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Topographic spatial summation in glaucoma

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PURPOSE. *Stimulus luminance (L) and area (A) are related by the equation* LxA^k*=constant. The authors evaluated the k value at 66 positions of the central visual field in patients with glaucoma, to modify L and A simultaneously in order to examine advanced glaucomas with a bigger dynamic range.*

METHODS. *The luminance limitation of a computer screen with automatic photometric control was compensated for by increasing the stimulus area in the range between 0 and 17 dB, using the k topographic values previously calculated on normal subjects. Four initial series of 21, 12, 10, and 10 glaucomas were sequentially examined with the Octopus 311 in which the stimulus size cannot be freely changed during the examination, and with the experimental method (Pulsar-SAP) modifying stimulus sizes to equal the results. k Final estimation was verified in 60 new cases.*

RESULTS. *k Values increase progressively with defect deepness. Values higher than those of the normal population with equivalent topographic differences were obtained. Correlation between indices was as follows: MD: r=0.94 (p<0.0001); square root of the loss of variance (sLV): r=0.93 (p<0.0001). Frequency of local defects was similar in both procedures. Average topographic differences between thresholds were usually less than 1 dB. The average threshold difference favored Pulsar-SAP by 0.45 dB at those points where the average threshold of both examinations was less than 18 dB and 0.37 dB where such average was higher than or equal to 18 dB.*

CONCLUSIONS. *k Value is higher in patients with glaucoma than in normal subjects, although the topographic features are similar. It is feasible to design a scale combining stimulus luminance and sizes to use screens with relative low brightness as surfaces for visual field examination. (Eur J Ophthalmol 2007; 17: 538-44)*

KEY WORDS. *Perimetry, Visual field, Spatial summation, Glaucoma, Threshold*

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INTRODUCTION

Kinetic perimetry allows the knowledge of the relation between stimulus luminance and area, which could be defined by the equation LxA^k=constant, where L is the stimulus luminance and A its area (1). k Is therefore a constant which defines spatial summation and was first estimated to be 0.83, although it was later observed that its value changed from the center to the periphery of the visual field.

Kinetic (2) as well as static (3) and later automatic perimetry (4-6) allowed defining these differences more precisely. k Was estimated to be approximately 0.3 in the fovea and close to 1 in the peripheral visual field. These values are not affected by age (7). In general, these calculations were carried out for stimuli sizes close to the most usual on perimetry (Goldmann III) and it was observed that k decreased for much bigger sizes.

Topographic estimation of k at 66 positions of the normal central visual field was carried out. The results of the equation LxA^k were calculated for all k values between 0.001 and 1 in 0.001 steps (1000 levels) using the luminance value corresponding to the aver-

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age threshold obtained at each of the 66 examined positions for five stimulus sizes. Pearson's variation coefficient for the five resulting levels at each 1000 level was then calculated and the k value at each position defined as that level with the smallest Pearson's variation coefficient. It was observed that while the averaged values in relation to eccentricity match those reported by other authors, there are important topographic differences, so that k is minimum on the upper nasal field, with a value similar to that at the fovea, and maximum at the lower quadrants (8).

All these studies were carried out on normal subjects, using an appropriate luminosity range. However, information about spatial summation on pathologic conditions is poor. It has been generally suggested to use size Goldmann V when the dynamic range of the conventional examination using the normal size III is not enough.

This article aims to value the spatial summation characteristics when the visual field is affected by glaucoma. In these cases, luminous intensity, or its equivalent area, should reach much higher values than those used for normal subjects. One practical application of this analysis would be the possibility of increasing the dynamic range of the examination for advanced glaucomas and using conventional screen monitors for perimetric examinations, since they have limited dynamic range as a result of their maximum luminance being much lower than in conventional perimeters. If the equivalence between stimulus area and its intensity was known, luminance limitation could be compensated for by appropriate size increases.

MATERIALS AND METHODS

Two perimeters have been used for this study: Octopus 311 and Pulsar Octopus experimental prototype (HAAG-Streit, Bern, Switzerland). The Octopus 311, which was used as gold standard, does not have the option to freely change stimulus size during the examination. The second one (Pulsar) has automatic photometric calibration using a digital photometer located at a corner of a 19-inch Sansung SyncMaster 959NF screen (Sansung Electronics Co., Suwon City, Kyungki-Do, Korea). The photometer sends luminance information to a computer via USB, and the computer periodically regulates brightness and contrast to achieve and maintain the desired luminance scale. This way, 256 white stimulus values common on conventional computer programs are achieved. Maximum luminance variation between the several screen areas was approximately 1%; 1024 × 768 pixels resolution was used. With this resolution stimulus size can be changed smoothly.

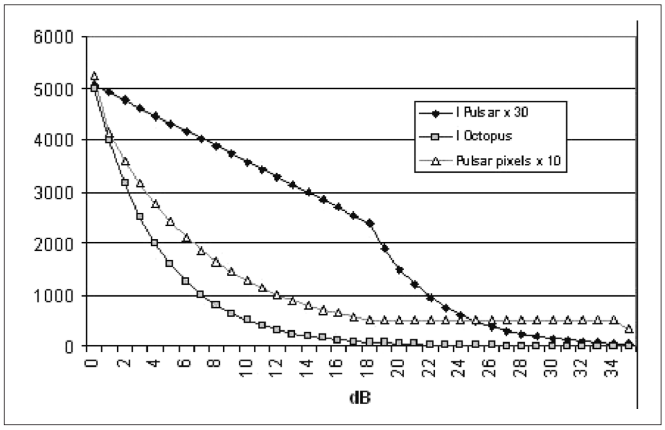

Fig. 1 - *Stimulus size in the Octopus 311 is constant and its intensity increases in a logarithmic fashion (in asb in the graph). Between 18 and 35 dB, Pulsar SAP uses a stimulus size equivalent to Goldmann III (in the graph, the number of pixels multiplied by 10 is indicated) and intensity similar to the one used by the Octopus 311 (in the graph asb ×30 to use the same y-axis scale). Below 18 dB, the Pulsar-SAP scale increases intensity linearly and increases the stimulus size progressively.*

In both cases a 31.5 asb background was used. The same intensity and stimulus size was also used in both cases on the normal thresholds range (18–35 dB) (Fig. 1). The PULSAR perimeter was initially designed for examining visual field functions such as spatial resolution, contrast, critical fusion frequency, color, and motion. In this case, it was used to generate stimuli similar to those used on conventional standard automatic perimetry (program Pulsar-SAP).

The usual intensities logarithmic scale was substituted on the Pulsar perimeter by a linear one between 0 and 17 dB, with a maximum of 168.5 asb for 0 dB (Fig. 1). Using the k topographic values previously obtained, the stimulus sizes needed to compensate for the difference between luminous intensity of the conventional scale and that of the lineal scale previously described were calculated. Considering maximum intensity corresponding to 0 dB in the Octopus 311 is

5000 asb, for an intermediate k value k=0.6:

$5000 \times 1^{0.6} = 168.5 \times A^{0.6}$

Therefore, at 0 dB, stimulus surface (A) should be 284.5 times bigger than usual (Goldmann III), which would be equivalent to a stimulus around 6° in diameter (close to Goldmann VII). The size of the rest of stimuli between 1 and 17 dB were calculated the same way (Fig. 1). Since every point in the visual field has a different k value, a specific scale for each one of them was calculated.

The patient's eye was placed at 31 cm from the center of a computer screen with 1024 × 768 pixels resolution, with the appropriate optical correction. The use of a tangent screen required correcting the stimulus sizes previously calculated at each point of the visual field as a function of eccentricity, to compensate for their angular size reduction. That is, a specific stimulus size weighted considering k and eccentricity was used at each point in the visual field.

The arrangement of examination points in the PULSAR perimeter was equivalent to that of Octopus program 32, excluding the upper and lower rows (horizontal = –30° to +30°) × (vertical = +24° to –24°), with a 6 degrees separation between stimuli. A total of 66 points was examined. From the statistical point of view, only coinciding points in both perimeters were analyzed. Tendency oriented perimetry (TOP) strategy (9) was used in both cases. Same normality and threshold deviation in relation to age was used to calculate perimetric indices in both cases. The order of examinations was randomized carrying them out on the same session with minimum rest of 10 minutes.

All subjects had wide perimetric experience and motivation in the tests. All subjects had visual acuity 1.0 or better, ametropia lower than 2.00 D sphere and 1.75 cylinder. Although they all had an adaptation period, a verification of less than 25%, catch trial errors was required. Distance refraction was used for examinations on the Octopus 311 and near vision correction was used for the Pulsar perimeter. Near visual acuity was tested before each examination with a specific test implemented in Pulsar.

Five consecutive series of cases diagnosed with chronic open angle glaucoma with local defects of variable deepness were examined. Only one eye per subject was included. The first four series consisted of 21, 12, 10, and 10 cases and were used to empirically correct the size scales until equivalent results between both perimeters was achieved. After the last adjustment was carried out, a fifth series of 60 patients was examined. The same patient was never used for successive series.

The procedure used was as follows: After examining the first series, the threshold frequency distribution at each point of the visual field was examined for both perimeters, calculating the mean difference in decibels throughout the scale. Pulsar-SAP stimulus sizes were proportionally adjusted to the difference observed. The resulting scale was applied to the following series. The same procedure was applied to the successive series. That way, the differences between the results of both perimeters was progressively reduced on the successive series until reaching the final scale which was applied to the fifth series.

Alter obtaining equivalent results with both perimeters, local k values were obtained following the following example: If the normal k value at certain visual field position was 0.728 and Goldmann size III is achieved by 56 pixels, a stimulus of 5000 asb (0dB) would produce the following result on the spatial summation equation:

$5000 \times 56^{0.728} = 93681$

If we achieve the same visual result with both perimeters in areas with very low sensitivity with an intensity of 168.5 asb and a size 580 pixels we would have:

$168.5 \times 580^{k} = 93681$

from which we can deduce a value of $k = \log(93681/168.5)/\log(580) = 0.9933$.

The studies were conducted in accordance with the tenets of the Declaration of Helsinki and informed consent was obtained from each subject.

RESULTS

Characteristics of the patients are shown in Table I.

Results of the first series indicated that the stimulus sizes estimated by normal k values to compensate for luminance limitation were excessive. The thresholds obtained were on average 4 dB higher than with

TABLE I - CHARACTERISTICS OF THE PATIENTS IN THE FIVE SERIES

Series	Male	Female	Age, yr, mean (SD)	MD<6 dB	6 dB<MD<12 dB	MD>12 dB	sLV, mean (SD)
1	11	10	59.4 (12.5)	5	10	6	6.1 (2.8)
2	6	6	54.2 (18.9)	5	4	3	4.7 (3.1)
3	5	5	59.2 (14.1)	4	3	3	5.3 (2.5)
4	4	6	49.7 (24.2)	4	2	4	4.5 (2.7)
5	25	35	51.3 (20.1)	32	17	11	4.4 (2.8)

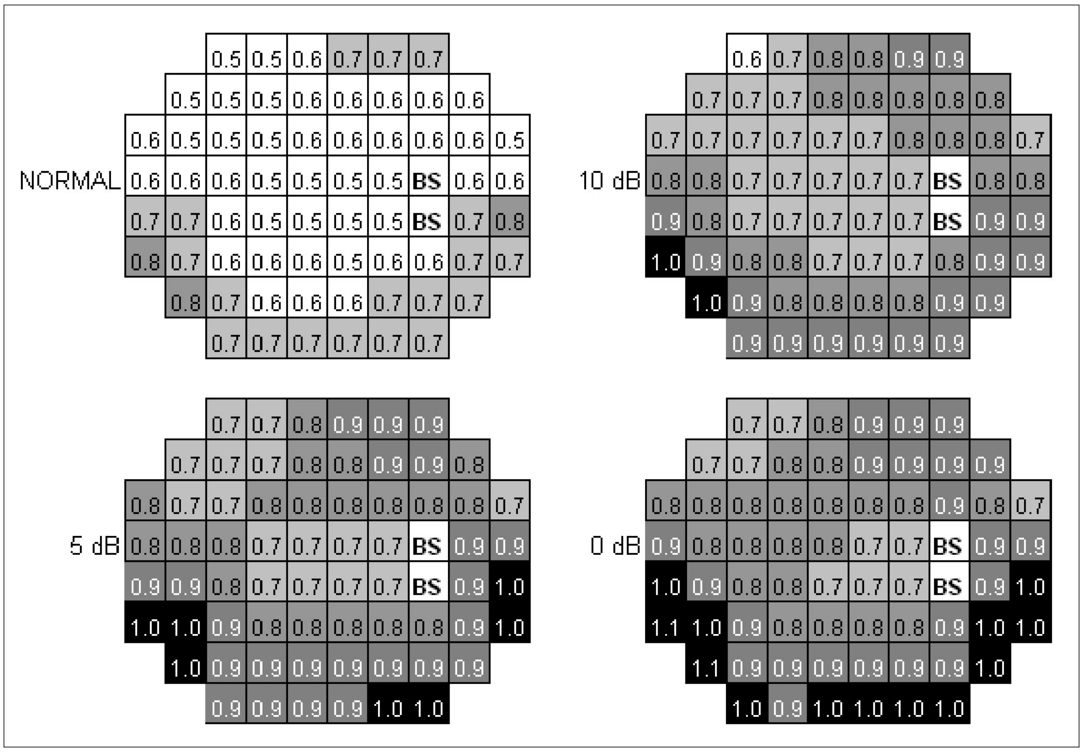

Fig. 2 - *k Values estimated for normal subjects and for glaucoma subjects in areas close to sensitivities of 10 dB, 5 dB, and 0 dB. A k increment for the deepest scotomas may be observed, while similar topographic differences are maintained.*

			0.5	0.5	0.6	0.7	0.7	0.7		
		0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	
	0.6	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.5
NORMAL	0.6	0.6	0.6	0.5	0.5	0.5	0.5	BS	0.6	0.6
	0.7	0.7	0.6	0.5	0.5	0.5	0.5	BS	0.7	0.8
	0.8	0.7	0.6	0.6	0.6	0.5	0.6	0.6	0.7	0.7
		0.8	0.7	0.6	0.6	0.6	0.7	0.7	0.7	
			0.7	0.7	0.7	0.7	0.7	0.7		

			0.6	0.7	0.8	0.8	0.9	0.9		
		0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	
	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.7
10 dB	0.8	0.8	0.7	0.7	0.7	0.7	0.7	BS	0.8	0.8
	0.9	0.8	0.7	0.7	0.7	0.7	0.7	BS	0.9	0.9
	1.0	0.9	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.9
		1.0	0.9	0.8	0.8	0.8	0.8	0.9	0.9	
			0.9	0.9	0.9	0.9	0.9	0.9		

			0.7	0.7	0.8	0.9	0.9	0.9		
		0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.8	
	0.8	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.7
5 dB	0.8	0.8	0.8	0.7	0.7	0.7	0.7	BS	0.9	0.9
	0.9	0.9	0.8	0.7	0.7	0.7	0.7	BS	0.9	1.0
	1.0	1.0	0.9	0.8	0.8	0.8	0.8	0.8	0.9	1.0
		1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	
			0.9	0.9	0.9	0.9	1.0	1.0		

			0.7	0.7	0.8	0.9	0.9	0.9		
		0.7	0.7	0.8	0.8	0.9	0.9	0.9	0.9	
	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.7
0 dB	0.9	0.8	0.8	0.8	0.8	0.7	0.7	BS	0.9	0.9
	1.0	0.9	0.8	0.8	0.7	0.7	0.7	BS	0.9	1.0
	1.1	1.0	0.9	0.8	0.8	0.8	0.8	0.9	1.0	1.0
		1.1	0.9	0.9	0.9	0.9	0.9	0.9	1.0	
			1.0	0.9	1.0	1.0	1.0	1.0		

Octopus 311. The following series were used progressively to adjust the results. It may be observed in Figure 2 that the k values progressively increase at areas with lower sensitivity. k Values higher than 1 are probably due to not having reached absolute precision on the measures. However, k topographic differences were equivalent, being maximum values at the lower peripheral areas and minimum at the center and upper nasal quadrants.

In the fifth series average Octopus 311 duration was 2:24 minutes (SD=0:07) and Pulsar-SAP duration was 2:27 minutes (SD=0:15).

Correlation between MD values is shown in Figure 3 (r=0.94, error of estimating X from Y = 1.86 dB, p<0.0001).

Correlation between the square root of the loss variance (sLV) is shown in Figure 4 (r=0.93, error of estimating X from Y = 1.1 dB, p<0.0001).

Correlation between the number of points with deviation higher than 5 dB in relation to the normal average for the subject's age (NPP) is shown in Figure 5 (r=0.93, error of estimating X from Y = 8.75, p<0.0001).

Frequency of local defects was similar in both procedures (Fig. 6).

The difference of local defects estimated by both perimeters was lower than 5 dB in 75% of cases and lower than 2% in 44% of cases (Fig. 7).

Average topographic differences between the Pulsar-SAP and Octopus-311 thresholds, examined point by point, were usually less than 1 dB, without significant

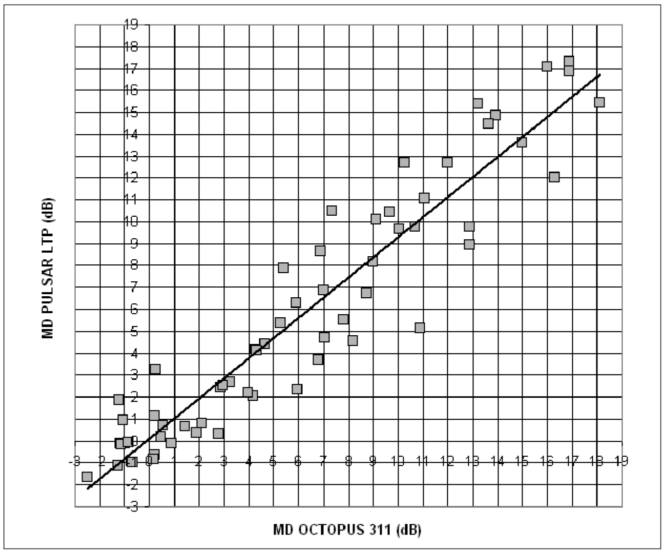

Fig. 3 - *Correlation of MD values.*

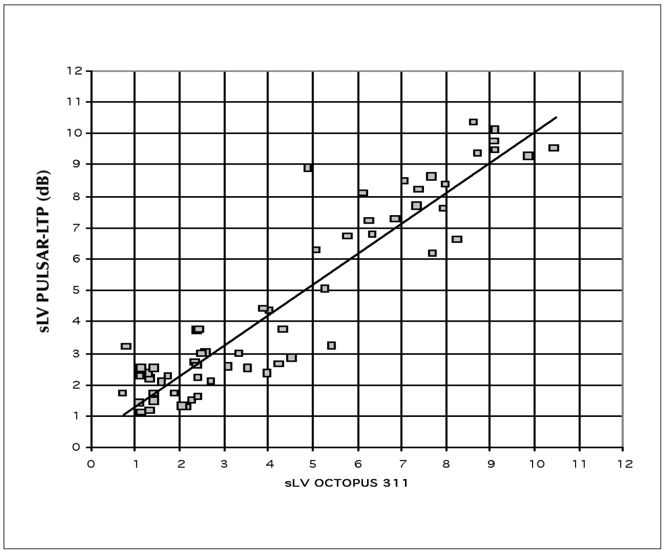

Fig. 4 - *Correlation of sLV values.*

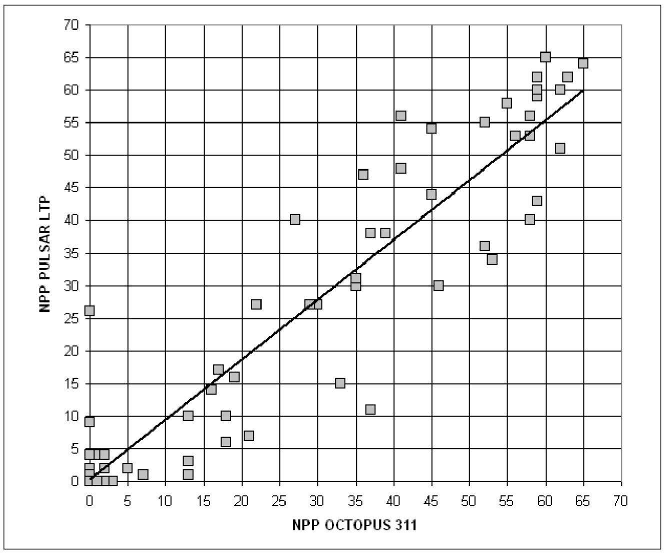

Fig. 5 - *Correlation of NPP values.*

differences between the four visual field quadrants (Fig. 8).

The average threshold difference favored Pulsar SAP 0.45 dB at those points where the average threshold of both examinations was less than 18 dB and 0.37 dB where such average was higher than or equal to 18 dB. Figure 8 shows the examinations from two eyes with scotomas of different location and severity using both instruments.

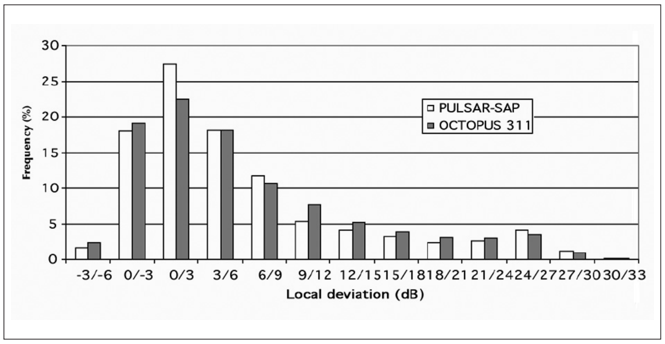

Fig. 6 - *Frequency of local defects (in dB) on the whole examined sample.*

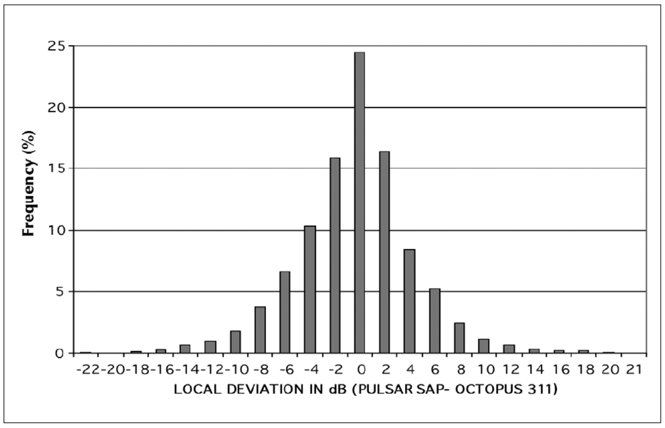

Fig. 7 - *Frequency of threshold differences (Pulsar SAP-Octopus 311).*

		0.4	0.2	0.4	0.6	0.9	0.9		
	0.7	0.5	0.4	0.5	0.6	0.8	0.8	1.0	
1.0	0.8	0.7	0.6	0.6	0.7	0.7	0.7	0.7	0.8
0.9	0.8	0.8	0.8	1.0	1.1	1.1		0.4	0.4
0.6	0.5	0.5	0.7	0.9	1.1	0.9		0.0	0.1
0.2	0.1	0.1	0.2	0.4	0.6	0.3	0.1	-0.2	-0.2
	-0.5	-0.5	-0.4	-0.2	-0.1	-0.2	-0.2	-0.2	
		-0.7	-0.7	-0.5	-0.4	-0.3	-0.3		

Fig. 8 - *Average topographic threshold differences (Pulsar SAP-Octopus 311).*

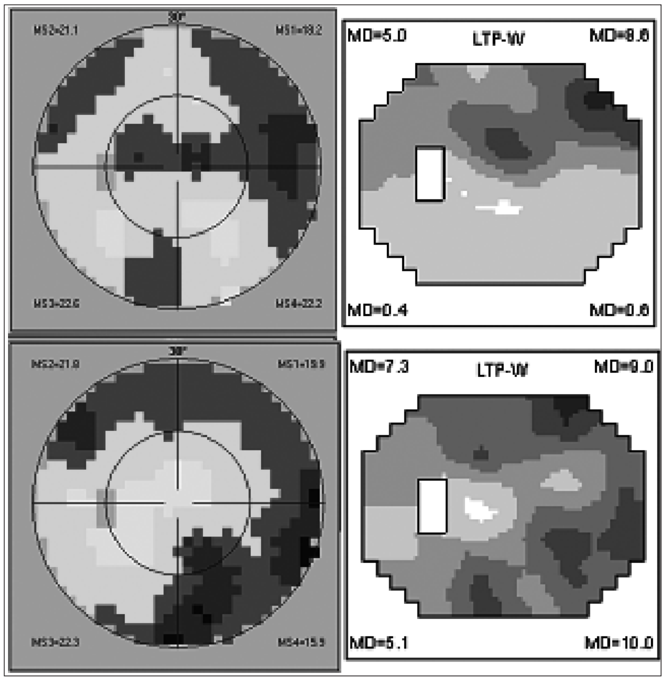

Fig. 9 - *Results of the examinations of two eyes with scotomas of different severity and locations. Left Octopus 311 and right Pulsar SAP.*

DISCUSSION

If the equation LxA^k=constant is admitted as true in glaucoma, the fact that there are k values close to 1 is very far from what has been described for normal subjects, even more considering that a k reduction should be expected when using very big stimuli.

In fact, when we expected to need stimuli close to Goldmann VII to obtain results equivalent to Octopus 311 0 dB, we observed that it was enough to use sizes slightly bigger than Goldmann V in the center and upper nasal visual fields and slightly lower than Goldmann V at the lower periphery.

We should then conclude that both the increment of the k value with eccentricity on normal subjects described by other authors (3, 6, 10-14) and our own topographic k values should be corrected for pathology cases.

Dannheim and Drance (15), using manual static perimetry with the Tubinger perimeter on areas with relative scotomas from glaucoma subjects, observed an inconstant k reduction for small stimuli, but not for sizes similar to the ones used in this article. They did not rule out that there may be alterations for bigger sizes which would suggest the interference of normal areas close to scotomas or fixation instability interfering on the observations. The second hypothesis seems more probable, since we now know that near areas have close interdependence relations in glaucoma (16), which makes these kinds of influences unlikely to be important. About fixation, automatic perimetry has progressed significantly, in relation to manual static perimetry, using shorter stimuli with unpredictable locations.

It has been previously stated that the observed k increment in glaucoma subjects using big stimulus sizes seems to be in contradiction with its reduction for big stimuli in normal subjects. Garway-Heath et al (5) have suggested that the area (A) in the spatial summation formula could be substituted by the number of ganglion cells. If such an idea is applied to our results, the increment of k in relation to normal subjects may reflect that less cell loss than expected from the formula would produce the same functional loss.

This article's results confirm that there are topographic differences in spatial summation, not only in relation to eccentricity, but also at the different visual field quadrants, and that such differences approximately hold in cases of glaucoma.

We may conclude that it is feasible to use a scale combining stimulus luminance and sizes for screens with relative low brightness to work as surfaces for visual field examination. The results from the last series are almost equivalent in both perimeters but they will also be used for small adjustments which will increase their similarity even more. Nowadays there are computer screens with much higher luminance than the one used for this article, which would allow manufacturing an instrument with a great dynamic range applying the same ideas. That way, deeper scotomas could be examined.

The first author has proprietary interest in the TOP strategy and in the Pulsar Perimeter.
None of the other authors has any proprietary interest.

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