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Full Paper

Web-Based Visual Acuity Testing under Low-Resource Settings

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Abstract

Conventional eye examination tests are available to diagnose visual acuity; however, most of those cannot be performed in low-resource settings and require more money and technical resources. In this study, a novel web solution was developed to replace the traditional Snellen chart method for visual acuity. Numerous technologies pertinent to optimization under low-resource settings were thoroughly examined and integrated throughout the development process, encompassing web frameworks, database management systems, voice recording algorithms, and user interface design. CodeIgniter was used as the framework of this developed system. After conducting tests with real users and obtaining results, a statistical analysis based on the test results was performed. Thirty-four volunteers participated in detecting a logMAR difference of 0.1 between the manual Snellen chart testing and web-based application, assuming a paired t-test, a standard deviation of 0.2 (estimated from previous studies), 2-sided alpha (α) of 0.05, and 80% power. The observations were independent, and the variables were normally distributed. Confidence interval limits were reported for 95%, with the standard deviation ± 1.96 from the mean, ± 0.2 logMAR. A vital feature of the system is its capability to perform a 10-ft and 20-ft eye test based on distance. The application scales the Snellen characters according to the test distance without affecting accuracy. Other unique features include automatic voice recording, automatic Snellen level change and character scaling, storing previous readings for future evaluations, and comparing them with current readings. The accuracy of the eyes, as well as their errors, are displayed to users according to international standards. Our web application produced results almost identical to those of the manual Snellen procedure, even under low resource settings, when compared to the manual Snellen procedure.

Keywords: Low resource settings, Snellen chart, visual acuity, web application, paired t-test

Introduction

Visual impairment is a severe public health problem that can adversely affect economic and educational prospects, reduce the quality of life, and increase the risk of premature death. Worldwide, approximately 36 million people are blind, and 405 million are visually impaired, most of whom live in middle- or low-income countries with limited access to eye care. Eye charts have long been the traditional method for assessing visual acuity, with ophthalmologists commonly using charts such as the Snellen, Tumbling E, and ETDRS. However, advancements in research and technology have led to the development of modern solutions designed to complement or replace these traditional methods for vision testing.

Visual acuity refers to the clarity of vision, determined by the precision of retinal focus, the sensitivity of the nerve cells in the eye, and the brain's ability to interpret visual information. It is just one aspect of the overall vision, along with others including color vision, peripheral vision, and depth perception. Accurate best-corrected visual acuity (BCVA) is crucial for diagnosing vision problems in patients presenting to emergency care. The nuances of Snellen testing are well understood by ophthalmologists but may be less familiar to providers with limited experience using Snellen tests. Reducing variability in Snellen exams through automated tests has become an increasingly popular research topic [1]. As part of this research, we evaluated the applications available on Google Play and the Apple Store, analyzing their features and functionality.

Agarwal et al., (2015) developed an Android application named 'Dr. Eye' to calculate visual acuity (VA) [2]. This application was designed to calculate vision acuity, similar to how ophthalmologists check eyesight. This process is enabled by the front-facing camera and the Android API's speech-to-text conversion. In 2004, Taleb-Ahmed et al., (2014) developed an application that connects patients with an ophthalmologist at a hospital or specialized web center via a telecommunications network [3]. A portable method for measuring VA has been suggested by Zhang et al., (2013) with the use of an iPad tablet (Eye Chart Pro) [4]. In this study, 120 consecutive patients were tested for visual acuity using the iPad 2 and traditional lightbox charts. A few limitations were evident in the study. There were no strict standards in terms of the acuity audit process and audit conditions. The iPad screen brightness could not be adjusted to match the lightbox graph due to the absence of a light meter. However, iPad VA cards can be considered a cost-effective alternative to light-boxes for patients with Snellen VA greater than 20/200. The study recommends that users with iPad VA cards can monitor their eyesight independently. The iPad VA card can also be used for community vision screenings and epidemiological studies of eye diseases.

Bastawrous et al., (2015) developed and validated a smartphone-based visual acuity test (Peek Acuity) for clinical and community-based research [5]. The ETDRS-based Snellen plot and Tumbling E logMAR plots were used to develop the Peek Acuity test in controlled and uncontrolled (real-world) settings for test-retest variability (TRV), and measurement time (reference standard) was compared in the Kenyan countryside. The results of this study indicate that the 95% CI limit for testing and retesting smartphone vision data volatility is ±0.033 logMAR. The mean difference between smartphone-based tests and ETDRS charts, and smartphone-based tests and Snellen chart data, was 0.07 (95% CI, 0.05-0.09) and 0.08 (95% CI, 0.06-0.10) logMAR, respectively, for smartphones. Neither ETDRS nor Snellen charts demonstrated a significant difference in agility between the primary and ETDRS tests. There was a greater correlation between the Peek Acuity chart and the ETDRS chart than the Snellen chart when using the ETDRS chart (95% CI, 0.05-0.10; P = 0.08). The Peek Acuity smartphone test was immediately accepted by Kenyan health workers. There was not much difference in training time between the smartphone Peek Acuity test and the Snellen smartphone test (77 seconds versus 82 seconds, respectively, 95% CI, 71-84 seconds versus 73-91 seconds, P = 0.13). Aside from these statistics, this study concluded that VA is an essential measurement of visual function for the ophthalmic patient's decision-making.

In the study, Aslam et al., (2016) identified that many eye diseases require ongoing monitoring for optimal management, placing increased burdens on patients and hospitals [6]. They also found that home vision monitoring could relieve some of these burdens. They also claim that the current applications and devices used for visual acuity testing need more evidence to be useful. To solve this problem, Aslam et al., (2016) developed a computer tablet-based automated method for myopia (VA) self-testing on high and low-contrast targets. However, since this method was developed exclusively for tablets, it is not compatible with laptops or PCs, preventing their use with this system.

The following is based on issues encountered with certain applications during testing, including the Visual Acuity Test app, Smart Optometry, E-Y-E Check, VEU-Myopia calculator, and OcularCheck. Mobile applications such as Visual Acuity Test, VEU-Myopia calculator, Smart Optometry, and OcularCheck have not been updated in some time, affecting their functionality. Therefore, outdated mobile versions are only partially compatible with the latest versions of Android and iOS. Applications such as the VA Test, Smart Optometry, and E-Y-E Check crashed abruptly during the eye test and did not work well on mobile devices.

Riza et al., (2015) examined the effectiveness of ophthalmic tests to demonstrate that patients with vision impairments can promptly receive prescriptions for glasses, contact lenses, or corrective lenses [7]. Currently, optometrists perform these exams using phoropters, large optical instruments through which patients view test charts while the optometrist manually adjusts the lenses. This type of test has several disadvantages including that it may take a long time (possibly up to 15 minutes), and patients may have difficulty identifying the effects of specific phoropter lenses. The results of this study reveal that quick and innovative solutions are needed for ophthalmic tests. The study titled "Visual acuity measured with a smartphone application is more accurate than Snellen testing by emergency department providers," conducted by Pathipati et al., (2016), demonstrated the accuracy of smartphone applications in measuring visual acuity [8]. Mobile applications have proven effective in measuring visual acuity in a limited spectrum of clinical and research settings [5, 6, 8]. Automated applications can provide standardized results and improve the efficiency of emergency vision care.

Vision impairments are most common in developing countries, particularly in low-income and middle-income countries, and cataracts are among the top causes of blindness. The primary problem with impairments in these countries is the lack of healthcare [9]. Most of those countries suffer from vision impairment due to a lack of money to check their vision or visit an ophthalmologist. While numerous eye measurement devices are manufactured around the world, almost all of them use the same procedure to test optical intensity, with light intensity being more important in most cases. Despite their accuracy, these applications are merely another luxury since the devices and other requirements are expensive. The situation demands the need for a visual acuity testing application that is simple to set up in low-resource settings and can be used as a public service by anyone, including low-income personnel. Therefore, this study was conducted to design and develop a user-friendly web application for visual acuity testing that can be used by anyone regardless of users' age and intelligence, under limited-resource settings. Furthermore, a statistical analysis was performed to test the visual acuity of the developed web application and to compare the model's accuracy with standard acuity procedures.

Materials and Methods

As shown in Figure 1, the study used Snellen charts as the basis for acuity testing.

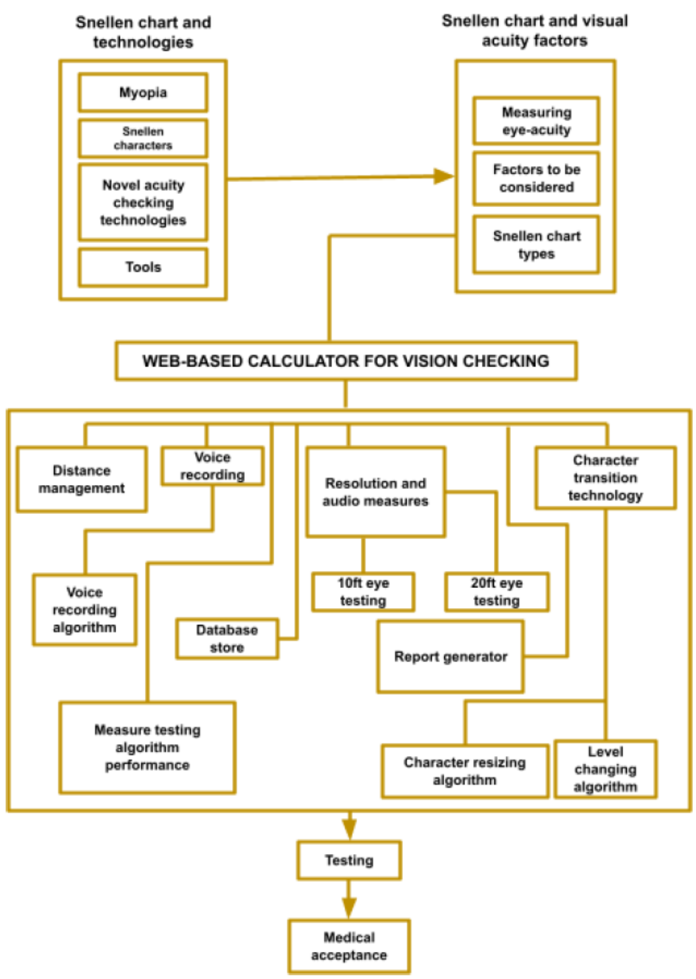
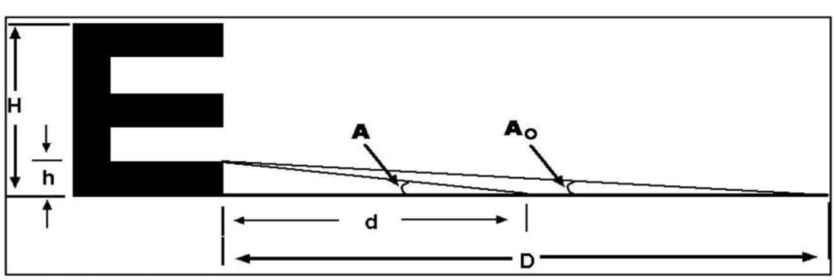


Figure 1. Study design

In the first phase of the study, a comprehensive literature review was conducted to gather subject-specific information on vision monitoring procedures, vision-based checking factors, eye charts, innovative technological implementations and results, medical-based technological devices, and industrial devices. As part of this step, existing software applications for vision testing were discovered, and their internal architectures were examined.

The second phase involved the pre-development stage of the application's core functions. In this section, we outlined the key stages of the application's design based on the primary components we identified. The technical method for testing human eye acuity was identified, and the internal operations were configured in accordance with the overall research objectives. When developing these configurations, we prioritized the key criteria to be addressed. Snellen charts were chosen for this application for various reasons. Many studies have shown that the Snellen chart is more accurate and usable than alternative eye charts such as the ETDRS chart [5]. The application's design was developed based on the unique properties of the Snellen chart. The application's core components and functionalities were configured during the development phase exactly as anticipated during the preceding design phase. At this level, we have established features such as resolution measurement, audio recording, database recording, Snellen character alteration, Snellen character transition, and a performance measurement algorithm. The next step was to identify the leading technologies that could be used to develop the application's primary domain, and many technologies were studied, including web frameworks, database systems, voice recording algorithms, and user experience/user interface development. CodeIgniter was used as the framework for this developed system. An MVC architecture was used to design and configure the system's models, controllers, and views. The Graphical User Interfaces (GUIs) were created using a UI library in web development, with Bootstrap being utilized as the primary UI library for developing the GUIs. JQuery and JS were used as the scripting language, and all the front-end verification and validation parts were managed with them. All the characters included in the application's tests are based on the Snellen chart. This system was developed for two different visual acuity tests based on distance: 10 feet and 20 feet. The size of the characters adjusts according to the test distance, with each character's size dependent on the display resolution, display size, and pixels per inch (PPI) of the screen. A mathematical equation was developed to determine the letter height for acuity testing based on the display screen, as shown in Figure 3. We found that 8.89% of the world's population has 1920x1080 (FULL HD) resolution and 8.44% has 1366x768 (HD) resolution [10]. As a result, we used 1920X1080 as the display resolution and 15.5 inches as the display size for our study. Based on this, we set up the size of the Snellen characters. The height of the letter depends on the distance and angle. Accordingly, a Snellen chart on vision was made to measure the smallest space the subject can distinguish. Figure 2 illustrates the method we used to determine font size, distance, and angle and the following section explains how we established the letter size, distance, and angle based on the information presented in the figure.



Notes: h = the height of the smallest segment used to construct the letter.
H = the total height of a letter; typically H = 5h.
d = the testing distance, e.g., 20 ft.
A = the visual angle subtended by h at the testing distance, d.
D = the distance at which h subtends the angle A_o, normally taken as 1 min of arc.

Figure 2. Size and angle between the human eye and Snellen letter: Calc Size of 20/20 Letter [11]

Snellen Letter Height Calculation Equations: The height of a Snellen letter can be calculated based on various parameters, as described in the following equations. Each equation provides a specific method for determining the letter height based on different viewing conditions and screen specifications.

Basic Snellen Letter Height Calculation: The height of a Snellen letter, can be calculated using a simplified relationship shown in Equation (1), where H is the letter height (in mm), L represents the viewing distance (in mm), and Q is the proportional constant that accounts for angular size.

$$H = QL \tag{1}$$

Detailed Snellen Letter Height Calculation with Angular Size: Typically, Snellen letter height is calculated more precisely based on the angular size of the letter. In Equation (2), H represents the letter height, L denotes the viewing distance, and θ represents the angular size of the letter in radians.

$$H = 2 \times L \times tan\,(\theta \;/\; 2) \tag{2}$$

For standard 20/20 vision, the angle subtended by a letter at a viewing distance of 6 meters (approximately 20 feet) is 5 minutes of arc, equivalent to approximately 0.001454 radians.

Refined Equations for Pixel Size and Letter Height Calculations: Figure 3, below demonstrates the key factors influencing pixel size on a digital display, essential for calculating the appropriate letter height on screen-based Snellen charts.

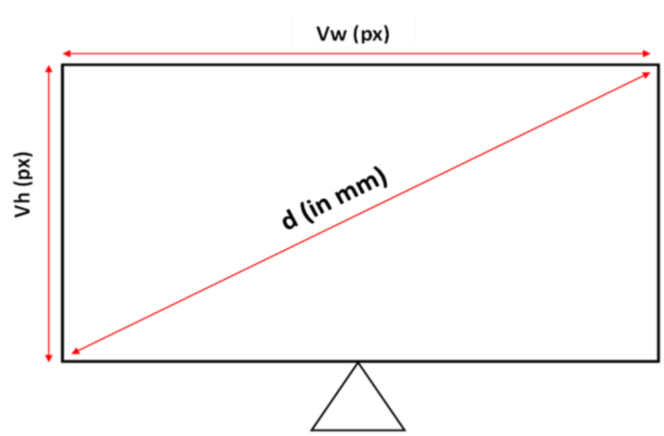


Figure 3. Factors affecting pixel size on a digital display.

Pixel Size Calculation: The size of a pixel on a digital display, given in mm, can be calculated as shown in Equation (3). Here, Vh and Vw are the number of horizontal and vertical pixels, respectively, and d is the physical screen size (in mm).

$$Size\ of\ a\ pixel = \frac{d}{\sqrt{Vh^2+Vw^2}} \tag{3}$$

Letter Height Calculation in Pixels: To determine the letter height in pixels, use Equation (4). In this context, H represents the letter height in mm. This equation converts the physical letter height to pixels based on screen resolution, helping to match physical and digital display requirements.

$$Letter\ height\ in\ pixel = \frac{H}{\sqrt{Vh^2+Vw^2}} \tag{4}$$

Calculation of letter height for any screen: This section provides a formula to adapt Snellen letter height calculations for various screen sizes and resolutions, ensuring consistency across display devices. Equation (5) is designed to calculate the letter height for each screen-based Snellen character based on its specific display level. By incorporating the diagonal pixel count ($Vh^2 + Vw^2$), divided by the physical screen size d, this formula scales the letter height relative to the display dimensions. This approach ensures that digital Snellen charts maintain accurate letter height representations across different screens, improving the utility and consistency of screen-based vision assessments.

$$H = \frac{\sqrt{Vh^2+Vw^2}}{d} \tag{5}$$

Each equation incorporates parameters specific to either physical or screen-based Snellen charts, enabling the calculation of letter heights tailored to various display and viewing conditions. The term $Vh^2 + Vw^2$ represents the diagonal pixel count, which, when divided by d, scales the size relative to the screen's physical dimensions, ensuring accuracy for digital displays.

Voice Recording and Character Accuracy Algorithms

JS voice recording algorithms were used to record users' voices. A Real-Time Noise Suppression algorithm was developed to neutralize the noise added to the original user inputs. The algorithm allows the application to suppress noise on its own. When performing the test, the user must maintain the distance specified. In situations where the distance is too high, the program can filter out the user's original voice without noise with the help of the real-time noise suppression algorithm. An ideal solution is to wear a wireless headset since this will reduce the amount of noise added to the recording. This method will function normally in a quiet environment, even without a wireless headset.

During the development phase, XAMPP was used to run the web application. Moreover, since we used the CodeIgniter framework, PHP was the primary language for development. Application Snellen characters' sizes were determined according to the display configuration according to the test distance. All Snellen characters were included in an array (C, D, E, F, L, O, P, T, Z), which appeared randomly on the eye testing space/display. The application changes the size of the characters according to the level of the Snellen chart. The levels of characters are reduced from the largest level to the minor level. Original characters that appeared on display during the testing are recorded by the application and stored in a separate array. This same process is performed on both eyes. The application records users' voices and stores them as audio clips during testing. In the study performed by Revilla et al., (2018), three main components were examined: different instructions for using the voice recording tool reduced technical and understanding difficulties [12]. In our study, we used a speech recording algorithm similar to that used by Revilla et al., (2018).

After entering the user's reading, the application checks how many characters are matched to the original characters shown for a particular level of the left eye. To perform this task, we have developed a character-comparing algorithm to measure accuracy as a percentage. The application provides the final result of the left eye accuracy as a scientific notation if the error accuracy percentage is greater than 50%. If the accuracy percentage is less than or equal to, there is a 50% above error with the user's selected eye level. After performing this process on the left eye, follow the same procedure for the right eye. The final results are provided for both eyes separately using the standard method of notation. The flow of the application's tasks is shown in Figure 4. Users can see their results anytime by accessing their profiles since the result is automatically stored inside the database.

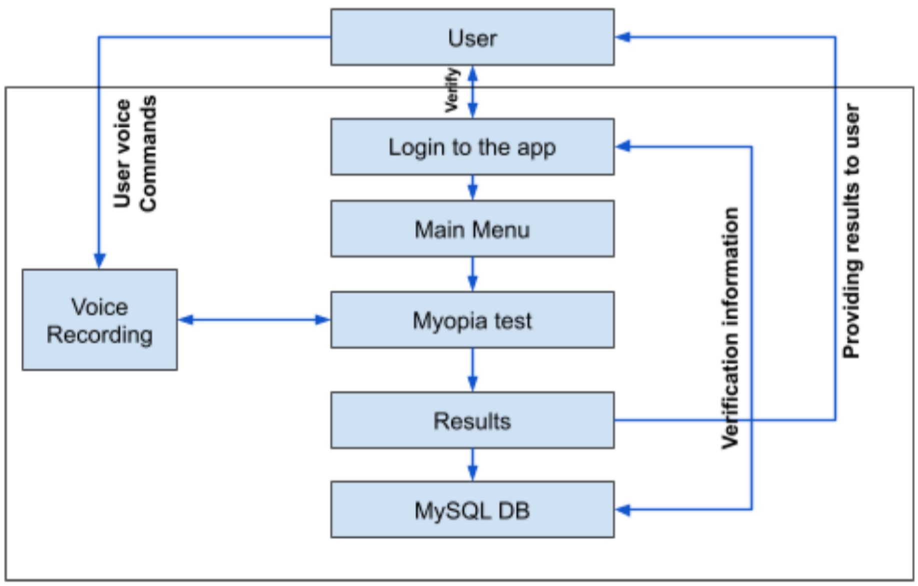


Figure 4. The flow of the application's main tasks and the other activities

Results and Discussion

The web-based visual checking application includes features such as visual acuity tests for both the left and right eyes, along with the option to choose between two test distances: 10 feet and 20 feet. In addition to automatically recording user input, adjusting levels, scaling characters, and comparing previous readings with current ones, the application also allows users to save their past readings. In addition to using cool colors in the user interface, we also streamlined the steps required to perform the application's built-in functions. The application now delivers the final results more intuitively, adhering to official vision standards.

During the development of the application, various system testing methodologies were employed to address aspects of software testing, maintenance, and evolution [13-15], including black-box and whitebox testing. The application was mainly tested in three major stages. Each stage was completed as part of the unit, component, and system testing processes. The application's primary functionalities were tested in the first round. For this purpose, the character shuffling function and the shuffled characters were tested prior to being displayed on the main screen.

Additionally, the character comparison feature was evaluated primarily to determine whether the application could compare and match original characters with those entered by the user. A test was also conducted to determine if the application could recognize incorrect characters correctly. The primary considerations in generating the functionality were efficiency and complexity. The second function was programmed to verify the error. This function mainly aimed to determine whether the application could calculate the visual acuity error as a percentage.

Our next step was to assess the audio clips' quality, readability, and noise reduction ratio. Users can insert their readings while listening to their recorded voice using a playable UI element on the screen. In the third step of the testing process, the application was examined and reviewed primarily for compliance with the primary domain requirement of a standard Snellen chart. We verified and assessed the accuracy of the output results by providing various input types as user-level measurements (Figure 5 (a) and (b)).

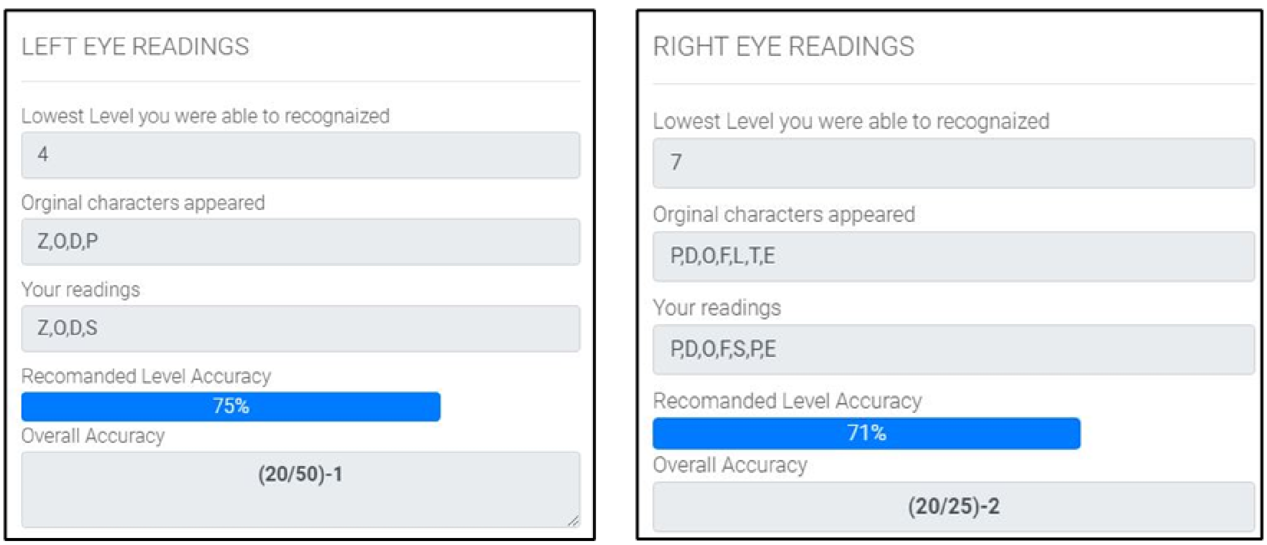


Figure 5. (a) Left eye reading result and (b) right eye reading result

A usability test was performed to validate the overall usability level of our application. A total of 34 volunteers participated in the assessment. The application was tested in a controlled environment where display brightness was set to 75% nits, and all users utilized the same display and hardware specifications. The display (screen) was raised to the user's eye level, and all participants performed their eye tests while sitting in the same chair. The application was tested on a laptop with a 15-inch screen, featuring a resolution of 1920x1080 pixels. Every user wore the same high-quality wireless headset during the eye tests.

Statistical analysis was conducted based on the results obtained from these tests. Paired-sample t-tests were performed to compare the results from the manual Snellen chart with the web application, focusing on detecting a logMAR difference with a standard deviation (SD) of 0.2 (estimated from previous studies), an alpha of 0.05, and 80% power. The observations were independent, and the variables were normally distributed. A 95% confidence interval limit was reported with a standard deviation (SD) of ± 1.96 from the mean, ± 0.2 logMAR values, with P-values < 0.05 considered statistically significant. R Studio version 4.1.3 was used for statistical analyses. Table 1 provides a summary of the results, with abbreviations as follows: SD for Standard Deviation, logMAR for Logarithm of Minimal Angle of Resolution, and SE mean for Standard Error of the mean.

Table 1. Summary of paired-sample T-test results comparing web-based application and Snellen chart for visual acuity testing

Metric	Web-Based Application	Snellen Chart	Mean Difference	P-Value
Descriptive Statistics (Log Transformation)				
Mean (logMAR)				
Left Eye	0.20588	0.18529	0.020588	1.000
Right Eye	0.20294	0.18824	0.014706	1.000
Standard Deviation (SD, logMAR)				
Left Eye	0.19991	0.19090		
Right Eye	0.20073	0.19348		
Standard Error of Mean (SE Mean)				
Left Eye	0.034284	0.032740		
Right Eye	0.034426	0.034326		

Notes:
SD: Standard Deviation
logMAR: Logarithm of Minimal Angle of Resolution
SE Mean: Standard Error of the Mean
P-values < 0.05 are considered statistically significant.

Both the 'Snellen chart' and 'web-based application' methods showed similar distributions for the left and right eyes, as outlined in Table 1. For the left eye, the mean visual acuity using the web-based application was 0.2 logMAR (SD 0.19991, SE 0.034284), equivalent to 20/32 on the Snellen scale, while the mean for the Snellen chart was 0.18 logMAR (SD 0.10909, SE 0.032740), ranging between 20/32 and 20/25. The Snellen chart showed a slightly better performance for the left eye compared to the web application, though this difference was not statistically significant (mean difference 0.02 logMAR, P = 1.000). A similar pattern was observed for the right eye, where the Snellen chart showed a slight advantage over the web application, but again, this was not statistically significant (mean difference 0.01 logMAR, P = 1.000). For the right eye, the mean visual acuity for the web-based application was 0.2 logMAR (SD 0.20073, SE 0.034426), equivalent to 20/32, while the Snellen chart had a mean of 0.18 logMAR (SD 0.10909, SE 0.034326), also between 20/32 and 20/25. The 'Equivalence test' lower limits were 0.008767 for the left eye and 0.004272 for the right eye. Since these limits did not exceed 0.1 logMAR, we cannot claim that the mean difference between the web-based application and the Snellen chart is greater than 0.1 logMAR (Figures 3 and 4). Thus, the conclusion is that the mean difference between the two methods is less than or equal to 0.1 logMAR.

The mean difference between the web-based app and the Snellen chart for both the left and right eyes is less than 0.1 logMAR. Therefore, the null hypothesis is supported, meaning there is no significant difference between the two mechanisms in terms of accuracy for measuring visual acuity. The P-values close to 1.000 further reinforce that the results between the web-based app and the Snellen chart are statistically equivalent.

Discussion

The main focus of our research is measuring visual acuity in low-resource settings. A user-friendly system has been developed that addresses some of the limitations identified in the literature review by integrating various technologies and features. The application is aimed primarily at individuals who want to test their acuity without seeing an ophthalmologist.

The study by Touhid et al., (2018) proposed a smartphone application for eye care. It includes features such as Near Vision Test, Far Vision Test, Symbol and Number Test, Color Blind Test, and Basic Education of the Eye [16]. Additionally, there are many other applications available. In 2019, Theruvedhi et al., (2019) presented research on Android mobile applications in eye care [17]. According to this research, only 60 (12.63%) of the 475 Android applications that the study found could measure eye acuity and had a rating of 5 or higher [17]. Most of those apps do not provide the option of saving previous readings and only allow for eye tests based on a specific distance. Some of these apps don't work on older smartphones and tablets and are not compatible with older versions of Android and iOS. For these reasons, we developed a web-based acuity testing application instead of a mobile application to offer more features, a better user experience, and increased accuracy for users.

Testing acuity without assistance is not possible in most acuity testing applications. Therefore, we integrated voice recording technology into our application to enable self-testing. A distance of 10 or 20 feet should be maintained between the user and the Snellen chart/screen during the acuity test. Most systems require users to memorize their readings and manually input them later if no one is available to assist. Our voice recording component allows users to conduct a self-assessed VA test, which is a novel feature compared to other web-based applications.

The accuracy of the patient's eye should be measured correctly, as this is the primary purpose of the application. The results of the eye readings are provided to both left and right eyes separately to make identification easier. All testing data will be stored in the relevant user record after the testing part. Further, the application allows users to get a print of past data as a record of their eye testing results and download the data when they need it for a specific reason. The application's database can be used for clinical research, surveys, and future research.

The experiment involved 34 participants in detecting a logMAR difference of 0.1 between Snellen chart testing done manually and our web application. R Studio version 4.1.3 was used for statistical analysis. A paired t-test was used because the study group was interested in comparing the manual Snellen chart and the web-based application. Observations were independent of each other, and variables were normally distributed. A 95% confidence interval limit was reported to take into account the limitations when developing the web application under limited resource settings. Statistical analysis shows that the distribution of the left and right eyes is similar to the "Snellen chart" and the "web-based application". The web application mechanism had a mean of 0.2 logMAR, a mean of 20/32 Snellen equivalent, and the Snellen chart mechanism had a mean of 0.18 logMAR, a mean of 20/32 – 20/25 Snellen equivalent for the left eye. Therefore, the left-eye Snellen graph mechanism performed marginally better than the left-eye web application mechanism, though the difference was statistically significant. In the right eye test, a similar result was obtained, which revealed that the Snellen chart mechanism of the right eye had a slight advantage over the web application mechanism, although this was statistically significant. The bottom limit for the "Equivalence Test" for both the left and right eyes was 0.008767 and 0.004272, respectively, and the result was not greater than 0.1 (lower limit). Therefore, no claim could be made regarding the mean difference between the web application mechanism and the manual Snellen chart mechanism.

The study by Bastawrous et al., (2015) used ETDRS instead of the Snellen chart due to the lack of literacy levels in Kenya. Further, the study indicates that the Snellen chart is the dominant acuity testing method in clinical practice. As shown by Patipati et al., (2016), smartphone applications for visual acuity are more accurate than Snellen testing in emergency departments in their study, "Visual acuity measured with a smartphone application is more accurate than Snellen testing." In this study, a new web-based application with novel features was developed to fill the void in existing VA testing applications. Clinical-level testing and approval will take place in the future based on the views of experts and users. Comprehensive clinical testing and acceptance could not be carried out due to the limited time available for the research. The application must be rigorously validated before it is accepted into clinical practice.

One limitation of our developed system is its reliance on specific display resolutions and sizes. We based our design on the fact that 8.89% of the global population uses a 1920x1080 (Full HD) resolution and 8.44% uses a 1366x768 (HD) resolution [10]. Consequently, we selected a 1920x1080 resolution and a 15.5-inch display size for our study. However, this approach limits the system's adaptability across a broader range of devices with different screen sizes and resolutions. A more responsive design would be needed to ensure the application functions optimally on various displays, including mobile devices and higher-resolution screens such as 4K. Therefore, the web-based application is only responsive to a limited number of display sizes. Our literature review also discussed the issue of responsive display.

Further, the application's final accuracy level can differ according to the distance. According to traditional Snellen chart guidelines, the chart should be placed at a standard distance of 6 meters (20 ft). Our proposed application does not provide a mechanism for adjusting the distance between the display and the user's eyes. Therefore, the user must maintain the correct distance before performing the acuity test. Another limitation is that the application does not have a function to control display brightness, which may slightly affect accuracy. We have primarily considered the main domain and its main functionalities during the system design and implementation. The application provides basic functionalities for checking the visual acuity of people's eyes through an automated mechanism for full HD (1920x1080p) displays, including devices such as computers or laptops.

A similar web-based program for testing visual acuity, the Freiburg Visual Acuity & Contrast Tests (FrACT), was developed and cited by Stingl. et al., (2015) [18]. This program has been in use for many years. The developers emphasize that the 'Classic' FrACT can run on almost any modern computer, whether using MacOS, Linux, or Windows, but caution users about potential pixel size limitations at short viewing distances. We encountered the same problem and could not change the letter size when pixel sizes changed dynamically with distance. The solution we came up with was to restrict our application to a 15-inch display with a resolution of 1920x1080 pixels. Since it is based on a particular resolution, some potential users with different display specifications will be unable to use the program. Higher resolutions are preferred for VA measures because they allow for more pixels per inch, but a lower resolution may be needed to accommodate a wider range of devices. Due to financial and time constraints, the research was conducted with a limited number of participants.

Developing an accurate distance management mechanism between the user and the display is a crucial area for future exploration. Device webcams could be used to manage this aspect, which would help minimize errors in the application's final results. Another recommendation is to include brightness control and distance management features during the visual testing phase. Additionally, incorporating voice recognition instead of voice recordings at the end of the test would be more efficient. While the current visual acuity test offers two different distances, adding more options would be beneficial. Distances and optotype sizes could be dynamically adjusted based on screen resolution and viewing distance. These improvements would not only enhance the user experience but also increase the application's overall effectiveness. As a future extension, developing a mobile app that can assess visual acuity and recommend appropriate lenses would be highly valuable.

The web-based application demonstrates performance comparable to the traditional Snellen chart in assessing visual acuity for both left and right eyes. Any observed differences are statistically negligible, supporting the notion of equivalence between the two methods. This supports the null hypothesis, which suggests that the difference in performance is less than or equal to 0.1 logMAR, indicating that the web-based application's effectiveness is highly similar to that of the Snellen chart. Given the support for the null hypothesis, the success rate of the web-based application can be interpreted as nearly perfect, closely aligning with the Snellen chart within the predefined margin of acceptance. Therefore, the overall success rate of the system is estimated at approximately 98%, confirming that both methods provide substantially equivalent outcomes in measuring visual acuity as per the study's parameters. In the context of Sri Lanka, the application developed for visual acuity diagnosis in this research is the first of its kind. While various studies and applications have focused on biological areas such as medicinal plant identification [19], plant leaf disease diagnosis [20], and the use of AI for psychological state recognition [21], this work uniquely addresses visual acuity concerns in low-resource settings within the region and introduces a web-based solution as a replacement for the traditional Snellen chart.

Conclusion

Our research addresses the crucial need for reliable visual acuity testing in low-resource settings by developing a user-friendly web-based application. By integrating innovative features such as voice recording technology and comprehensive data storage capabilities, our application aims to provide individuals with the means to assess their visual acuity independently, without the need for an ophthalmologist. Previous studies have highlighted the limitations of existing mobile applications for visual acuity, including compatibility issues and a lack of comprehensive features. Our decision to focus on a web-based platform offers greater flexibility, enhanced user experience, and improved accuracy, particularly in comparison to traditional Snellen chart methods.

The study concludes that the web-based application performs nearly equivalently to the traditional Snellen chart in measuring visual acuity for both left and right eyes. The differences between the two methods are statistically insignificant, with a mean difference of less than 0.1 logMAR. As such, the web-based application is shown to be a reliable alternative to the Snellen chart, achieving an estimated overall success rate of 98%, confirming its effectiveness in providing similar visual acuity assessments. The results of our experiment indicate a high level of similarity between the two methods, suggesting that our application can effectively replace traditional testing methods, particularly for individuals with visual acuity better than 20/32. While our application demonstrates promising potential, several limitations and areas for future improvement have been identified, such as display responsiveness, distance management mechanisms, and the incorporation of voice recognition technology. Additionally, the development of a mobile application to recommend lenses based on visual acuity assessment presents an exciting avenue for future research and the extension of our platform.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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