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MAC-U-Vision+: An Improved Application for Individuals with AMD

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Abstract

An estimated one in ten people in the United States above the age of 50 have a form of age-related macular degeneration (AMD). AMD is a retinal disease that causes a slow and irreversible loss of central vision. Additionally, it can progress to causing legal blindness. Currently, many assistive technologies for patients with AMD are expensive, and they become less effective as vision deteriorates with disease progression. Rehabilitation interventions are also a core clinical intervention for the treatment of functional loss in AMD. However, a practical and systematic pathway to guide people with AMD through disease progression is currently unavailable. In response, we developed an application, MAC-U-Vision+, an improvement of its predecessor MAC-You-Vision. This platform supports patients through the early stages with information and social support opportunities, to gamification of oculomotor control training and accessibility tools, among others. This would be one more steady step toward a comprehensive mobile/tablet application that combines both low-vision rehabilitation methods and assistive technology. Our application development is guided by a user study.

Keywords

Vision rehabilitation, assistive technology, macular degeneration, gamification, eye movement training, object recognition.

Introduction

Age-related macular degeneration (AMD) is the leading cause of vision loss affecting more than 19 million people aged 40 and older in the United States. Of this, 18.34 million people were diagnosed with early-stage AMD, and up to 1.49 million people have late-stage AMD (Rein et al., 2022). AMD causes damage to the outer retinal layers in the macular, which leads to a gradual loss of central vision. In the late stages of the disease, central scotomas (i.e., blind spots) are often present bilaterally (Schuchard and de Castro, 1999). As a result, the progression of the disease has consequences on a patient's ability to perform daily tasks including but not limited to reading and driving. Since there is currently no medical cure for AMD, patients are commonly referred for low-vision rehabilitation. Interventions to the loss of central visual function include current assistive technologies (e.g., head-worn magnifiers) and rehabilitation training such as eccentric-viewing training and reading practice (e.g., Hooper et al., 2008; Hamade et al., 2016; Maniglia et al., 2016). Current assistive technologies are generally expensive, may not be useful for all tasks (van der Aa et al., 2024), and may not continue to benefit patients if they have increased vision loss due to the disease progression. Other rehabilitation techniques are focused on improving visual search and scanning abilities and increasing reading speed. For example, Seiple et al. (2005; 2011) developed eye-movement-control exercises that have been shown to significantly improve reading speed solely by practicing eye positioning and movements.

Although low-vision rehabilitation is a critical part of clinical intervention in AMD, an effective and systematic pathway to guide people with AMD through disease progression is unavailable. In response, we built a mobile platform, MAC-You-Vision, as a progressive training application aimed at helping patients through each stage of the disease (Tepoxtecatl et al., 2023).

The application was organized into three stages that correspond to the three stages of AMD. It included key features such as oculomotor control training and augmented reality among others. However, the features and oculomotor control training were still in their early development and predominantly sparse. Therefore, we continue the development of **MAC-U-Vision+** to improve the functionality of the platform by including gamification of training and accessible features as well as proposing the integration of an essential AI-based assistive technology tool. The contributions of this work include: (1) new features tailored for AMD stage-specific scenarios and needs and (2) new research opportunities in telerehabilitation and supplemental diagnostic tools. The present work offers solid steps toward building a comprehensive and accessible mobile/tablet application that combines access to information about AMD and its progression, low-vision rehabilitation, and assistive technology for patients with age-related macular degeneration. Our method also proposes potential advancement in telerehabilitation that could decrease the frequency of clinic visits.

Discussion

MAC-U-Vision+ is an application that can run on mobile/tablet devices with an accessible interface for people with vision loss. Figure 1 shows the home screen of the MAC-U-Vision+ application in tablet view. The layout of the interface is designed to be accessible throughout the stages of loss of the central vision of individuals with AMD. On the home page, users can navigate to the features, including auditory presented educational pages, questionnaires, scotoma tracking, rehabilitation games, and object recognition. The object recognition is an ongoing work that will be integrated into the app.

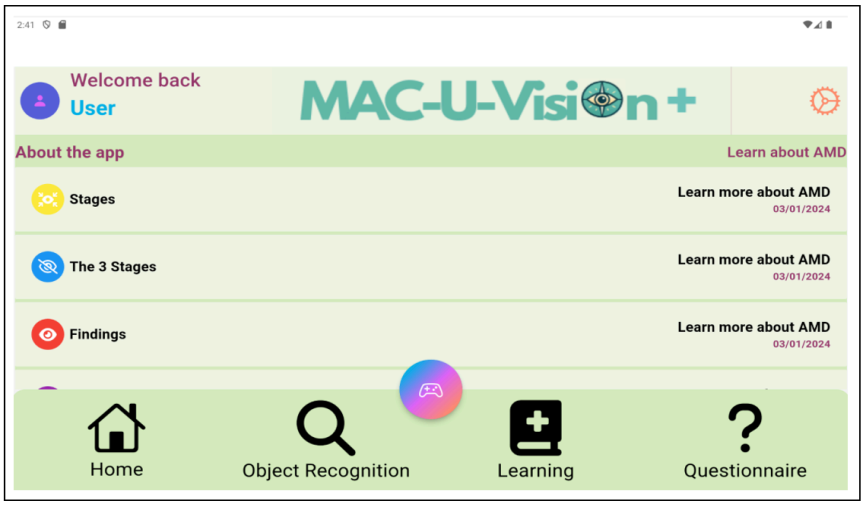

Fig. 1. Home screen of the application in tablet view.

Mental Health Assessment

A daily **assessment** is incorporated into the application as a feature that can be used from the early stage through the late stage of AMD. The questions are based on the National Eye Institute Visual Function Questionnaire 25-Item (NEI-VFQ-25) and two questions on suicidal and non-suicidal self-injury as follows (NEI, 2000):

1. How much time do you worry about your eyesight? (1) None of the time (2) A little of the time (3) Some of the time (4) Most of the time (5) All of the time
2. Do you feel frustrated a lot of the time because of your eyesight? (1) Definitely true (2) Mostly true (3) Not sure (4) Mostly false (5) Definitely false
3. Do you feel you have less control over what you do because of your eyesight? (1) Definitely true (2) Mostly true (3) Not sure (4) Mostly false (5) Definitely false
4. Have you thought about harming yourself? Y/N
5. Have you thought about attempting suicide? Y/N
6. How is your day going? Short response

Patients can take the questionnaire daily or as appropriate starting from the time of diagnosis of AMD. Therefore, this feature can be used for all three stages. We aim to have a dashboard display that allows users to track their response to vision loss.

Scotoma Tracking

As central scotoma is a commonly associated symptom of AMD, the **scotoma tracking feature** can be used to track the development of blind spots and disease progression over time. Similar to the mental health questionnaire, the scotoma tracking feature can be used throughout all stages of the disease starting from the time of diagnosis.

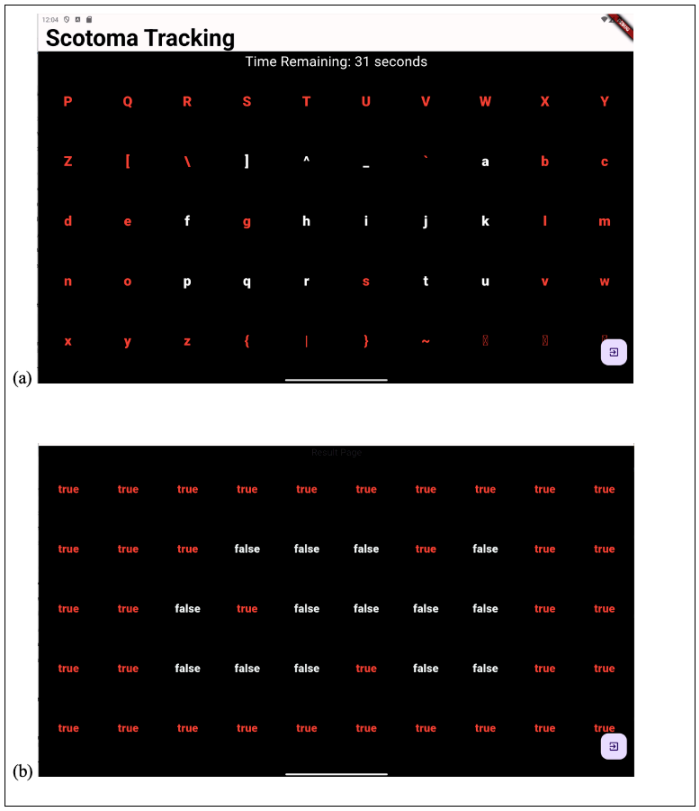

Fig. 2. Intended use of the scotoma tracking feature. (a) Letters and characters are placed across the entire screen. The highlighted red texts denote areas that have been clicked - i.e., where patients can see. Unclicked areas are presumably where the patients' blind spots are. (b) Result recorded from the session.

At the beginning of each session, letters and characters consisting of lowercase and uppercase alphabet and miscellaneous characters appear on the tablet screen in a grid layout. Users will look at the center of the screen and then click on the letters and characters they can see without moving their eyes. At the end of the session, a screen will appear, with "seen" areas written in red, as in Figure 2. Areas not clicked are presumed to be where the patients' blind spots are - in these, the color of the text will not change. At the end of the session, a true/false color-coded screen will appear, corresponding to the areas clicked. User results will be able to track changes in the visual field as the disease progresses.

Eye Movement Training

Eye movement training is tailored for patients with moderate visual impairment, usually in the intermediate and late stages of AMD where patients may often have central scotoma. For this training, we developed a soccer balls-catching game that uses the open-source Flame package and is inspired by a public YouTube tutorial video for creating a 2D game (Trey Codes, 2022; Flame Engine, 2024). Flame is a game development framework for Flutter apps, the software development kit that is used in our application (Flutter, 2024). Our game session begins with a scene of a soccer field. The user controls the hands using an embedded virtual joystick on the screen to "catch" the balls. Performance is timed.

Users use their eyes and "catch" the balls by moving the hands through all the balls (Figure 3). Each time the user catches a ball, a sound "you caught it" is played to serve as auditory feedback. The session completes when all the balls have been caught, and the timer stops to record the duration of the screen. There are three levels of difficulties in the game: easy, medium, and difficult. In the first mode, the game proceeds as described above. In the medium mode, there is an addition of asteroids on the screen. Users are instructed to avoid the asteroids,

and if they contact with them, the hands will temporarily freeze. In the final difficulty level, the asteroids move at a faster speed, making them harder to avoid.

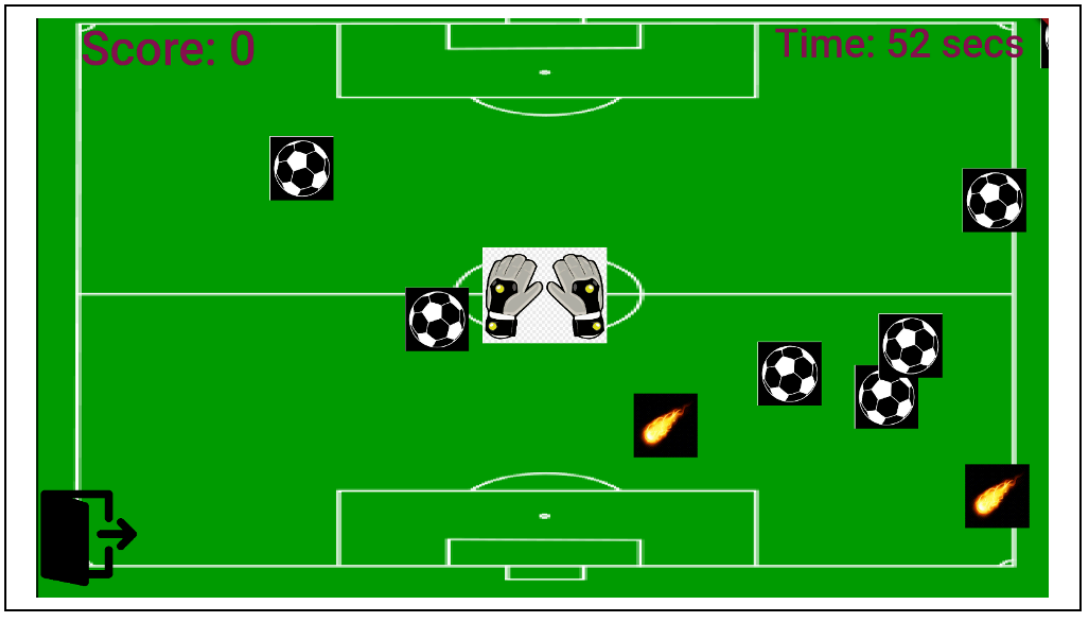

Fig. 3. A sample play of the soccer ball-catching game. Soccer balls are placed randomly throughout the screen. Two "asteroids" move around and freeze the hands if they come in contact. A timer is on the top right corner to record the duration for completing the game session.

Object Recognition

In the late stage of AMD, the **object recognition** feature can help users identify objects that are in their environment (Figure 4). Users would be able to move to search with the camera, and the tool generates a voice output of what the object(s) are every 5 seconds. This technology utilizes Tensorflow Lite and OpenCV, as well as the YOLOv5 deep learning model (Jocher, 2020; OpenCV, 2024; TensorFlow, 2024). In particular, the YOLOv5 model is pre-trained on a large dataset, allowing for the image to be processed and classified. This is an ongoing work that we are working to integrate into the app and add advanced add-on features that will be useful to most users.

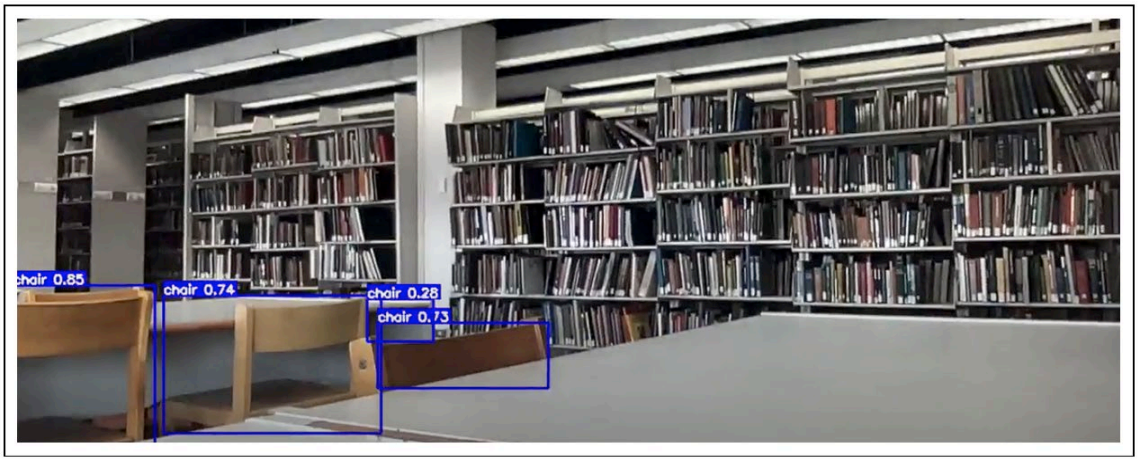

Fig. 4. Sample usage of the object recognition feature in a library. Here, the camera detects chairs that are directly in front.

Throughout the application, as a standard and expected feature, we have a text-to-speech functionality that reads to users and relies on sound as the primary feedback.

An Informal User Study

Five patients with central-vision-related ocular disease participated in the study (four females and one male; mean age, 71.6 years, and range 54-86). The survey was basically asking about their information as shown in Table 1 and then undertaking a discussion about how they think we can improve the application (app). Three patients either have AMD or a combination of AMD and glaucoma. Patients 1 and 2 have macula hole and Stargardt Disease, respectively. Both macular hole and Stargardt Disease affect the macula and lead to the loss of central vision. In all patients in the study, their vision was severely affected, and none were able to read small texts. User study sessions were approximately 1-hour long for each and were conducted either in person or virtually. During the session, we allowed the patient to explore the app and the developed features. We then took their suggestions to build upon further – which will be described in the discussion section below, highlighting their thoughts and comments, e.g., mental health and feedback on the gamification.

Table 1. Demographics, mobile phone proficiency, and current vision of patients in our study.

SA = severely affected.

Patient	Age (y)	Sex	Cause of vision loss	Current vision	Mobile phone use	Able to read/see small texts?	Able to read/see large texts?	Able to read/see shapes?	Able to read/see light?
1	54	F	Macular hole, glaucoma	SA		N	N	Y	Y
2	62	F	Stargardt	SA		N	Y	Some	Y
3	72	F	AMD, glaucoma	SA		N	N	Y	Y
4	84	M	AMD	SA		N	N	Y	Y
5	86	F	AMD, glaucoma	SA		N	N	Y	Y

Further Discussions

MAC-U-Vision+ provides features that help AMD patients optimize their understanding of the disease and its progression and maximize functional adaptation to vision loss. In the following, we will discuss the rationale for the designs of new features and considerations in user interface designs. Our application development is guided by our informal user study during the development.

The new **mental health assessment** was added as a measure for alerting the user to potential problems adapting to the disease-related vision. The literature and our user study with patients show a strong relationship between depression and vision loss (Virgili et al., 2022). Depression occurs frequently among patients, and since AMD is a progressive disease leading to vision loss and associated functional declines, depression should be monitored throughout the stages of the disease (Casten and Rovner, 2008). Our short assessment, which is available in the app, can serve this need. Medical and mental health providers may also use the results as a gauge

for depression, anxiety, and suicidal and non-suicidal self-injury, which can lead to prompt intervention as needed. Additionally, since AMD is a progressive disease spanning many years, results can be used for future longitudinal studies. The questions and short responses can also be studied further from the perspectives of sentiment analysis and classification.

A **scotoma tracking feature** has been added to allow patients and vision professionals to track and observe the development of blind spots in the central vision over time. In the early stage of the disease, patients may be able to see most of the letters and characters in the chart. But as the disease progresses and a central scotoma begins to develop, frequent at-home assessments could be used to supplement the medical providers' understanding of the patients' current vision and how well they can see and use an electronic device. We note here that this tracker is clearly not a substitute for a visual field test. Instead, we aim to alert patients to changes and gauge how they can optimize their vision. For example, results from the tracker can help patients find where their eccentric viewing "sweet spots" (preferred retinal locations, PRLs) are when using a tablet. This is important because the effective use of PRLs can greatly improve functional vision (Stigchel et al., 2013). One component that may need to be considered further in this feature is to distinguish between visual field and acuity. In one patient with macular degeneration in our user study, the patient has no scotoma present but has lost visual acuity in the central vision. That is, if the patient were to take the scotoma tracker, the patient would still be able to see that there are letters and characters at the center of the screen. They will, however, appear lacking in clarity and sharpness. In the future, this feature can be extended to allow for the recording of visual acuity.

Gamification has been added based upon the previous user study conducted in Tepoxtecatl et al. (2023). Therefore, the rehabilitation in the paper's current version of the app

comes in the form of games for daily practice. Patients in our current user study reported that the task continues to be helpful in finding "sweet spots" for screen use and practicing visual search. The soccer balls-catching game also allows patients to practice anchoring their eyes and following the hands image on the screen. User study was extremely helpful in how we set the difficulties of the game. At one point, patients report that the game can be too challenging with both the number of asteroids and their speed. Their feedback helped us decide how many asteroids to use in the medium and difficult levels as well as how fast they move.

The **object recognition** feature is primarily designed for patients in the later stage of AMD, where central scotomas are generally larger. This tool is designed so that it would be able to help patients identify objects that are in front of them in real-time using their device's camera. We are not saying that this is the best possible version for this feature. In fact, other apps like *Seeing AI* have more advanced and thorough assistive features that are used frequently by AMD patients, including those in our study. In MAC-U-Vision+, however, we are suggesting that a combination of rehabilitation and assistive features can make a comprehensive platform that fits the needs of many patients in one app.

Conclusion

Our application developed over the last few years, to our knowledge, took the first step toward combining both low-vision rehabilitation and assistive technology for patients with AMD. MAC-U-Vision+ takes steps further from its early counterpart (Tepoxtecatl et al., 2023) with the gamification of training, the addition of new completed features such as the scotoma tracking feature and mental health assessments, and the proposal to integrate essential assistive technology tools like object recognition. Patients with AMD could use our platform from the time of diagnosis and throughout disease progression. In our user study, patients overall shared

positive feedback about the application and particularly liked how the features are tailored to help teach and optimize remaining vision. Recently, the FDA has approved Syfovre (pegcetacoplan) and Izervay (avacincaptad pegol), which have been shown to be able to slow the rate of progression of late-stage dry AMD, also known as geographic atrophy (NEI, 2023). While we wait for more all-inclusive treatment of AMD, our application could serve as a temporary umbrella platform that pushes forward advancement in telerehabilitation during the onset of AMD.

Since this paper involves just a short-term study for AMD patients, future work may analyze the effectiveness of rehabilitation intervention in the clinic versus at home. It will also be interesting to follow the patients' use of the application long-term, from the time of diagnosis to various stages of the disease. Results can be projected toward the analysis of low vision telerehabilitation. Additionally, a longitudinal study focusing on the mental health aspect can also offer an in-depth understanding of the patients' adaptation to disease trajectories starting from the time of diagnosis of a vision-impacting disease. Such a study could, for example, help detect warning signs of the onset of depression. This should not only cover depression but also anxiety and somatic symptom disorder among others. For example, since AMD is a progressive degenerative disease, there can be a study on anticipatory anxiety of vision loss and its effects on the physiology of disease progression. One of the goals is to, ultimately, supplement direct medical interventions by addressing rehabilitation, assistive technology, and overall quality of life of the patients throughout the stages of AMD.

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