Design and Evaluation of a VR-Enabled Visual Acuity Testing Platform

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Abstract—Traditional visual acuity assessments depend on printed charts, which are sensitive to lighting conditions, viewing distance, limited patient engagement, and environmental inconsistencies. With recent advances in Virtual Reality (VR), new opportunities have emerged to transform vision assessment through immersive, controlled, and patient-friendly experiences, thereby overcoming these limitations. This paper presents EyeSee, a digital vision testing system that leverages VR and a web-based platform to deliver standardized visual acuity assessments in an immersive six-meter simulated environment, aiming to improve visual acuity testing and patient experiences compared to traditional methods. User Evaluation revealed strong acceptance of the system, with 97.6% user comfort, 92% overall satisfaction, and 99.2% agreeing that VR reduces testing time and creates an interactive experience.

Keywords—Virtual reality (VR), Visual acuity assessment, Digital vision testing, usability evaluation, Immersive healthcare systems

1. INTRODUCTION

Healthcare systems continue to evolve, and the demand for accessible, efficient, and accurate diagnostic tools in optometry is steadily increasing. Visual acuity assessment plays a critical role in diagnosing refractive errors and vision impairments [1]. Traditional assessment methods, such as paper-based Snellen charts, remain widely used but suffer from several limitations, including inconsistent testing conditions, low patient engagement, and restricted accessibility in non-clinical or rural environments [2],[3]. These challenges can compromise accuracy, delay diagnosis, and reduce the overall effectiveness of vision care.

Recent advancements in VR present an opportunity to modernize this process by enabling the creation of a simulated and controlled immersive environment. VR allows for standardized testing distances, precise optotype scaling, consistent illumination, and a distraction-free experience that enhances the reliability of visual acuity assessments [4],[5]. From a human-computer interaction perspective, immersive systems can also improve user engagement, reduce testing anxiety, and streamline clinical workflow.

In this paper, we present EyeSee, a VR-based visual acuity assessment system integrated with a web-based platform. The system provides an immersive environment that simulates a 6-meter testing distance where patients interact using a handheld controller to identify the orientation of the letter "E," which changes in size and direction throughout the test. It enables specialists to manage patient records, initiate test sessions, monitor patient progress in real time, and generate patient reports. The key contributions of this work include:

- Developing a VR-based, web-integrated platform that modernizes visual acuity assessment.
- Providing an immersive, anxiety-free testing experience that improves engagement and enhances user satisfaction compared to a physical test setup examination.
- Improving testing consistency and operational efficiency through automated vision measurements and reporting.
- Evaluating system concept and acceptance through a structured user acceptance assessment.

2. RELATED WORK

Eye charts consist of rows of visual letters or symbols of varying sizes, and they are the primary method used for assessing visual acuity in clinical practice. Common types, such as the Snellen and Tumbling

E charts, have been adopted for digital and VR-based systems. The Snellen chart includes letters and numbers organized in multiple rows, as shown in Figure 1, with the font size decreasing from top to bottom, where patients need to read these letters and numbers from the chart. The Tumbling E, on the other hand, contains rows of the letter “E” in different rotational shapes, as shown in Figure 2, where patients need to point the direction of the ends of the E: "up, down, left, or right". In this paper, we adopt the Tumbling E chart in our VR environment because it is easy to create and manipulate in a virtual reality environment.

Figure 1. Snellen char

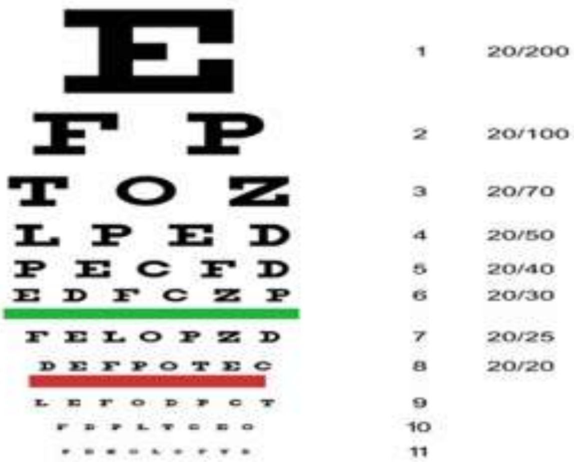
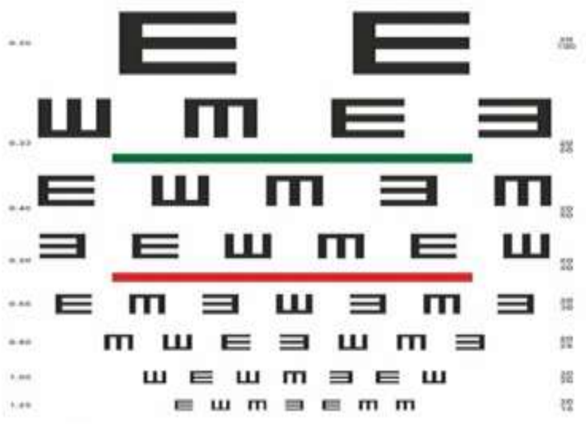


Figure 2. Tumbling E chart



Several studies have explored the feasibility of integrating such charts into immersive virtual reality environments to enhance testing consistency and user interaction. Related work 1 A study was proposed in [6] that developed VREye, a VR-based Snellen acuity test, demonstrating the viability of VR for simulating traditional eye-chart testing at controlled distances. Their findings showed that VR enables consistent optotype presentation, supports controller-based interaction, and encourages user focus. However, VREye in its current form did not appear to include backend data management or automated reporting. EyeSee extends this line of work by integrating Tumbling-E charts, adding web-based session management, and automating report generation. Related work 2 Another study presented in [1] introduced a VR-based vision testing system that included multiple visual tests such as visual acuity, stereopsis, and color blindness. Their system demonstrated the feasibility of expanding VR beyond a single measurement domain. While EyeSee currently focuses on Tumbling-E acuity testing, it shares similar goals regarding standardization, immersive testing, and improved clinical efficiency.

The expanded applications of virtual reality (VR) and user experience in healthcare have demonstrated that the benefits of VR extend far beyond mere functional accuracy. Studies in relevant healthcare fields have proven the experiential advantages offered by VR systems. For example, related work 3 in [7] focused on nursing education, documented strong user endorsement, immersion, and satisfaction with the use of VR technology. They observed that VR environments have the potential to increase engagement and reduce task-related anxiety, findings that directly align with the usability goals of clinical tools designed for patient interaction. Another related work 4, which was presented in [8], examined the accuracy of VR visual acuity tests compared to real-world Snellen charts. Their results confirmed that VR-based acuity measurements can achieve clinically comparable outcomes, reinforcing the reliability of VR as a diagnostic tool. This supports EyeSee's evaluation results, which showed strong user acceptance and high perceived accuracy. Furthermore, [9] provided a contemporary overview of VR and Augmented Reality (AR) applications in ophthalmology. Their review highlighted VR's value in diagnostics, clinical training, and therapeutic interventions, emphasizing its ability to create highly controlled, immersive environments for visual function testing. Although not limited to acuity measurement, the study confirmed that VR offers standardized test conditions, reduced environmental variability, and improved patient engagement—factors directly relevant to the EyeSee system. Collectively, these studies demonstrate increasing interest in VR-based eye assessment solutions and support the feasibility of immersive systems like EyeSee. The features offered by each of the similar solutions discussed are summarized in Table 1, highlighting EyeSee's contributions in this context.

Table 1. Feature comparison between existing systems and the proposed EyeSee system

Features	1	2	3	4	EyeSee
Stand-alone system	✓	✓	✓	✗	✓
VR + Web	✗	✗	✗	✗	✓
Interactive VR	✓	✓	✓	✓	✓
Arabic Language	✗	✗	✗	✗	✓
Sign in	✗	✗	✗	✗	✓
Eye Test	✓	✓	✗	✓	✓
View Test Results in VR	✓	✓	✗	✓	✓
View Results on Web	✗	✗	✗	✗	✓
Report Generation	✗	✗	✗	✗	✓

3. METHODOLOGY

The methodology for the proposed system follows the system development lifecycle (SDLC), which includes the following phases: requirement analysis, design, implementation, integration, and testing.

1.1 Requirement Analysis

To understand user acceptance of VR for visual acuity testing and to ensure that the EyeSee system meets its core functions, two methods were employed: a structured survey and expert interviews. The survey included 127 participants and was designed to capture the following (P1) background and prior experience with traditional and digital vision testing methods; (P2) confidence in VR-based eye testing; (P3) interest and engagement; (P4) expected benefit; (P5) acceptance and willingness to choose VR eye testing if applicable; and (P6) system requirements and expectations. Table 2 summarizes the key survey findings, presenting the survey statements and their corresponding response percentages. It shows that 74% of participants reported having experience with digital vision testing, such as computerized eye exams in clinics, but not with VR technology. In addition, the results showed that 90% expressed enthusiasm for experiencing virtual reality eye testing, which indicates participants' acceptance and willingness to undergo this experience. To complement the survey insights, an interview was conducted with two ophthalmologists, both of whom confirmed their reliance on the traditional Snellen chart for routine visual acuity assessment. The interview aimed to gain a deeper understanding of current clinical workflows, expectations, and desired system features that can enhance the user experience. During the interview, the idea of the proposed EyeSee system was explained, followed by open-ended questions related to evaluating familiarity with digital tools and to identifying feature expectations. Both ophthalmologists supported the importance of monitoring exactly what the patient sees in real time and considered that essential to ensure confidence, accuracy, and ease of use. They also expressed strong interest in EyeSee, noting that it could streamline the workflow, reduce testing time, and enhance patient comfort. The information gathered from participants provided essential input for understanding user readiness and requirements, and this information directly contributed to the design and implementation for the EyeSee system.

Table 2. Key Survey findings (N = 127)

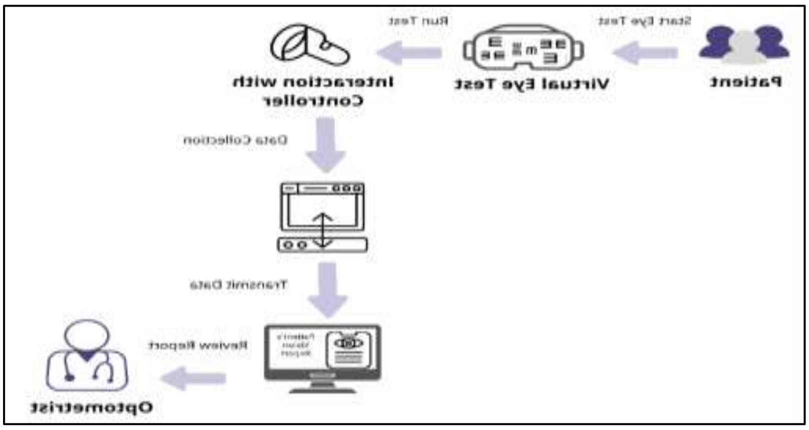
Point	Survey statement	Percentage %
P1	Experienced vision difficulties with traditional methods	67%
P1	Prior use of digital vision testing systems	74%
P1	Prior use of VR technology acuity testing systems	0%
P2	Would feel confident in VR-based eye testing	78%
P3	Excited to try VR-based eye testing	90%
P4	VR could improve the eye-testing experience	89%
P5	Willingness to choose a VR-based eye exam if available	74%
P5	VR eye exam in optical shops is highly beneficial and would enhance comfort and convenience	70%
P6	Accuracy is the most important feature in any eye-exam system	77%
P6	Clear instructions are at test initiation	76%

1.2 System Design

1.2.1 Architecture Design

The proposed EyeSee system comprises three primary components: 1) a VR testing module, deployed on a standalone VR headset, which is used to display the immersive test environment, manage user interaction, administer the visual acuity test, capture user responses, and handle real-time collection. 2) a web-based platform serves as an interface for the clinician to initiate the test session, receive user responses from the VR environment, process user data, and generate a report. 3) a backend unit, which contains the centralized database that ensures secure data storage and real-time data synchronization between the interactive testing environment and the interface. The overall architecture design is illustrated in Figure 3.

Figure 3. The architecture of EyeSeee system



1.2.2 VR Environment Design

The VR environment simulates a standard six-meter viewing distance, which is the approved reference distance for visual acuity testing. This enables the system to simulate clinical testing environments irrespective of space constraints, ensuring consistency across usage settings.

The VR environment adopts the animated Tumbling E chart format due to its language-independent structure, suitability for directional input, and ease of construction and manipulation in the VR environment. The optotype is displayed in four directions, allowing responses without relying on character recognition skills. The optotypes are displayed in progressively decreasing sizes to simulate the gradient of a standard visual acuity chart. Optotype size adjustment for each level is represented by the dynamic adjustment of the letter "E" size based on predefined levels.

To enhance reliability, the environment maintains controlled lighting and a constant background contrast to minimize ambient contrast. Constant lighting conditions reduce glare, visual distortion, and distractions that could affect assessment accuracy.

The interface is designed for ease of use, allowing users to select the orientation of the visual symbols via the VR controller buttons. This interface reduces mental effort and contributes to a smooth testing experience.

1.2.3 Data Flow

- The patient starts the eye test using the VR headset.
- The VR module handles test logic, "E" optotype presentation.
- The patient responds to each optotype using the VR controller and selects the direction of the ends of the E (up, down, left, or right).
- The VR captures and records the patient's response, including optotype size and progression levels.
- Test results are transmitted to a backend server and stored in a database.
- The web platform retrieves processed results and generates structured assessment reports.
- The optometrist accesses and reviews the patient's report through the web interface.

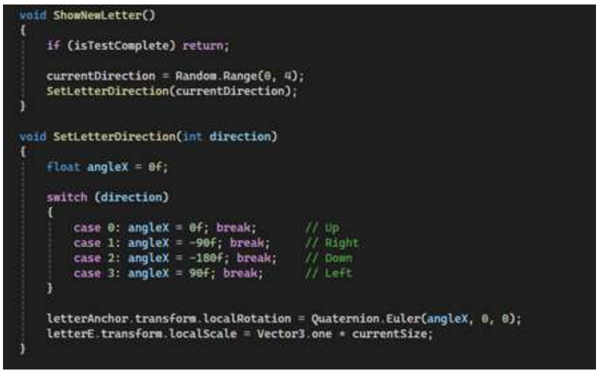
3.3 Implementation

Various tools were utilized during the implementation phase to develop the system's VR environment, web platform, backend, and database, as illustrated in Figure 4. The core hardware tool was the Oculus Quest 2 VR headset—selected for its accurate hand and controller tracking capabilities, thus enhancing user interaction during the visual acuity assessment. The VR headset and controller are shown in Figure 5. A laptop is used for coding, testing, and connecting the VR module with the backend web application. The VR application was developed using Unity 3D, a widely adopted game engine for immersive application development. It was selected due to its cross-platform compatibility, extensive VR headset support, and robust development environment. The visual acuity test logic was implemented using C#, which provides flexibility for developing interactive features and user interfaces for virtual reality applications. C# scripting was used to implement randomized Tumbling-E orientation, optotype scaling, test level progression, and response capture. Figure 6 shows a C# script for randomized Tumbling-E orientation.

Figure 4.Core tools utilized during the implementation phase

Figure 5. Oculus Quest 2 headset and a standard controller

Figure 6. C# Script for randomized Tumbling-E orientation



```
void ShowNewLetter()
{
    if (isTestComplete) return;

    currentDirection = Random.Range(0, 4);
    SetLetterDirection(currentDirection);
}

void SetLetterDirection(int direction)
{
    float angleX = 0f;

    switch (direction)
    {
        case 0: angleX = 0f; break;       // Up
        case 1: angleX = -90f; break;     // Right
        case 2: angleX = -180f; break;    // Down
        case 3: angleX = 90f; break;      // Left
    }

    letterAnchor.transform.localRotation = Quaternion.Euler(angleX, 0, 0);
    letterE.transform.localScale = Vector3.one * currentSize;
}
```

To ensure standardized visual acuity measurement within the virtual environment, the Tumbling-E optotype scaling was based on established visual angle principles used in clinical acuity testing. The angular size θ of the optotype is defined as:

$$\theta = \frac{h}{d} \qquad (1)$$

where h represents the optotype height and d denotes the viewing distance, fixed at six meters in accordance with standard Snellen-based visual acuity definitions [2], [3], [8]. Different acuity levels were generated by progressively reducing the optotype size while maintaining the same viewing distance, ensuring consistency across test sessions.

User response accuracy at each acuity level was evaluated using a binary correctness model. For each presented optotype i, the response variable was defined as:

$$R_i = \begin{cases} 1, & \text{if the response is correct} \\ 0, & \text{if the response is incorrect} \end{cases} \qquad (2)$$

The performance score A for a given level, was calculated as:

$$A = \frac{1}{N}\sum_{i=1}^{N} R_i \qquad (3)$$

where N is the number of optotypes presented at that level.

Progression to smaller optotype sizes was implemented by a two-attempt decision rule commonly used in computerized and VR-based visual acuity tests [1]. If the first response was correct ($R_1 = 1$), progression to the next smaller optotype size occurred immediately. If the first response was incorrect ($R_1 = 0$), a second optotype of the same size was presented. The test terminated at the current acuity level if both attempts were incorrect ($R_1 = 0$ and $R_2 = 0$).

For the web platform, HTML, CSS, and JavaScript were used to develop an intuitive interface for optometrists to manage patient records and access visual acuity reports. The backend was implemented using ASP.NET Core, which handled authentication, report generation, and communication between the VR application and the SQL database.

3.4 Integration and Testing

The integration process connected the VR application, backend services, database, and web platform to ensure seamless communication between the units and to enable real-time exchange, storage, and report generation within the system's workflow. Integration was achieved using RESTful APIs and HTTP requests. The VR application transmits and receives results via HTTP POST requests. On the server side, the ASP.NET backend receives and processes the requests. The SQL Server database stores details and test results. The web platform retrieves stored records through backend queries. Once all system components were fully integrated, the testing phase was conducted to evaluate overall functionality and performance.

Extensive testing was conducted, including functional testing to ensure that the core functionalities operate as expected and meet the specified requirements. In addition, the system testing was conducted, which is a high-level testing phase where a complete, integrated system is evaluated to verify that it meets the specified requirements. The goal is to answer the question: Does the entire, integrated system work together as a unified tool to fulfill its intended purpose? [10]. This phase validated the coordination between the VR headset, the web platform, and the backend services. Performance evaluation metrics included the system response time, which was measured from the time the user entered information (e.g., pressing arrows to indicate the direction of the "E") until the system recognized it. This metric shows how fast user interactions are processed by the system. Scene load times, which were recorded to guarantee seamless transitions, especially when moving from one eye test to another or between test levels. Frame rate consistency was continuously monitored to maintain a high and stable frame rate, which is essential for providing a comfortable VR experience and for preventing visual lag or motion discomfort [11], [12]. Finally, usability testing was performed to assess interaction clarity, task completion success, ease of navigation, and overall comfort. The results provided insights into the system's usability, efficiency, and learnability.

4. RESULTS

The current study provides an initial evaluation of the EyeSee system. The results are organized into functional validation, system performance, and usability assessment. The functional testing results demonstrated that all core tasks performed as expected, i.e., optometrist account creation, login, password management, patient registration, VR test initiation, real-time monitoring, automatic transmission of results from VR to backend, and report display, all achieved a 100% successful task execution rate.

The system performance was evaluated on system response time to user interaction, scene load times, and frame rate consistency. Results showed that the system demonstrated rapid input recognition within milliseconds. Scene load time and transition between test levels was efficiently with no delays during transitions, and the Oculus Quest 2 maintained a stable and high frame rate throughout testing, minimizing motion discomfort and ensuring a realistic tumbling "E" optotypes test experience.

Usability testing involved eight participants who were evenly distributed by gender, four males and four females, with a median age of 36.5 years (range 18–55). Six participants reported having a good experience with technology, meaning they are familiar with using digital tools or devices, whereas two participants reported having basic to intermediate knowledge of digital technologies. Table 3 presents the demographic characteristics of the participants. Participants were assigned to complete nine tasks as follows: (1) create a new account, (2) log in to the system, (3) log out, (4) change password (5) search for report, (6) start the VR test from the web platform, (7) read instructions in the VR environment, (8) select "E" direction in VR, (9), and switch eyes during the VR test. The evaluation was measured by objective metrics (time and error) to provide quantitative insight into the ease of use and efficiency of the system's interface on both the VR and web platforms. The results of the usability evaluation are shown in Table 4. All tasks showed successful completion within a reasonable time and zero errors, indicating the system was clear and easy to learn. Only minor errors were observed during the instruction-reading task, primarily due to low text contrast. The findings from the usability testing phase are considered for future work.

Table 3. Participant demographics

Characteristic	(n = 8)
Gender	Male 4, Female 4
Age (years)	36.5 (18–55)
Technology skill	
Yes	6
No	2
Language	
English	3
Arabic	5

Table 4. Usability test results

Task	Avg. Time (sec)	Avg. Errors
Create a new account	30- 40	0
Log in to the system	10 - 15	0
Log out	3 – 7	0
Change password	20 – 30	0
Search for a report	15 – 22	0
Start VR test from web platform	21 - 40	0
Read instructions in VR*	30 – 40	0.25
Select "E" direction in VR	3 – 5	0
Switch eyes during VR test	10 – 20	0

* Minor errors occurred due to low text contrast.

After completing all system tests, the user experience was further evaluated through a post-test questionnaire to collect participants' subjective feedback. Figure 7 shows the results, indicating 97.6% reported high comfort during the VR-based eye testing and felt comfortable using the headset and controller. Additionally, 93.7% expressed overall satisfaction with the system, agreeing that VR could serve as a suitable alternative for those who feel uncomfortable with traditional exams. Moreover, time efficiency was rated highly, with 99.2% agreed that the VR system significantly reduces the duration of testing. Compared to conventional visual acuity testing, which often requires manual setup and clinician intervention, the VR-based workflow enabled faster test initiation and automated result recording, thereby reducing overall examination time. These results demonstrate high user acceptance and support the feasibility of integrating virtual reality technology into the visual acuity assessment workflow.

Overall, 98% of users (68% strongly positive and 30% moderately positive) reported a positive experience, as illustrated by Figure 8, showing that the EyeSee system was well-received and functionally effective. These findings are consistent with previous controlled studies of VR-based visual acuity testing. For example, the evaluation of the visuALL VR headset in [19] found that 95.5% of participants were comfortable using the device, and 81.8% preferred the VR-based examination over the conventional manual methods. Additionally, the VR interface received a higher mean satisfaction score compared to conventional testing (mean = 4.55 vs. 4.14). These findings align with the user responses observed in EyeSee and demonstrate that high user satisfaction with VR testing has been observed even when directly compared to traditional methods, supporting the validity of our findings.

The designing, implementing, and testing phases of the system were successfully completed. Representative screenshots of the EyeSee web platform and VR testing environment are provided in Figures 9-14.\

Figure 7. Positive response rates for VR Comfort, Suitability, and Time Efficiency

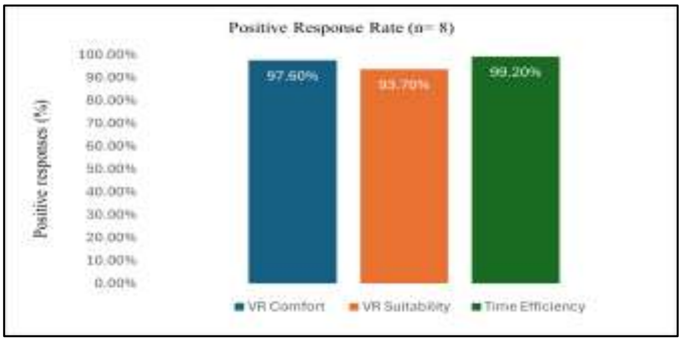
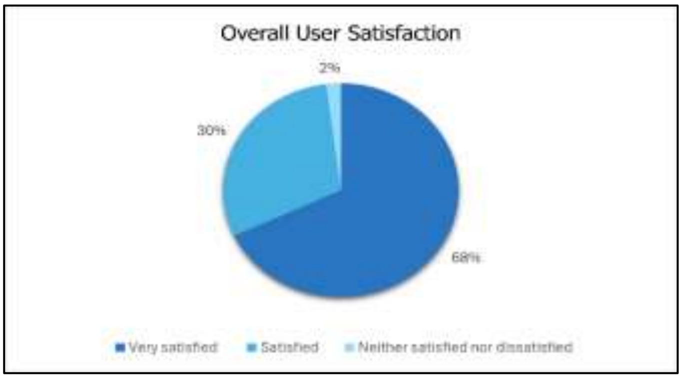


Figure 8. Overall User Satisfaction



5. DISCUSSION

The results of the EyeSee system evaluation demonstrate that VR technologies can be an effective and reliable alternative to traditional methods of measuring visual acuity. VR-based testing offers several advantages, including increased comfort, better control over examination conditions, and improved user interaction—results that align with recent trends in VR-based ophthalmology research [13],[14],[15]. In addition, [16] indicated that VR environments can reliably support both static and dynamic visual acuity tests, confirming the effectiveness of immersive systems. Similarly, [6] and [17] reported that VR provides standardized, distraction-free examination settings, improving test repeatability and reducing common problems associated with traditional, printed-chart testing. Recent comparative studies [3],[8],[18],[19] further demonstrate that the VR-based acuity tests can achieve accuracy comparable to traditional Snellen charts, reinforcing the growing evidence that VR can be a reliable platform for visual function testing. The high levels of comfort and satisfaction observed in the EyeSee align with the findings of the previous studies mentioned here. Time efficiency is a critical factor in the success of any system, particularly in clinical settings where streamlining workflows and reducing examination time directly impacts patient speed and service quality. According to [1],[20] VR-based systems can automate the display of optotypes, dynamically adjust their sizes, and minimize manual intervention, thus accelerating the testing process compared to traditional methods. EyeSee reflects these advantages through automated response capture and structural level progression, resulting in faster and more consistent assessments. From a user experience perspective, high acceptance (92%) further confirms the suitability of immersive interaction models and their enhancement of user comfort and interaction during testing. A study in [6] demonstrated that interaction via VR controller enhances focus and engagement, which is reflected in EyeSee's usability outcomes. Furthermore, VR technologies have shown effectiveness outside the field of ophthalmology as described in [7]. A relevant comparison can be made with a study [16] that investigated a virtual reality-based approach to dynamic visual acuity testing. While its results confirmed the feasibility of using virtual reality for vision testing, it identified a major limitation related to the inherent limitations of virtual reality rendering, which restricted the accurate rendering of small visual symbols in a 3D virtual space. In contrast, the EyeSee system did not encounter such limitations. Rolling E symbols were rendered clearly across progressively larger magnification levels, and the virtual scenes maintained high visual clarity and stability throughout the test. Last but not least, clear instructions, controlled environments, and high concentration in VR environments are crucial elements in visual acuity tests, as interaction quality directly impacts measurement accuracy. The results of this study suggest that EyeSee successfully integrates these elements, offering a structured and immersive assessment experience.

Figure 9. Login/registration interface

Figure 10. Create account interface

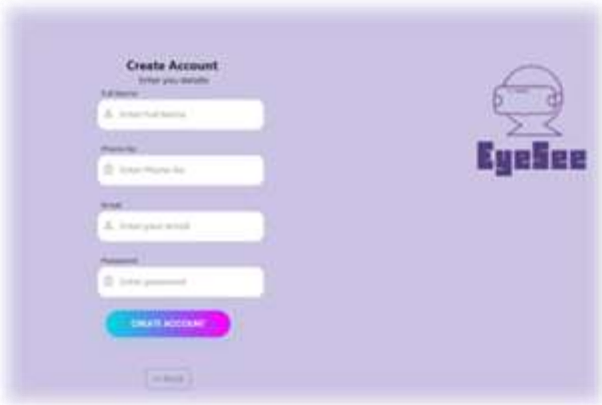


Figure 11. Patient profile interface

Figure 12. Welcome screen in VR

Figure 13. Instruction screen in VR

Figure 14. The Tumbling-E in VR

6. CONCLUSION AND FUTURE WORK

This paper presented the development, integration, and evaluation of EyeSee, a VR-based visual acuity assessment system developed as a modern alternative to traditional paper-based eye examination. By integrating an immersive six-meter simulated VR environment with a web-based management platform and backend database, the system provides a seamless workflow for conducting and documenting visual acuity tests.

The evaluation results demonstrated high levels of comfort, satisfaction, and perceived time efficiency with 97.6%, 93.7%, and 99.2%, respectively, indicating strong user acceptance and practical feasibility.

While the system showed high usability outcomes, broader validation across more diverse demographic groups is necessary to ensure accessibility and generalizability. Future work will focus on expanding the verification scope to include a larger representative sample and improving the reduced text contrast in the interface. Overall, EyeSee represents a promising step towards the next generation of digital vision testing tools, supporting the integration of immersive technologies into modern optometric practice and smart healthcare ecosystems.

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