

**Raffles Institution**

**Research Education**

**2020 SMP Project Report**

**Developing a Web-Based**

**Virtual Reality Visual Field Test**

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# ABSTRACT

As Singapore faces an aging population, cases of old-age-onset diseases such as Glaucoma will sharply rise. However, the traditional Humphrey Visual Field Test used to detect and monitor Glaucoma is expensive, slow and inefficient. This project aims to develop a lean, fast and cost-effective visual field test that patients can take at their convenience with smart features to reduce the number of retakes necessary. A Unity-based program was coded and tested on the Google Cardboard platform with a web application backend. Though the program and results collection are not yet finished, the product has great potential in telemedicine applications especially in the COVID-19 pandemic.

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**CHAPTER 1: INTRODUCTION**

Glaucoma is the leading cause of blindness in the world. As Singapore faces an aging population, the number of Glaucoma patients is set to sharply rise. Unfortunately, Glaucoma symptoms are very gradual and mild in the earlier stages of disease. Consequently, many patients are diagnosed with Glaucoma only after the disease has progressed when medical intervention is less likely to result in favourable prognosis.

Furthermore, Glaucoma progression must be monitored throughout treatment as individual response to medication varies significantly. Consequently, patients must return on a regular basis to healthcare facilities to check their visual field.

Unfortunately, the traditional Humphrey Visual Field Test has numerous drawbacks: it requires multiple retakes for valid results, test duration is lengthy and it requires large, expensive machinery.

This project aims to develop a cheaper, portable version of the Humphrey Visual Field Test that patients may take at their convenience. The engineered product (Web-Based Virtual Reality Visual Field Test) would provide an indication of visual field quality for patients and physicians, such that whether further medical testing is required for diagnostic / monitoring purposes can be hinted at.

The research would significantly reduce the number of hospital visits a patient must make. This saves the patient money and time, optimises physician deployment and allows a hospital with a given capacity to handle more Glaucoma patients concurrently. It also has potential in telemedicine applications highlighted by the current COVID-19 pandemic.

* 1. **Definitions of Key Terms**

***Web-Based:*** Hosting the application on a server such that it is accessed via an internet browser and is platform-independent (it works regardless of device, browser or operating system used).

***Virtual Reality***: Presenting the application using 3-Dimensional graphics cast on a 2-Dimensional screen that gives viewers the illusion of perspective.

***Visual Field Test***: Assessment of the visual field; often sensitivity to light at points dispersed throughout the field of vision is used as an indicator of overall visual field health.

These terms will be explored further in the literature review.

**CHAPTER 2: LITERATURE REVIEW**

* 1. **Glaucoma in Singapore**

Glaucoma is medically defined as an acquired chronic optic neuropathy characterized by optic disk cupping and loss of regions of the visual field caused through pressure and damage to the optical nerve (Riordan-Eva & Augsburger, 2018). In primary glaucoma, this pressure is caused due to a build-up of aqueous humour in the eye that is unable to be properly drained.

The two predominant types of glaucoma are open-angle and angle-closure glaucoma. Open-angle glaucoma is caused when the iris of the eye remains in the correct position but drainage of aqueous humour is impeded due to resistance from the trabecular network. On the other hand, angle-closure glaucoma is caused by the blockage of drainage by the iris. Whilst angle-closure glaucoma tends to be more severe than open-angle glaucoma, open-angle glaucoma is much more prevalent (Navid *et al*., 2020), and onsets rather slowly. Patients may ignore the symptoms in the earlier stage of disease which makes timely testing for glaucoma important. Therefore, open-angle glaucoma will be the focus of the literature review.

There are also subtypes of glaucoma, such as congenital glaucoma, pseudoexfoliative glaucoma, pigmentary glaucoma, traumatic glaucoma, irido corneal endothelial syndrome, neovascular glaucoma, and uveitic glaucoma. However, these forms of glaucoma are either too uncommon, or progress too rapidly for detection to yield actionable results, and thus are not the target of this research.

In the local context, the prevalence of Glaucoma is set to shoot up in the near future due to a combination of demographic and epidemiological characteristics of the population. Firstly, Singapore, an advanced economy, is currently about to face an ageing population crisis (Rahul *et al*., 2018). As glaucoma is an old-age onset disease, the ageing population will invariably lead to a greater number of cases of glaucoma. Additionally, many people in Singapore’s population trend towards having some form of myopia. More than 70% of Singaporean students completing college education are myopic, and cases of severe myopia in Singapore (cases where myopia exceeds –6.0D) make up approximately 10% of Singapore’s population (Seet *et al*., 2001). This is concerning, as severe myopia is one of the risk factors to open-angle glaucoma. Furthermore, hypertension and diabetes are known to be comorbidities that increase one’s risk of experiencing glaucoma (Regan & Neima, 1984). Therefore, it is imperative that current healthcare infrastructure available be made more efficient to cope with the surge in Glaucoma cases predicted by the literature review – namely improving the diagnostic and monitoring capabilities of the healthcare system.

* 1. **Role of Visual Field Testing in Glaucoma**

Glaucoma has no known cure and is a lifetime condition. Hence, management of the disease through medication, laser surgery and incisional surgery remains the only option (Schwartz & Budenz, 2004). Given that earlier medical intervention has demonstrated more positive outcomes (Heijl *et al*., 2002), it is paramount Glaucoma be diagnosed early and monitored throughout disease progression (Phu *et al*., 2017).

Visual Field Tests (VFTs) are used to construct a patient’s visual field to identify peripheral vision loss which can be used to characterise progression of glaucoma in a patient. VFTs predominantly fall into two categories: kinetic or static perimetry. In kinetic perimetry, a dot of light with constant brightness is moved from the periphery to centre of the visual field to find the edge of the visual field to judge visual field loss. In static perimetry, dots of light laid out across the visual field appear with different brightness to judge both the visual field and the sensitivity of the visual field at the respective locations (Aref, 2020).

Static perimetry is preferred in clinical practice due to its ability to give a judgement of the visual field in terms of both region(s) of visual field loss and sensitivity which can allow a better understanding of the extent of progression of the causative disease. However, kinetic perimetry is more suited for patients unable to concentrate for long periods of time. This project focuses on emulating Static Perimetry as a larger number of patients would be able to benefit from this research.

* 1. **Static Automated Perimetry Methodology**

Of the different forms of static perimetry, Standard Automated Perimetry is most commonly employed in modern clinical practice to judge a patient’s visual field to aid the physician in diagnosing and monitoring their condition.

A machine called the Humphrey Visual Field Analyser (HFA) is used to conduct static perimetry. The patient places their face into the large machine in a darkened room. Light of varying intensities is presented at various points in their field of view. The patient presses a physical button whenever they can see a given flash of light. Afterwards, their field of view is reconstructed based on the points they were able to see and the respective intensities at which they were able to do so (Landers *et al*., 2010). The HFA improves on manual predecessor tests by eliminating physician bias, reducing results processing time and providing more quantitative data points for visual field characterisation.

The pattern in which test points are arranged affects the test. These are denoted in terms of lateral range of field followed by spacing between points; for example a 24-2 test has dots arranged 2° apart over 24° extending to the left and right respectively (Khoury *et al*., 1999). Each of these patterns, or testing protocols, test the eye in different ranges and sensitivities.

The existence of a natural blind spot is notable, a scotoma in the hill of vision where dots should not be perceived. (Spillmann *et al*., 2006) A lack of vision in this region is expected and thus is not a defect. In fact, patients pressing the button when stimulus is presented in this region can suggest unreliable results as their gaze or attention has been compromised.

Compared to manually testing all points in a patient’s visual field at all possible brightness levels, algorithms have been developed that aim to balance accuracy with rapidity. The crux of most of these algorithms is staircase testing, in which patients are provided stimuli that are shifted up or down in intensity based on the patient’s responses, so as to find the minimum brightness at which the patient can see the stimulus, the patient’s response threshold (Cornsweet, 1962).

Every algorithm makes trade-offs between time taken and accuracy. The utilisation of overly large steps in the staircase will lead to inaccuracies and lack of resolution in the measured threshold values; The usage of steps in the staircase that are too small will result in needlessly long testing times that tire out patients, lowering accuracy and increasing waiting times (Bengtsson *et al*., 1997).

A common algorithm implemented in modern VFTs is the Swedish Interactive Thresholding Algorithm, which combines the staircase methods with predictive statistics based on the patient’s age and previously tested thresholds. The algorithm changes the step accordingly to provide both accuracy and rapidity (Heijl *et al*., 2019).

Due to the lack of patient VFT data specific to Singapore available to us, an alternative algorithm was proposed, as presented under the methods section.

* 1. **Lean Healthcare and Shortcomings of Visual Field Testing**

Unfortunately, the HFA has numerous drawbacks which are analysed using the Lean Healthcare Practice (LHP) framework. LHP is informed by the Lean Six Sigma method pioneered by Toyota, and has the propensity to make hospital processes more time and cost efficient through the analysis of various wastes including but not limited to reducing waiting times, minimising inventory and minimising movement (Shazali *et al*., 2013).

The HFA takes up too much precious space in healthcare facilities. It necessitates long waiting times for patients due to the length of the test and the need for a physician to be present for every patient. This time-inefficiency is an issue as Glaucoma patients need to attend regular follow-up sessions to monitor disease progression. Commuting to the hospital can also be a challenge for elderly patients, especially in the context of the COVID-19 pandemic at the point of writing.

Another major limitation of HFA is that it fails to provide real-time feedback to the patient during the test itself to guard against several human factors that compromise the reliability of results (Carl Zeiss Meditec Incorporated, 2012) summarised in Table 1.

**Table 1:** Summary of Human Factors Compromising Reliability of Visual Field Testing Results

|  |  |  |
| --- | --- | --- |
| **Type** | **Explanation** | **Indication** |
| Fixation Loss | Patient responds to stimulus projected onto their blind spot. | Loss of attention |
| False Positives | Patient is “trigger-happy”; presses button even when there is no stimulus presented at that point in time. | Anxiety, Concern about getting a result indicating vision loss |
| False Negatives | Patient has responded to dimmer stimulus but fails to respond to brighter stimulus. | Fatigue, Inattentiveness, Malingering, Extreme vision loss |

* 1. **Survey of Virtual Reality Technologies**

Virtual Reality technologies (VR) currently not only include a digital environment presented to be 3-Dimensional but also Augmented Reality where digital content is overlaid in the real-world. However, VR was chosen as there is significant literature for us to refer to and VR has reached a sufficient level of resolution to be used for medical purposes.

Web-based VR involves hosting traditionally locally-running applications on a server such that it can be accessed over the internet. The advantages of web-based VR are its platform and browser independence as well as reduced strain on client device. This means that patients will be able to take the test on their smartphone or laptop screen regardless of what browser or operating system their device uses. Furthermore, web-based VR can more easily integrate with a web application that can consolidate and track patient test results for long-term monitoring and diagnostics, increasing future expandability of this research.

The Unity Engine will be used for development given its fast runtime and reliability such that the product can be developed as fast as possible.

**2.6 Review of Existing Technological Implementations of Virtual Reality Visual Field Tests**

The literature review highlighted existing implementations of VR assisted VFTs. Tsapkasis *et al*. (2017) studied the reliability of Visual Field Testing utilising Virtual Reality glasses on 10 subjects (ie. 20 eyes) by comparing said method’s results with those of an actual Humphrey Field Analyser.

Based on their research, the mean difference value between the VR and HFA methods was statistically significant, this could be explained by subtle differences in the devices themselves such as stimulus brightness. Correlation between the results from both methods was extremely statistically significant at the p<0.0001 significance level. Although the sample size was small, this suggests that a VR test can provide comparable results as an HFA and thus suggests that this product can indeed be a reliable complement to off-site VFT monitoring. However, one limitation of this study was that its VR test necessitated a specialised headset connected to a laptop which the project aims to improve on by creating a more portable test.

Another study by Prea *et al*. (2018) also found favourable results regarding digitally-enabled VFTs. A 6-month longitudinal study was conducted on 60 suspected or confirmed glaucoma or ocular hypertension patients. At each 2-monthly visit, patients were administered an iPad-based VFT and also a HFA-based test. It was concluded that the iPad-based VFT was faster than conventional HFA, its results were comparable to the HFA results and it had decent repeatability. Hence, digitally-enabled VFTs are a suitable alternative for traditional HFA. However, a problem with a PC or Tablet based solution to VFTs is that there is no way to fix the viewing distance the patient takes from the screen, which may potentially affect patients’ testing.

In both cases, these tests fail to address the issue of time wastage due to retakes necessary. This project aims to provide users with real-time audio-visual warnings if they are over-pressing or under-pressing. The project also aims to implement gaze tracking so product can warn patients if their gaze shifts from central fixation point.

**CHAPTER 3: METHODOLOGY**

The different components of the product will now be described with special focus on how these satisfy its functionalities, with salient algorithms or implementation details discussed along the way. Given the limited timeframe, product functions have been split into three phases.

**3.1** **Phase 1: Minimum Viable Product**

In phase 1, the minimum viable product in the form of a rudimentary 24-2 Humphrey VFT is built. The outline of the program is described below.

The test utilises test points with a brightness from 0 (not seen) to 3 (brightest). Choose increments of 1 such that it can be shown at brightness level 1, 2 or 3. First, the test pattern for each eye is algorithmically generated by mapping 1° of visual field to a planar distance and accounting for natural blind spot. Then, the program iterates for grid points such that cartesian distance from origin is equal to or lesser than radius of test field. This enables future customisation of tests.

A binary search is conducted on randomly selected points of the visual field. For each point the program saves the lowest brightness at which point was seen and highest brightness at which point was not seen in a dictionary. While the difference in these two values is not 1, the program chooses the middle value between the two, akin to a binary search. Per point, the program thus take on average 2 shows of a point to achieve conclusive result.

The program iterates over the points until 1/3 of the points are conclusively tested whence, it write the two values corresponding to each point and the point co-ordinates to file for persistence.

Between every two consecutive shows of points, there is a random wait interval. Once point has been shown, there is a three second response window for the patient to press the button to acknowledge seeing it. The first press in the window closes it.

Unreliable results are as follows:

* Lowest brightness seen highest brightness not seen
* Points in blind spot seen

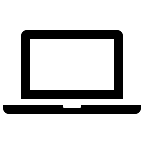
A concurrent thread notes key presses. Excessive key pressing will cause a warning and pause the test.

Test time is optimised by labelling point as conclusively tested given either sufficient condition:

* Point not seen at brightness level 3
* Point seen at brightness level 1

**3.2 Phase 2: Web Application Integration**

The following architecture describes the web application



User data

Past tests

Authentication

Serve Pages

Handle data



MongoDB

Server

Client

**Fig 1:** Web application architecture

The web application is written in Django to serve a simple home page, about page, physician page and test page. User authentication is also implemented in the web application.

User can log in to the system to take a test. Upon completion, test data is stored in a MongoDB database and an indicative score is shown to the patient to advise them on the urgency of contacting their physician. MongoDB is used as a database due to its flexible schema and support for big data that future-proofs the product for big data applications.

Physicians can review patient data and monitor their progress on a dedicated page.

**3.3 Phase 3: Further Scope for Development**

Future scope for research includes expanding the functionality of the product even further. A test generation page could allow physicians to administer custom tests to their patients. Machine learning can be used to suggest Glaucomatic progression based on historic test results.

As a long term goal, more tests can be implemented on this web application to create an eye-health portal.

**3.4 Proposed Product Testing**

Unfortunately, due to the COVID-19 pandemic, the surveying and testing part of this study was suspended. Thus, the project was unable to collect any meaningful results about the efficacy and reliability of the Visual Field Test.

In future, if the situation permits, the project aims to test the Visual Field Test on patients to gather both qualitative feedback about the ease of use of the device, as well as quantitative feedback in terms of error rate as compared to the test results of a Humphrey Visual Field test, and testing times.

This would enable the evaluation of the effectiveness of the design, and make appropriate adjustments possible. The primary aim of this phase would be to adjust the test to have an appropriately high correlation coefficient to the Gold-standard Humphrey Visual Field test, which would legitimise it as a reliable and convenient alternative test. Additionally, the project aims to gain feedback from doctors about the setup of the web-based backend, and its efficiency in allowing doctors to access patient’s data easily.

**CHAPTER 4: PRELIMINARY PROGRESS**

**4.1** **Minimum Viable Product**

Progress has been made on coding the minimum viable product. Screenshots of the code are presented with a brief description of each in Figures 2 to 5.

A screenshot of a cell phone

Description automatically generated

**Fig 2:** Snippet of code defining variables in program

The program uses a dictionary to map each Light GameObject to a list containing the brightest brightness at which light was not seen and dimmest brightness at which light was seen.

A screenshot of a computer

Description automatically generated

**Fig 3:** Screenshot of code showing loop to initialise eye test pattern

The program generates the test pattern by accepting a value for spacing between adjacent test points and radius of field of vision tested. It starts in the 1st quadrant (positive x and positive y values) before reflecting about the x and y axes respectively to initialise the test pattern across all 4 quadrants.

In the first quadrant, the program iterates over each grid point on the square described by the origin and diagonally opposite corner with co-ordinates whose value equalled the radius of visual field. For each point, if the Cartesian distance from origin is determined to be smaller than or equal to radius, the program adds a light GameObject to the main array at that position.

Note that initial position is shifted by the value of spacing divided by 2 to ensure points do not fall on principal axes (akin to x-y axes in conventional Cartesian plane) such that it conforms to professional standards.

A screenshot of a cell phone

Description automatically generated

**Fig 4:** A screenshot of code showing part of the main testing loop

The code runs two threads in parallel; the main one tracks keyboard presses while the other one runs the actual point selection and presentation. Notable is that fact that in selecting each point, time is used as a unique seed for the pseudo-random number generator to prevent clustering of points chosen because there are very few points in the test A screenshot of a cell phone

Description automatically generated**Fig 5:** Screenshot of code showing test logic

The program opens a 3.0s window after showing the light for 0.2s for patients to press a button to acknowledge seeing the light. To prevent double-counting, the first press deactivates the window and subsequent presses are registered as noise.

If the light is not seen at the brightest brightness or seen at the dimmest brightness then it has been conclusively tested and is promptly removed from the list.

If dimmest seen brightness is brighter than brightest not seen brightness, the results for that point is immediately known to be invalid and it is also removed from testing.

Else if the dimmest seen brightness is just 1 level above the brightest not seen, the point has been tested conclusively and is removed from testing.

Finally, all points that are not yet conclusively tested are re-inserted in the testing list.

**REFERENCES**

Aref A. A. (2019). Standard Automated Perimetry. Retrieved from<https://eyewiki.aao.org/Standard_Automated_Perimetry#Static_vs._Dynamic_Perimetry>

Burdea, G., & Coiffet, P. (2006). Virtual reality technology. *International Journal of e-Collaboration, 2*(1), 61-64.

Carl Zeiss Meditec Incorporated. (2012). *Humphrey Field Analyzer II-i series User Manual.* Dublin, CA: Carl Zeiss Meditec Incorporated.

Chua, J., Baskaran, M., Ong, P. G., Zheng, Y., Wong, T. Y., Aung, T., & Cheng, C. Y. (2015). Prevalence, risk factors, and visual features of undiagnosed glaucoma: the Singapore Epidemiology of Eye Diseases Study. *JAMA ophthalmology, 133*(8), 938-946.

Cornsweet, T. N. (1962). The Staircase-Method in Psychophysics. *The American Journal of*

*Psychology,* *75*(3), 485. doi:10.2307/1419876

Google LLC. (n.d.). Google Cardboard. Retrieved from <https://arvr.google.com/cardboard/>

Heijl, A., Patella, V. M., Chong, L. X., Iwase, A., Leung, C. K., Tuulonen, A., . . . Bengtsson, B.

(2019). A New SITA Perimetric Threshold Testing Algorithm: Construction and a Multicenter

Clinical Study. *American Journal of Ophthalmology,* *198*, 154-165. doi:10.1016/j.ajo.2018.10.010

Heijl, A., Leske, M. C., Bengtsson, B., Hyman, L., Bengtsson, B., & Hussein, M. (2002). Reduction of intraocular pressure and glaucoma progression: results from the Early Manifest Glaucoma Trial. *Archives of ophthalmology*, *120*(10), 1268-1279.

Khoury, J. M., Donahue, S. P., Lavin, P. J., & Tsai, J. C. (1999). Comparison of 24-2 and 30-2 perimetry in glaucomatous and nonglaucomatous optic neuropathies. *Journal of neuro-ophthalmology : the official journal of the North American Neuro-Ophthalmology Society*, *19*(2), 100–108.

Landers, J., Sharma, A., Goldberg, I., & Graham, S. L. (2010). Comparison of visual field sensitivities between the Medmont automated perimeter and the Humphrey field analyser. *Clinical & experimental ophthalmology, 38*(3), 273-276.

Mahabadi N, Foris LA, Tripathy K. Open Angle Glaucoma. [Updated 2020 Jul 4]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2020 Jan-.

Phu, J., Khuu, S. K., Yapp, M., Assaad, N., Hennessy, M. P., & Kalloniatis, M. (2017). The value of visual field testing in the era of advanced imaging: clinical and psychophysical perspectives. *Clinical and Experimental Optometry, 100*(4), 313-332.

Prea, S. M., Kong, Y. X. G., Mehta, A., He, M., Crowston, J. G., Gupta, V., ... & Vingrys, A. J. (2018). Six-month longitudinal comparison of a portable tablet perimeter with the humphrey field analyzer. *American journal of ophthalmology, 190*, 9-16.

Regan, D., & Neima, D. (1984). Low-contrast letter charts in early diabetic retinopathy, ocular hypertension, glaucoma, and Parkinson's disease. *British journal of ophthalmology*, *68*(12), 885-889.

Riordan-Eva, P., & Augsburger, J. J. (2018). *Vaughan & Asburys general ophthalmology* (19th ed.). New York: McGraw Hill Education.

Schwartz, K., & Budenz, D. (2004). Current management of glaucoma. *Current opinion in ophthalmology*, *15*(2), 119-126.

Seet, B. (2001). Myopia in Singapore: Taking a public health approach. *British Journal of Ophthalmology,* *85*(5), 521-526. doi:10.1136/bjo.85.5.521

Selvaraj, D. (2018). Using Google Cardboard to perform a visual field screening test.

Shazali, N. A., Habidin, N. F., Ali, N., Khaidir, N. A., & Jamaludin, N. H. (2013). Lean healthcare practice and healthcare performance in Malaysian healthcare industry. *International Journal of Scientific and Research Publications*, *3*(1), 1-5.

Spillmann, L., Otte, T., Hamburger, K., & Magnussen, S. (2006). Perceptual filling-in from the

edge of the blind spot. *Vision Research,* *46*(25), 4252-4257. doi:10.1016/j.visres.2006.08.033

Tham, Y. C., Li, X., Wong, T. Y., Quigley, H. A., Aung, T., & Cheng, C. Y. (2014). Global prevalence of glaucoma and projections of glaucoma burden through 2040: a systematic review and meta-analysis. *Ophthalmology, 121*(11), 2081-2090.

Tsapakis, S., Papaconstantinou, D., Diagourtas, A., Droutsas, K., Andreanos, K., Moschos, M. M., & Brouzas, D. (2017). Visual field examination method using virtual reality glasses compared with the Humphrey perimeter. *Clinical ophthalmology (Auckland, N.Z.), 11*, 1431–1443. <https://doi.org/10.2147/OPTH.S131160>

Vaughan, D., Asbury, T., & Riordan-Eva, P. (1995). *General ophthalmology*. Norwalk, CT,

Connecticut: Prentice Hall International.