Characteristics of the Normative Database for the Humphrey Matrix Perimeter

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Purpose. The Humphrey Matrix (Carl Zeiss Meditec, Dublin CA; Welch-Allyn, Skaneateles, NY) is a high-spatial-resolution perimeter that uses frequency-doubling stimuli. It incorporates an efficient test strategy that assumes that age, eccentricity, and test procedure type have only small effects on sensitivity. The results used to create the normative database for the perimeter were examined, to see whether these assumptions were met and to examine the form of the normative data.

Method. Visual fields were measured (Matrix 30-2, 24-2, 10-2 and Macula patterns) in >275 subjects judged to be normal by a battery of clinical procedures. The right eye was always tested first.

Results. Sensitivity decreased by approximately 0.7 dB per age decade across all eccentricities; sensitivity decreased with eccentricity, typically by <5 dB at the most peripheral points tested. Although there was no systematic difference in sensitivity between the 30-2 and 24-2 tests, the Macula test sensitivities were typically 1 dB higher than for the 10-2 test. Sensitivity in the left eye was slightly lower than in the right, with the difference being significantly greater in the temporal visual field. In most test locations, the 95% confidence interval of normal sensitivity was approximately 6 dB below the median sensitivity.

Conclusions. The performance of the test strategy in the Matrix perimeter is appropriately matched to the response characteristics of the normal population. The finding of a spatially nonuniform difference in sensitivity between left and right eyes is attributable to light-adaptation differences between the eyes. This effect is accounted for in the perimeter's normative database. (*Invest Ophthalmol Vis Sci.* 2005;46:1540–1548) DOI:10.1167/iovs.04-0968

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The frequency-doubling technology (FDT) perimeter (Carl Zeiss Meditec, Dublin, CA; Welch-Allyn, Skaneateles, NY) measures contrast sensitivity to low-spatial-frequency grating stimuli (0.25 cyc/deg) that are counterphase flickered at a rapid rate (25 Hz). Many studies have demonstrated that FDT perimetry shows good sensitivity and specificity for detecting glaucoma.[1–7] The 10° square stimuli in the perimeter restrict the ability to localize visual field defects spatially, however, which limits the feasibility of using FDT perimetry to grade and monitor progression of visual field damage[8] and to classify neuro-ophthalmic disorders.[9]

Johnson et al.[10] developed a custom FDT perimeter with 4° square stimuli, spaced in a 6° grid similar to the 24-2 pattern used in the Humphrey Field Analyzer (HFA; Carl Zeiss Meditec), which improved the spatial localization of visual field defects. Studies have found that the within-test variability is not adversely affected when stimulus size is reduced from 10° to 4°,[10,11] which suggests that the increased spatial resolution of the test is not at the expense of sensitivity resolution. The use of a higher spatial frequency of 0.5 cyc/deg (in comparison to 0.25 cyc/deg) and a lower temporal flicker frequency of 18 Hz (in comparison to 25 Hz) also provides a dynamic range that is compatible with that of the original FDT perimeter. Therefore, the availability of a commercial FDT test similar to that described by Johnson et al.[10] would be a potentially useful tool, not only for detecting visual field defects, but also for the classification and longitudinal monitoring of such defects. The recently released Humphrey Matrix perimeter makes use of 5° stimuli located over a pattern similar to that described by Johnson et al.[10] as well as a pattern extended to more peripheral points, spaced similarly to those in the HFA 30-2 program.

In addition, the Matrix perimeter incorporates test patterns containing 2° wide stimuli, for assessing function within the central visual field (10°). Sensitivity to flickering stimuli is reduced in age-related maculopathy[12–15] and central serous chorioretinopathy,[16] and so such stimuli may be useful for spatially localizing such macular visual field defects. Macular tests may be used also for assessing and monitoring advanced glaucomatous visual field loss or other optic neuropathies in which only a small central island of vision remains and further progression may quickly lead to complete blindness.

Developing an appropriate normative database for a perimeter is essential for clinical use, and the characteristics of the normative database for the original FDT perimeter are well described.[17] The normative database for the Humphrey Matrix would be expected to differ significantly from the FDT database in several ways, however. First, an increased effect of eccentricity on sensitivity may arise because of the smaller size and higher spatial frequency of the stimuli, as has been reported for the custom test developed by Johnson et al.[10] The 30-2 test pattern on the Matrix perimeter presents stimuli at even greater eccentricities than the C-20 FDT pattern, and so a steeper decline in sensitivity may occur in these most peripheral points.

Second, the Matrix uses a different psychophysical strategy from the FDT (Zippy Estimation by Sequential Testing [ZEST][18] and modified binary search [MOBS],[19] respectively). ZEST is a

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Bayesian estimator of sensitivity, making use of the information gained from every response at a given location when determining the final estimate of sensitivity. The Matrix perimeter uses a flat prior probability density function (PDF)[20] to model the expected distribution of sensitivities, thereby assuming that nothing is known about the final estimate of visual sensitivity for a given subject, save that it is between 0 dB (the perimeter's maximum contrast) and 38 dB (the approximate upper limit for contrast sensitivity in young observers). This approach allows the sensitivity of both normal and abnormal visual field locations to be estimated with similar efficiency. Most important, the perimeter uses a fixed PDF for all ages, eccentricities, and test types, and so the suitability of this approach should be assessed.

Third, the average test duration for the Matrix 24-2 test (~6 minutes) is slightly longer than for the FDT C-20 procedure (~4.5 minutes), and so both inter-eye adaptation[21] and fatigue[22] effects may differ between the two tests. In addition, sensitivity to an identical stimulus in an identical location may differ between 24-2 and 30-2 tests, or 10-2 and Macula tests, for the same reasons.

In this article, we analyze the characteristics of the normative database generated for the Matrix perimeter, paying particular attention to the effects of aging, eccentricity, and inter-eye differences. The suitability of using a fixed PDF for all tests is examined also. Finally, we present some examples of test results from both normal and diseased subjects, to demonstrate the form of the data that is provided to the clinician.

METHODS

Test Stimulus Arrangement

All testing was performed on prototype versions of the Humphrey Matrix perimeter, which had optics and calibrated video monitor hardware identical with that available in the commercial version of the instrument. In addition, the video monitor, mean background illumination, and stimulus duration used for all Matrix tests were the same as in the original FDT perimeter. The 30-2 test contained 69 stimuli that were 5° square (except for the 5° diameter circular central target), distributed in a pattern (Fig. 1, top, large squares) similar to that of the 30-2 HFA test (Fig. 1, top, small squares). The spatial frequency of the test stimuli was 0.5 cyc/deg and the flicker rate 18 Hz. The spacing between stimuli running either side of the horizontal and vertical midlines was slightly larger than elsewhere in the test pattern, to improve the spatial localization of hemianopic and quadrantanopic defects (Wall M, et al. *IOVS* 2001;42:ARVO Abstract 820)[9] The 24-2 test used a subset of 55 points from the 30-2 test pattern (Fig. 1, top, solid outlines). The 10-2 test pattern (Fig. 1, bottom, large squares) contained 44 stimuli located over roughly the central 10° of the visual field, with the Macula test evaluating a subset of 16 of these points located over roughly the central 4° of the field (Fig. 1, bottom, solid outlines). Test stimuli were 2° square, with a spatial frequency of 0.5 cyc/deg and a temporal frequency of 12 Hz used to increase normal sensitivity to these small stimuli to a level comparable with that of the 30-2 and 24-2 test strategies. These spatiotemporal parameters are still within the gamut of those expected to show the frequency-doubling effect.[23,24]

For all tests, the perimeter estimated fixation losses by the method of Heijl and Krakau,[25] wherein a small, high-contrast stimulus (1°, 25% contrast) is periodically presented in the expected location of the physiological blind spot. False-positive (0% contrast) and -negative (100% contrast) catch trials were interleaved also. With the 30-2, 24-2, and 10-2 test strategies, there were 10 fixation-loss, 10 false-positive, and 6 false-negative stimuli. With the Macula test strategy, there were three fixation-loss stimuli, three false-positive stimuli, and one false-negative stimulus.

The N-30 tests of the original FDT perimeter are duplicated in the Humphrey Matrix perimeter, using the same testing strategy and normative database as the original instrument, and so we do not review these tests in this article.

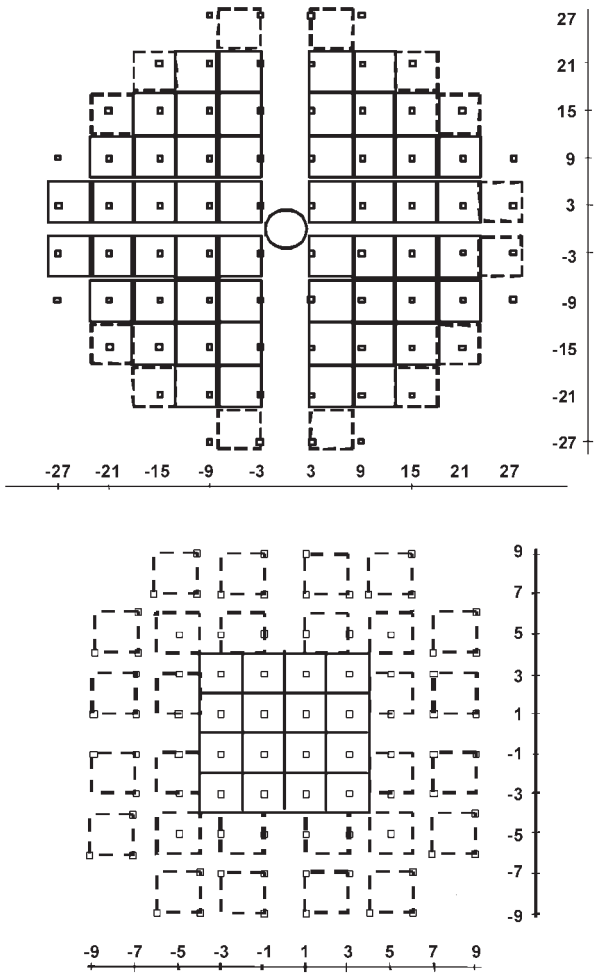

FIGURE 1. *Top*: layout of the test stimuli for the 30-2 and 24-2 test patterns of the Humphrey Matrix perimeter. Each of the larger stimuli is a 5° square patch of a 0.5-cyc/deg, vertically oriented grating, counterphase flickered at 18 Hz. *Solid outlines*: subset of points tested by the 24-2 test pattern; *dashed outlines*: additional points tested in the 30-2 pattern. The locations for the right eye only are shown, with the left eye pattern being the mirror reverse. The stimulus locations in the HFA 30-2 test are marked by the *smaller squares*. *Bottom*: layout of the 10-2 and Macula test patterns of the Matrix perimeter. Each stimulus is a 2° square patch of a 0.5-cyc/deg, vertically oriented grating, counterphase flickered at 12 Hz. *Solid outlines:* subset of points tested by the Macula test pattern; *dashed outlines*: additional points tested by the 10-2 pattern. The stimulus locations in the HFA 10-2 test are marked by the *smaller squares*. Scales are in degrees.

Thresholding Technique

The perimeter used a four-presentation ZEST procedure[18] to determine sensitivity in the patients. Although it is possible to alter the number of presentations dynamically, based on the confidence interval about the predicted threshold (a *dynamic termination criterion*), this approach does not offer any benefits in reducing the error in sensitivity measurements.[26] The prior PDF was flat, thereby ensuring that it did not dominate the final sensitivity estimate,[27] and it was identical for all test types and stimulus locations. Testing commenced at the mean of the PDF independent of age, which was 20 dB.

Sensitivities were expressed in decibels, as given by the equation:

$$dB = -20\log_{10}C$$

TABLE 1. Number of Subjects Tested, as a Function of Age and Test Type

Age Range (y)	30-2	24-2	10-2	Macula
10–20	5	4	3	4
20–30	70	70	52	48
30–40	43	48	39	40
40–50	79	83	75	75
50–60	61	69	61	58
60–70	24	29	25	28
70–80	9	24	20	21
80–90	0	2	2	2

The lower and upper limit was applied to each age range inclusively and exclusively, respectively.

Where C is the threshold Michelson contrast (i.e., $[L_{max} - L_{min}]/[L_{max} + L_{min}]$). As contrast is derived from amplitude information, rather than power, a change of 20 dB indicates a 10-fold (1 log unit) change in contrast. Unlike the original FDT test, the Matrix perimeter does not use proprietary scaling factors,[28] thereby making direct comparison of sensitivity data with other clinical and research measurement of contrast sensitivity possible.

Once all sensitivities in a given visual field pattern were estimated, the Matrix perimeter used an algorithm to check for any points that differed by more than 4 dB from four neighboring points. The perimeter then determined sensitivity afresh for these points, and these new values were used as the final sensitivity estimates. This algorithm was designed to detect isolated points with sensitivity that might be mistakenly high or low through erroneous subject responses, although the efficacy of this algorithm has not yet been established.

Subjects

We tested >275 subjects (291, 329, 277, and 276, for the Matrix 30-2, 24-2, 10-2, and Macula test patterns, respectively) whose ages were as given in Table 1. The database in the commercial version of the Matrix perimeter uses a large subset of these data (262, 278, 265, and 261 subjects for the Matrix 30-2, 24-2, 10-2, and Macula test patterns, respectively). All subjects had refractive errors of <5 D sphere and <3 D cylinder, normal white-on-white fields (HFA Swedish interactive threshold algorithm [SITA] standard 24-2 or 30-2: pattern standard deviation [PSD] and mean deviation [MD], $P > 0.05$; no explicit criterion for false responses or fixation losses), acuity of better than 6/12 (20/40), no history of ocular or neurologic disease or surgery, no history of amblyopia, and no medications or systemic disorders known to affect vision. Controlled hypertension and/or migraine were not grounds for exclusion. All subjects had normal findings in slit lamp and ophthalmoscopic examinations.

All subjects had performed at least one prior visual field examination (HFA) at a session prior to the main study and so had experience with visual field testing, consistent with those subjects used to develop the database for the HFA.[29] Subjects were examined in two separate sessions lasting approximately 1 hour each and performed only two of the four Matrix tests in each session. They were instructed to respond to targets that flickered or shimmered or were striped,[30] and each test commenced once the instructor was satisfied that a subject was responding appropriately to the preliminary demonstration stimuli. All completed test results were included in the subsequent analysis and were not subject to acceptance or rejection based on reliability indices (false responses and/or fixation losses). We randomized the order of the tests, but the right eye was always tested first to be consistent with typical clinical practice. We gave a minimum of 5 minutes' break between each test type, but not between the testing of each eye on a given test. All subjects achieved better than 6/12 acuity with the distance optical correction used to take the test. In some cases, this correction was in the form of trial lenses either worn in a frame or affixed to the eyepiece of the Matrix perimeter. Bifocal or progressive spectacles were used by some subjects, although darkly tinted or photochromatic lenses were excluded.

The study complied with the tenets of the Declaration of Helsinki and was approved by each author's institutional human experimentation committee, with all subjects giving informed consent before participation.

Statistical Analyses

We calculated the probability limits from the entire data set using a linear model for age changes in sensitivity.[31] We calculated probability limits empirically, using linear interpolation, as the distribution of perimetric sensitivities for normal observers is non-Gaussian.[29,32] Although all subjects had normal visual field results (MD and PSD ≥5% probability limit) on the HFA, such an outcome is unlikely to result in important biases in the Matrix perimeter database, owing to the poor correlation between standard achromatic and frequency-doubling sensitivity in normal observers.[33] By means of the formulas used for the HFA,[34] we calculated the following statistical indices: total deviation,

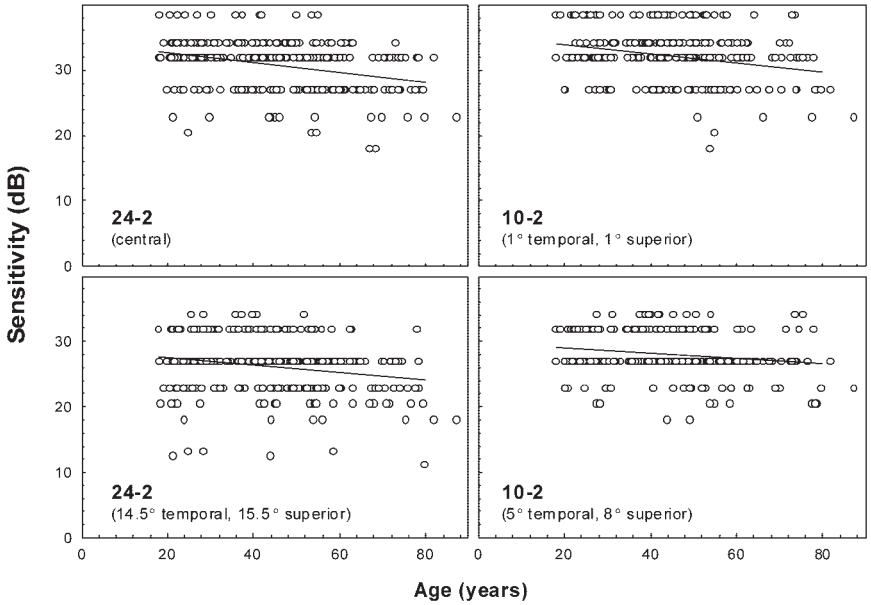

FIGURE 2. Scattergrams showing sensitivity as a function of age, at a central (*top*) and a peripheral (*bottom*) point with the 24-2 and 10-2 tests (*left* and *right*, respectively). *Straight lines*: linear regression through the data. Pearson r^2 coefficients were 0.11, 0.07, 0.03, and 0.05, proceeding clockwise from the *top left.* All data were from the right eye.

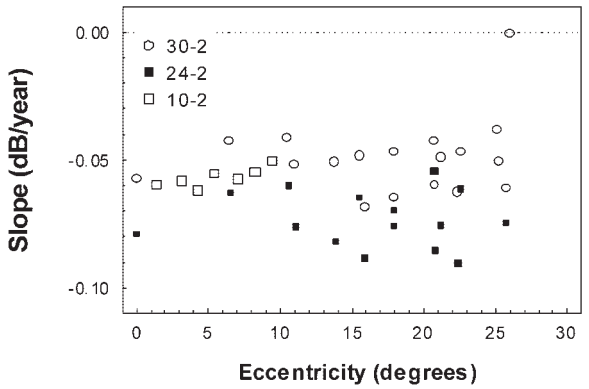

FIGURE 3. Average age-versus-sensitivity regression slopes, as a function of eccentricity, for the 30-2, 24-2, and 10-2 tests. Data were taken from the right eye and eccentricity expressed as the length of the polar vector from fixation. For the 30-2 test, all averages were from four test locations (i.e, four quadrants), save when eccentricity was zero (one location only). The data for the 24-2 were similarly derived, except when eccentricity was 25.7° (average of two locations). For the 10-2 test, averages were derived from four and eight locations alternately, as eccentricity increased. There was no significant correlation between eccentricity and slope with results of any test (Pearson, 30-2: $r^2 = 0.05$, $P = 0.68$, $n = 69$; 24-2: $r^2 = -0.11$, $P = 0.43$, $n = 55$; and 10-2: $r^2 = 0.26$, $P = 0.09$, $n = 44$). Average ± SEM regression slopes: -0.049 ± 0.004, -0.073 ± 0.003, and -0.057 ± 0.001 dB/deg for the 30-2, 24-2, and 10-2 tests, respectively.

pattern deviation, MD, and PSD. For the 10-2 and Macula test patterns, we used all test locations when calculating the MD and PSD indices. We also calculated a glaucoma hemifield test (GHT) index for the 30-2 and 24-2 protocols, using an identical pattern of points for each protocol.

RESULTS

Figure 2 shows a scattergram of test sensitivity versus age for a central and a peripheral point for both the 24-2 (left) and the 10-2 (right) test patterns. In general, there was little change in sensitivity with age, with a linear regression of the data suggesting that sensitivity changed approximately 0.7 dB per decade. Correlation coefficients (Figure 2) were low for these regressions, indicating that most of the variability in the scattergrams was not due to age changes but rather to intersubject variability. Nonlinear regressions did not significantly improve the relationship between sensitivity and age for any of the test procedures. There was no significant change in the slope of the regression line with eccentricity (Fig. 3). Normal sensitivities were quantized as expected, given the four-presentation ZEST procedure, with most values falling across four quantized levels. The average duration of the tests, along with the slowest and fastest tests, are listed in Table 2.

Figure 4 shows both horizontal and vertical cross sections through the age-normalized hill of vision for all tests. Considering the data for the 30-2 first (top left), there was only a small change in sensitivity with eccentricity that was roughly symmetrical about the fixation point. There was some quantization of the median thresholds, as manifest by the transition bump seen at approximately 15° eccentricity, but this quantization was small compared to the intersubject variability for the test, as given by the 95% confidence limits for normal sensitivity (error bars). The variability at each point changed little with eccentricity. The results of the 24-2 test (bottom left) were qualitatively similar to those of the 30-2 test. For the 10-2 test (top right), median sensitivity with these smaller stimuli was similar to that with the larger stimuli used in the 30-2 and 24-2 tests (left), and there was little change in either sensitivity or variability with eccentricity. There was effectively no change in sensitivity over the small changes in eccentricity used in the Macula test (bottom right).

Figure 5 shows the difference in sensitivity estimates between tests that use the same stimulus type in the same location. There was no significant difference (average difference, −0.04 dB; 95% confidence interval [CI], −0.23 to +0.15) between sensitivity estimates in the 30-2 and 24-2 tests. In contrast, the Macula test returned sensitivity estimates that were slightly greater (average difference, −1.22 dB; 95% CI, −1.60 to −0.83) than for the same locations in the 10-2 test.

Inter-eye comparisons for each test are shown in Figure 6, as a function of eccentricity. At all locations in all tests, the average sensitivity in the right eye was greater than in the left, although the differences typically were <2 dB. For both the 30-2 and 24-2 tests, the average difference for nasal points (negative eccentricities) was significantly smaller than for temporal points (*t*-test: $P < 0.01$ and $P < 0.001$ for 30-2 and 24-2, respectively; average difference, 0.8 and 1.1 dB, respectively). A significant difference was also seen in the 10-2 results, provided the two points in apposition to the fixation point were ignored ($P < 0.001$; average difference, 1.3 dB).

Examples

Normal Observer. Figure 7 shows visual field test results on the Matrix 30-2 test procedure for the left eye of a 50-year-old subject with healthy eyes. The top left result displays the raw sensitivity data, in decibels. A gray scale sensitivity representation, visual field indices (MD, PSD, and Glaucoma Hemifield Test [GHT]) and Total and Pattern Deviation probability plots are also presented, along with demographic information. As the flat PDF used in the Matrix does not change shape as a function of eccentricity, the Matrix returns sensitivity estimates that do not change as smoothly with eccentricity as do those of the HFA.

Glaucoma. Figure 8 shows the visual field results for the left eye of a 66-year-old white female patient with open-angle glaucoma. Figure 8A shows the HFA 24-2 test result, revealing a mild superior partial arcuate defect and a borderline GHT result. Figure 8B gives the result of the Humphrey Matrix 24-2 test. It should be noted that although both tests return sensitivity estimates in decibels, the two values are not directly

TABLE 2. Average Test Durations, along with the Fastest and Slowest Times

	OD				OS			
	Macula	**10-2**	**24-2**	**30-2**	**Macula**	**10-2**	**24-2**	**30-2**
Mean ± SD	1′33″ ± 0′5″	4′18″ ± 0′9″	5′10″ ± 0′10″	6′21″ ± 0′6″	1′33″ ± 0′6″	4′15″ ± 0′8″	5′10″ ± 0′11″	6′22″ ± 0′13″
Slowest	2′7″	4′56″	5′55″	8′30″	2′8″	5′6″	6′25″	8′11″
Fastest	1′25″	4′15″	4′54″	5′57″	1′24″	4′45″	4′50″	5′52″

′, minutes; ″, seconds.

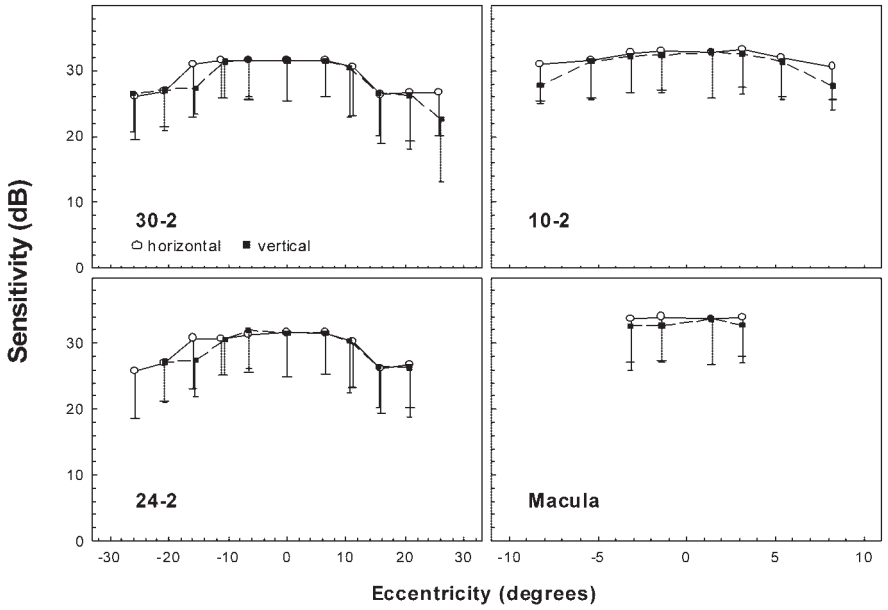

FIGURE 4. Horizontal and vertical cross section through age-corrected median sensitivity data for all tests types. Error bars show the 95% confidence limits for normal sensitivity, with smaller error bar caps for the vertical data points. Data are from the right eye. As no eccentric test locations lie precisely on the horizontal or vertical axes, for the 30-2 and 24-2 tests we took the horizontal data points lying 3.5° superior to the horizontal midline and the 5.5° temporal to the vertical midline. For the 10-2 test, horizontal locations were displaced either 2° or 3° superiorly, and vertical locations either 1° or 2° temporally. We show eccentricity as the length of the polar vector from fixation, with positive values signifying either the temporal or superior direction.

comparable. In particular, the HFA results are based on Weber contrast and are scaled relative to the maximum intensity stimulus of the perimeter (i.e., 0 dB). The Matrix perimeter results, however, are based on Michelson contrast (see equation in the Methods section), with 0 dB fixed as the theoretical maximum contrast of a sinusoidal grating (100%).

Age-Related Macular Degeneration. Figure 9 shows the visual field results for the left eye of a 76-year-old white female patient with age-related macular degeneration and a best-corrected visual acuity of 6/24 (20/80). Figure 9A shows the HFA 10-2 test, revealing a central scotoma. Both the MD and PSD were outside normal limits. Figure 9B gives the results for the 10-2 test procedure on the Matrix perimeter, which shows results that are highly similar to those obtained with the HFA.

DISCUSSION

The Humphrey Matrix perimeter improves the spatial resolution of frequency-doubling perimetry, providing test patterns spaced similarly to those found on the HFA (Fig. 1). Its Bayesian test strategy, ZEST, for estimating sensitivity is somewhat novel, in that it uses the same prior PDF for all tests types and test locations. Our results show that the effects of ageing (Fig. 2), eccentricity (Figs. 2, 4), and test type (Fig. 4) are of small magnitude when compared with the intersubject variability among normal observers (Fig 2), which indicates that using a

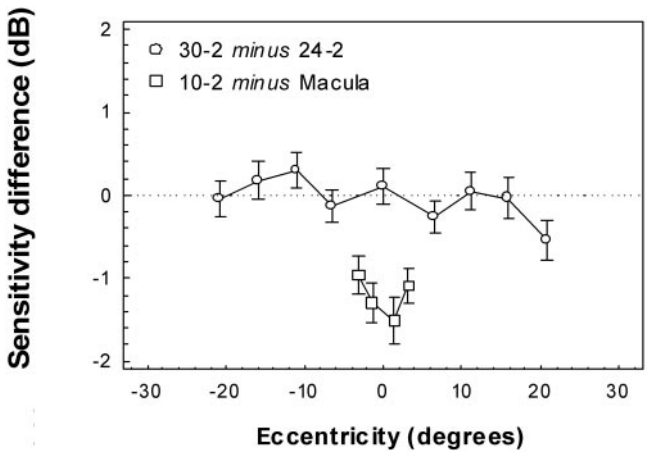

FIGURE 5. Average difference in sensitivity between the 30-2 and 24-2 and the 10-2 and Macula tests. Data were from 270 paired observations for the 30-2/24-2 data and 258 for the 10-2/Macula data, taken from the right eye. Horizontal test points are as defined in Figure 4, and error bars are ±SEM. Average difference for the 30-2/24-2 data is −0.04 dB (95% CI, −0.23 to +0.15, $df = 8$) and for the 10-2/Macula, −1.22 dB (95% CI, −1.60 to −0.83, $df = 3$).

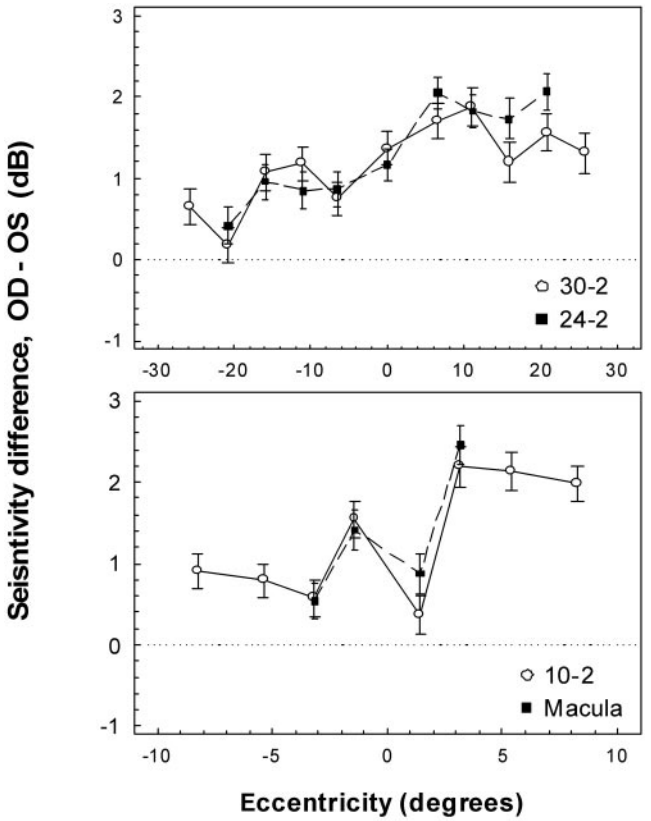

FIGURE 6. Average difference in sensitivity between the right (first test) and left (second test) eye for the 30-2 and 24-2 tests (*top*) and the 10-2 and Macula tests (*bottom*). Horizontal test points are as defined in Figure 4, and error bars are ±SEM.

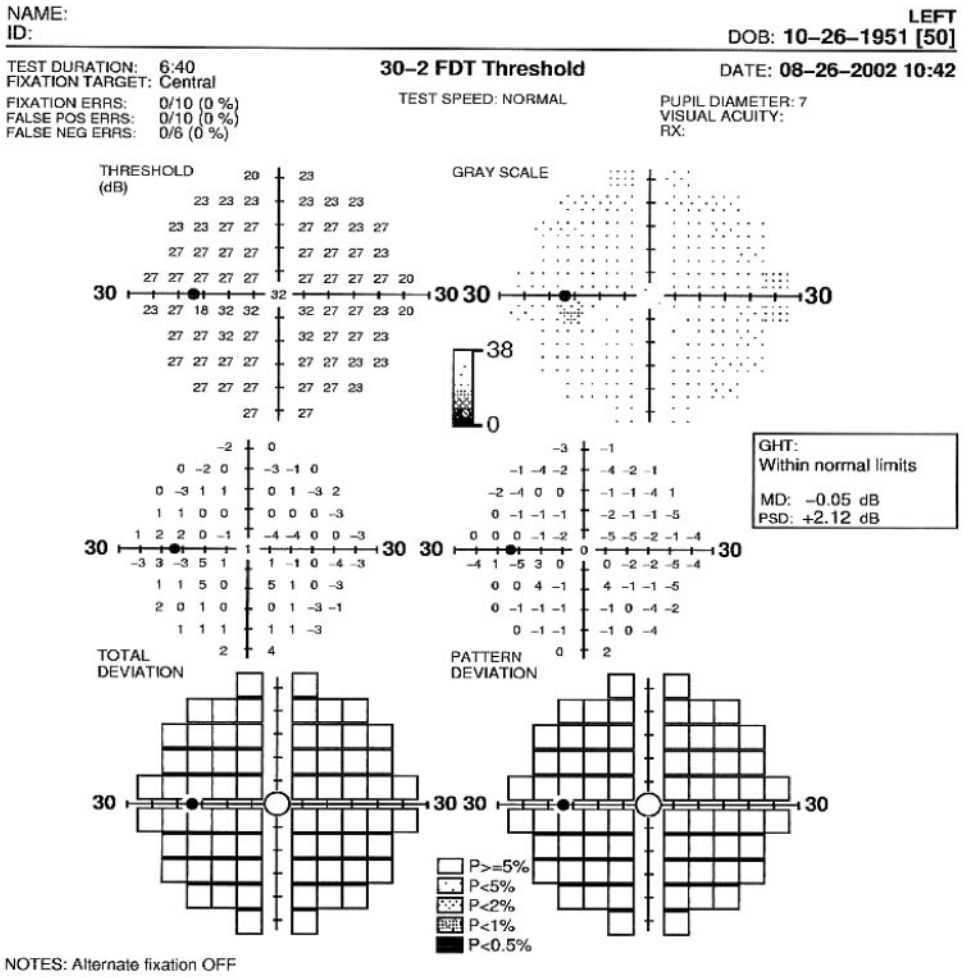

FIGURE 7. Humphrey Matrix 30-2 visual field results for a left eye of a 50-year-old subject with normal ocular health. It should be noted that the grayscale plot from the Matrix perimeter (*top right*) is not spatially smoothed, unlike that for the HFA.

single prior PDF is appropriate and is unlikely to have any detrimental effects on the ability of the Matrix perimeter to determine sensitivity. In addition, the fixed number of presentations in the ZEST procedure gives steps in contrast that are much less than intersubject variability (Fig. 2) and should be appropriately spaced given published reports of intrasubject variability.[11] The use of a fixed number of presentations in the test procedure means that both normal and abnormal visual fields should be estimated in similar time and may reduce the significant increase in test time of dynamically terminated test procedures.[35]

An additional feature of the prior PDF is that it is flat, thereby making no a priori assumptions as to where in the perimeter's range the subject's sensitivity is located. Bayesian estimators use a prior PDF that reflects the expected distribution of both normal and abnormal sensitivities in the test population, and some investigators have suggested what shape this prior PDF should take.[18,36,37] Typically, the prior PDF weights most highly to normal age-adjusted sensitivities, and relatively lower to abnormal sensitivities, thereby assuming that a point is most likely to be normal. It is not clear that these population-derived data necessarily apply to an individual, however. Indeed, perimetry in a given subject is often undertaken either because his or her expected sensitivity is unknown (reflected by a flat initial PDF) or because visual field loss is suspected (reflected by a prior PDF with greater weighting to abnormal sensitivities). Given this, the flat PDF used in the Matrix perimeter appears to be a sensible compromise, allowing sensitivity of both normal and abnormal visual field locations to be estimated with similar efficiency. The difference in performance between differently constituted PDFs is not dramatic, however,[37] and so it is likely that any broad distribution would return useful estimates of sensitivity. An additional feature of using a flat PDF is that its effects do not dominate the final sensitivity estimate,[27] and so the shape of the estimated hill of vision is predominantly the result of a patient's responses and not the assumed form of the population sensitivity data. Although it may be thought that biasing toward normal thresholds is responsible in part for the increase in threshold variability, as sensitivity declines in standard automated perimetry, studies using a method of constant stimuli have shown this to be untrue.[11,38]

Although we found that perimetric sensitivity decreased with eccentricity (Fig. 4) the rate of this decline did not

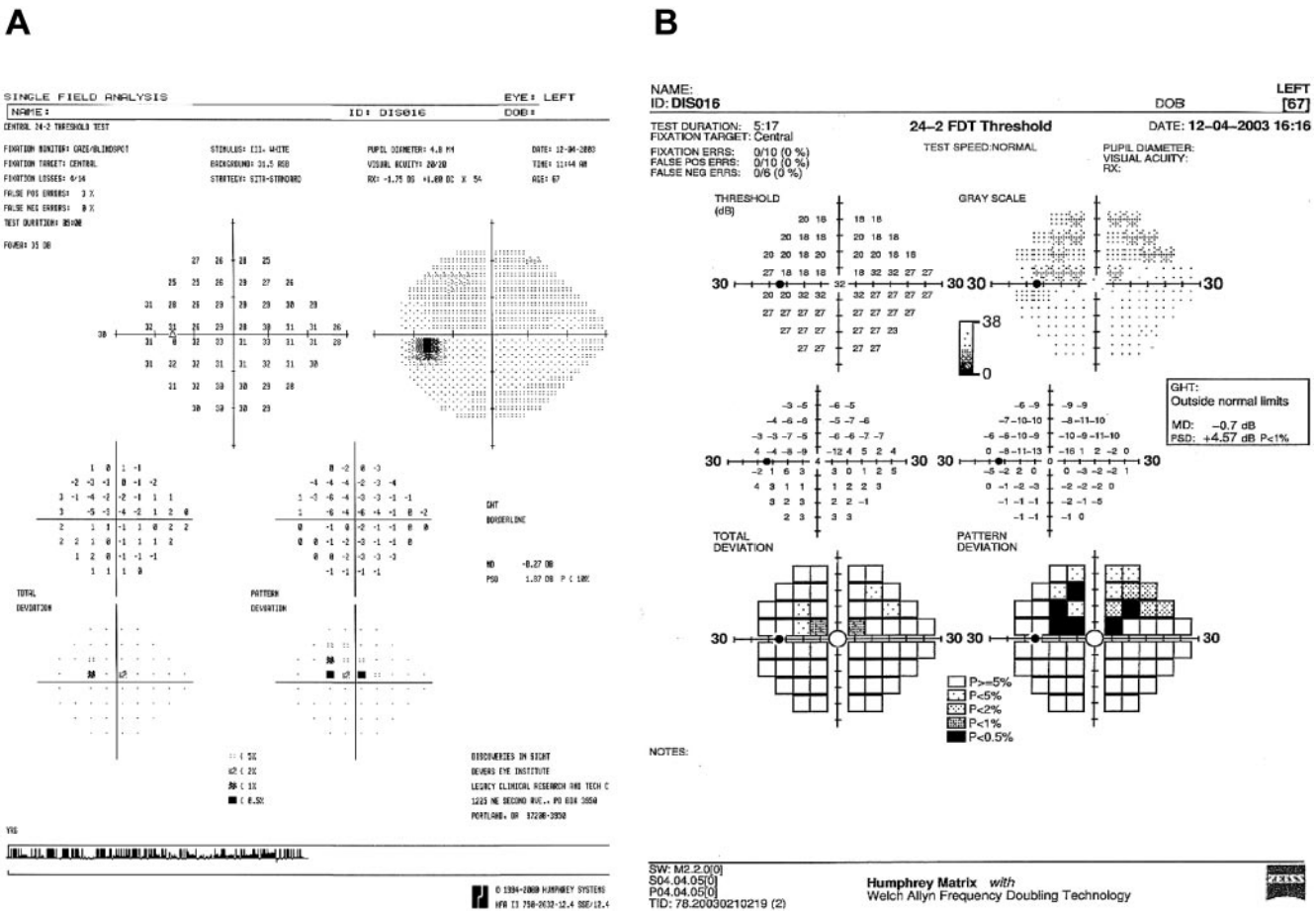

FIGURE 8. Visual field results for the left eye of a 66-year-old subject with open-angle glaucoma. (**A**) HFA 24-2; (**B**) Humphrey Matrix 24-2.

increase with age (Fig. 3), in keeping with previous findings for frequency-doubling perimetry.[10] Perimetric sensitivity changed by approximately 0.5 to 0.7 dB per decade across the visual field, which is similar to the 0.6-dB loss reported for both the custom 24-2 frequency perimeter of Johnson et al.[10] and the original FDT.[17]

We found little difference between sensitivity estimates from the 30-2 test and 24-2 tests (Fig. 5), but found that the Macula test returned consistently higher sensitivity estimates than the 10-2 tests (Fig 5). The reason for this difference is not clear, although the difference in test times is much greater between the 10-2 and Macula tests than between the 30-2 and 24-2, and so subject fatigue is possible. Also, test stimuli are presented over a very small area for the Macula test, and so increased spatial certainty as to where a stimulus might appear could slightly improve performance.[39,40] Irrespective of the exact cause, this finding indicates that sensitivity estimates from 30-2 and 24-2 test patterns may be compared without any particular problem, but that a small error results when Macula and 10-2 test results are compared.

Sensitivity in the second eye tested was significantly reduced when compared to the first (Fig. 6), consistent with what Adams et al.[17] reported for the FDT perimeter. Previous work[21] has attributed this sensitivity loss primarily to asymmetries in the light-adaptation state between the two eyes after removal of the occluder from the second eye, rather than to fatigue[22,41,42] or dichoptic contrast adaptation,[44] and so it is likely that a similar mechanism is responsible for our results. This difference in adaptation state would be expected to cause an increased frequency of Ganzfeld blankout,[43] or transient "graying out" of the visual field, in the second eye, as has been anecdotally reported in FDT perimetry.[8] An interesting finding is that the decrease in sensitivity in the second eye is greater in the temporal hemifield, which is opposite to the reports of a "perceptual curtain" in Ganzfeld blankout that originates in the nasal periphery and creeps nasotemporally across the field.[45] Because of this, further detailed experiments of the type previously used to investigate dichoptic effects[21] may be useful in determining the precise spatial characteristics of adaptation effects in frequency doubling perimetry and whether these effects are directly related to the Ganzfeld blankout phenomenon. Fatigue seems to be an unlikely explanation of our results, given that our effect was of similar magnitude across tests of markedly differing duration (Table 2) and that this result has also been reported to have maximum effect on the nasal visual field.[41] There is a suggestion that the central stimuli abutting the fixation point (Fig. 6, bottom) may behave differently with regard to this effect. Most important, the database for the Matrix incorporates this spatially asymmetric reduction in sensitivity in the second eye, and so diagnostic performance of the perimeter should not be affected. This finding holds true even if the left eye is tested first, as the right eye/left eye data in this study are incorporated into the Matrix perimeter database as first eye/second eye.

In summary, the Humphrey Matrix perimeter offers improved spatial resolution similar to that of the HFA 30-2 test, and so should provide a useful means for both classifying the spatial extent of visual field damage and monitoring for progression. In addition, the incorporation of customized tests for assessing central vision opens the possibility for assessing tem-

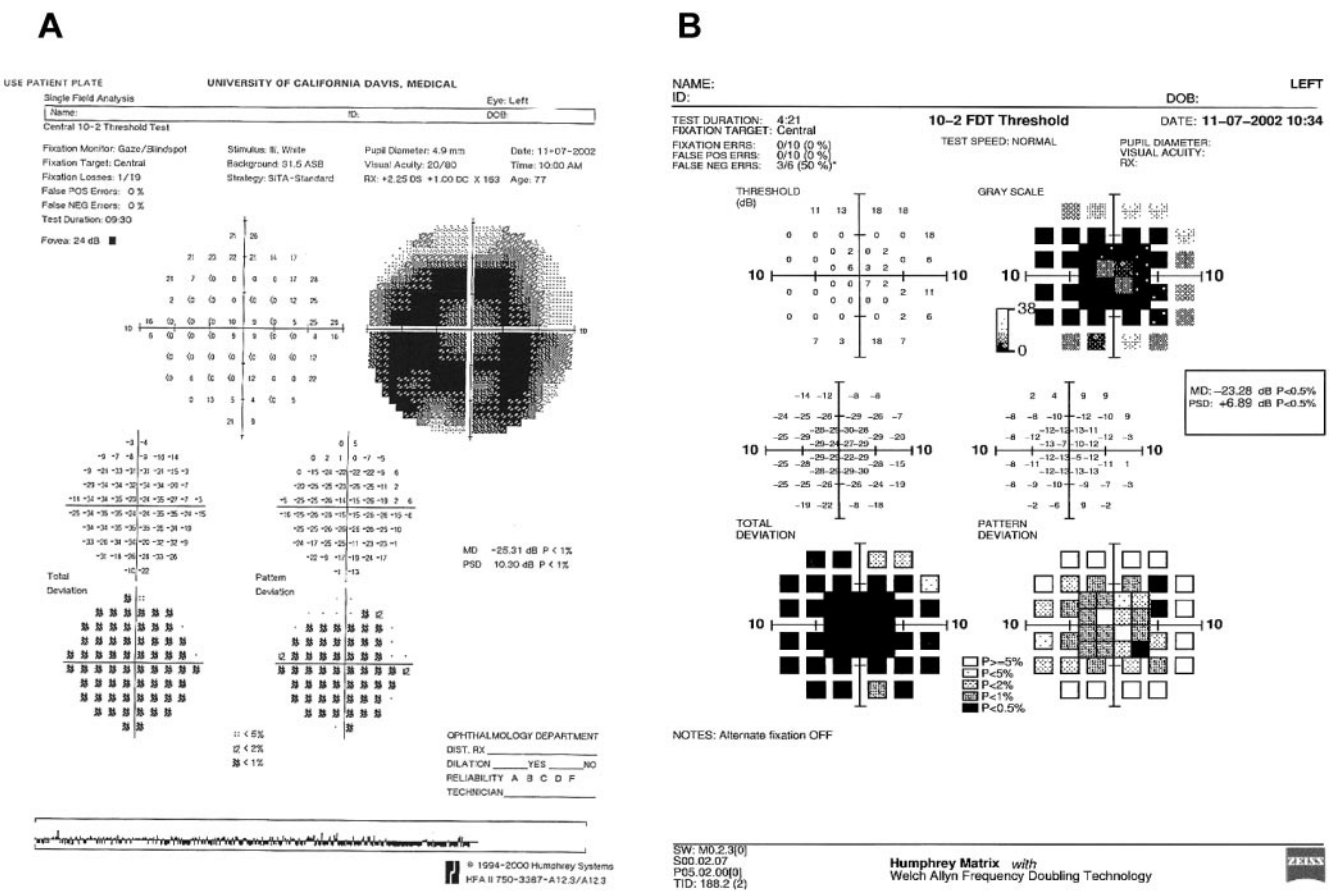

FIGURE 9. Visual field results for the left eye of a 76-year-old subject with age-related macular degeneration. (**A**) HFA 10-2; (**B**) Humphrey Matrix 10-2.

poral contrast sensitivity losses in maculopathies in a clinical setting. The novel design philosophy behind the perimeter means that the form of the perimetric data differs in some ways from that obtained by the HFA, particularly in the presentation of quantized threshold levels. Although this may initially surprise some clinicians, this quantization is well within the 95% confidence limits for normal sensitivity values and is well matched to the intersubject variability in frequency-doubling perimetry.

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