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Integrated visual fields: a new approach to measuring the binocular field of view and visual disability

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Abstract *Background:* We have developed a method of quantifying the central binocular visual field by merging results from monocular fields (Integrated visual field). This study aims to compare the new measure with the binocular Esterman visual field test in identifying patients with self-reported visual disability. *Methods:* Forty-eight patients with glaucoma each recorded Humphrey 24-2 fields for both eyes and an Esterman on the same day, and each completed a binary forced-choice questionnaire relating to perceived visual disability. Computer software merged sensitivity values from monocular fields to generate an integrated visual field and a related score of the number of defects at the <10 dB and <20 dB level. Receiver operating characteristic (ROC) analysis was used to compare the integrated visual field score and the Esterman disability score with individual responses to the questions on perceived difficulty with visual tasks. *Results:* Comparison of areas under ROC curves revealed that a score based on the integrated visual field was generally better (median area: 0.79) than Esterman scores (median area: 0.70) in classifying patients with or without a self-reported perceived difficulty with visual tasks. *Conclusions:* The integrated visual field offers a rapid assessment of a glaucoma patient's binocular visual field without extra perimetric testing. As compared to an actual binocular field test (Esterman), the integrated visual field provides a better prediction of a glaucoma patient's perceived inability to perform certain visual tasks.

Keywords Visual fields · Perimetry · Esterman · Glaucoma · Visual disability · ROC curves

Introduction

Visual field damage is conventionally measured using automated perimetry. It is assumed that binocular testing gives the best indication of a subject's visual field in terms of functioning and visual disability [3, 12]. For example, the availability in various automated perimeters of the binocular Esterman visual field test has meant this has become the standard to implement the guidelines recommended by the Driving and Vehicle Licensing Authority (DVLA) in assessing patients' legal fitness to drive in the UK. Moreover, the binocular Esterman test has been widely used in many studies that have examined the link between visual function and visual disability [10, 11, 13, 15–17, 19, 21]. However, binocular visual field testing is not routinely performed because monocular visual fields are clinically more relevant in both detection and follow-up of degenerative retinal disease such as glaucoma.

We have previously described a novel method of estimating a patient's binocular field of view from their monocular measurements (Fig. 1) [2]. Computer software merges individual sensitivity values from left and right visual fields to generate a map of the central binocular visual field known as the integrated visual field (IVF). The main advantage of this approach is providing an estimate of a patient's binocular field of view without any

Fig. 1 An image captured from the software developed to produce the integrated visual field. The example shows a patient with visual defects in both eyes. The left and right monocular fields are shown as Humphrey-type greyscales. The corresponding sensitivity values from the "overlapped" monocular eyes are simply compared with the maximum or better value used in the IVF (shown in the *lower left panel*). The *lower right panel* is the same binocular reconstruction with *superimposed symbols* denoting defects with a sensitivity of less than 10 dB (equivalent to threshold measured in the Esterman) and defects less than 20 dB (*open symbols*). The IVF score is displayed, and the *superimposed circle* indicates the 20° field
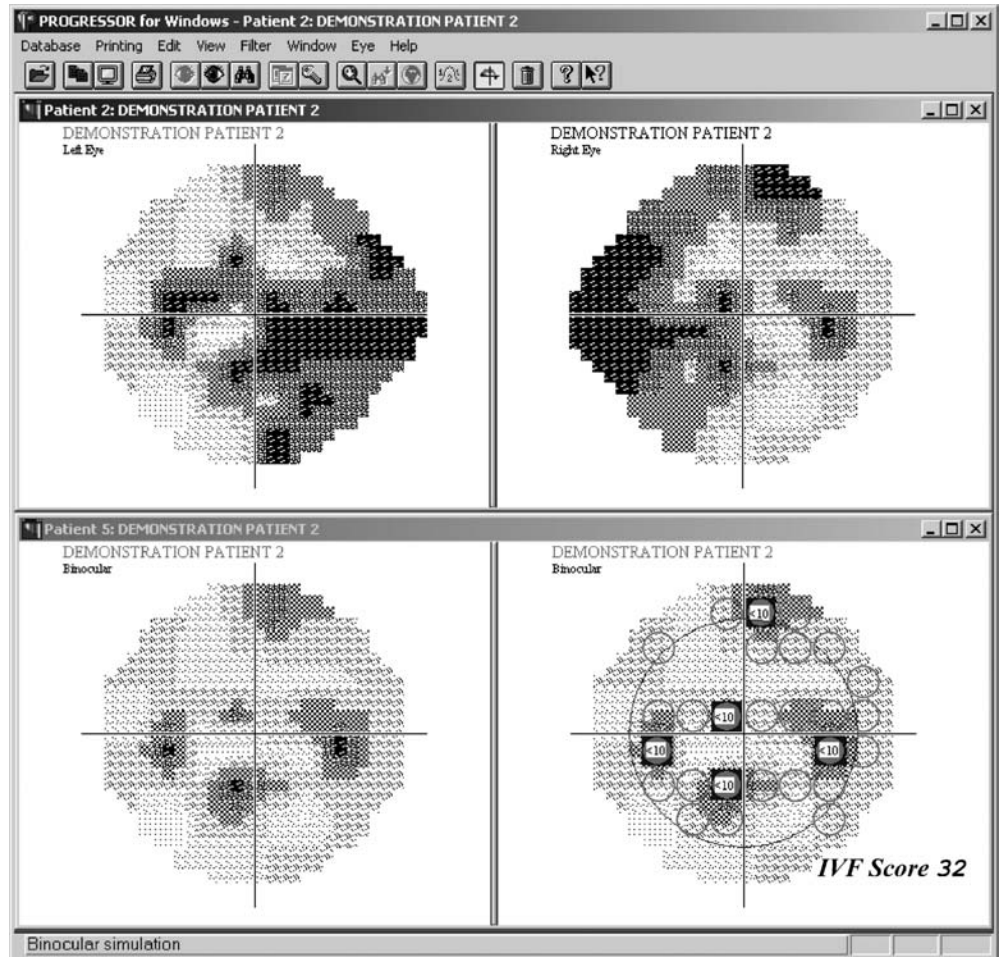
extra testing beyond monocular examination. This technique has been scrutinized by other researchers: Nelson-Quigg and colleagues (2000) examined different ways of "merging" results from monocular visual fields and recommended that the IVF technique is one of the best at representing the central binocular visual field in patients with glaucoma [14].

We have previously shown there is a significant association between some types of perceived visual disability and the severity of the binocular field loss as measured by the Esterman in patients with glaucoma [21]. The purpose of this study is to reexamine this data to compare the performance of the IVF with the Esterman in identifying patients with self-reported visual disability.

Methods

Patients and data

The original patient data for this study has been fully described elsewhere [21]. In short, consecutive patients attending a glaucoma

service at Moorfields Eye Hospital, London, were recruited. Visual acuity in each eye was required to be better than 20/40, and eligible patients had no other significant ocular pathological conditions apart from primary open-angle glaucoma. Sixty-two patients, all giving informed consent, were recruited in this fashion and were interviewed using a binary forced-choice (yes or no) questionnaire. The questionnaire consisted of ten questions related to perceived visual disability and were derived from those validated in previously published research in this area [12]. These questions have subsequently been used elsewhere and proven to be useful in examining patients' perceived visual disability [9]. One of the ten original questions was excluded from our study (Have you noticed deterioration in your sight over the last few years?) because this was more appropriate for the stability/progression aspect of the original study and did not indicate a perceived difficulty with an actual task like the other questions. (The exact wording of the nine questions used is shown in Fig. 3.)

Patients then underwent a binocular Esterman visual field test with a Humphrey Field Analyzer (HFA), model 630 (Humphrey Instruments, Dublin, CA, USA) (Fig. 2). The binocular Esterman examines more than 130° visual field and consists of a grid of 120 test points. Each location is tested once, in a suprathreshold manner, with a Goldmann size III white stimulus at intensity of 10 dB. Missed points are retested, with a second negative response resulting in a recorded defect at that point. In the binocular mode stability of fixation is monitored indirectly by observation. The output includes an "Esterman efficiency" score, which is simply the
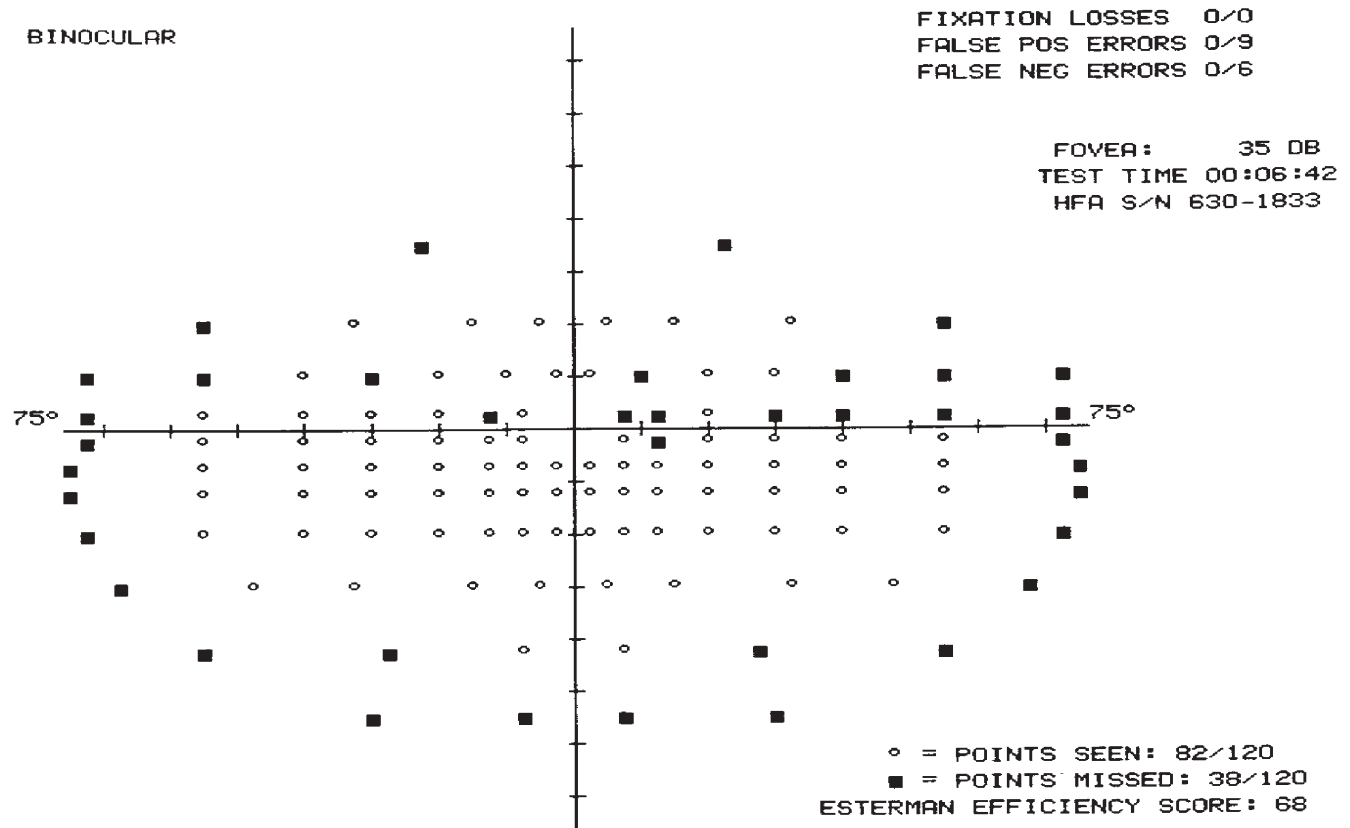
Fig. 2 Example of a printout from the binocular Esterman visual field test

percentage of points that are seen. We converted this to an "Esterman disability" score for each patient, which simply represents the percent of defects.

We retrospectively examined the Moorfields visual field database to find the monocular visual fields that were recorded for each of the patients at the same time of the original study. We excluded patient records if they did not have right and left monocular fields (HFA 24-2, full threshold) recorded on the same day as the Esterman. In addition, patient records were excluded if they had produced unreliable monocular fields at their clinical visit (i.e., unsatisfactory false negative, false positive, or fixation losses adhering to the HFA criteria) or were inexperienced in perimetry (at least three previous field tests were required).

Integrated visual fields

Integrated visual fields were constructed for each patient using the PROGRESSOR software (Institute of Ophthalmology, University College London, London, UK) [2, 4, 20]. In short, each location in the right monocular visual field has a corresponding point in the left monocular field in binocular viewing. The maximum raw sensitivity from each of the two overlapping locations is determined to give an estimate of the sensitivity at that point, as if the subject was viewing in the binocular mode. These merged or integrated results are displayed as a grid of sensitivity values or a greyscale. Individual locations with sensitivity values below 10 dB are flagged with symbols. This technique is equivalent to what has been referred to as the "Best Location" algorithm used by Nelson-Quigg et al. (2000) and by Jampel et al. (2002). We also modified the

software to calculate an IVF score (Fig. 1). Simply, each of the 52 points that make up the integrated visual field was considered in turn. A point scored 0 if it exhibited a measured threshold of 20 dB or better, scored one if it had a threshold between 10 dB and 19 dB, and scored 2 for a threshold below 10 dB. The scores at each point were added across the whole of the IVF giving a summary value of the damage across the field: a completely defective integrated visual field would result in an IVF score of 104 whereas a normal, unaffected integrated visual field would yield an IVF score of 0. The IVF score (an ordinal value ranging from 0 to 104) used in this study was based on an attempt to make the scale close to that used by the Esterman (ordinal, 0–100).

Statistical analysis

The data was transferred to statistical software (S-PLUS for Windows; Insightful Corporation, Seattle, USA). Each question was considered separately, with the patient's binary response acting as a classification about whether they had a perceived difficulty with a visual task or not. We then considered how good the Esterman disability score was at picking patients with a perceived difficulty with a visual task (sensitivity) and how good it was at picking patients without a perceived difficulty with a visual task (specificity). In other words, we evaluated the sensitivity and specificity for all possible cutoff values for the Esterman disability score and plotted these as a receiver operating characteristic (ROC) curve [1]. We repeated this for the IVF score, plotting the ROC curve for this measure on the same graph. We then sought to compare the diagnostic precision of the two scores using the area under the ROC

curve; a perfect diagnostic procedure has an area under the ROC curve of 1 whereas a diagnostic procedure of no use has an area of 0.5. We inspected the ROC curves visually and used a statistical technique, appropriate in this case where two tests are applied to the same set of patients, to determine statistically significant differences between areas under the ROC curves [6] to establish whether the IVF score was notably better at predicting a perceived visual disability than the Esterman.

Results

Forty-eight of the 62 patients that took part in the study described by Viswanathan et al. (1999) [21] fulfilled the inclusion criteria. The mean age of these patients at examination was 67.4 years (range 38–85 years). Patients presented with a wide range of visual field damage: the sample mean Humphrey mean deviation (MD) was −10.4 dB (SD =7.6 dB; range −0.6 to −27.1 dB) for the left eye and −9.7 dB (SD =8.3 dB; range −0.3 to −28.1 dB) for the right eye. Esterman disability scores ranged from 0 to 92% (mean: 13.3%, SD: 18.6%). IVF scores constructed from the integrated visual fields ranged from 0 to 93 (mean: 16.0, SD: 23.1).

ROC plots describing the diagnostic performance of the Esterman disability score and the IVF score for each individual question (along with the precise wording for each question) are shown in Fig. 3. The binary response to each individual question was used as the gold-standard classification about whether or not a patient had a perceived difficulty with the task(s) described. The perfect diagnostic test would obviously have an ROC curve that follows the vertical axis up to the top left-hand corner and then continues along the top of the graph. Visual inspection revealed that the majority (five out of nine) of

Fig. 3 Receiver operating characteristic (ROC) curves describing the relative performance of the integrated visual field (IVF) score and the Esterman disability score in predicting the response to individual questions. The exact wording of the questions is shown, and the area under the ROC curves is given for the IVF score and the Esterman. An *asterisk* indicates that the areas are significantly different to at least the $P<0.05$ level
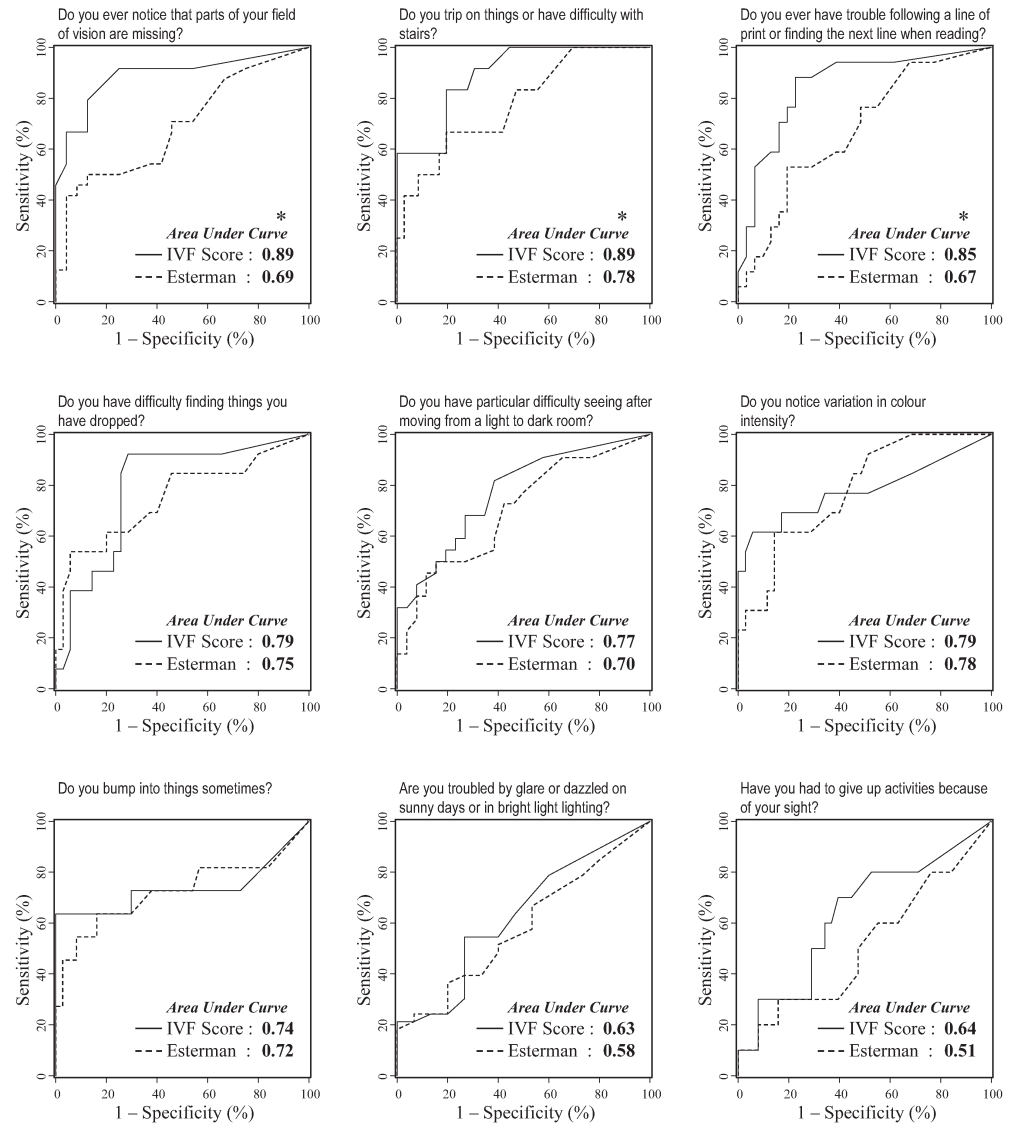
the ROC curves for the IVF score were closer to the top left-hand corner of the graph than the ROC curve for the Esterman with, significantly, no overlapping of the curves. Better still is to consider the area under the ROC curves. In all nine questions, the IVF score gave greater areas (median=0.79) than the Esterman score (median=0.70), and these differences are beyond what would be expected by chance (P=0.009, Wilcoxon matched pairs signed rank sum test), though it would be difficult to assume that the questions were independent. Differences between the areas under the ROC curves for individual questions were further analyzed using an appropriate statistical technique [6]. This demonstrated that the IVF score had significantly better diagnostic precision than the Esterman disability score in predicting three of the question responses (parts of vision missing, P<0.001; difficulty following a line of print P<0.001; tripping and difficulty with stairs P<0.05). The differences for a fourth question about giving up activities because of sight problems approached statistical significance (P=0.07). There was no statistically significant difference between the areas under the ROC curves for the scores in diagnosing responses to the other five questions, but this indicates that the IVF score is no worse than the Esterman disability score in predicting these perceived difficulties. Of course, these results have important meaning in the context that the IVF is constructed without any extra testing beyond what would be routinely performed in a clinical situation.

Discussion

The integrated visual field makes it easy for a clinician to see a reconstruction of a patient's binocular field of view and could be carried out as a regular feature of a visit to the clinic with no extra cost or test time. We first described the novel technique in the context of predicting binocular Esterman test results used for assessing legal fitness to drive in the UK [2]. Subsequently, Nelson-Quigg and colleagues (2000) obtained Humphrey monocular and binocular visual fields for 111 patients with varying degrees of glaucomatous damage, and they examined different ways of combining the monocular fields and concluded that the technique used in generating the integrated visual field provides good estimates of binocular visual field sensitivity [14]. In their work, they described this approach as the "Best Location" model. They also reported an alternative, described as "Best Summation," in which binocular visual field sensitivity was predicted by a probability or quadratic summation of the sensitivities of the two eyes. (The greater the difference in sensitivity between eyes, the smaller the improvement in binocular sensitivity over the best monocular sensitivity.) They concluded that the two techniques (namely best location and best summation) would be equally useful for

evaluations of functional visual-field influences on task performance, daily activities, and related quality of life.

We previously reported a strong association between some types of perceived visual disability and the severity of binocular visual-field loss as measured by the Esterman. Questionnaire responses consistently identified as being strongly associated with Esterman binocular disability scores related to bumping into things, problems with stairs/tripping, and finding things that have been dropped [21]. The questionnaire was based on one originally derived by Mills and Drance (1986) [12] and has been further validated by other workers [9]. In the present study, we revisited this data to demonstrate that an alternative measure of binocular visual-field disability based on the integrated visual field is significantly better than the Esterman disability rating in predicting self-reported difficulty with certain responses to the questionnaire, namely, noticing part of field of vision missing, trouble with following a line of print, and problems with stairs/tripping. Moreover, the measure based on the integrated visual field is certainly at least equivalent to the Esterman disability score in predicting patients' perceived difficulty with all the other tasks examined by this questionnaire. This finding has obvious practical meaning because the integrated visual field does not require any extra binocular testing beyond that measured in a monocular fashion.

The results from this study support recent findings by Jampel and colleagues (2002) that monocular fields are more relevant to patients' perceived assessment of vision than Esterman results and other customized binocular visual field tests [10]. Their work differs from ours because they used the National Eye Institutes Visual Function Questionnaire (VFQ)-25 and their own linear rating instrument for estimating perceived visual disability. A score based on what they describe as a best-location (BL) algorithm for combining sensitivity values from monocular tests gave consistently higher correlations than the Esterman when compared to composite scores from the questionnaire responses, but the differences in these correlations were not statistically significant. Conversely, in our study, we focused on patients' difficulty with individual visual tasks and show that the IVF has statistically significant better diagnostic precision in identifying some of these when compared to the Esterman. The BL algorithm score is based on the same principle (and the same method of combining monocular fields) as the IVF score although the actual indices differ.

There are several plausible explanations for the integrated visual field appearing to be better than the Esterman in better representing a patient's binocular field of view despite it being based purely on monocular results. The integrated visual field is based on more detailed full-threshold testing whereas the Esterman is a single-threshold test. In addition, the Esterman has no direct strategy for testing fixation, and the simple test strategy

used is open to bias [7, 18]. The spatial configuration of points in the integrated visual field may simply be more important functionally than the pattern used by the Esterman. Indeed, noticing parts of vision missing and difficulty following a line of print are probably more reliant on the central field of view, and it is not surprising that the integrated visual field (based solely on central areas) did so much better than the Esterman at predicting these perceived difficulties.

In conclusion, we suggest that a measure based on the integrated visual field will be more meaningful, and certainly more practical, than a customized binocular test for assessing the visual field component of visual disability. Further work is required to establish what summary measure(s) will be best to quantify the severity of defects in the integrated visual field. The score used in this study is very simple and does not, for example, take into account age-related values or relative functional importance of different sectors within the integrated visual field; in addition, it is an ordinal value, which for the purpose of this study meant it could be easily compared to the Esterman output. Some real advantage, with no cost, could be gained from using an average (possibly a weighted one) of the thresholds that constitute the IVF as has been described by Jampel et al. (2002) [10]. However, an evidence-based study is required to evaluate the best measure, and this should be founded on measures of actual patient capability with regard to mobility, driving, reading, and other activities to complement and confirm perceived disability gleaned from questionnaire or interview responses [5, 8]. This type of study would be difficult, but the important benefit would be to derive maps of the integrated visual field that could act as "milestones to blindness" which, in turn, may have an impact on quantifying disease progression and patient management decisions in glaucoma.

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