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Article

A Comparison of Perimetric Results from a Tablet Perimeter and Humphrey Field Analyzer in Glaucoma Patients

Yu Xiang George Kong[1,2], Mingguang He[1], Jonathan G. Crowston[1,2], and Algis J. Vingrys[3]

[1] Centre of Eye Research Australia, Department of Ophthalmology, The University of Melbourne, East Melbourne, Australia
[2] Royal Victorian Eye and Ear Hospital, East Melbourne, Australia
[3] Department of Optometry and Vision Sciences, The Melbourne School of Health, The University of Melbourne, Parkville, Australia

Correspondence: Yu Xiang George Kong, Centre of Eye research Australia, Department of Ophthalmology, The University of Melbourne, 32 Gisborne St, East Melbourne Vic 3002, Australia. e-mail: gkong008@hotmail.com

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Purpose: To determine the correlation between the perimetric outcomes from perimetry software Melbourne Rapid Fields (MRF) run on an Apple iPad tablet and those from the Humphrey Field Analyzer (HFA).

Methods: The MRF software was designed with features including variable fixation and fast thresholding using Bayes logic. Here, we report a cross-sectional study on 90 eyes from 90 participants: 12 had normal optic nerves and 78 had glaucoma with various degrees of visual field loss (41 mild and 37 moderate-severe). Exclusion criteria were patients with worse than 20/40 vision or recent intraocular surgery. The visual field outcomes of MRF were compared against those returned from the HFA 24-2 SITA standard. Participants were tested twice on the MRF to establish test–retest repeatability.

Results: The test durations were shorter on MRF than HFA (5.7 $\pm$ 0.1 vs. 6.3 $\pm$ 0.1 minutes, $P < 0.001$). MRF showed a high level of concordance in its outcomes with HFA (intraclass coefficient [ICC] = 0.93 for mean defect [MD] and 0.86 for pattern deviation [PD]) although the MRF tended to give a less negative MD (1.4 dB bias) compared with the HFA. MRF also showed levels of test–retest reliability comparable to HFA (ICC = 0.93 for MD and 0.89 for PD, 95% limits of agreement −4.5 to 4.3 dB).

Conclusion: The perimetry results from the MRF have a strong correlation to the HFA outcomes. MRF also has test–retest reliability comparable to HFA.

Translational Relevance: Portable tablet perimetry may allow accurate assessment of visual field when standard perimetry machines are unavailable or unsuitable.

Introduction

Standard automated perimetry (SAP) plays an important role in the detection, diagnosis, and monitoring of glaucoma patients,[1] however most modern SAPs are not easily portable. Recent growth of portable tablet devices such as the iPad (Apple, Cupertino, CA) have seen these devices become suitable as low-cost, portable, and reliable vision testing instruments due to its good dynamic range of luminance and high spatial resolution.[2–4] Portable tablet devices have been shown to be useful in tests of visual acuity and contrast sensitivity, and for the assessment of macular sensitivity.[4–6] The development of a tablet-based perimeter follows from an early suprathreshold test developed on iPad generation 1 (Visual Field Easy app), which was found to be useful in visual field screening in Nepal.[7] For a tablet based perimeter to be useful in monitoring and in detecting early changes in the visual field, it needs to be able to return threshold estimates. To achieve this we have developed a tablet perimeter application called the Melbourne Rapid Fields (MRF) on the iPad platform and preliminary testing shows that this software can be made to return visual field thresholds accurately.[8] In this preliminary study, we found that the iPad perimeter could detect early and mild simulated scotoma with mean defect (MD) of 3 to 6 dB.[8] Moreover, our design returns thresholds that are robust to variation in pupil size, blur, viewing distance, and ambient illumination.[8] What is not known is whether this promising performance allows

detection of visual field defects for patients with glaucoma in the clinic.

The purpose of the present paper is to investigate the level of agreement between the results of MRF by comparing it against outcomes obtained with the Humphrey Field Analyzer (HFA) using the Swedish Interactive Thresholding Algorithm (24-2) SITA-Standard protocol (Carl Zeiss Meditec, Inc., Dublin, CA) in patients with glaucoma in a clinical setting.

Methods

Melbourne Rapid Fields Application

The Apple iPad luminance output was calibrated and found to return approximately 31 dB of operating range on a 5-cd.m^{-2} background. In our preliminary study, we showed that this background should return a Weber fraction similar to the HFA preserving dynamic range as well as minimizing intrusions by veiling glare.[8] For threshold estimation we used seven discrete steps over the 0 to 30 dB range (0, 6, 12, 17, 22, 26, 30 dB) that were determined by Bayes methods as detailed by Vingrys et al.[8] For this purpose, a rapid three-presentation protocol was developed to sample over this range. Thresholding commences at a single initial luminance with subsequent levels being predetermined by a modified Zippy Estimation by Sequential Testing procedure.[9]

The testing grid for the MRF uses a radial pattern,[8] with the locations of test points informed by establishing the detection efficiency on 360 clinical cases whose data have been reported elsewhere.[10,11] The MRF radial pattern is centered at fixation and tests 66 locations throughout 30° of the visual field for loss of sensitivity in the macula, paramacula, and peripheral regions (Fig. 1A). As the screen of an iPad tablet subtends 17.4° × 12.9° when viewed at 33 cm, we test the peripheral region beyond 18° from fixation by changing the location of the fixation point. The testing proceeds in two phases: an initial central field test (36 points tested with fixation in the center of the screen) followed by a peripheral field test (30 test points) that requires the patient to fixate at each corner of the iPad screen sequentially to increase target eccentricity. In this manner, the visual field can be tested out to 34° horizontal and 25° vertical. Our measurements find that stimulus contrast is acceptable when presented in the periphery of an iPad screen consistent with past reports.[2] Implementing a radial test grid means that the test stimuli become further apart with eccentricity, so our test logic places additional test points in 'gaps' between peripheral locations if the patient returns an abnormal result in terms of its adjacent neighbors: this helps to confirm any unexpected loss and define the edge of a defect.

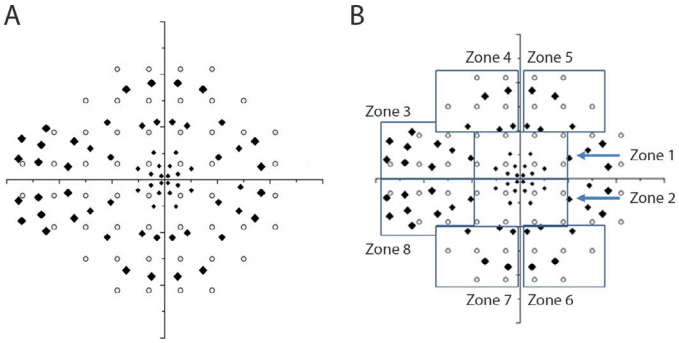

Figure 1. (A) Testing grid used for testing the right eye in the MRF software (*filled diamonds*) superimposed on the HFA 24-2 pattern (*circles*). The blind-spot location is shown as a *small black diamond*. The variable size of the MRF test stimuli is shown schematically but not accurately scaled. (B) To examine for regional effects, the threshold estimates are grouped into eight zones to allow for comparison based on location. Shown here are the zones for the right eye.

Fixation monitoring was implemented with a blind-spot monitor using a 19-dB stimulus approximately 40% larger in area than Goldmann size II spot. Testing is undertaken by locating the blind spot at the start of each test and a stimulus is presented (8–10 times) in this location throughout the test using central fixation. For peripheral testing, the blind-spot monitor cannot be implemented and an iPad voice instruction reminding the patient to fixate to the appropriate corner is replayed at regular intervals to facilitate patient compliance. False-positive and false-negative checks are presented throughout the test. False-positive checks are performed by interspacing periods (1000–1400 ms) throughout the test during which no stimulus is presented on the screen. A false-positive is recorded if a user gives a response (touches screen or keyboard) during this period.

Stimulus size is increased with eccentricity based on the data of Sloan, such that a constant threshold is expected across the field instead of a 'hill of vision' (i.e., a plateau).[12,13] Having a plateau in threshold value across eccentricities increases the dynamic range of the iPad for scotoma located at noncentral positions and reduces test variability. The stimulus size was also adjusted to allows for the tangent effect of a planar tablet screen.[8] The stimulus size approximates Goldmann size III (0.43°) at 6° eccentricity and is scaled to be just smaller than GIII at 1° eccentricity and approximately Goldmann size IV at 17° eccen-

tricity: this largest stimulus is used to test the peripheral field greater than 17°. Stimuli are circular spots generated with soft edges to remove confounding effects caused by spatial high frequency detail.[13] Stimulus duration is 300 ms, which was chosen because the critical duration for stimulus detection is typically approximately 1 to 200 ms and an additional 100 ms was allowed for the greater complexity of free space viewing.[8] This timing means full threshold using three presentations would require approximately 4 to 6 minutes, depending on the nature of the field loss and reliability of the patient. A neighborhood logic has been included in a later version of the MRF, which reduces test time by approximately 1 to 2 minutes but this was not implemented in the present study.

Voice prompts for the test procedure are provided in English by the iPad device to guide the user throughout the test. A patient's response to the presentation of a stimulus can be recorded by touching the screen but for the present study it was polled by touching the spacebar on a Bluetooth keyboard connected to the tablet. The Bluetooth keyboard method of response polling was used instead of screen touch because it removes the patients' fingers from the screen so that they do not potentially obscure a stimulus, and it keeps the screen clean from the smear of finger marks. We have also found that the keyboard method of response provides better tactile feedback to the patient on making a response.

Participants

Ninety participants were recruited from the Glaucoma Investigation and Research Unit of Royal Victorian Eye and Ear Hospital (age: 18–91, mean: 69.5, standard deviation [SD]: 12.5). All patients had comprehensive eye examination that included visual field test on HFA, gonioscopy, fundus examination of optic nerve head, posterior pole and peripheral retina with slit-lamp biomicroscopy, optical coherence tomography, and optic disc photography. One eye of these 90 people was randomly selected for the study provided it met the inclusion criteria. All eyes had a visual acuity of 6/12 (20/40) or better and gave reliable HFA-SITA Standard 24-2 test outcomes within 3 months of MRF testing. A reliable field is defined as false-positive less than or equal to 15% and fixation losses and negative responses less than or equal to 20%.[14] All HFA test were performed prior to iPad MRF test. Approximately 90% of patients had HFA on the same day as MRF, the others had HFA performed no more than 3 months prior to MRF testing. All patients have had repeated HFA testing in the past and are therefore 'experienced' in performing HFA visual field tests. Participants were excluded if they had retinal or corneal disease, required an English interpreter (as they would not be able to follow iPad instructions) or had intraocular surgery within 6 months of the study. Lens status was not a criterion for exclusion, although any lens opacity could not limit visual acuity to worse than the 6/12 (20/40) inclusion criterion.

Of the 90 eyes, 78 had glaucoma (mean age: 70.2, SD: 12.3, 41 had mild HFA defect with MD > -6 dB, 19 had moderate HFA defect with MD between -6 and -12 dB, 18 had severe HFA defect with MD worse than -12 dB) and 12 had healthy optic nerves and normal visual field tests on HFA (mean age: 63.4, SD 12.3). Clinical diagnosis included 51 patients with primary open angle glaucoma, 22 with primary angle closure, and 5 patients with mixed-mechanism glaucoma. All patients with glaucoma had well controlled intraocular pressure below their target pressure at the time of the study and were taking their usual medications. This study has approval from our institutional Human Research & Ethics Committee (HREC No. 15/1220H) and adheres to the tenets of the Declaration of Helsinki. All participants gave informed consent prior to partaking in the study.

Testing Procedure

MRF thresholding was conducted using an iPad generation 3, running iOS 8.0. Calibration of iPad has been detailed previously.[2,8] In brief, calibration was performed using an IL1700 radiometer with a photopic Vλ filter (International Light Technologies Inc., Peabody, MA). The calibration found that the iPad had an operational range of 30.9 dB.[8]

Patient testing was performed in a quiet room without distractions. The background lighting in the room was dimmed such that the illumination of the iPad screen due to room lighting was below 10 lux. The iPad screen was cleaned before each test and we ensured no glare was evident on the screen with careful arrangement of the iPad and participant, this is because screen glare can cause reductions in contrast sensitivity.[2,8] Full-field thresholding was performed using the radial test pattern (Fig. 1A). Testing was performed with natural pupils. Prior to commencing testing, clinician administering the test gives the patient explanation of the test and what they are expected to do including not to move their head position throughout the test. The fellow eye was

patched and the clinician ensures that the patient was seated comfortably at a table with the iPad tablet placed on a typing stand that accompanied the Bluetooth keyboard, 33 cm from the patient. This viewing distance was measured using a fixed piece of string (33 cm) from the iPad screen to bridge of patient's nose at the start of the test. Care was taken to ensure that the iPad screen was not tilted with respect to the viewing plane as tilt has been shown to reduce target luminance and contrast.[2] This was done by sitting the patient at the correct height with respect to the iPad screen by adjusting the height of the patient's chair. Testing was performed in free space with no constraints to head movement apart from an initial check at the start to ensure the proper viewing distance (33 cm). The clinician administering the test ensured that the viewing distance was maintained during the test and paused the test if a change in viewing distance was noted. In these rare events, patients were repositioned to the 33-cm viewing distance and the test was restarted. iPad screen intensity is automatically set to maximum (100%) for every test by the software and the iPad was turned on for at least 10 minutes prior to patient testing to ensure stability of luminous output.[2] Patients were asked to wear their habitual reading glasses (single vision, bifocal, or multifocal) as required for normal near viewing.

Two MRF tests (Test 1 and Test 2) were conducted on the same eye using the radial pattern with a 5-minute break between tests. Three patients could not be retested in the same sitting due to time constraints and were retested within 4 weeks of the original test. Prior to each test, a short practice test lasting approximately 1 minute was administered to ensure each participant understood the test procedure and had become familiar with the voice prompts and response method used by the MRF.

Statistical Analysis

Mean deviation (MD) was calculated from the average point-wise deviations using the age-adjusted expectation returned from the analysis of 17,390 thresholds adjusted for grid and size effect.[8] Pattern deviation (PD) was calculated using standard formulae as the average residual after allowing for the patient's MD.[15] The two points on the testing grid adjacent to the blind spot were excluded from calculations because they showed high variability in outcomes. Comparison of point-wise retinal threshold estimates between eyes was performed by reflecting all left eye data in the vertical to produce equivalent right eye fields. Threshold estimates were grouped into eight zones to examine regional effects on visual field outcomes (Fig. 1B). This analysis provide a better comparison to local HFA outcomes and provide an assessment of the reliability of testing peripheral locations when fixation is constrained to the corner of the screen. The result of the second MRF test (Test 2) was used instead of Test 1 to compare with the HFA for a fairer comparison given that the participants had extensive past experience with HFA.

Intraclass coefficients (ICC) were calculated using SPSS for Windows (SPSS version 15.0; SPSS Inc., Chicago, IL). Linear regression was used to calculate slopes of the best-fitting regression lines and to derive Pearson coefficients that gauge the strength of association. Linear regression was performed using a least squares method (SigmaPlot version 10.0; Systat Software, Inc., San Jose, CA) fixing the intercept at the origin. Both Pearson's statistic and ICC have been reported to enable comparison with past studies.[16–18] A Bland-Altman analysis was used to consider bias and 95% Limits of Agreements (LoA) when comparing HFA versus MRF and MRF retest data. Group comparisons were performed with *t*-test or repeat measure analysis of variance (ANOVA) as appropriate with an alpha of 0.05.

Results

MRF Eccentricity-Related Threshold

The MRF increases stimulus size with eccentricity in an attempt to yield a plateau for thresholds across the visual field such that dynamic range is maintained across eccentricity. Testing on normal eyes confirms that there is no change in threshold with eccentricity up to the 30° (Fig. 2). Figure 2 shows average group threshold as a function of eccentricity for eyes with glaucoma, subdivided by severity of visual field defect in terms of HFA MD For glaucoma eyes with mild ($n = 41$, MD > -6 dB) defects, there is general depression (average −3.0 dB) in threshold across all eccentricities compared with normal eyes but the eccentricity interaction term was not significant (two-way ANOVA, $P < 0.001$ for group and $P = 0.92$ for interaction). For glaucomatous eyes with moderate or severe MD defects, there is a greater depression in threshold, which becomes more pronounced in the peripheral field (two-way ANOVA, $P < 0.001$ for group and $P = 0.05$ for interaction).

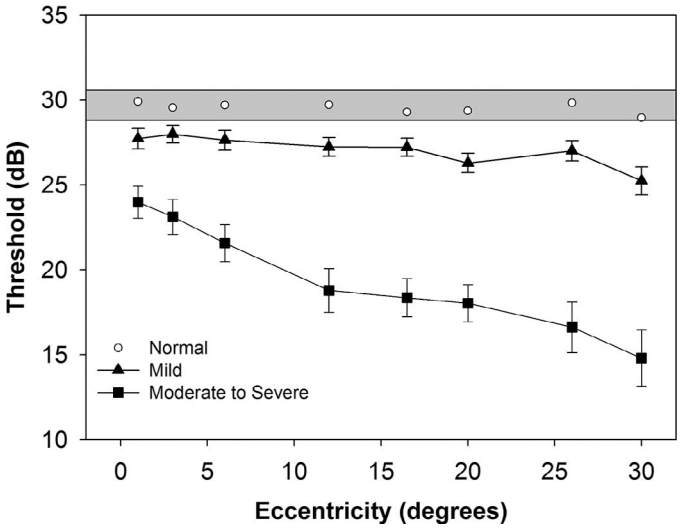

Figure 2. Retinal threshold across eccentricity for normal eyes ($n = 12$) and those with glaucoma ($n = 78$) subdivided into mild (HFA MD > -6.0, $n = 41$) and moderate to severe (MD ≤ -6.0, $n = 37$) cases. *Gray area* represents 5% and 95% confidence limit for the mean of the normal group ($n = 12$). Mean thresholds for normal eyes are represented by *unfilled circles*. *Error bars*, SEM.

Comparison of MRF and HFA

Average test duration for the MRF was 5.7 ± 0.1 minutes (mean ± SEM: for both test and retest), which is shorter than the average HFA test time for these same patients of 6.3 ± 0.1 minutes ($P < 0.001$). Of interest for eyes with mild MD greater than −6 dB, test time for MRF (5.4 ± 0.1 minutes) was similar to HFA test time (5.6 ± 0.1 minutes, $P = 0.28$). However, for eyes with MD less than or equal to −6 dB MRF test times were on average nearly 1 minute shorter than they were on HFA (6.1 ± 0.1 vs. 7.2 ± 0.1, $P < 0.001$). The MRF test duration included time required for the iPad to play voice prompts and for the patient to move their fixation when tested in the periphery. MRF recorded a higher percentage of fixation losses (MRF both tests 36 ± 4%) compared with the HFA (6 ± 1%: $P < 0.001$) suggesting that the blind-spot monitor is more likely corrupted by free-space viewing.

MD from MRF (Test 2) is compared with HFA MD from the same eye in Figures 3A and 3B. There is an overall strong correlation between MD results from MRF test and MD from HFA (ICC = 0.93). The MD values form a linear relationship with a slope of 0.8, which indicates that less negative MD values are returned from the MRF compared with HFA. Bland-Altman analysis confirms less negative MD returned by MRF with a bias of 1.4 dB (Fig. 3B, Table 1). Linear regression of the Bland-Altman plot for MD gave a slope of 0.09, suggesting the HFA returns slightly more negative MD values compared with the MRF for participants with greater field loss. Subgroup analysis for 53 eyes, which are either normal or have mild HFA defect (MD > -6 dB) is listed in Table 1 and the linear relationship has a similar slope (0.8). The level of agreement between MRF with HFA is less for this subgroup (ICC = 0.77). Table 1 and Figures 4C and 4D show there is also a good overall agreement between the PD indices (ICC = 0.86). The correlation between PD and PSD for eyes with mild HFA defects (MD > -6.0, Table 1) is weaker than for moderate to severe defects (ICC = 0.53 vs. 0.76).

To examine regional effects that are not well represented by global indices, threshold estimates from MRF and HFA were compared across the eight zones shown in Figure 1B. These zones were developed to compare local regions on the HFA and MRF in the presence of the different test patterns. As can be seen in Table 3, the highest correlation was in the peripheral nasal zone (zones 3 and 8, ICC = 0.91–0.92) and least strong in the peripheral temporal zones (zones 5 and 6, ICC = 0.71). Figure 4 shows representative results obtained with the MRF software and the corresponding HFA outputs for participants having mild, moderate, and severe field loss. As shown, the degree and location of defects are comparable.

Test and Retest With the MRF

The results of MRF Test 1 and Test 2 are compared with examine for repeatability of the MRF test. We found an overall ICC of 0.93 for MD and 0.89 for PD (Fig. 5 and Table 2). This is similar to test–retest reliability of HFA SITA-Standard, which has been reported as 0.95 for MD and 0.90 for PSD.[19] Bland-Altman analysis shows a small bias (0.1–0.5 dB) between Test 1 and Test 2 for all parameters (Table 2). The amount of bias is constant across the range of field loss. Regional zone analysis shows a high degree of repeatability across all zones, with the central and peripheral nasal zones having the highest repeatability (ICC = 0.86–0.91, zones 1, 3, and 8) and least repeatable in Zone 5 (ICC = 0.74, superior peripheral temporal zone; Table 3). While peripheral nasal zones 3 and 8 has good repeatability on ICC, they have a wider 95% LoA compared with other zones.

To express point-wise test–retest variability in retinal threshold Figure 6A shows the 5th and 95th percentiles of retest values for each threshold level measured at Test 1. This pattern of distribution

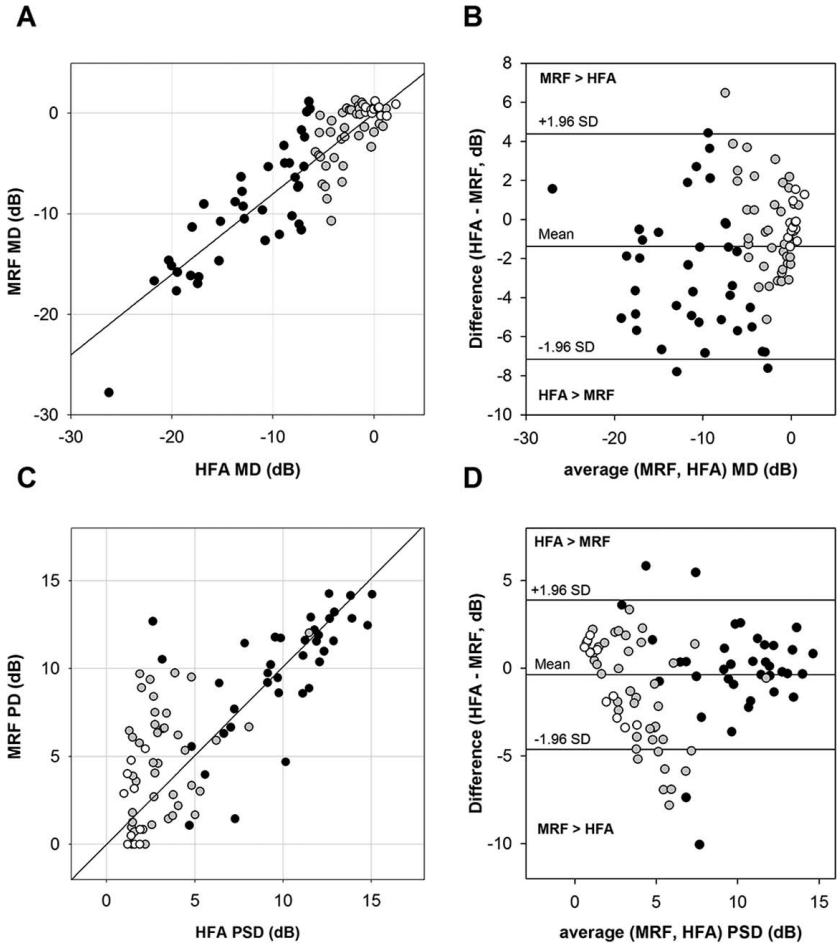

Figure 3. (A) Linear regression and (B) Bland-Altman plot of outcomes for MD of MRF and HFA for the overall group ($n = 90$). (C) Linear regression and (D) Bland-Altman plot of comparison of MRF PD and HFA Pattern Standard Deviation for overall group ($n = 90$). Normal eyes ($n = 12$) shown as *unfilled circles*, eyes with mild glaucoma (HFA MD > -6.0, $n = 41$) shown as *gray filled circles* and eyes with moderate to severe glaucoma (HFA MD ≤ -6.0, $n = 37$) shown as *black filled circles*.

Table 1. Comparison between and HFA for MD and PD

	MD				PD			
	ICC (95% CI)	R (m)	Bias, dB	95% LoA, dB	ICC (95% CI)	R (m)	Bias, dB	95% LoA, dB
Overall	0.93 (0.87, 0.96)	0.9 (0.8)	−1.4	−7.2, 4.4	0.86 (0.79, 0.91)	0.7 (1.0)	−0.8	−6.5, 4.9
Mild	0.77 (0.60, 0.87)	0.6 (0.8)	−0.4	−4.6,3.9	0.53 (0.18, 0.73)	0.3 (1.3)	−1.3	−6.9, 4.3
Moderate to severe	0.85 (0.41, 0.95)	0.8 (0.8)	−2.9	−9.3,3.6	0.76 (0.54, 0.88)	0.5 (1.0)	−0.1	−5.7,5.6

Pearson's correlation, R; linear regression slope, m. Analysis is shown for the overall group ($n = 90$) as well as for subgroups of eyes with mild (MD > -6.0 dB, $n = 53$) and moderate to severe defects on HFA (MD ≤ -6.0 dB, $n = 37$). CI = confidence interval.

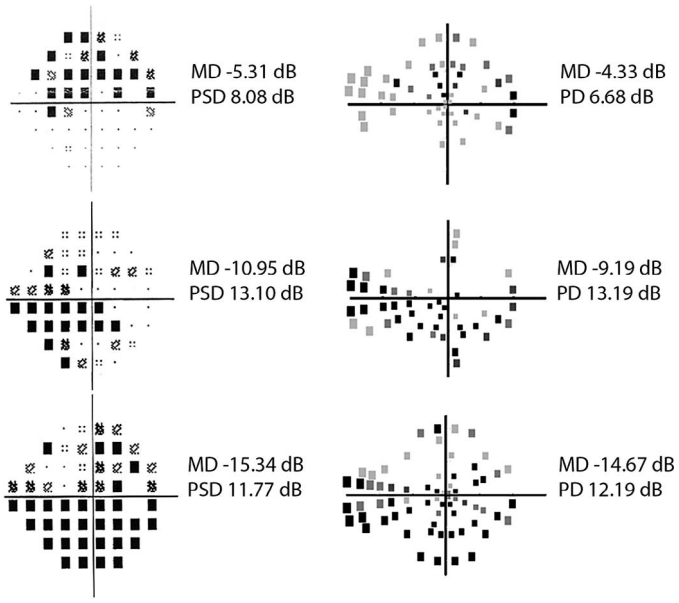

Figure 4. Representative visual fields from eyes with mild, moderate, and severe visual field defects. Humphrey Field total deviation probability plots are on the left hand side and MRF outputs are on the *right hand side*.

similar to that found in other forms of SAP.[20] Pointwise histogram distributions of retest outcomes for each MRF threshold estimate levels determined at Test 1 (from 0–30 dB) is shown in Figure 6B. The histogram shows the test–retest variability is wider for points with threshold estimates of 12, 17, and 22 dB on MRF Test 1. This histogram distribution is similar to those reported for other contemporary automated perimeters.[20]

Discussion

Tablet computers such as Apple iPad have significant potential for use as perimeters because of its quality screen outputs, portability, and affordability. However, it has many shortcomings compared with traditional perimeters including the relatively small screen size compared with a full visual field dome, and a smaller dynamic range of stimulus intensity. By using special software design features (including adjusting positioning of fixation point and increasing stimulus size according to eccentricity), the MRF software is able to overcome several of these limitations. We previously demonstrated that MRF output is robust to small changes in viewing distance, ambient room lighting (4 vs. 600 lux), miosis, and refractive blurring (0 vs. +3 diopter).[8] This study shows that the MRF is able to provide reasonable perimetric outcomes that correlate well to the HFA in a controlled environment in patients with glaucoma. From this study, we found strong agreement between MRF and HFA for the common perimetric indices (MD ICC = 0.93 and PD ICC = 0.86). This level of agreement is similar to the degree of agreement between other SAPs and HFA.[17,18] A small regional effect was noted, with the peripheral nasal and central fields having higher agreement compared with temporal fields. Subgroup analysis of eyes having mild HFA defects was found to be less strong but still with good levels of agreement for the same indices (MD ICC = 0.77, PD ICC = 0.53), suggesting that the MRF test performs well in quantifying mild field defects. Our data indicate a bias for underestimation of MD of moderate-to-severe defects by the MRF of 2.9 dB (Table 1). This discrepancy is most likely due to the difference in locations and number of stimuli as well as the variable size stimulus used in MRF.[21] The test–retest reliability in this study was found to be comparable with that of HFA.[16,22] This suggests minimal learning effect between test and retest. This result is a little surprising as one would expect some learning if a person is exposed to a test for the first time. However, the lack of learning effect may indicate that for this group of patients who are

Table 2. MRF Test–Retest Reliability for MD and PD

	MD				PD			
	ICC (95% CI)	R (m)	Bias, dB	95% LoA, dB	ICC (95% CI)	R (m)	Bias, dB	95% LoA, dB
Overall	0.93 (0.90, 0.95)	0.9 (1.0)	−0.1	−4.5, 4.3	0.89 (0.84, 0.93)	0.9 (1.0)	−0.2	−4.2, 3.7
Mild	0.73 (0.57, 0.83)	0.7 (0.8)	−0.2	−4.3,3.9	0.74 (0.59, 0.84)	0.7 (0.9)	0.1	−4.4, 4.6
Moderate to severe	0.91 (0.84, 0.96)	0.9 (1.0)	−0.1	−4.9,4.8	0.86 (0.74, 0.92)	0.9 (1.0)	−0.5	−3.7, 2.7

Analysis is separated into overall group analysis ($n = 90$) and subgroup analysis of eyes with mild (HFA MD > -6.0 dB, $n = 53$) and moderate to severe defects on HFA (MD ≤ -6.0 dB, $n = 37$).

Table 3. Comparison of Threshold Estimates According to Location

	HFA vs. MRF Test 2		MRF Test 1 vs. MRF Test 2	
	ICC (95% CI)	Bias, 95% LoA (dB)	ICC (95% CI)	Bias, 95% LoA (dB)
Zone 1, superior-central	0.87 (0.80, 0.91)	−2.29 (−13.04, 8.47)	0.87 (0.81, 0.91)	−0.39 (−7.17 , 6.38)
Zone 2, inferior-central	0.75 (0.63, 0.84)	−1.55 (−11.64, 8.53)	0.84 (0.76, 0.89)	−0.31 (−5.75, 5.13)
Zone 3, superior-peripheral-nasal	0.91 (0.86, 0.94)	−2.25 (−13.62, 9.13)	0.86 (0.80, 0.91)	0.58 (−8.96, 10.12)
Zone 4, superior-nasal	0.77 (0.65, 0.85)	−4.16 (−17.26, 8.93)	0.78 (0.68, 0.85)	−0.03 (−6.10, 6.05)
Zone 5, superior-temporal	0.71 (0.56, 0.81)	−3.42 (−16.63, 9.79)	0.74 (0.63, 0.82)	−0.12 (−6.46, 6.22)
Zone 6, inferior-temporal	0.71 (0.55, 0.81)	−2.11 (−11.52, 7.29)	0.84 (0.76, 0.89)	−0.30 (−4.53, 3.93)
Zone 7, inferior-nasal	0.77 (0.65, 0.85)	−3.02 (−13.26, 7.21)	0.84 (0.76, 0.89)	−0.16 (−4.80, 4.49)
Zone 8, inferior-peripheral-nasal	0.92 (0.88, 0.95)	−1.39 (−10.63, 7.86)	0.91 (0.86, 0.94)	−0.58 (−7.39, 6.23)

Regional effects of different visual field locations is analyzed by grouping stimuli into zones as shown in Figure 1B. First column shows ICC for the comparison between MRF and HFA. Second column show ICC for MRF test–retest reliability.

experienced in HFA perimetry, methods of performing HFA may have carried over to the MRF.

The fact that the Apple iPad can return sound estimates of thresholds confirms a similar finding for foveal thresholds reported by Wu et al.[4] who compared an iPad-based test applied to 30 patients with ARMD against outcomes returned by a commercial microperimeter. This group tested foveal sensitivity (within 1° of fixation) using the same test grid locations in both instruments. They concluded that the iPad gave reliable threshold estimates in comparison to the microperimeter (Tablet 25.7 ± 0.4 dB, microperimeter 26.1 ± 0.4) with 95% LoA spanning 9 dB. Our study demonstrates that the ability of assessing threshold sensitivity by the iPad can be extended beyond the foveal region.

The Apple iPad, like most commercial tablet devices, uses a liquid crystal display screen and has high spatial resolution with 8-bit luminance resolution. Portable tablet devices have been shown to be useful in visual acuity and contrast sensitivity testing as well as for retinal sensitivity estimates in foveal locations.[4–6] The extension of a portable tablet device to peripheral visual field testing, as detailed here, has the potential to allow detection and management of glaucoma in communities where access to traditional field testing machines is limited. Furthermore it will allow future investigation into the use of such testing devices in terms of home monitoring, especially as

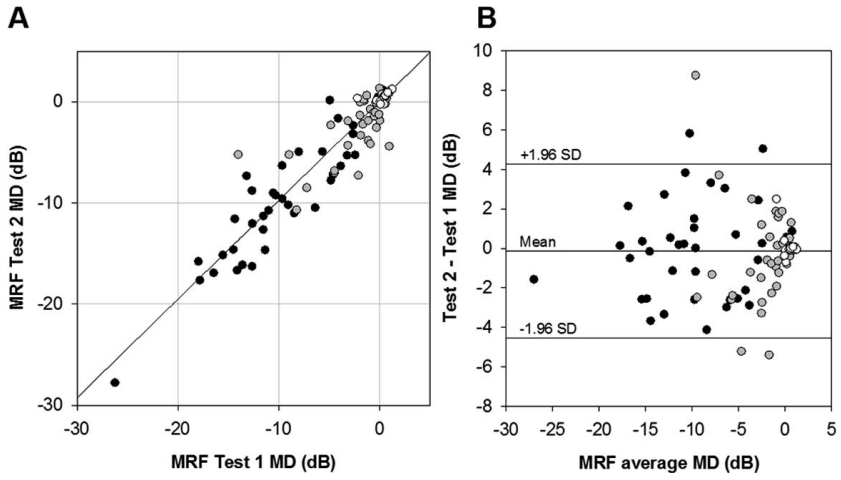

Figure 5. (A) Linear regression and (B) Bland-Altman plot of test- retest reliability for the MD returned from MRF Test 1 and Test 2. Normal eyes ($n = 12$) shown as *unfilled circles*, eyes with mild glaucoma (HFA MD > -6.0, $n = 41$) shown as *gray filled circles* and eyes with moderate to severe glaucoma (HFA MD ≤ -6.0, $n = 37$) shown as *black filled circles*.

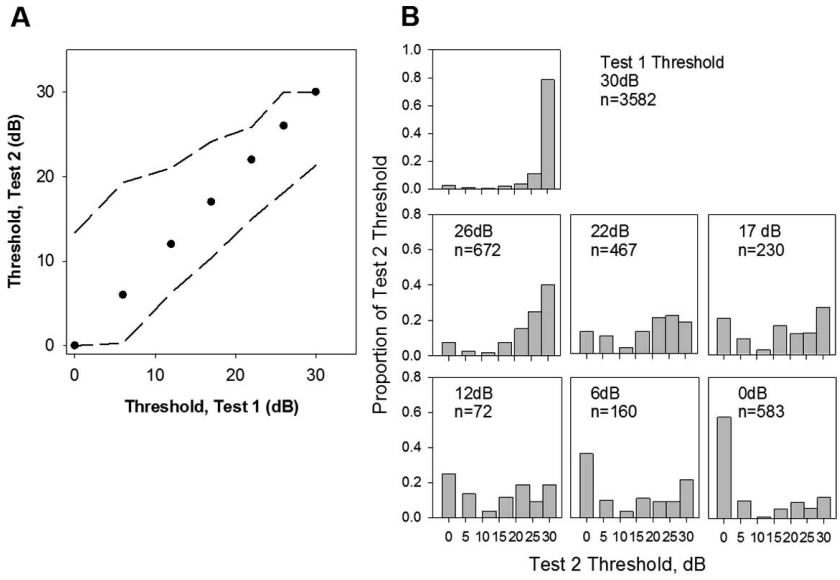

Figure 6. (A) Point-wise analysis of retinal threshold estimates for MRF Test 2 plotted against the threshold of the same point returned at Test 1. *Dashed lines* in *Panel A* indicate 95% and 5% percentiles. Note the floor and ceiling effect sat 0 and 30 dB, respectively. (B) Histograms showing distributions of MRF Test 2 thresholds for a given MRF Test 1 threshold value (0, 6, 12, 17, 22, 26, and 30 dB) for all 90 participants. The y-axis shows the proportion of Test 2 estimates at each level. It is apparent that if a person returns 0 or 30 dB at Test 1, they have a high likelihood to do so at retest.

ownership of tablet devices is increasing in the average household. Home visual field monitoring can complement existing technologies such as HFA, resulting in reduced resource burden on clinics and allowing frequent field testing to yield earlier detection of visual field change.[23]

There are some limitations of the MRF application that requires further investigation and development. Firstly, further development is needed in establishing fixation accuracy. The future development of an effective tracking system for monitoring head and eye positions in real time using the camera of the iPad would allow fixation monitoring during peripheral field testing as well as for the central test. In the version of the software used in this study we attempt to reduce fixation loss in peripheral regions with regular voice prompts played by the device to remind participants to maintain fixation. However, this is not a robust solution. Despite this limitation, in the current sample of participants who are experienced in performing HFA, MRF is able to detect peripheral retinal sensitivity loss in glaucoma patients and to do so reliably. Secondly, a significant amount of research is required before tablet devices can be implemented for visual field testing out of the clinical setting. This current study was conducted in a controlled environment in the clinic on patients who are experienced in HFA testing, with strict control of viewing distance and viewing environment. This may be the reason for the high correlations between MRF with HFA in this study. These factors are less likely to be as controlled out of the clinical setting such as in the home environment. The performance of patients who are not experienced in visual field testing will also need to be evaluated in terms of learning how to use a tablet in both supervised and unsupervised (home) environments. The instructions and training required for these patients to achieve reliable visual field results on MRF needs to be developed. Nevertheless, our current data, and that of Wu et al.,[4] indicates that reliable outcomes can be readily achieved on an iPad perimeter when administered by trained assistants. This makes the present implementation of iPad a potentially useful device for the purpose of telemedicine or remote-site testing, provided it is administered by trained personnel. Finally, the capacity of home monitoring to detect visual field progression with a tablet under variable conditions and life's distractions needs further evaluation.

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Author/s:
Kong, YXG; He, M; Crowston, JG; Vingrys, AJ

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