Abstract—Age-related Macular Degeneration (AMD) is one of the leading causes of blindness in the elderly. Visual loss associated with AMD often results in a central scotoma which is an alteration in the central vision, leading to distortion or loss of vision. Current methods of detecting AMD are typically manual, require holding fixation and an external response trigger. In this paper, we propose the use of eyegaze tracking to detect for the presence of AMD, using a simple set of test patterns. Experimental results show that the derived eyegaze measurements can help to identify individuals with AMD from healthy individuals. This could lead to the detection of AMD using eye tracking data, and could result in a potential system device for screening.

Index Terms—AMD, Vision Assessment, Impairment Detection, Gaze Analysis, Eye Tracking

I. INTRODUCTION

Age-related macular degeneration (AMD) is an eye condition that deteriorates central vision in affected individuals. It is one of the leading causes of blindness worldwide, and has been projected to affect 196 million people in 2020, and up to 288 million by 2050 [1]. It is the main cause of blindness in patients over 65 years [2], with disease prevalence drastically increasing from 2.1% for 40 to 49-year-olds, to 35% for individuals aged over 80 [3]. It has been estimated that the direct costs of AMD amount up to US$570 million annually [4].

AMD can be subcategorized into sub-types, dry AMD and wet AMD. Dry AMD, also known as non-exudative AMD, is characterized by the presence of drusen, which are yellowish fatty deposits under the retina, which also thins in this condition. At this stage, vision loss is mild and may not be perceivable. As dry AMD progresses, it can lead to atrophy of the photoreceptors responsible for central vision. Later stage dry AMD is also known as geographic atrophy, where a large region of the photoreceptors have degenerated in the central retina.

Wet AMD, or exudative AMD, is the more severe form of AMD and is responsible for 90% of the blindness due to the condition. The wet form of AMD is characterized by swelling in the retina and the growth of fragile new retinal vessels, called choroidal neovascularization. These new vessels often break, leading to bleeding in the retinal and resulting in scarring. It is this scarring that leads to central vision loss in wet AMD. Current methods of treatment for wet AMD typically involved regular injections of an anti-vascular exudative growth factor (anti-VEGF) to limit the growth of new vessels.

The alteration of central vision, surrounded by the remaining relatively normal visual field, is one of the main visual symptoms in AMD-related vision loss. This visual degeneration, also known as a central scotoma can present itself as a distortion in the visual field, and can progress to total loss of vision in the affected area, as can be seen in Figure 2(b).

Currently, in clinical practice, clinicians rely on the assessment of the visual field as a key indicator of AMD. One of the most commonly employed methods is the use of the Amsler grid (Figure 2). In this test, which is conducted for each eye separately, patients are required to fixate their eye at the center of the grid, and indicate areas of distortion. Patients with AMD may notice wavy or missing lines in the
grid. Such a test is highly subjective, manual and tiring for the patient. Automated microperimetry is another technique of assessing the visual field of an individual by probing the light sensitivity at specific locations in the retina. During the microperimetry test, the individual is required to fixate at a central point while manually activating a response trigger when a stimulus is observed. Though the microperimetry test is automated, patients are still required to fixate at a fixed location and the test still requires hand-eye coordination to activate the stimulus response trigger, which can be challenging for elderly. Such a device is also not suitable for self-monitoring or home use. Other recent techniques include preferential hyperacuity perimetry (PHP)\(^5\), which presents the patient with a series of dot stimulus, who is then required to indicate the location of distortion. Similar to automated perimetry, the PHP test also requires central fixation and good visual-motor coordination.

Eye tracking refers to the process of measuring where the eye is looking as well as the movements of the eye. Eye tracking has found increasing use as a technique for understanding human behavior, as a means for natural human computer interaction, as assistive tools and as a means for detecting diseases such as Alzheimer’s disease and glaucoma, which are brain and eye conditions respectively.

In this paper, we present a study to detect AMD eyes by measuring and analyzing the natural eye movements and eye tracking data in response to visual stimuli. Such eye movements are natural and intuitive responses, and can thus be used as trigger responses to visual stimulus without the need for additional triggers, compared to the other aforementioned techniques. This study will be part of a proposed system for the detection of AMD called AVIGA (Automated Vision Impairment detection through Gaze Analysis). The AVIGA system will automatically detect the presence of visual function changes through intelligent analysis of changes in the gaze patterns. Through variable targets and test scenarios, the proposed AVIGA system could also reduce patient fatigue by allowing eye movements to different points of fixation through the test. Target patterns are presented at the patients’ current location of fixation. Current methods of visual field assessment require the patient to fixate at the same point throughout the assessment.

This paper is organized as follows. Section 1 of this paper provides an introduction and clinical context to the work, including an overview of current methods used to assess visual loss in AMD, as well as a brief introduction to the proposed system. In Section 2, we will describe the steps in the study, followed by a description of the experiments and results in Section 3. Finally, the conclusion is presented in Section 4.

II. METHODS

In this section we describe the hardware platform used in this system, the testing protocols and the metrics used to compare the obtained results.

A. Eye tracking platform

We used the Tobii Pro TX-300 (Tobii AB, http://www.tobii.com) to acquire the eye tracking measurements in this paper. The Tobii TX-300 platform is a heads free binocular eye tracker able to capture data at 300 Hz. By not requiring the use of a chin rest, the test and data collection process is made unobtrusive for the individual and does not hinder natural head moments. Further, the high sampling rate of 300 Hz enables the study of saccades and fixations. The TX-300 comes with an inbuilt 23-inch monitor, on which the target stimulus is presented to the individual.

B. Test Protocol

The following test protocol is performed for each individual undergoing the test. Figure 3 shows a gaze tracking setup with the subject sitting in front of the eye tracking device displaying the test pattern.

![Figure 3. Gaze tracking setup](image)

![Figure 4. Test flow](image)
(a) Environmental Conditions.

The test was carried out in an enclosed room in the eye clinic, with no other possible distractions present. To administer the test, a member of the research team accompanied each patient and verbally communicated the test procedures. Direct sunlight was avoided as this could affect the tracking accuracy. The room was lit using normal office illumination without dimming the environment as recommended by the device manufacturer usage guide.

(b) Calibration

At the beginning of the test, participants will go through a monocular calibration procedure with one of the eyes covered using the eye occluder. The calibration setting with 5 points is adopted. These 5 points with positions of (0.1, 0.1), (0.1, 0.9), (0.5, 0.5), (0.9, 0.1), and (0.9, 0.9), are shown in the right illustration in Figure 5. Before carrying out the calibration procedure, the participant will be instructed to adjust their position and make sure that both eyes are detected and displayed at the centre of the virtual tracking box on the screen. The position of the eyes and the distance from the eyes to the eye tracker are shown on the screen in the calibration software (left image in Figure 5). The participant will also be advised to find a comfortable and relaxed posture. After the position adjustment, the calibration procedure starts by showing the 5 points randomly one by one. Participants are required to fixate their gaze on the dots. The collected gaze data will then be used to calculate the calibration parameters. This calibration procedure is carried out again on the other eye. Finally, the calibration results from both eyes are merged and applied into the system.

(c) 5-points Test

In this 5-points test, 5 spots are displayed consecutively on the screen. The locations and sizes of the spots follow the calibration test pattern in Figure 5. Each spot is presented for 4 seconds, after which the next spot is presented. Gaze data is acquired during the subsequent 3 seconds, with the first second in each spot presentation reserved for eye movements to the new spot. Once the test is completed, the accuracy of the eye movements with respect to the dot presentation is calculated (see Section C. Evaluation metrics) and averaged across all the gaze points. This average accuracy will be used as the minimum threshold distance between a target and the gaze point to determine if a target is ‘seen’.

(d) Dot Detection Test

The next study was used to determine if the participant is able to detect dot present in the field of view while maintain fixation at a fixed central location. First, the participant will be instructed to fixate their gaze on the cross displayed at the center of the screen. When fixation on the cross is detected, it will automatically display a dot size of 4 pixels at a random position within a region 2° to 6° from the centre of the fixation point. This was calculated using the distance the participant is sitting away from the screen. For this test we collected eye gaze data for 3 seconds, amounting to 300 points. If more than a third of the data (100 points) was within the minimum threshold calculated earlier, the dot is considered to have been seen by the participant. However, if the number of points is less than 5 seconds, the spot is deemed unseen, and a larger dot size is tested at an alternate location. If the number of points is between 50 and 100, the same dot size is used but the test is restarted with the dot presented at an alternate location.

C. Evaluation Metrics

Each test consists of multiple events. An event consists of target presentation and the subsequent gaze measurement. For example, in the 5 points Test, one presentation of the fixation target with the gaze measurement is considered as one event. The subsequent presentation of the dot is also another event with the corresponding gaze data. Under the frame rate of 300Hz for the TX-300, there will be around 300 gaze samples per second. We calculate the accuracy and precision as follows by considering all the gaze samples for the event.

Let $E$ be an event, $n$ be the number of events, $g_{ij}$ be the detected 2D gaze position of the $j$th gaze sample of the $i$th event, $p_{ij}$ be the “true” position of the gaze, which is the position of the dot (or cross) displayed on the screen. Then accuracy and precision of event $E_i$ are calculated as

$$a_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \|g_{ij} - p_{ij}\|_2$$

$$p_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \|g_{ij} - \bar{g_i}\|_2$$

Here $n_i$ is the number of gaze sample of $E_i$, $\bar{g_i}$ is the average of $g_{ij} = 1, 2, 3, ..., n_i$, $\|\cdot\|_2$ is L-2 norm. Figure 6 illustrated the accuracy and precision for 4 different types of gaze pattern.

![Figure 5. Screenshot of calibration software (left), 5-points calibration with dot positions (right)](image)

![Figure 6. Illustration of accuracy $a$ and precision $p$ (a) Low $a$, low $p$ (b) high $a$, low $p$, (c) low $a$, high $p$, (d) high $a$, high $p$.](image)
III. RESULTS

A. Data

To evaluate the difference in gaze measurements between healthy and AMD eyes, we conducted the described test protocol on a group of 7 healthy volunteers and 7 AMD patients. The AMD patients were recruited from the eye clinic of a local hospital (National Healthcare Group Eye Institute, Tan Tock Seng Hospital), and have undergone injection treatment for their conditions. Consent was obtained from the patients prior to participation in the test, and their identities were also subsequently anonymized. Each of the participants went through the described protocol. After which the gaze data was evaluated using the accuracy and precision metrics for each event. Finally, to obtain an overall measure for each participant, the calculated metrics were then averaged across the test.

| TABLE I. STATISTICAL COMPARISON BETWEEN NORMAL AND AMD PARTICIPANTS |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
|                                 | Healthy         | AMD             |                 |                 |
|                                 | Accuracy | Precision | Accuracy | Precision |
| Mean                            | 59.5     | 25.1       | 249.7   | 103.7     |
| Std Dev                         | 24.5     | 20.3       | 108.9   | 62.1      |
| Pearson’s correlation            | 0.59     |             | 0.74    |             |

Figure 7. Plot of the average accuracy and precision results for healthy and AMD participants in the study.

B. Results

The results obtained from the gaze measurements are shown in Figure 7. Statistical measures are tabulated in Table I. It can be observed that the normal participants typically had accuracy values less than 100 pixels, and precision scores less 50 pixels. In contrast, for the participants with AMD, there is a much larger variation in the accuracy and precision metrics. It is also interesting to note that there observed correlation between the calculated precision and accuracy. The Pearson’s correlation coefficient between accuracy and precision for the AMD participants’ data was calculated to be 0.59, while that for the normal was calculated to be 0.74. The overall correlation between accuracy and precision is 0.79 for all the data collected from both healthy and AMD participants.

C. Discussion

AMD patients typically have central scotomas due to the degeneration of the central macular region. In terms of the visual function, this often presents in individuals as an inability to focus well or to retain fixation, leading to a larger variation in the gaze plots, which is expressed in the larger precision values. Further, as part of the rehabilitation process, AMD patients often adjust for central scotomas by training the use of a Preferred Retinal Locus (PRL) which is eccentric to the foveal axis. This is supported by the obtained results, in which individuals with AMD have a larger accuracy values, as possible compensation for the present central scotomas. The accuracy values can be alternatively seen as offsets of the PRL to the foveal axis.

IV. CONCLUSION

In this paper we have presented results which could potentially differentiate AMD patients from healthy individuals. AMD is a blinding disease which is increasingly prevalent worldwide, particularly in rapidly ageing societies. Current techniques of assessment are manual, time consuming and labour intensive. We present a study using an eye tracker which measures the natural visual response of an individual to visual stimulus. Experimental results already show differences in the accuracy and precision between AMD and healthy individuals. This could be further extended to determine the severity of visual loss in AMD though further test pattern design, and could be a potential platform for an automated, intelligent system for the assessment and detection of AMD.

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REFERENCES