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Design of a Visual Field Test Prototype in VR for Spatial Perception Evaluation

***Abstract*—Visual field evaluation is essential for understanding spatial perception and detecting potential visual impairments. This study proposes the design of a basic visual field test prototype using virtual reality (VR) technology. The system was developed in Unity and implemented on Meta Quest Pro headsets. It simulates the presentation of peripheral visual stimuli in a controlled immersive environment and records user responses through the VR controller to generate a basic visual field map. The study also examines technical limitations related to the use of VR in this application, including headset ergonomics, stimulus visibility, and system usability. Although the prototype is currently intended for academic and experimental purposes only, it establishes a foundation for future development toward potential clinical diagnostic applications.**

***Index Terms*—diagnostic tools, immersive environment, spatial perception, Unity, visual field, virtual reality.**

I. Introduction

Imagine not noticing a cyclist while crossing the street or watching text fade from the edges of a page; this is the everyday reality for individuals with partial visual field loss. Such impairments can affect independence, safety, and quality of life. Although visual field testing is critical for detecting early signs of neurological or ophthalmologic conditions, conventional confrontation perimetry remains limited by its reliance on examiner expertise and lack of objective recording.

In recent years, virtual reality (VR) has emerged as a promising tool in medical simulation, offering immersive, interactive environments ideal for replicating clinical procedures. This study explores the development of a VR based visual field test, modeled on the Humphrey 24-2 standard, using Unity and the Meta Quest Pro headset. The prototype allows users to respond to controlled visual stimuli in a virtual environment, enabling the generation of visual field maps.

Virtual reality is no longer just a tool for entertainment, it is reshaping how we assess vision. In recent years, researchers have begun to reimagine visual field testing through immersive environments that offer not only precision, but also comfort and accessibility. A 2024 pilot study revealed that children responded more positively to VR based testing compared to traditional methods [1], while studies with glaucoma patients reported high acceptance and usability, signaling a promising future for clinical integration, although challenges remain in the refinement of stimulus standardization and precision [2].

Globally, glaucoma affects an estimated 60 million people in 2010, projected to increase to 80 million by 2020, with 3.5 to 5% of people over 40 experiencing the early stages of the disease [3]. Moreover, loss of visual field, common in glaucoma, dramatically increases the risk of traffic collisions: drivers with bilateral field defects have a 84% higher chance of being involved in a crash [4]. These statistics underscore the urgent need for early detection technologies to preserve vision and enhance public safety.

The main objective is to design a visual field assessment system that simulates traditional clinical conditions in an immersive environment, evaluating both its technical performance and practical limitations. Although this is a purely academic and experimental study with no clinical application, a comparison with conventional equipment (Zeiss HFA) is conducted to assess the feasibility and challenges of VR based perimetry in resource limited settings.

A. Background and Related Work

1) Perimetry: In 2023, a systematic review highlighted the use of virtual reality (VR) devices to perform visual field tests, demonstrating that these systems can produce results comparable to traditional automated perimetry methods, while offering significant advantages in terms of portability and accessibility. In addition, the immersive nature of VR improves patient experience, which is particularly beneficial for pediatric populations or individuals with limited access to specialized care [5]. On the other hand, a prospective study conducted by a group of researchers directly compared VisuALL virtual reality perimetry with Humphrey automated perimetry in patients with glaucoma [6]. The results showed a strong correlation between both methods, validating the accuracy of VR based visual field testing and paving the way for its potential clinical implementation in the near future. This type of research highlights the importance of maintaining high standards of calibration and design to ensure the reliability and validity of the data obtained.

2) Visual Field: The visual field refers to the area that a person can perceive without eye or head movement and is essential for the diagnosis and monitoring of ophthalmologic conditions. A 2024 narrative review described the progression of perimetric methods, from basic confrontation to advanced computerized systems, highlighting how digitalization has improved precision and early detection of visual impairments [7].

Likewise, [8] outlines the crucial role that visual field evaluation plays in detecting conditions such as glaucoma, strokes, and tumors of the central nervous system. The text also highlights the growing integration of new technologies, including virtual reality, to improve the accessibility and accuracy of these examinations, which is especially relevant in low resource settings or for the remote monitoring of patients.

3) Virtual Reality: Recent studies have explored the use of virtual reality (VR) as a tool for visual field testing in ophthalmology. A 2024 pilot study comparing VR with traditional methods in pediatric populations found comparable results, with higher ease of use among children [9]. Other studies have reported good acceptance and tolerability of VR based perimetry in glaucoma patients, though improvements in stimulus precision and methodological standardization are still needed [10].

4) Unity as a Platform for VR Based Perimetry: Unity has become a widely used engine for developing virtual reality (VR) software in visual assessment due to its versatility, compatibility, and ease of integration. It has been successfully employed to create controlled environments for automated VR based perimetry, enabling precise stimulus presentation and technically rigorous testing [11].

In 2023, the development of the "VisualR" platform demonstrated Unity's scalability for implementing modular visual function tests in both clinical and research settings [12]. Its broad compatibility with various VR hardware systems makes it a practical and adaptable choice for developing ophthalmologic applications, including customizable visual field tests that can be configured by clinicians before administration.

5) Automated Visual Diagnostics: A 2020 study validated the reliability and repeatability of an automated system based on the ETDRS chart for measuring near and intermediate visual acuity, showing strong agreement with standard printed chart results (95% limits of agreement) [13].

Automated methods are particularly valuable in pediatric ophthalmology, where cooperation and examiner observation can be challenging. A 2022 study introduced the AACP system, which uses eye tracking to assess visual acuity in children aged 5 to 36 months. By detecting whether the child fixates on grid patterns at varying spatial frequencies, the system produced results consistent with previous findings, supporting its effectiveness as a non invasive and objective diagnostic tool [14].

6) Computerized Perimetry: A 2024 review examined its current role and future perspectives, identifying areas for improvement such as spatial distribution of test points and intra individual variability caused by attention or patient comprehension [15].

A 2022 study further questioned SAP's usefulness for AMD assessment, reviewing multiple commercially available devices. While early and intermediate functional changes were detectable, the utility of SAP under non standard lighting conditions was limited [16].

7) Innovation in Ophthalmology: Innovation in ophthalmology involves the adoption of new technologies to improve the diagnosis, prevention, and treatment of eye diseases. Advances such as virtual reality, artificial intelligence, telemedicine, and portable devices have enabled earlier and more accurate detection of visual disorders, particularly in low resource settings [17].

8) 24-2 Protocol: The 24-2 protocol is a standard automated perimetry configuration that evaluates 54 points across the central visual field, distributed every 6 degrees. It covers 24° toward the temporal region and 30° toward the nasal side. This pattern is widely used in the diagnosis and monitoring of ocular pathologies, as it allows the detection of characteristic visual field defects such as nasal steps and arcuate scotomas. When appsuch as SITA Faster,like SITA Faster, the test duration is significantly reduced without compromising clinical result quality [18].

II. Methodology

This study followed an experimental methodology with a technological orientation focused on designing a prototype for basic visual campimetry using virtual reality. Initially, a conceptual review of static campimetry principles was conducted to adapt them to an immersive digital format. The prototype was developed in Unity and executed on Meta Quest Pro headsets, projecting visual stimuli in predefined peripheral positions while users maintained gaze on a central fixation point. Stimuli appeared randomly and could be adjusted in duration and intensity. Each stimulus was shown three times during the test, and was marked as "detected" if the participant responded to it at least two out of three times.

To validate the technical performance of the prototype, a comparative procedure was carried out. Five subjects (referred to as Subject 1 through Subject 5) first underwent a conventional visual field exam using a Zeiss Humphrey Field Analyzer 3, following the SITA Faster 24-2 protocol. This clinical test served as a gold standard reference. All participants used their own corrective lenses during this phase if needed, and the procedure was performed under the supervision and assistance of trained personnel from the ophthalmology clinic that owned the equipment. A summary of lens usage by each subject and its potential impact on test results is provided in Table 1.

TABLE I
USE OF CORRECTIVE LENSES AMONG STUDY PARTICIPANTS

Subject	Wears corrective glasses
1	Yes
2	Yes
3	No
4	Yes
5	Yes

After completing the clinical test, the same participants performed a second visual field exam using the VR prototype. Although the VR exam was not conducted at the clinic itself, similar environmental and ergonomic conditions were replicated (e.g., ambient lighting, sitting posture, and visual fixation guidelines) to maintain consistency. Each test was performed monocularly. In both the clinical and VR tests, the left eye (OS) was tested first, while the right eye (OD) was covered using an external patch. After completing the test for OS, the patch was switched to cover the left eye, and the same sequence was repeated for OD. During the VR test, participants responded to visual stimuli by pressing a button

on the VR controller when detection occurred. The system recorded these interactions and stored the spatial coordinates of the detected stimuli. At the end of each test, a binary array was generated representing which points were perceived. These data were later visualized as 2D visual field maps to assess spatial correspondence with the clinical results.

A. Scope

The scope of this research is centered on the design and internal evaluation of a VR based prototype that simulates a standard 24-2 Humphrey visual field test. Its purpose is to explore the potential of virtual reality in the context of ophthalmological evaluations, specifically focusing on the feasibility, comfort, and precision of the stimuli presented in a controlled virtual environment. This study does not include clinical validation with patients nor aims for diagnostic use. Instead, it serves as an academic and experimental proposal to assess the adaptability of VR technology for low resource healthcare settings like those in Honduras. The analysis includes identifying technical and clinical limitations such as viewer ergonomics, user interaction methods, and the reliability of results compared to conventional perimetry equipment.

The Meta Quest Pro headset and Unity development platform were used to support the perimetry exam. Meta Quest Pro includes real time head tracking, ergonomic controllers for input, and a high quality LCD display that ensures consistent brightness and color. Unity was used to design the virtual environment and control the precise location and timing of visual stimuli.

For the operation of the prototype, the flow chart in Fig. 1 was generated to explain how the exam data was generated, processed and displayed.

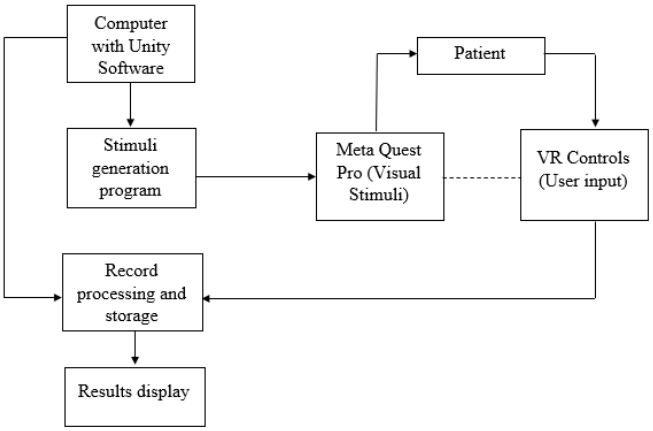

Fig. 1. Prototype flow chart.

The prototype begins with a computer, which has the Unity software installed, and was used to create the code and execute the perimetry exam. The program in charge of generating the stimuli was executed through the Meta Quest Pro Headset and controls. The headset was responsible for displaying the visual stimulus generated by the program to the patient, who was in charge of pressing the buttons on the control to register a perceived stimulus. The records were then sent back to the computer for processing and storage, which were then displayed as the final exam results.

B. Development Steps

The development of the visual field testing system in virtual reality was carried out using the Unity platform and Meta Quest Pro headset, with the purpose of simulating a Humphrey visual field test following the 24-2 standard. The process involved several stages, starting with the setup of the virtual environment, where a fixed camera was placed at the origin to represent the patient's point of view, along with the black background, a static fixation point (a red cube), and visual stimuli (white spheres) presented at specific positions. These stimuli were distributed in a circular structure with angular radii of 6°, 12°, 18°, and 24°, totaling 54 positions. Specific timings were programmed for stimulus appearance and pause intervals, ensuring proper execution within the environment. To initiate the test in a controlled manner, a condition was implemented that activates the sequence through the X button on the left controller, thus preventing automatic executions. During the test, patient responses were recorded based on whether each stimulus was detected and, in the end, the data were transformed into a JPG image representing the detected visual field, preserving the original layout of the stimuli.

C. Signal Processing

The signal processing component of the visual field system aims to translate the patient's response into a visual map of the field of vision, using C# hprogramming. Predefined coordinates list bases on the 24-2 pattern are used, where each stimulus is shown three times to confirm detection. Stimulus duration, pause times, and alignment with the visual axis are carefully managed to ensure accuracy. The test dynamically adapts to the patient's head movements, ensuring that all stimuli remain visible within the virtual reality environment. Each eye is evaluated separately, starting with the right eye, and the sequence is managed through programmed delays. During the test, the system registers whether a stimulus is detected by monitoring button presses, creating individual records for each eye. Afterward, a binary array is generated to represent which points were detected, and these data are transformed into a 2D image where detected stimuli appear in white and undetected ones in black, including the X and Y axes for orientation. Finally, the system exports a JPG image that visually summarizes the visual field results for both eyes.

III. Analysis and Results

To evaluate the reliability and utility of the visual field testing system developed in virtual reality (VR), a comparative analysis was conducted against the standard method based on the SITA Faster 24-2 protocol of the Zeiss Humphrey Field Analyzer. This comparison involved five subjects who underwent the test on both the Zeiss Humphrey and the VR prototype system.

The analysis considered both quantitative and qualitative aspects, including test duration per eye, percentage of stimuli detected, and spatial overlap between the visual field maps obtained from each system. On average, the VR test duration ranged from 2.03 to 2.40 minutes per eye, slightly exceeding the Zeiss Humphrey range (1.36–1.43 minutes), yet remaining within an acceptable time frame.

However, the percentage of stimuli detected by the VR system was significantly lower (ranging from 0% to 48.1%) compared to the Zeiss Humphrey values (96%–100%). Likewise, spatial map correlation also varied considerably, with match rates ranging between 0% and 60%, as shown in Table II.

A subject by subject breakdown reveals the following patterns:

- Lowest detection rates (0%–5.6%) were associated with technical or user related factors such as improper headset positioning, uncorrected refractive errors, or distraction during the test. The absence of lens adapters likely impaired the perception of peripheral stimuli.
- Intermediate detection rates (18%–33%) may be linked to fatigue, slow reaction times, or difficulty maintaining fixation, resulting in delayed or missed responses.
- Higher detection rates (above 40%) were observed in cases where the headset was properly positioned, the subject had good visual acuity, and familiarity with the VR interface. These instances also showed spatial match rates over 55%, indicating better consistency with the Zeiss output.

TABLE II
COMPARATIVE RESULTS OF VISUAL FIELD TESTING BY AUTHOR

Subject	Eye	Device	Duration (min)	% Stimuli Detected	Map Match (%)
1	OD	VR	2.35	18.5% (9/54)	~30%
		Zeiss HFA 2	1.43	99%	-
	OS	VR	2.35	33.3% (19/54)	~50%
		Zeiss HFA 2	1.39	99%	-
2	OD	VR	2.21	42.6% (23/54)	~60%
		Zeiss HFA 2	1.43	98%	-
	OS	VR	2.25	44.4% (24/54)	~65%
		Zeiss HFA 2	1.39	99%	-
3	OD	VR	2.37	48.1% (26/54)	~60%
		Zeiss HFA 2	1.36	100%	-
	OS	VR	2.35	38.9% (21/54)	~55%
		Zeiss HFA 2	1.38	100%	-
4	OD	VR	2.37	9.3% (5/54)	~20%
		Zeiss HFA 2	1.36	98%	-
	OS	VR	2.35	27.8% (15/54)	~40%
		Zeiss HFA 2	1.38	97%	-
5	OD	VR	2.40	5.6% (3/54)	~15%
		Zeiss HFA 2	1.36	99%	-
	OS	VR	2.03	0.0% (0/54)	~0%
		Zeiss HFA 2	1.38	96%	-

The following limitations were identified, which may explain the reduced performance of the VR system when compared to the clinical gold standard:

- Absence of eye tracking: The system does not confirm visual fixation, increasing the likelihood of false negatives when gaze deviates.
- Lack of corrective lens support: Subjects with uncorrected myopia or astigmatism experienced blurred perception of peripheral stimuli.
- Fatigue, distraction, or misalignment: These conditions affected attention and performance during prolonged sessions.
- Slow reaction times: The VR system relied on real time responses, and delays often caused missed detections.

Despite these challenges, most stimuli detected in the VR tests were concentrated in the temporal, inferior, and superonasal regions that partially overlapped with Zeiss HFA maps. This suggests potential for refinement in the VR based approach, particularly with the incorporation of eye tracking, optical correction, and adaptive stimulus programming.

Most stimuli detected in the VR tests were concentrated in the temporal, inferior, and superonasal regions that partially overlapped with Zeiss HFA maps. The following figures present the visual field maps corresponding to the right eye of the Subject 3. Figure 2 shows the full distribution of clinical stimuli according to the SITA Faster protocol, while Figure 3 displays the points detected using the VR system.

Subject 3. Figure 2 Figure 3

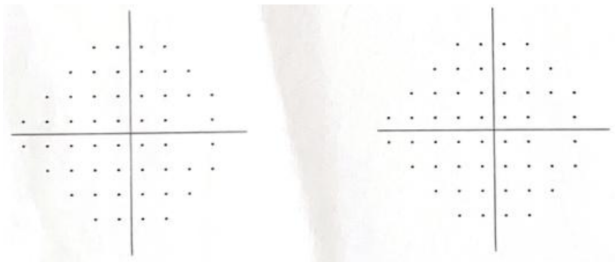

Fig. 2. Distribution of clinical stimuli(Zeiss HFA – OD, Subject 3.)

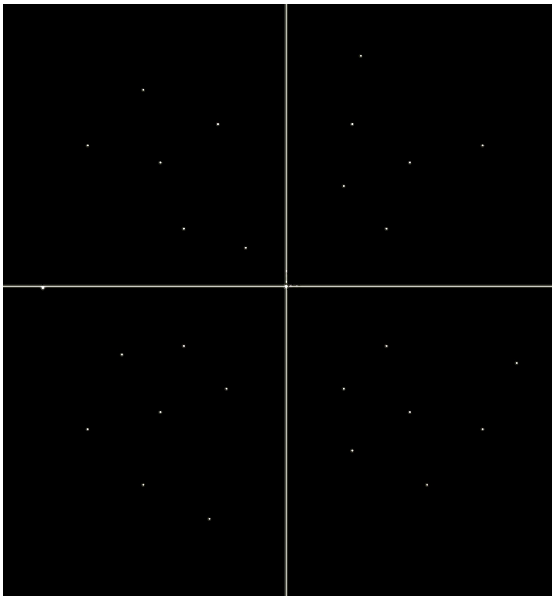

Fig. 3. Stimuli detected by the VR system(OD, Subject 3.)

IV. Conclusions

The implementation of a virtual reality based prototype for visual field testing demonstrated the feasibility of replicating key spatial patterns of standard perimetry in an immersive environment. Although the system did not achieve the same detection rates or precision as the Zeiss Humphrey HFA 24-2, it provided a distraction free setting that facilitated head alignment and user engagement. Its partial alignment in stimulus localization supports its potential for low cost, scalable applications.

A key challenge identified was the uncorrected refractive error in several participants, which directly affected visual clarity and, consequently, the system's sensitivity. The absence of integrated optical correction and eye tracking functionalities limited both fixation control and the reliability of stimulus registration.

Despite these limitations, the VR prototype represents a valuable proof of concept. With technical enhancement, such as corrective lens integration, dynamic stimulus adaptation, and real time gaze monitoring, the system could evolve into a practical tool for preliminary visual field screening, especially in underserved or remote settings. Further development and validation are necessary to achieve clinical grade accuracy, but the results presented here underscore a promising foundation for innovation in accessible ophthalmic diagnostics.

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