temporary dissociation of vergence and accommodation has been linked to typical motion sickness symptoms such as headaches and fatigue. One of the aims of this paper is to offer a versatile system that provides an initial empathetic understanding of visually impaired people by experiencing both central vision loss and peripheral vision loss without experiencing dissociation of vergence and accommodation.

3 OUR APPROACH: TRANSPARENT LCD WITH REAL-TIME EYE TRACKING

As stated by Ates et al. [6], visual impairments are subjected to a large amount of inter-individual variation, which pointed out the necessity to simulate different types of visual impairments and different degrees of severity for each condition as realistically as possible. In this paper, we focus on the simulation of open-angle glaucoma and age-related macular degeneration (AMD).

Visual Impaired Simulation System

We used two monochrome 2.9-inch (55 mm x 55 mm viewing area, 128 x 128 pixels) liquid crystal display panels[1] as our optical see-through lenses, which were inspired by Hiroi et al. and Ma et al. [30, 52, 80, 81], for the generation of a semi-transparent layer in between the real world and our eyes, as illustrated in Figure 5. The LCD modules ensure the generated visual impaired effects cover the majority of a person's most natural visual field like ordinary optical glasses, see figure 3. Although wearing glasses will reduce parts of our visual field, in particular one's peripheral vision, GAUTHIER et al. [23] suggests we have the ability to fast adapt to that narrowed visual field and react as usual.

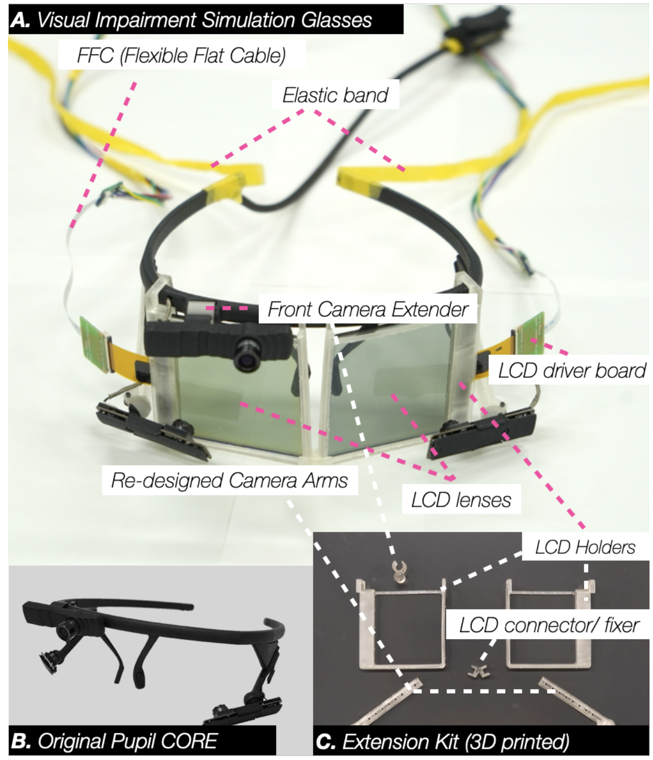

Figure 2: A. depicts the assembled Visual Impairment Simulation Glasses with two extra elastic bands to fasten the device to the user's head minimizing undesired displacement. B. indicates the original Pupil CORE eye-tracker. C. is the extension kit that we designed and 3D printed for modifying Pupil CORE into Real-time Visual Impaired Effects Rendering Glasses.

We designed semi-transparent patterns to be shown on the LCDs to be able to simulate two visual impairment symptoms; loss of central vision and loss of peripheral vision. Loss of central vision is represented as a filled circle with a transparent peripheral field of view. On the other hand, loss of peripheral vision is shown as a transparent circle with a filled peripheral, see figure 5. The severity of the vision loss is controlled over the opacity setting of the filled region. Based on consideration of generalizability, we use filled circles and center-transparent patterns to simulate loss of central vision and loss of peripheral vision. Since visual impairments can vary greatly between individuals [43], our visual impairment simulation glasses enable a high degree of customization to better simulate various situations, see figure 5. To allow others to replicate the hardware, we provide the 3D models of our device[2].

Real-time Gaze Tracking and Mapping. Since visually impaired effects such as loss of peripheral vision and loss of central vision are gaze-dependent [48], we use Pupil Core Eye Tracker [41] to obtain the eye movements as well as to generate mapping clues for the corresponding visual impaired effects. Pupil CORE has been

[1] JHD128128-G56BFW-G

[2] https://github.com/qzkiyoshi/visual-impairment-simulation-glasses

Visual Impairment Simulators	Central and Peripheral Vision Loss	Visual Acuity	Eye Tracking	VAC Free	Weight	FOV	Real-world Adaptive
Analog Tools [19, 27, 33, 61, 65, 83]	✓	Natural vision	X	✓	≥ Normal glasses	≤ Normal glasses	✓
2D image-based simulation [17, 54, 77]	✓	Limited resolution	✓	N/A	N/A	N/A	X
VR-based simulation [36, 43, 47, 78]	✓	Limited resolution	✓	△	468g [76]	≈109°(H),112°(V) [56]	X
AR-based simulation [48] (VST)	✓	Limited resolution	✓	△	550g [76]	≈107°(H),108°(V) [56]	Pre-design Needed
Our simulation Glasses (OST)	✓	Natural vision	✓	✓	89.6g	≈ 160°(H),140°(V)	✓

Note: (VAC) is short for vergence-accommodation conflict. (△) meant no computational heavy nor optical VAC-free method was implemented. (VST) is short for Video see-through. (OST) stands for optical see-through. In the Weight column, the weight that we used to represent VR-based simulators is the minimum in their groups. The weight of our OST visual impairment simulation glasses only counts the glasses themselves (Pupil CORE + LCDs + 3D printed extension kit + wires). In the FOV column, the horizontal and vertical visual fields that we used to represent the VR and AR-based simulators are the maxima in their groups.

Table 1: Comparison of related studies and commercial products.

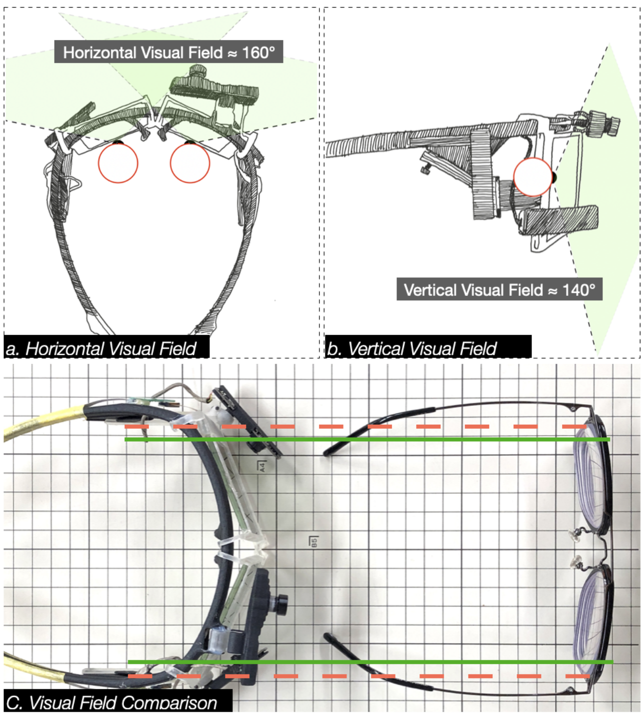

Figure 3: (a). indicates the horizontal vision field of our visual impairment simulation glasses. (b). indicates the vertical visual field. (c). is the lenses-width comparison between our visual impairment simulation glasses and ordinary myopia glasses, in which orange dash lines are the outermost edges of the ordinary myopia glasses, and the green lines indicate the outermost left and right boundaries of our visual impairment glasses.

widely used in various studies because of its robust eye-tracking performance and lightweight (22.75g[3]) [20, 29, 80, 82]. The specific type of Pupil CORE that we used consists of two 200Hz 192x192 pixel infrared cameras (8.5ms latency) and a 120Hz 480p World (Front) Camera (Latency is typically greater than 3ms, CPU depending) [50]. To drive the Pupil CORE, we followed the official requirements of Pupil lab (Intel i5 or greater, 8GB or more RAM) and used a laptop equipped with Intel i7 CPU(11 Generation) and 16GB RAM (ddr4 3200MHz). This configuration allowed us to reduce the

[3]https://pupil-labs.com/products/core/tech-specs/

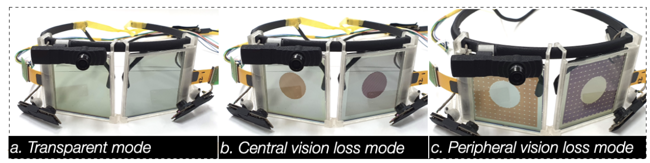

Figure 4: Three basic modes of the visual impairment simulation glasses.

delay between the eye movements and the generated corresponding visual impaired effects to approximately 100ms.

The LCD displays are controlled through a SparkFun ESP32 ThingsPlus[4] with a USB cable connecting to the laptop aforementioned to minimize potential data transmission delay. We designed two resin frames to hold the two LCD lenses in between the eyes and the Pupil Core eye-tracking cameras. To ensure that the eye movement tracking cameras could detect eyeball movements successfully and stably through the LCD panels, we replaced the original camera arms with our re-designed and 3D printed ones, see figure 2. This modification enabled us to set the cameras at an optimal angle to detect the pupils' movements successfully. Moreover, we also designed an LCD connector/ fixer to join the two LCD modules together to enable successive and stable visual impaired simulation. Finally, to minimize the potential displacement of the visual impairment simulation glasses, we attached two elastic bands to the ends of the legs of the Pupil CORE. To drive the LCD modules as well as to minimize the size and weight of the prototype, we designed the driver board based on the manual of the LCDs manufacturer.

Benefits and Limitations

The advantages of our approach: (1) instant real-world adaptability: our approach enables the user to experience visually impaired vision instantly in real-world scenarios. Users can check whether a visual design is low-vision friendly or not by simply switching on and off the visually impaired modes, as well as checking if an environmental design is inclusive for visually impaired people. While analog visual impairment simulation tools and 2D image-based methods offer only static effects and are unable to respond to eye movements. Current HMD-based methods need a pre-designed environment such that the user cannot instantly interact with real-world visual stimuli. (2) VA-conflict-free: our lightweight optical-see-through design avoids the vergence-accommodation conflict which links to visual fatigue, headaches as well as serious side effects long after cessation. They are parts of the main challenges in HMD-based

[4]https://www.sparkfun.com/products/15663

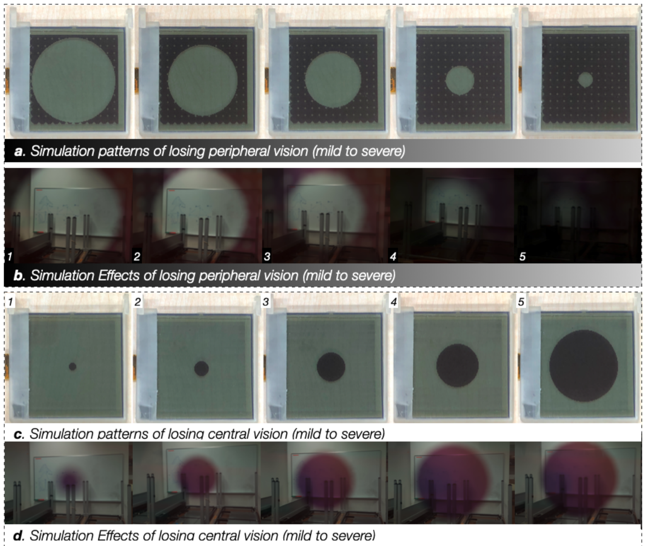

Figure 5: (a). are the generated peripheral vision loss effects from mild to severe. (b). simulates the overlapped effects with the real-world scene. (c). are the generated central vision loss effects from mild to severe. d. simulates central vision loss effects.

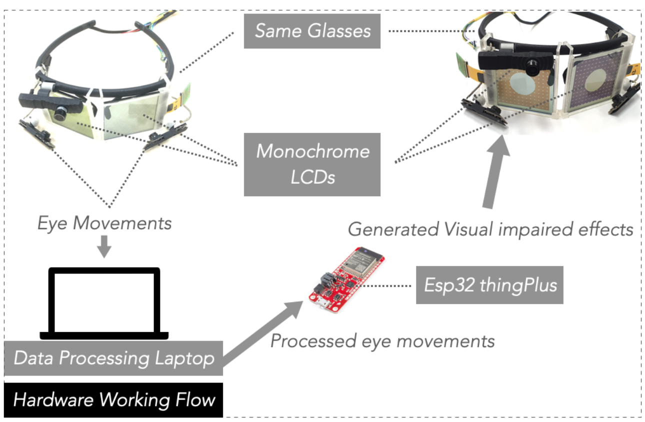

Figure 6: Hardware's working flow: Pupil CORE detects eye movements and sends them to the data processing laptop, the laptop is running a Python script that converts eye movements into x and y coordinates to the attached Esp32 thingPlus microcontroller that generates the visually impaired effects to the LCD lenses.

systems [46]. (3) versatility: our programmable LCD-based and modular design suggests we can not only simulate loss of peripheral or central vision, but can also simulate other impairments such as Retinitis Pigmentosa, Floaters, Cataracts, or even rare and complex cases such as people experiencing multiple visual impairments (e.g. age-related macular degeneration in amblyopic). (4) walkable: alike our experiment suggests, one can walk up doing their daily routines while wearing our device when accompanied, which enables the further realistic and immersive experience of visual impairments. (5) computationally simple: our method does not require heavy computational power which is crucial for high-resolution rendering and complex calibration that is needed in HMD/HWD-based studies. (6) optical-glasses-like field of view: our device can reach the largest field of view (160° horizontal, 140° vertical) when compared to the related AR & VR-based studies and the mainstream commercial HMDs (Oculus QUEST 2 (104° horizontal, 98° vertical), Varjo XR-3 (115° diagonal)).

In terms of other optical see-through devices that might potentially be used as visual impairment simulation platforms such as HoloLens2 or MagicLeap2. First, HoloLens2 can only generate additive RGB mixing-based luminous pixels, while our device generates black/ opaque pixels which are more suitable to simulate the degenerated macula or affected optic nerves. Additionally, MagicLeap2's dimming layer can only be adjusted wholly, while our device can adjust each pixel individually.

Limitations. Our optical glasses-like design suggests that this current prototype could not completely cover all of the wearer's visual field, especially on the left and right sides. Although, with a horizontal visual field of 160 degrees and a vertical visual field of 140 degrees, our OST visual impairment simulation glasses ensure significantly better coverage than most available HMD [56], see table 1.

Although our visual impairment simulation glasses (without counting the laptop's weight) were significantly lighter than popular HMDs, it was heavier than ordinary glasses, which requires further lightweight design modification. Another notable hardware limitation was linked to the refresh rate of the current monochrome LCD and the sampling rate of the pupil labs eye tracker (up to 250 Hz). The LCD and eye-tracking setup is currently not fast enough to match the speed of natural eye movements. As described in the qualitative feedback section, the lag for larger saccades was noticeable, about 100ms. Yet, this issue also persists for software approaches using eye-tracking and HMD-type simulations.

Regarding the reliability of our simulation, we observed our simulated peripheral vision loss effect could not be seen by one participant (1/14), which indicates the individual variations (nose height, interpupillary distance, head circumference, ears' place) among the participants could have made certain individuals see through the polarizers of the LCDs. We believe that future versions of this OST visual impairment simulation glasses will overcome this demerit by leveraging specifically designed polarizers or more suitable transparent display modules.

4 USER STUDY

4.1 Participants

We recruited 14 graduate students who were currently enrolled in either the MSc or Ph.D. program. Participants were recruited through a combination of departmental emails, student message boards, and word of mouth. Six of them identified themselves as male and eight as female. They were on average 26.9 years old (SD = 3.7, Min = 22, Max = 34). Seven participants were nearsighted or farsighted. Amongst them, one participant was nearsighted in the right eye and farsighted in the left. Three of the seven nearsighted participants wore their contact lenses throughout the experiment.

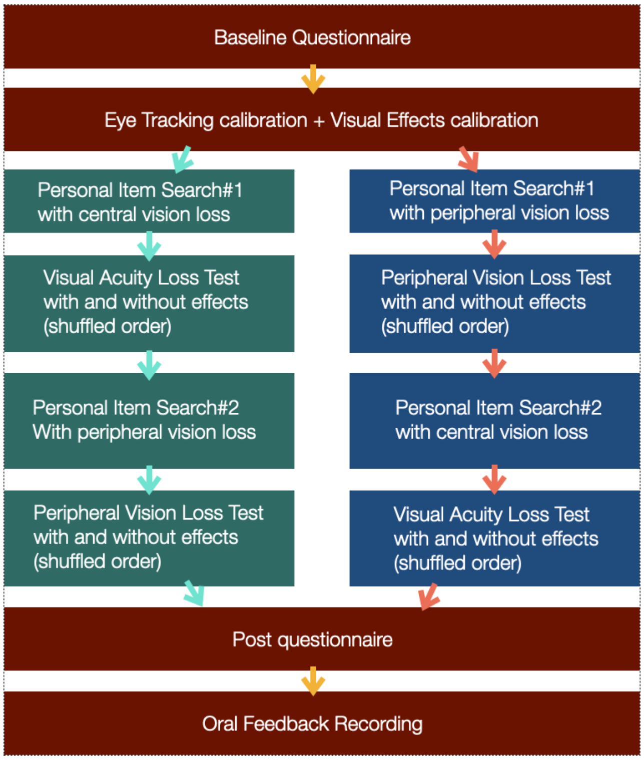

Figure 7: A diagram summarizing the complete procedure of the user study.

On the other hand, the remaining four took part in the experiment without wearing corrective glasses as they self-reported that they can do their daily routines without wearing glasses. Participants were compensated with a gift card for their time.

4.2 Study procedure

After obtaining informed consent and collecting demographic information, participants were asked to fill in a baseline questionnaire assessing their general awareness and empathy in relation to individuals with vision loss (see the following subsection for details about the questionnaire design). Before the start of the experiment, the researchers helped the participants to put on the device and fastened the yellow elastic bands (see figure 2) behind the participants' heads minimizing the undesired displacements of the smart glasses for the duration of the study. The order of the two visual impairment effects, central vision loss, and peripheral vision loss were randomized among participants, while the overall study procedure remained consistent. After confirming that the device was held in place stably and correctly, the calibration was carried out to ensure that the chosen first visual impairment simulation effect would be located in the appropriate region of the participant's field of view was initiated using the GUI operating system.

After the end of the calibration of eye tracking and the corresponding place of pupils on the displays, the participant was asked to navigate around the room to locate their mobile phone which had been previously hidden by the experimenter. See section 4.2.4 for the full details of the task. Once the *personal item search* task was successfully completed, the participants were asked to undergo either the visual acuity test (if the central vision loss effect was been applied as the first condition) or the field of view test (if the peripheral vision lost test was being applied as a first condition). Participants underwent the selected test twice, once with the glasses set in full transparent mode, and once with the glasses displaying the appropriate visual impairment filter (the order between these two conditions was randomized among participants).

After completing the first either central vision loss or peripheral vision loss test, participants were asked to perform another *personal item search* task with the opposite visual impairment filter applied followed by the remaining corresponding vision test. At the end of the study, participants were asked to fill in the empathy questionnaire again, followed by open questions to elicit additional feedback. The complete Experimental procedure is summarised in figure 7.

4.2.1 Questionnaire Design. One goal of our user study was to evaluate if the simulated experience provided by the smart glasses could effectively increase design students' awareness of visual impairment and the importance of accessibility, leading to greater interest to interact with visually impaired users. Although many disability simulation tools claim to be designed with the goal to increase empathy amongst designers, their impact in this regard is not often specifically assessed [6, 11, 69]. Most available scales that assess empathy or attitudes toward people with disabilities are not specific to designers and do not necessarily provide insights on shifting priorities in relation to accessibility and future design practices [25, 45].

More recently Drouet et al. 2022 [18] have developed an 18-item Empathy in Design Scale to assess the empathetic tendency of designers and stakeholders toward particular groups of users along four different dimensions Emotional interest / Discovery, Sensitivity/ Immersion, Personal experience/ Connection, and Self-awareness/ Detachment. To ensure that design students remained aware that while the glasses could provide an experience of visual impairment they could not, and indeed should not [8], create a truly embodied experience of disability we removed the sections on Sensitivity/ Immersion and Personal experience/ Connection from our evaluation. Furthermore, the original scale measures overall empathetic tendencies, whereas our study design could only assess the change in the empathetic state before and after the simulation. To this end, we modified the phrasing of the questions to represent one's state of mind at a specific moment in time rather than a more generic personal inclination. The result was an 8-item questionnaire, in which participants could express their level of agreement or disagreement with each statement using a 5-point scale. In particular, question 1 to 4 assesses the potential change of "Emotional Interest/ Discovery (EI)", whereas question 5 to 8 examined the "Self-awareness/ Detachment (SA)" level [18]. The questionnaire was administered to participants at the start of the study and after they completed the experiment.

Additionally, to assess whether our device could simulate central vision loss and peripheral vision loss without triggering typical motion sickness symptoms, such as headaches and visual fatigue, which have been associated with other simulation strategies [13],

Questionnaire:
1. I am interested to learn about the experiences and needs of people with vision loss.
2. I imagine how people with vision loss think, feel or behave in different situations.
3. I am curious about the experiences and needs of people with vision loss.
4. I want to learn about the people with vision loss's experiences and opinions about my research and design work.
5. I imagine how I would feel and think if I were a person with vision loss rather than a person without vision loss.
6. I am aware that my experiences as a person without vision loss are different from the ones of people with vision loss.
7. I realize that there are similarities and differences between my experiences and the ones of people with vision loss.
8. I understand why people with vision loss perceive things differently than I do as a researcher and designer.
MS.1. When using VR headsets I experience headaches and/or visual fatigue.
MS.2. I experienced headaches and/or visual fatigue when switching my gaze from distant objects to closed objects or vice versa while wearing the glasses.

Table 2: The 5-scaled Likert answers are: Strongly Disagree/ Disagree/ Neither Agree or Disagree/ Agree/ Strongly Agree.

we added two items to the questionnaire that was administered after the simulation experience. The full questionnaire used in the user study is shown in Table 2. At the end of the study, participants were asked for any additional feedback they wanted to share about the use of the simulation glasses and how the effect of the visual impairment simulation experience.

4.2.2 Loss of Central Vision Simulation. The aim of the loss of central vision test was to evaluate if the simulated effect created by our glasses could effectively reduce the visual acuity of participants. This particular measure was chosen as loss of visual acuity has been identified as a strong indicator of age-related macular degeneration (AMD) [60].

When applying the central vision loss effect we refer to the estimation provided by previously related studies [4, 32, 68] which classifies the median 10 degrees of the visual field as the central vision area. However, it is worth noticing that there are some other variations in regards to the definition of central vision [71].

To conduct the visual acuity test we had participants sit down on the chair we placed 10 feet away from an A4-sized Snellen Chart. The visual acuity test was conducted twice consecutively, once with our device in its fully transparent mode and the second time with the central vision loss filter applied. Both tests were conducted with participants using their binocular vision. Although the Snellen chart is usually used to test the visual acuity by blocking one eye at a time, since our aim was to examine whether the central vision loss mode of our visual impairment simulation glasses could reduce the general (binocular) visual acuity, we chose to perform the test with the participant using binocular vision.

To minimize the undesired influence of learning effects from past experience, and considering the Snellen chart's popularity, we used two character-shuffled charts that rearranged the order of the characters while maintaining their characteristics including type, font size, and layout design, see figure 10. We also shuffled the order in which Snellen Chart was used for each condition.

4.2.3 Loss of Peripheral Vision Simulation. The loss of peripheral vision test was to evaluate if the simulated effect created by our glasses could significantly reduce the visual field of participants. This particular measure was chosen as the reduced visual field is a strong indicator of open-angle glaucoma and retinitis pigmentosa [24]. To explore the changes in the peripheral vision area of the participants, we designed a [5]Processing program which is used to generate dots from 8 directions of the display edges (randomized order, upper right, up, upper left, left, right, bottom left, bottom, bottom right) one by one towards a red cross that located in the center of the display. This program mimicked the automated static perimetry test which is commonly used to assess the individual field of vision.

During the test, participants were required to sit at a chair as figure 8 indicates, in front of a 65 inches IPS display. The distance between the display and the participant's head was fixed to 25 cm by an adjustable chin rest. This distance was calculated using trigonometric functions to make sure the display area was sufficient to cover the participant's peripheral vision vertically and horizontally. To correct for individual variations of the field of view, we asked participants to self-report whether the display area well coincided with their visual field. If this was not the case, we slightly adjusted the distance between the display and the chin rest until they confirmed that the horizontal and vertical boundaries of their visual field were within the four sides of the display. Notably, the visual field that we expected the display to cover was the point of view from the two LCD lenses.

When the appropriate chin rest position was determined the peripheral vision test was carried out with two conditions in randomized order. Once with our device and in its fully transparent mode, see figure 4a, and another is the peripheral vision loss mode, see figure 4c. To minimize fatigue, a two minutes break was introduced in between the two conditions.

When applying the peripheral vision impairment filter, the experimenter made sure that the generated effects were aligned with the pupils of the participant, as well as examining that the visually impaired effects would move correspondingly with the eyes' movements. This eye-tracking examination enabled the generated effects would act along with microsaccades, which resulted in a more realistic intuitive simulation of visual impairments.

During the field of vision test, participants were required to fix their gaze on the red cross located in the center of the display and

[5]Processing: Homepage (https://processing.org/)

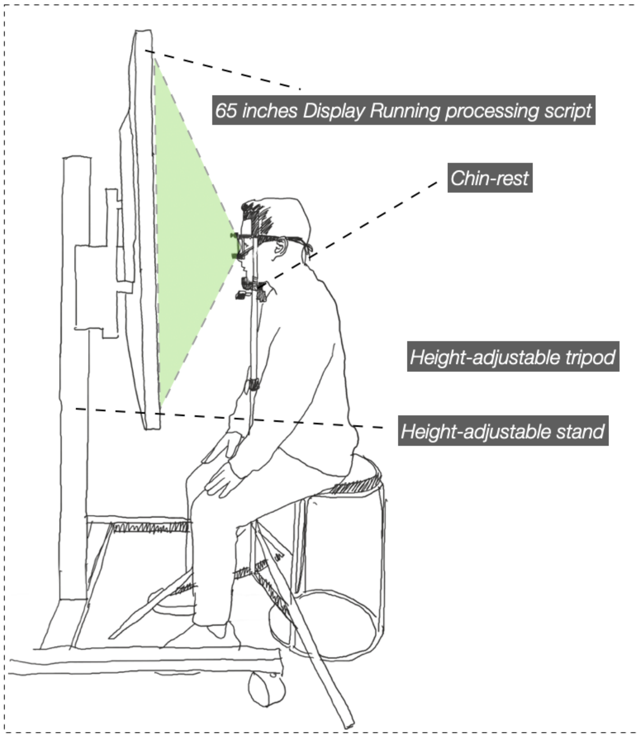

Figure 8: Participants were required to sit in front of the 65 inches display and gaze at the center where the processing script generates a red cross.

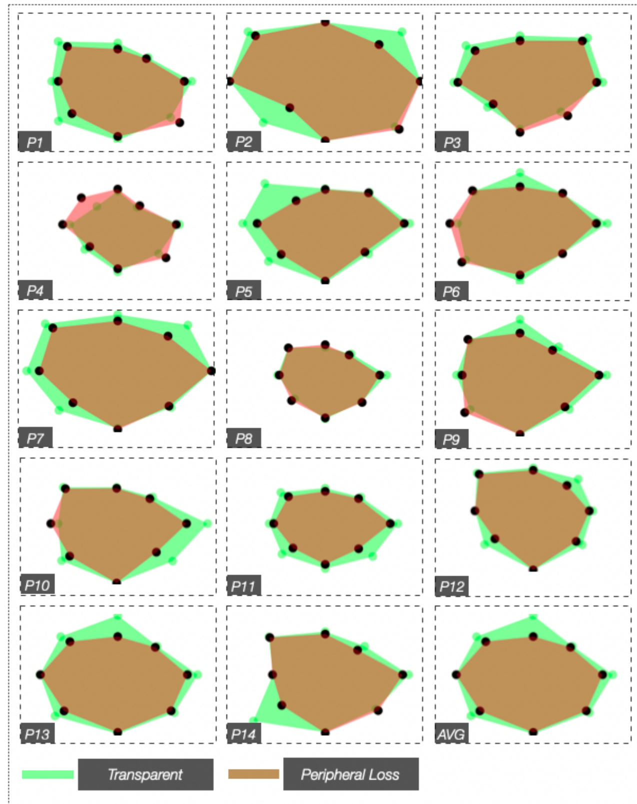

Figure 9: From P1 to P14 are the results of both transparent mode and peripheral vision loss mode. Polygons in light green color are the visual field of the transparent mode. Khaki polygons indicate the results of the peripheral vision loss mode. The semi-transparent pink polygons.

asked to press a button as soon as they noticed a white circle approaching out of their visual field towards the red cross. We used the custom-made *processing* script to display the white dots 10 times, shuffling their order of approach across 8 directions (upper-left, up, upper-right, left, right, bottom-left, bottom, bottom-right). The first two trials were used as non-recording baselines. The approaching speed of the dots is 15 frames per second. The button that participants were asked to press was placed around their right hand. To avoid false triggering, participants were asked after they pressed the button to make a hand sign pointing in the direction of the perceived dot, which means only correct triggering would be recorded. Participants were informed that blinks were allowed during the tests.

4.2.4 Personal-item-search tasks. Since visually impaired symptoms are generally not of short-time duration but long-lasting experiences, most visually impaired people who are affected by the loss of central vision or peripheral vision, will likely carry out their daily routines experiencing either narrowed visual field or reduced visual acuity and contrast. Thus, to better represent and simulate the experience of losing central vision and losing peripheral vision, we had participants perform two personal-item-search tasks in the experimental environment before the visual acuity and peripheral vision tests, utilizing the corresponding visual impairment effect. Before the beginning of each task, participants were informed by the experiment that they did not need to uncover anything to locate their phone, nor were they allowed to use other wearable devices such as a smartwatch or an AirTag to activate their smartphone or by voice. As part of the task, they could freely walk around the room to find their smartphone which had been previously hidden by the experimenters. To challenge their ability to recognize objects of similar nature, along the potential search paths, the experimenter placed 3 different smartphones in different locations.

During the personal item search task, we prioritized the safety of the participants while maintaining our goals to increase awareness of visual impairment. Two experimenters accompanied the participants from behind (back left and back right) making sure no injury would occur as a result of accidental collision. One of the experimenters held the laptop to run the visual impairment simulation system and ensure that the USB cable connection between the simulation glasses and the laptop was not tense, to minimize unnecessary discomfort.

4.3 Result

4.3.1 Changes in peripheral vision loss mode. In the most cases, we observed reduced peripheral vision in in the peripheral vision loss mode of our device. On average, the upper half of the participant's

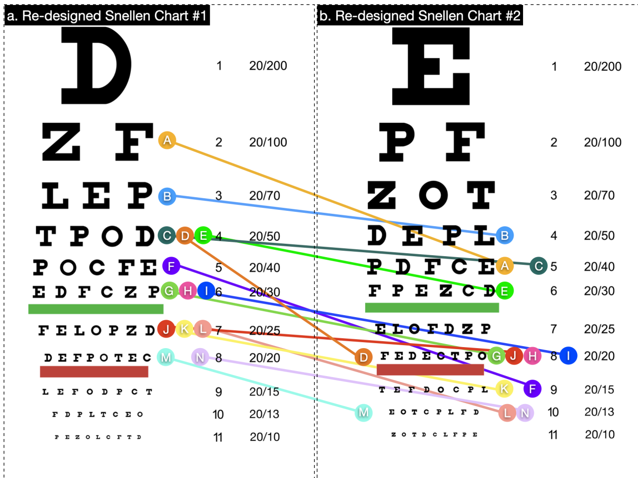

Figure 10: Two re-designed Snellen Charts maintain the original visual design. (a). indicates the central vision loss condition, (b). reveals the result of using the transparent mode of our visual impairment simulation glasses.

field of vision was more affected by the presence of the peripheral loss filter compared to the lower half. Specifically, we observed a statistically significant decreased field of vision from 6 out of all 8 directions including upper left (p<.0046), up (p<.0076), upper right (p<.006), right (p<.0001), bottom left (p<.0017), and bottom (p<.04). Participants' field of vision was also decreased by the application of the peripheral vision loss filter in the left and bottom right direction, but these differences were found to be not significant (p= .15, and p=.25 respectively). Notably, in the case of P4, we found a opposite result compared with others. We observed almost no significant difference in the field of vision between full transparent mode and peripheral vision loss mode in the case of P8.

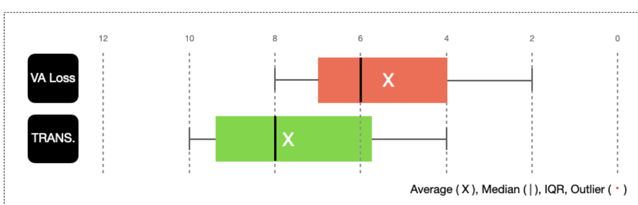

Figure 11: Visual acuity changes of central vision loss simulation. VA Loss is the result of central vision loss mode. TRANS. indicates the result of using transparent mode.

4.3.2 Changes in central vision loss mode. The application of the central vision loss filter caused a reduction in the visual acuity of all participants as shown in Figure 10. On average, with the simulation glasses set in the transparent mode, participant visual acuity was 7.7 (max 10, min 2), with 10 out of 14 participants scoring between 8 and 10. On the other hand, when the central vision loss effect was applied, average visual acuity was reduced to 5.5 (max 8, min 2), with the majority of participants scoring between 6 and 8, see

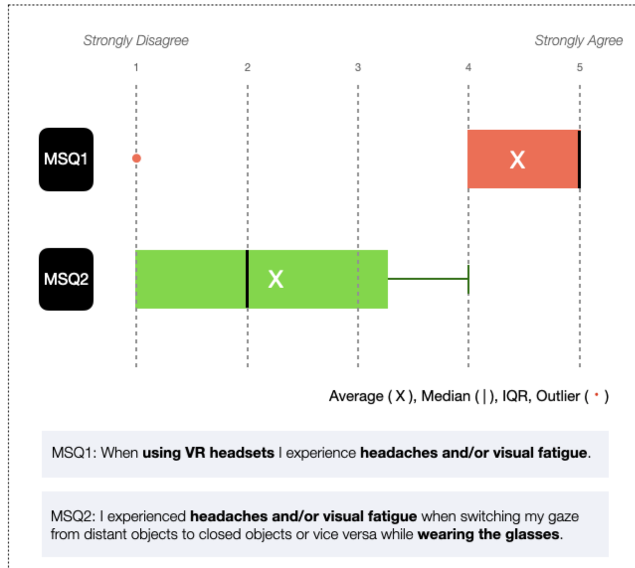

Figure 12: MSQ1. is the result that reveals the baseline VR headsets experience of the participants. MSQ2. suggests that our visual impairment simulation glasses could simulate the visually impaired effects without triggering headaches and visual fatigue.

figure 11. The decrease in visual acuity was found to be statistically significant using a paired t-test, p <.0001.

4.3.3 Awareness and empathy. When examining the impact of the simulation on the "Emotional Interest/ Discovery" and the "Self-awareness/ Detachment" of participants towards individuals with visual impairment, the comparisons of pre and post-study questionnaires showed a statistically significant increase in both dimensions. Table 2 and figure 13 show that for all items included in the questionnaire, participants reported a significant positive shift in awareness and empathy. In particular, 8 participants stated that after taking part in the study they had more interest in learning about the experiences and needs of people with vision loss (Q1); 8 participants were more likely to imagine how people with vision loss would think, feel or behave in different situations (Q2); 9 participants had an increased interest in learning about the experiences and opinions of people with vision loss's in relation to their research and design work (Q4); 8 participants were more likely to imagine how they would feel and think if they were a person with vision loss (Q5), and 8 participants had increased awareness of the similarities and differences between their own experiences and the ones of people with vision loss (Q7).

4.3.4 Motion sickness symptoms. When asked whether the visual impairment simulation provided by our glasses ever triggered typical motion sickness symptoms such as headaches and or visual fatigue. 9 out of all 14 participants answered either Strongly Disagree or Disagree, while two answered Neutral, and three answered, Agree. To further enquire about the potential causes of their discomfort, we asked participants about the specific effects or tasks that triggered their headache and or visual fatigue, and if these

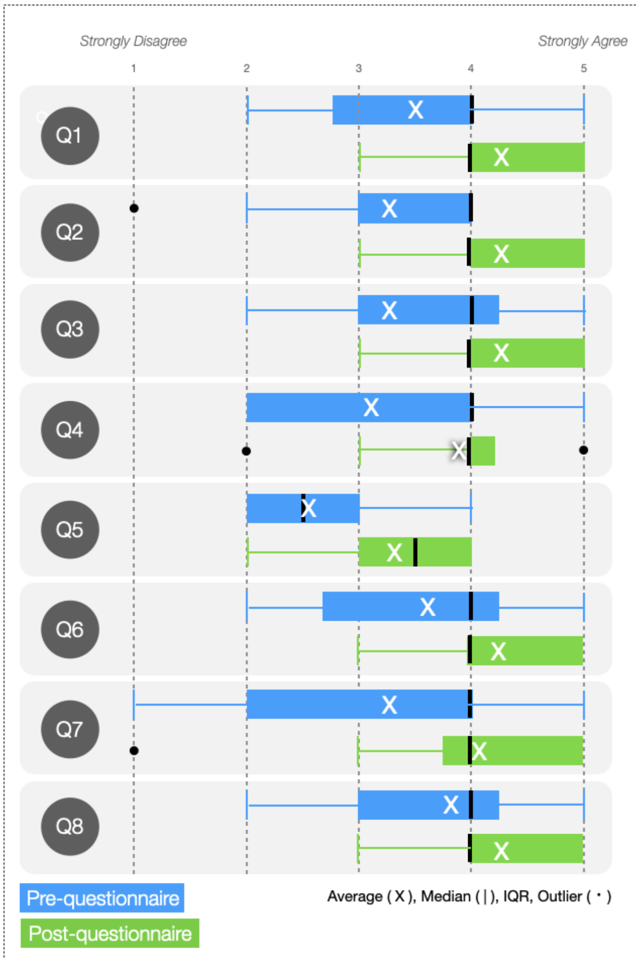

Figure 13: Comparison of pre and post-questionnaires. Full questions can be found in table 2.

unpleasant signs lasted as long as they usually experience when using VR. Two participants stated that the visual fatigue occurred as a result of the presence of the central dots (central vision loss effects), which made them spend more energy seeing things' details. In turn, they mentioned that the central dots led to the feeling of visual fatigue, but no headaches were experienced. Moreover, it was added that as soon as the smart glasses were removed the visual fatigue disappeared immediately.

On the other hand, when talking about the headache and or visual fatigue ever experienced in connection to the use of VR headsets, 11 out of 14 participants answered either "Strongly Agree (8)" or "Agree (3)". Of the remaining 3 participants, two had never tried wearing VR headsets and 1 answered strongly disagree. See figure 12.

4.3.5 Qualitative Feedback. In terms of the oral feedback that we received from the participants, we identified contrasting opinions regarding their impaired central and peripheral vision experience. Concerning the personal-item-search task, half of the participants stated that the impaired peripheral vision caused more challenges, whereas the other half found the impaired central vision condition more difficult. Amongst the people who mentioned peripheral vision loss as most challenging, the majority stated that it was not very difficult for them to quickly scan the area even when their central field of vision was covered by the central vision loss effects. On the contrary, among participants who found the impaired central vision most difficult, the majority stated that it was challenging to distinguish details of the surrounding objects when their central vision overlapped with the effects. Moreover, they felt that the clarity of the environment would also decrease.

Interestingly, one participant stated that the impaired peripheral vision helped her focus more on the personal item searching tasks. However, all participants agreed that both conditions narrowed their vision and reduced their confidence in walking around a familiar environment. During the visual acuity test with the Snellen charts, all participants mentioned that clarity was significantly reduced when the central vision impaired mode was active. In particular, it was difficult for them to distinguish small details and minor differences. For example, they felt frequently confused by distinguishing E and F, F and P, and O and C in the Snellen Charts.

When comparing the differences between VR headsets and the OST visual impairment simulation glasses used in this study, participants unanimously stated that they found this device offered a more comfortable experience. In particular, none of the participants experienced dizziness as a result of using the OST visual impairment simulation glasses, which were frequently mentioned in connection to VR HMD use. Moreover, many of our participants mentioned that the simulation provided by our glasses made the experience feel more natural and gave them a better experience than just placing a screen in front of their eyes.

One of the participants has a fascinating take on the differences between VR and our glasses. She mentioned that the premise between VR headsets and our smart glasses was for her entirely different.

Based on the oral feedback from the participants it was also clear that the awareness of vision loss increased. One of the participants told us that she didn't put much consideration into vision loss before the experiment. However, after our experiment, she really felt frustrated and annoyed by the barriers faced by people with vision loss.

5 DISCUSSION

Our experimental results show that our method can statistically and significantly reduce visual acuity and field of vision, which are the key factors when defining visually impaired levels. While relevant works such as [14] & [73] highlight how static filters and superimposed black occlusions on standard spectacles have been reported as unrealistic by individuals with both glaucoma and AMD.

Our approach of using programmable transparent LCDs to simulate visual impairment represents a more real-world adaptable and intuitive way to capture the variability of visual impairment symptoms. Key hardware features of our prototype include adjustable severity of visual acuity loss by altering the contrast level of the simulating patterns, while also can control the size and location to represent the affected area of the vision system. The further advantage of incorporating eye-tracking means that the simulated effect follows the gaze of the individual, providing a more realistic experience. The result of the personal item searching tasks also suggests the potential that our optical see-through visual impairment simulation glasses can support daily routine-like tasks easily. The observed hesitation that happened when the participants were distinguishing whether the detected phone is a dummy or their own phone indicates the reliable and stable visually impaired simulation experience that our method can offer.

In the qualitative feedback section, we found participants who had negative VR experiences are likely voluntarily to draw a line between our device and HMDs, they could have rejected to join our study if we need them to try on an HMD for the experiments. Additionally, they categorized our device as either glasses or AR glasses, none of them used either HMD (head-mounted display) or HWD (head-worn display) to describe our prototype. It suggests that the appearance design and the visual information providing mechanism (OST or VST) may correlate with the acceptance level and subjective categorization.

Results from the empathy scale show that experiencing our glasses had a positive impact on the level of awareness of design students, in particular increasing their willingness to engage with individuals with lived experience of visual impairment.

Regarding how accurate our system can simulate, despite our best efforts, overall it is very difficult to know if a simulation mimics a subjective experience of a person with visual (or other) impairment [33]. Thus we chose to leverage programmable optical see-through displays as our lenses to approach the individual variation and different severities.

In the next step, we plan to evaluate if our visual impairment simulation glasses can provide a sufficiently good approximation for peripheral and central vision loss modeling of the accuracy and efficiency loss in standard vision tests (similar to Godman et al.'s experiments with static glasses [27]).

6 CONCLUSION

In this paper, we introduced the first optical see-through (OST) visual impairment simulation glasses with real-time eye tracking. These glasses enabled significantly reduced visual acuity and visual field without causing typical motion sickness symptoms such as headaches and or visual fatigue. By experiencing these OST visual impairment simulation glasses to do daily routines, the wearers showed significantly increased awareness and empathy for the visually impaired experience.

Unlike analog visual impairment simulation goggles, 2D image-based simulation applications, and video see-through HMD-based visual impairment simulation methods, our OST visual impairment simulation glasses have the largest FOV and enable a VAC-free visual information processing experience.

We conducted two visual impairment simulations, one is central vision loss, and the other is peripheral vision loss. During the experiment, participants experienced two personal item searching tasks under those two visually impaired simulations one to another followed shifted order. To address the potential changes in both awareness and empathy after the visual impairment simulation, we had the participants fill out a pre and a post questionnaire, the pre-questionnaire was filled out before the simulation started, and the post-questionnaire was filled out after all the two visually impaired experience. We found our optical see-through visual impairment simulation glasses enabled significantly visually impaired experience for both reduced visual acuity and visual field. Combining the personal item searching tasks, we found significantly increased awareness and empathy for visual impairment.

Altogether, we find our visual impairment simulation glasses are the first optical see-through based method that enabled VAC-free visually impaired experience and can be real-time and real-world adaptive for various simulating scenarios such as doing daily routines and checking if a product's or an environmental design is friendly enough for visually impaired peoples.

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REFERENCES

[1] Samuel Aballéa and Aki Tsuchiya. 2007. Seeing for yourself: feasibility study towards valuing visual impairment using simulation spectacles. *Health economics* 16, 5 (2007), 537–543.

[2] Z. Ai, B.K. Gupta, M. Rasmussen, Ya Ju Lin, F. Dech, W. Panko, and J.C. Silverstein. 2000. Simulation of eye diseases in a virtual environment. In *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences.* 5 pp.–. https://doi.org/10.1109/HICSS.2000.926803

[3] Peter M Allen, Rianne HJC Ravensbergen, Keziah Latham, Amy Rose, Joy Myint, and David L Mann. 2018. Contrast sensitivity is a significant predictor of performance in rifle shooting for athletes with vision impairment. *Frontiers in psychology* 9 (2018), 950.

[4] Shotaro Asano, Ryo Asaoka, Hiroshi Murata, Yohei Hashimoto, Atsuya Miki, Kazuhiko Mori, Yoko Ikeda, Takashi Kanamoto, Junkichi Yamagami, and Kenji Inoue. 2021. Predicting the central 10 degrees visual field in glaucoma by applying a deep learning algorithm to optical coherence tomography images. *Scientific Reports* 11, 1 (2021), 1–10.

[5] Halim Cagri Ates, Alexander Fiannaca, and Eelke Folmer. 2015. Immersive Simulation of Visual Impairments Using a Wearable See-through Display. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (Stanford, California, USA) *(TEI '15)*. Association for Computing Machinery, New York, NY, USA, 225–228. https://doi.org/10.1145/2677199.2680551

[6] Halim Cagri Ates, Alexander Fiannaca, and Eelke Folmer. 2015. Immersive simulation of visual impairments using a wearable see-through display. In *Proceedings of the ninth international conference on tangible, embedded, and embodied interaction.* 225–228.

[7] Mark S Baldwin, Sen H Hirano, Jennifer Mankoff, and Gillian R Hayes. 2019. Design in the public square: Supporting assistive technology design through public mixed-ability cooperation. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (2019), 1–22.

[8] Cynthia L Bennett and Daniela K Rosner. 2019. The Promise of Empathy: Design, Disability, and Knowing the" Other". In *Proceedings of the 2019 CHI conference on human factors in computing systems.* 1–13.

[9] Puran S Bora, Zhiwei Hu, Tongalp H Tezel, Jeong-Hyeon Sohn, Shin Goo Kang, Jose MC Cruz, Nalini S Bora, Alan Garen, and Henry J Kaplan. 2003. Immunotherapy for choroidal neovascularization in a laser-induced mouse model simulating exudative (wet) macular degeneration. *Proceedings of the National Academy of Sciences* 100, 5 (2003), 2679–2684.

[10] Rupert Bourne, Jaimie D Steinmetz, Seth Flaxman, Paul Svitil Briant, Hugh R Taylor, Serge Resnikoff, Robert James Casson, Amir Abdoli, Eman Abu-Gharbieh, Ashkan Afshin, et al. 2021. Trends in prevalence of blindness and distance and near vision impairment over 30 years: an analysis for the Global Burden of Disease Study. *The Lancet global health* 9, 2 (2021), e130–e143.

[11] Kenny Tsu Wei Choo, Rajesh Krishna Balan, and Youngki Lee. 2019. Examining augmented virtuality impairment simulation for mobile app accessibility design. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.* 1–11.

[12] Hugo Chow-Wing-Bom, Tessa M Dekker, and Pete R Jones. 2020. The worse eye revisited: Evaluating the impact of asymmetric peripheral vision loss on everyday function. *Vision research* 169 (2020), 49–57.

[13] Tanvir Irfan Chowdhury, Sharif Mohammad Shahnewaz Ferdous, and John Quarles. 2017. Information recall in a virtual reality disability simulation. In *Proceedings*

of the 23rd ACM symposium on virtual reality software and technology. 1–10.

[14] David P Crabb, Nicholas D Smith, Fiona C Glen, Robyn Burton, and David F Garway-Heath. 2013. How does glaucoma look?: patient perception of visual field loss. *Ophthalmology* 120, 6 (2013), 1120–1126.

[15] Michael Crabb, Michael Heron, Rhianne Jones, Mike Armstrong, Hayley Reid, and Amy Wilson. 2019. Developing Accessible Services: Understanding Current Knowledge and Areas for Future Support. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300446

[16] Carolyn Czoski-Murray, Jill Carlton, John Brazier, Tracey Young, Natalie L Papo, and Hyong Kwon Kang. 2009. Valuing condition-specific health states using simulation contact lenses. *Value in Health* 12, 5 (2009), 793–799.

[17] Roger Davis. 1994. *(WEB)Vision Simulations*. http://visionsimulations.com

[18] Luce Drouet, Kerstin Bongard, Vincent Koenig, and Carine Lallemand. 2022. Empathy in Design Scale: Development and Initial Insights. In *Proceedings of the Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems*.

[19] Visual Impairment North East. 1984. *Sim Specs*. https://www.vinesimspecs.com

[20] Augusto Esteves, Eduardo Velloso, Andreas Bulling, and Hans Gellersen. 2015. Orbits: Gaze interaction for smart watches using smooth pursuit eye movements. In *Proceedings of the 28th annual ACM symposium on user interface software & technology*. 457–466.

[21] Paul J Foster and Gordon J Johnson. 2001. Glaucoma in China: how big is the problem? *British journal of ophthalmology* 85, 11 (2001), 1277–1282.

[22] Timothy R Fricke, Monica Jong, Kovin S Naidoo, Padmaja Sankaridurg, Thomas J Naduvilath, Suit May Ho, Tien Yin Wong, and Serge Resnikoff. 2018. Global prevalence of visual impairment associated with myopic macular degeneration and temporal trends from 2000 through 2050: systematic review, meta-analysis and modelling. *British Journal of Ophthalmology* 102, 7 (2018), 855–862.

[23] Gabriel M. GAUTHIER, Gerard OBRECHT, Claude PEDRONO, Jean-Louis VERCHER, and Lawrence STARK. 1987. ADAPTIVE OPTIMIZATION OF EYE-HEAD COORDINATION WITH DEGRADED PERIPHERAL VISION (*). In *Eye Movements from Physiology to Cognition*, J.K. O'REGAN and A. LEVY-SCHOEN (Eds.). Elsevier, Amsterdam, 201–210. https://doi.org/10.1016/B978-0-444-70113-8.50032-1

[24] Florian Gekeler, Andre Messias, Max Ottinger, Karl Ulrich Bartz-Schmidt, and Eberhart Zrenner. 2006. Phosphenes electrically evoked with DTL electrodes: a study in patients with retinitis pigmentosa, glaucoma, and homonymous visual field loss and normal subjects. *Investigative ophthalmology & visual science* 47, 11 (2006), 4966–4974.

[25] Kathrin Maria Gerling, Regan L Mandryk, Max Valentin Birk, Matthew Miller, and Rita Orji. 2014. The effects of embodied persuasive games on player attitudes toward people using wheelchairs. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 3413–3422.

[26] Joy Goodman-Deane, Patrick M Langdon, P John Clarkson, Nicholas HM Caldwell, and Ahmed M Sarhan. 2007. Equipping designers by simulating the effects of visual and hearing impairments. In *Proceedings of the 9th international ACM SIGACCESS conference on computers and accessibility*. 241–242.

[27] Joy Goodman-Deane, Sam Waller, Alice-Catherine Collins, and John Clarkson. 2013. Simulating vision loss: what levels of impairment are actually represented?. In *Contemporary Ergonomics and Human Factors 2013: Proceedings of the international conference on Ergonomics & Human Factors 2013, Cambridge, UK, 15-18 April 2013*. CRC Press, 347.

[28] Joy Goodman-Deane, Sam Waller, Katie Cornish, and P John Clarkson. 2014. A simple procedure for using vision impairment simulators to assess the visual clarity of product features. In *International Conference on Universal Access in Human-Computer Interaction*. Springer, 43–53.

[29] Kunal Gupta, Gun A Lee, and Mark Billinghurst. 2016. Do you see what I see? The effect of gaze tracking on task space remote collaboration. *IEEE transactions on visualization and computer graphics* 22, 11 (2016), 2413–2422.

[30] Yuichi Hiroi, Yuta Itoh, Takumi Hamasaki, and Maki Sugimoto. 2017. Assisting Eye Adaptation Via Occlusive Optical See-Through Head-Mounted Displays AdaptiVisor.

[31] Chad Hochberg, Eugenio Maul, Emilie S Chan, Suzanne Van Landingham, Luigi Ferrucci, David S Friedman, and Pradeep Y Ramulu. 2012. Association of vision loss in glaucoma and age-related macular degeneration with IADL disability. *Investigative ophthalmology & visual science* 53, 6 (2012), 3201–3206.

[32] Donald C Hood, Ali S Raza, Carlos Gustavo V de Moraes, Jeffrey G Odel, Vivienne C Greenstein, Jeffrey M Liebmann, and Robert Ritch. 2011. Initial arcuate defects within the central 10 degrees in glaucoma. *Investigative ophthalmology & visual science* 52, 2 (2011), 940–946.

[33] Fork in the Road. 1994. *Low Vision Simulators*. https://www.lowvisionsimulators.com

[34] Braille Institute. 1994. *Telephone Reader Program (TRP)*. https://brailleinstitute.org/technology-for-vision-impaired/mobile-applications

[35] Kodai Ito, Mitsunori Tada, Hiroyasu Ujike, and Keiichiro Hyodo. 2021. Effects of the Weight and Balance of Head-Mounted Displays on Physical Load. *Applied Sciences* 11, 15 (2021), 6802.

[36] Bei Jin, Zhuming Ai, and Mary Rasmussen. 2005. Simulation of Eye Disease in Virtual Reality. *Conference proceedings : ... Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Conference* 5 (02 2005), 5128–31. https://doi.org/10.1109/IEMBS.2005.1615631

[37] Bei Jin, Zhuming Ai, and Mary Rasmussen. 2006. Simulation of eye disease in virtual reality. In *2005 IEEE engineering in medicine and biology 27th annual conference*. IEEE, 5128–5131.

[38] Pete R Jones, Tamás Somoskeöy, Hugo Chow-Wing-Bom, and David P Crabb. 2020. Seeing other perspectives: evaluating the use of virtual and augmented reality to simulate visual impairments (OpenVisSim). *NPJ digital medicine* 3, 1 (2020), 1–9.

[39] Valerie Juniat, Rabia Bourkiza, Aditi Das, Raja Das-Bhaumik, Panagiota Founti, Christopher Yeo, Rashmi Mathew, and Narciss Okhravi. 2019. Understanding visual impairment and its impact on patients: A simulation-based training in undergraduate medical education. *Journal of medical education and curricular development* 6 (2019), 2382120519843854.

[40] Christoph M Kanzler, Jens Barth, Jochen Klucken, and Bjoern M Eskofier. 2016. Inertial sensor based gait analysis discriminates subjects with and without visual impairment caused by simulated macular degeneration. In *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, 4979–4982.

[41] Moritz Kassner, William Patera, and Andreas Bulling. 2014. Pupil: an open source platform for pervasive eye tracking and mobile gaze-based interaction. In *Proceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing: Adjunct publication*. 1151–1160.

[42] Claire Kearney-Volpe, Devorah Kletenik, Kate Sonka, Deborah Sturm, and Amy Hurst. 2019. Evaluating instructor strategy and student learning through digital accessibility course enhancements. In *The 21st International ACM SIGACCESS Conference on Computers and Accessibility*. 377–388.

[43] Wonjung Kim, Kenny Tsu Wei Choo, Youngki Lee, Archan Misra, and Rajesh Krishna Balan. 2018. Empath-d: Vr-based empathetic app design for accessibility. In *Proceedings of the 16th Annual International Conference on Mobile Systems, Applications, and Services*. 123–135.

[44] Sharon Kingman. 2004. Glaucoma is second leading cause of blindness globally. *Bulletin of the World Health Organization* 82 (2004), 887–888.

[45] Devorah Kletenik and Rachel F Adler. 2022. Let's Play: Increasing Accessibility Awareness and Empathy Through Games. In *Proceedings of the 53rd ACM Technical Symposium on Computer Science Education V. 1*. 182–188.

[46] Gregory Kramida. 2015. Resolving the vergence-accommodation conflict in head-mounted displays. *IEEE transactions on visualization and computer graphics* 22, 7 (2015), 1912–1931.

[47] Katharina Krösl, Dominik Bauer, Michael Schwärzler, Henry Fuchs, Georg Suter, and Michael Wimmer. 2018. A VR-based user study on the effects of vision impairments on recognition distances of escape-route signs in buildings. *The Visual Computer* 34, 6 (2018), 911–923.

[48] Katharina Krösl, Carmine Elvezio, Laura R Luidolt, Matthias Hürbe, Sonja Karst, Steven Feiner, and Michael Wimmer. 2020. CatARact: Simulating cataracts in augmented reality. In *2020 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 682–693.

[49] Kim Kullman. 2016. Prototyping bodies: A post-phenomenology of wearable simulations. *Design Studies* 47 (2016), 73–90.

[50] Pupil Lab. 2014. *(WEB)Pupil CORE*. https://pupil-labs.com/products/core/tech-specs/

[51] Laurence S Lim, Paul Mitchell, Johanna M Seddon, Frank G Holz, and Tien Y Wong. 2012. Age-related macular degeneration. *The Lancet* 379, 9827 (2012), 1728–1738.

[52] Chao Ma, Minoru Taya, and Chunye Xu. 2008. Smart sunglasses based on electrochromic polymers. *Polymer Engineering & Science* 48, 11 (2008), 2224–2228.

[53] Rhouri MacAlpine and David R Flatla. 2016. Real-time mobile personalized simulations of impaired colour vision. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*. 181–189.

[54] J. Mankoff, H. Fait, and R. Juang. 2005. Evaluating accessibility by simulating the experiences of users with vision or motor impairments. *IBM Systems Journal* 44, 3 (2005), 505–517. https://doi.org/10.1147/sj.443.0505

[55] Paul Mitchell, Gerald Liew, Bamini Gopinath, and Tien Y Wong. 2018. Age-related macular degeneration. *The Lancet* 392, 10153 (2018), 1147–1159.

[56] Richard Musil. 2022. *HMD Geometry Database*. https://risa2000.github.io/hmdgdb/

[57] Jun Nishida, Soichiro Matsuda, Mika Oki, Hikaru Takatori, Kosuke Sato, and Kenji Suzuki. 2019. Egocentric Smaller-person Experience through a Change in Visual Perspective. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–12.

[58] Jun Nishida and Kenji Suzuki. 2019. HYPERSPECTIVE: Shaping Experiences beyond Perspectives. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 1546–1549.

[59] World Health Organization et al. 2019. World report on vision. (2019).

[60] CG Owen, AE Fletcher, M Donoghue, and AR Rudnicka. 2003. How big is the burden of visual loss caused by age related macular degeneration in the United Kingdom? *British Journal of Ophthalmology* 87, 3 (2003), 312–317.

[61] Produkt+Projekt. 1994. *Aging Simulation Suit GERT*. https://www.gtsimulators.com/products/aging-simulation-suit-gert-ppd1002

[62] Harry A Quigley. 1996. Number of people with glaucoma worldwide. *British journal of ophthalmology* 80, 5 (1996), 389–393.

[63] S Rae, Keziah Latham, and Maria F Katsou. 2016. Meeting the UK driving vision standards with reduced contrast sensitivity. *Eye* 30, 1 (2016), 89–94.

[64] Barry W. Rovner and Robin J. Casten. 2002. Activity Loss and Depression in Age-Related Macular Degeneration. *The American Journal of Geriatric Psychiatry* 10, 3 (2002), 305–310. https://doi.org/10.1097/00019442-200205000-00010

[65] Marilyn E Schneck, Anthony J Adams, Kenneth Huie, and Ellen Lee. 1993. A filter for simulating color and spatial vision of the elderly. In *Colour Vision Deficiencies XI*. Springer, 357–364.

[66] Ximing Shen, Yun Suen Pai, Dai Kiuchi, Kanoko Oishi, Kehan Bao, Tomomi Aoki, and Kouta Minamizawa. 2021. Dementia Eyes: Perceiving Dementia with Augmented Reality. In *SIGGRAPH Asia 2021 XR* (Tokyo, Japan) *(SA '21 XR)*. Association for Computing Machinery, New York, NY, USA, Article 5, 2 pages. https://doi.org/10.1145/3478514.3487617

[67] Kristen Shinohara, Cynthia L Bennett, Wanda Pratt, and Jacob O Wobbrock. 2018. Tenets for social accessibility: Towards humanizing disabled people in design. *ACM Transactions on Accessible Computing (TACCESS)* 11, 1 (2018), 1–31.

[68] Barbara Sivak and Christine L. MacKenzie. 1990. Integration of visual information and motor output in reaching and grasping: The contributions of peripheral and central vision. *Neuropsychologia* 28, 10 (1990), 1095–1116. https://doi.org/10.1016/0028-3932(90)90143-C

[69] Simon Stock, Christina Erler, and Wilhelm Stork. 2018. Realistic simulation of progressive vision diseases in virtual reality. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology*. 1–2.

[70] Kevin M Storer and Stacy M Branham. 2019. " That's the Way Sighted People Do It" What Blind Parents Can Teach Technology Designers About Co-Reading with Children. In *Proceedings of the 2019 on Designing Interactive Systems Conference*. 385–398.

[71] Hans Strasburger, Ingo Rentschler, and Martin Jüttner. 2011. Peripheral vision and pattern recognition: A review. *Journal of vision* 11, 5 (2011), 13–13.

[72] Ancret Szpak, Stefan Michalski, Dimitrios Saredakis, Celia Chen, and Tobias Loetscher. 2019. Beyond Feeling Sick: The Visual and Cognitive Aftereffects of Virtual Reality. *IEEE Access* PP (09 2019), 1–1. https://doi.org/10.1109/ACCESS.2019.2940073

[73] Deanna J Taylor, Laura A Edwards, Alison M Binns, and David P Crabb. 2018. Seeing it differently: self-reported description of vision loss in dry age-related macular degeneration. *Ophthalmic and Physiological Optics* 38, 1 (2018), 98–105.

[74] B Thylefors and AD2486713 Negrel. 1994. The global impact of glaucoma. *Bulletin of the World Health Organization* 72, 3 (1994), 323.

[75] Garreth W Tigwell. 2021. Nuanced perspectives toward disability simulations from digital designers, blind, low vision, and color blind people. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–15.

[76] Wikipedia. 2022. *Comparison of virtual reality headsets, 2022-07-26 access*. https://en.wikipedia.org/wiki/Comparison_of_virtual_reality_headsets

[77] Joanne Wood, Alex Chaparro, Kaarin Anstey, Philippe Lacherez, Aaron Chidgey, Jared Eisemann, Alison Gaynor, and Peter La. 2010. Simulated visual impairment leads to cognitive slowing in older adults. *Optometry and Vision Science* 87, 12 (2010), 1037–1043.

[78] Haojie Wu, Daniel H Ashmead, Haley Adams, and Bobby Bodenheimer. 2018. Using virtual reality to assess the street crossing behavior of pedestrians with simulated macular degeneration at a roundabout. *Frontiers in ICT* (2018), 27.

[79] Matteo Zallio, Sam Waller, Camelia Chivaran, and John Clarkson. 2021. Visual Accessibility and Inclusion. An Exploratory Study to Understand Visual Accessibility in the Built Environment. (2021).

[80] Qing Zhang, Yifei Huang, George Chernyshov, Juling Li, Yun Suen Pai, and Kai Kunze. 2022. GazeSync: Eye Movement Transfer Using an Optical Eye Tracker and Monochrome Liquid Crystal Displays. In *27th International Conference on Intelligent User Interfaces*. 54–57.

[81] Qing Zhang, Hiroo Yamamura, Holger Baldauf, Dingding Zheng, Kanyu Chen, Junichi Yamaoka, and Kai Kunze. 2021. Tunnel Vision–Dynamic Peripheral Vision Blocking Glasses for Reducing Motion Sickness Symptoms. In *2021 International Symposium on Wearable Computers*. 48–52.

[82] Xucong Zhang, Yusuke Sugano, Mario Fritz, and Andreas Bulling. 2017. Mpiigaze: Real-world dataset and deep appearance-based gaze estimation. *IEEE transactions on pattern analysis and machine intelligence* 41, 1 (2017), 162–175.

[83] George J. Zimmerman. 1979. *Zimmerman Low Vision Simulation Kit*. http://www.lowvisionsimulationkit.com