Graefe's Arch Clin Exp Ophthalmol (1986) 224:389–392

Graefe's Archive
for Clinical and Experimental
Ophthalmology

The concept of visual field indices*

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Abstract. Statistical methods for the evaluation of quantitative visual fields are presented in addition to a mathematical description of the calculation of different visual field indices. The "mean defect" is important for diffuse damage as well as for follow-up in advanced stages. "Short-term fluctuation" provides information about the reliability of the results as well as about possible early damage. "Corrected loss variance" quantifies local defects in an early stage; it also separates real local defects from increased scatter. "Skewness" is a test for very early local defects, and "spatial correlation" provides a measurement of the clustering of any local defects that may be present.

Introduction

Perimetry is an important psychophysical test for ophthalmology and neurology. Since many types of visual field defects are more or less specific for various disease states, perimetry can be of great help for diagnosis and differential diagnosis.

Perimetry is the most important test for the diagnosis of glaucoma. It is our intention to detect glaucomatous visual field defects as early as possible (Aulhorn and Harms 1967) and to detect deterioration or improvement as quickly as possible. It is for these two goals that we have developed the visual field indices. They replace neither the measurement nor the interpretation of visual fields. They should rather be considered as tools for a global quantitative comparison of measured visual fields with previous examinations of the patient, on the one hand, and with visual fields of normals on the other.

Why do we need visual field indices?

Perimetry is, as previously mentioned, a very important test for the diagnosis and follow-up of glaucoma. It is routinely done in all eye clinics and most private practices. The introduction of automation into perimetry has markedly improved its quality and reproducibility. Quantitative perimetry provides the largest amount of information concerning a visual field. Despite the availability of good hard and software to perform such quantitative tests, we are still faced with some problems:

1. How can we separate normal visual fields from pathological visual fields? How can we separate a real small local deviation from a deviation due to scatter?
2. How can we follow up the visual fields? How can we be sure whether the visual field is deteriorating or improving?
3. How can we compare results from an eye clinic with results done in a private practice or how can we compare visual field results with other parameters including psychophysical tests?

Traditionally, the outcomes of perimetry have been represented with various kinds of graphs. Kinetic manual perimetry is mainly represented by isopters. With the introduction of automated perimetry the gray scale seems to be the most useful representation to recognize a visual field change quickly. Three-dimensional graphs are quite helpful for teaching purposes, but do not help much in practical terms. All graphical displays are relatively poor in representing diffuse damage. The recognition of time-related changes with the help of graphs is based on subjective interpretation. Finally, graphs do not allow the investigator to distinguish real scotomas from deviations due to scatter. Our intent, therefore, was to search for new parameters to quantify and separate different entities that occur in visual fields (Flammer et al. 1985). Basically, we can apply different methods for statistical data reduction to the results of a visual field test. Any type of data reduction loses some information and emphasizes some. It is therefore worthwhile to apply several types of data reduction to the visual field. Some, for example, may be more helpful for early detection, while others are more useful for the follow-up of visual defects in later stages. The calculated parameters do not replace graphical representations of a visual field; instead they help in their interpretation.

It is the purpose of this paper to present different mathematical methods of visual field evaluation and to discuss their usefulness in different situations. The parameters calculated are designated as visual field indices. They are derived from the set of numerical threshold results obtained at the test locations of a static perimetric examination. A visual field index, therefore, is defined as a parameter resulting from a special type of data reduction and presenting definite information concerning the visual field area examined as a whole. Visual field indices do not refer to the location of a defect and are therefore of no help in differential diagnosis such as in neurological diseases. They are, however, of great help in glaucoma patients and those suspected of having glaucoma. The methods described here

* Supported by the Swiss National Fund (no. 3'790-0.84)

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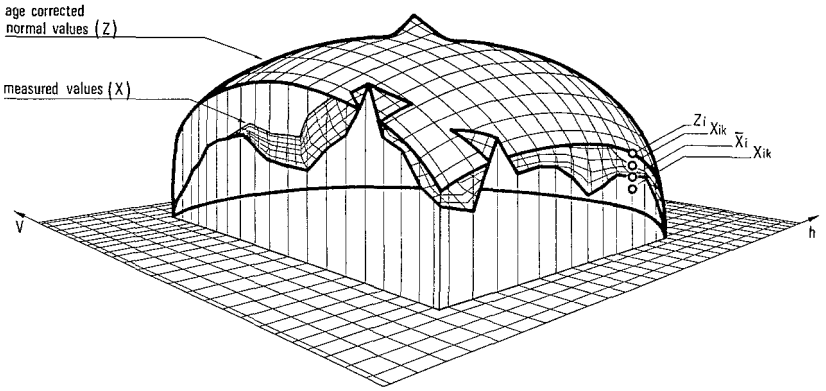

Fig. 1. Schematic drawing of a visual field with the measured values (x) and age-corrected normal values (z) at different test locations (i). x_{ik} is the measured sensitivity at the test location i as determined in replication k. $\bar{x}_i$ represents the mean sensitivity at the test location i over the repetitions

are not new in a mathematical or statistical sense, but their application to the visual field is new.

Figure 1 shows our set of data schematically, which consists of age-corrected local means of normal values (z) at the different test locations (i). The measured values (x) may be larger or smaller than the mean of the normal values. The results of repeated thresholding at the same test location i are subject to scatter. The individual value x_{ik} is the measured sensitivity at test location i as determined in repetition k; $\bar{x}_i$ represents the mean sensitivity at the test location i averaged over the repetitions. Based on the measured values (x) and the normal values (z), we are now able to calculate visual field indices.

The calculation of visual field indices and their meaning

Mean sensitivity. The mean sensitivity (MS) represents the arithmetic mean of the differential light sensitivity of all test locations in the visual field that have been tested.

$$\mathrm{MS}=\frac{1}{m}\cdot\sum_{i=1}^{m}\bar{x}_i$$

where $\bar{x}_i=\frac{1}{n}\cdot\sum_{k=1}^{n}x_{ik}$. x_{ik}=result of thresholding at test location i, replication k; $\bar{x}_i$=average of local results at test location i; n=number of replications (independent measurements within the same session); m=number of test locations.

Computation of the MS does not involve any normal values. It is greatly independent of the short-term fluctuation and the heterogeneous component of long-term fluctuation if the number of test locations is large enough (Flammer et al. 1983). It is sensitive to all kinds of diffuse damage. Defects in small areas have little influence on the MS. MS has been shown to be helpful in studies of the effect of drugs on the visual field (Flammer and Drance 1983a, b), as well as for comparisons of visual fields with other types of psychophysical tests (Flammer and Drance 1984).

Mean defect. The mean defect (MD) is the arithmetic mean of the difference between measured values and normal values at the different test locations. MD is very similar to MS but refers the values obtained to normal values. This makes the interpretation for the clinician much easier, as zero means normal and a positive number expresses directly the extent of the damage (Augustiny and Flammer 1985; Flammer et al. 1985).

$$\mathrm{MD}=\frac{1}{m}\sum_{i=1}^{m}(z_i-\dot{\bar{x}}_i)$$

where z_i=age-corrected normal value at test location i.

Short-term fluctuation. Short-term fluctuation (SF) represents the scatter observed when the same threshold is measured independently (twice or repeatedly) during a single examination of the visual field. It is the average of the local scatter over the total visual field. Statistically, this is done by squaring the local standard deviations, averaging them over the total visual field and taking the square root. In some Octopus standard programs, the short-term fluctuation is expressed as RMS (root mean square fluctuation; Octopus Manual 1978). It is calculated as follows:

$$\mathrm{SF}=\sqrt{\frac{1}{m}\sum_{i=1}^{m}(\mathrm{SD}_i)^2}$$

where SD_i=standard deviations of the x_{ij} at the test location i.

SF depends fundamentally upon the strategy used to measure the visual field (Bebie et al. 1976), the cooperation of the patient (Flammer et al. 1984a), and the characteristics of the threshold to be measured (Flammer 1985b). As the strategy is normally the same for any given program and the cooperation of the patient can be estimated by the false responses in the catch trials, we can conclude from a significantly increased scatter that a change in the characteristics of the threshold itself has occurred (Flammer 1985b). It has been shown that SF is increased in defective areas of the visual field but also in patients with so-called ocular hypertension (Flammer et al. 1984b). An increased scatter, therefore, may be an early sign of damage. [A reliable estimate of SF requires many test locations to be measured twice, such as is done by Octopus program J0 (Jenni et al. 1983); ten double determinations are done routinely in some of the other Octopus programs and yield only a rough estimate of SF (Fankhauser 1976).]

Loss variance. The loss variance (LV) represents the local nonuniformity of a visual field defect. It is small if visual field damage is more or less even. On the other hand, it is very large in the presence of deep scotomas. It is calcu-

lated as follows:

$$LV = \frac{1}{(m-1)} \sum_{i=1}^{m} (z_i - MD - \bar{x}_i)^2$$

LV may be helpful in the detection of early defects, as it increases with small defects as well as with increased SF. If LV is increased, one needs further evaluation to see whether it is an expression of a true early defect, an expression of increased scatter, or possibly both. Double measurements are not needed for the calculation of LV, which is important for time-saving screening programs (Flammer 1984).

Corrected loss variance. As mentioned above, LV may be increased by scatter or by real deviations. An additional visual field index, corrected loss variance (CLV), was therefore introduced (Flammer et al. 1985). CLV helps to separate real deviations from deviations due to scatter (Augustiny and Flammer 1985). With the help of double determinations, one can estimate the scatter, calculate how much of the LV is due to scatter, and how much is due to an additional component expressing real local deviations. In a statistical sense it is a component of variance and is calculated as follows:

$$CLV = LV - \frac{1}{n}(SF)^2$$

Third central moment. The third central moment (M3) of the distribution of the deviation of measured values from expected values is sensitive to deviations restricted to a very low number of test locations. It may therefore be helpful in the detection of very early visual field defects (Brechner and Whalen 1984). It is calculated as follows:

$$M3 = \frac{1}{m} \sum_{i=1}^{m} (z_i - MD - \bar{x}_i)^3$$

Skewness. Skewness (Q) yields principally the same information as M3. It is a standardized M3 and is calculated as follows:

$$Q = \frac{M3}{\sqrt{(LV)^3}}$$

Spatial correlation. The visual field indices introduced so far do not account for the spatial arrangement of the defects. We may be interested in the clustering of the defects. This can be done by the calculation of spatial correlation (SC). SC is low if the defects are distributed all over the visual field randomly and becomes larger if the defects are clustered. It is calculated as follows (Bebie 1985):

$$SC = \frac{1}{p} \sum_{(ij)} (z_i - MD - \bar{x}_i)(z_j - MD - \bar{x}_j)$$

where p = number of pairs involved in the summation and ij indicates a summation over pairs of adjacent test locations.

Application and illustrative examples

The calculation of these indices can be applied to different types of programs of different types of perimeters. A prerequisite for this calculation, however, is the knowledge of normal values (Flammer 1985a), a sufficient number of test locations, and thresholding with an appropriate strategy. We have to be aware, though, that the mean values

Table 1. Three examples of measurements with the Octopus program J0 and the corresponding visual field indices

a)

17	17	20	18		19	21	20	21	+18
18	12	15	19		20	21	20	21	
21	17	21	24		24	23	22	18	
21	21	23	22		22	21	23	21	
23			26		24	23	21	23	
18			22	28	25	25	19	19	
		26	27	26	25				0
		25	22	25	26				
22			25	26	24	24	22	18	
22			23		24	26	21	18	
21	24	28	22		24	22	18	17	
20	21	24	22		24	22	18	16	
18	20	21	20		22	17	09	11	
19	19	19	22		23	15	17	20	−18
−24				0				+24	

MS = 21.17 dB
MD = 4.91 dB
LV = 4.58 (dB)^2
CLV = 2.58 (dB)^2
SF = 1.99 dB
M3 = 2.00 (dB)^3
Q = 0.94
SC = 1.86 (dB)^2

b)

23	27	25	24		26	26	25	26	+18
23	27	25	21		26	23	19	25	
25	28	29	29		28	26	26	24	
25	23	29	28		29	26	23	25	
25	23	08	00		30			27	
25	23	01	05	32	29			25	
			25	31	30	33			0
			30	33	32	28			
26	27	30	33	32	31			27	
25	22	29	30		30			25	
26	28	28	29		30	29	29	28	
23	26	29	27		25	27	26	24	
26	25	24	26		26	26	29	26	
25	26	27	27		25	25	27	29	−18
−24				0				+24	

MS = 25.80 dB
MD = 2.58 dB
LV = 28.27 (dB)^2
CLV = 26.68 (dB)^2
SF = 1.94 dB
M3 = 8.41 (dB)^3
Q = 1.58
SC = 6.73 (dB)^2

c)

23	22	12	10		14	00	26	00	+18
23	18	20	05		04	00	23	04	
20	24	16	10		22	00	04	00	
25	23	18	19		19	00	01	04	
23			28		18	16	01	00	
24			26	25	18	17	00	00	
		29	27	26	27				0
		29	29	29	28				
21			29	29	29	24	25	21	
21			27		30	23	22	11	
25	24	25	25		25	25	24	21	
23	25	23	27		25	25	25	26	
16	21	21	26		25	24	26	24	
08	23	21	25		27	25	26	26	−18
−24				0				+24	

MS = 19.40 dB
MD = 8.28 dB
LV = 68.88 (dB)^2
CLV = 47.86 (dB)^2
SF = 6.42 dB
M3 = 7.83 (dB)^3
Q = 0.94
SC = 34.57 (dB)^2

of any index and its distribution should not be transferred from one program to another and that they are totally meaningless from one type of perimeter to another. Knowledge of this distribution, however, is necessary to separate pathological visual fields from normal visual fields at a given level of statistical significance (Bebie 1985).

A large multicenter study for the evaluation of normal values and the distribution of the visual field indices is currently being carried out for the Octopus glaucoma program G1 (Flammer 1984). In this program the indices are calculated routinely and automatically at the end of the measurement.

Figure 2 illustrates the indices calculated from the results of the Octopus program J0 (Jenni et al. 1983). The first visual field (Table 1a) is from the left eye of a 71-year-old glaucoma patient. MD is remarkably increased, 4.91 dB (normal range up to 1.8 dB; Bebie 1985), whereas CLV is only very slightly increased, 2.58 dB^2 (normal range up to 2.2 dB^2; (Bebie 1985). This is an example of diffuse visual field damage (Flammer et al. 1985).

The second example (Table 2b) is a visual field of the right eye of a 57-year-old glaucoma patient. CLV is markedly increased (26.68 dB^2), whereas MD is only slightly increased (2.58 dB), indicating a localized scotoma in an otherwise normal visual field.

The third example (Table 2c) is the visual field of a left eye of a 66-year-old patient with low-tension glaucoma. Extensive damage has occurred, with a corresponding increase of MD (8.28 dB) and CLV (47.86 dB^2). Since this defect is spatially correlated (continuous scotoma), the SC is also notably increased.

We would like to emphasize that in order to interpret the results of a visual field test, one does not need to check all indices. Some may be useful for the early detection of defects, others for follow-up, and so on.

Discussion

We have described some statistical methods for data reduction that may be applied to the visual field. Some of these methods have already been applied in different Octopus programs. The SF is calculated routinely in a number of programs with so-called normal strategy. The mean sensitivity is calculated in program DELTA (Program DELTA, Interzeag) as well as STATJ0 (Jenni et al. 1983). The other parameters, such as MD, LV and CLV, have already been shown to be useful in the evaluation of the glaucomas (Flammer et al. 1985).

Future routine calculation of these indices will help the clinician to interpret a visual field. At a very early stage small local defects may be detected by using the skewness index (Brechner and Whalen 1984). The CLV may help to decide whether a local deviation is due to scatter or whether it is more likely to be a genuine local field defect. The LV may help in screening tests to decide whether a visual field is normal without local deviations and without increased scatter or whether there are some changes. In the case of increased LV, retests will be needed to calculate the CLV, which separates scatter from true deviations (Flammer 1984). At a later stage of disease, MD or the MS may be specially helpful to recognize a trend toward improvement or deterioration. The SC helps ascertain whether the defects found by the other indices, like LV or CLV, are clustered or not. It should be emphasized that calculation of the visual field indices does not provide the topography of the defects. A graphic display such as a gray scale will still have to be included in the evaluation of the visual field abnormalities.

We hope that the application of the statistical principles described will be of help to the clinician in the detection and follow-up of glaucomatous visual field defects and perhaps others.

Acknowledgements. The author would like to thank Dr. H. Bebie, Dr. S.M. Drance, Ms. C. Augustiny, and Dr. U. Guthauser for their help.

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Received March 11, 1985 / Accepted January 27, 1986