Spatial Resolution of the Tendency-Oriented Perimetry Algorithm

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**Purpose.** Tendency-oriented perimetry (TOP) is a new strategy designed to estimate the sensitivity of the visual field quickly, by using linear interpolation between test locations. This study determined the spatial resolution characteristics of TOP.

**Methods.** A Monte-Carlo technique was used to simulate visual fields, and incorporated realistic amounts of subject response variability as well as variability in the average sensitivity of the field. Visual field defects of various depths, ranging from a single point through to 18 contiguous points, were added to the simulated fields. An estimate of the visual field was made using the TOP algorithm. Global indices (mean deviation [MD] and loss variance [LV]) were calculated for both the true visual field and the TOP estimate.

**Results.** For small defects of one or two points, the TOP algorithm typically overestimated sensitivity. Sensitivity estimates tended to stratify into one of two possible values, with the lower value being dependent on the absolute position of the defect within the visual field. Although MD was satisfactorily predicted by TOP, LV was underestimated and reached a plateau when defects were deep, especially with smaller defects. For relatively large defects of nine contiguous points, both defect depth and LV was predicted with reasonable accuracy by TOP. The TOP sensitivity estimate for normal locations surrounding a defect was systematically reduced.

**Conclusions.** The TOP procedure has a number of unusual spatial characteristics that prevent it from accurately estimating the spatial extent and absolute sensitivity of visual field defects. (Invest Ophthalmol Vis Sci. 2003;44:1962–1968) DOI: 10.1167/iovs.02-04828

Assessment of the integrity of the visual field by static automated perimetry is commonplace in clinical ophthalmic practice. In the interests of increasing the patient’s comfort and throughput, as well as reducing fatigue, faster thresholding strategies have been developed to estimate the sensitivity of the visual field in significantly less time than conventional staircase techniques.1-3 Recently, the Octopus perimeter (Interzeag AC, Schlieren, Switzerland) has incorporated an accelerated thresholding algorithm called tendency-oriented perimetry (TOP).

The TOP algorithm uses a subject’s response at a given point, not only to estimate the sensitivity at that point, but also to modify the sensitivity estimate of surrounding points within the visual field.4,5 Stimuli are presented only once at each test location, resulting in a marked reduction in test times compared with conventional staircase strategies and allowing the sensitivity of the visual field to be estimated in approximately 2.5 minutes.6

González de la Rosa et al.4 reported that correlations between global indices of the visual field (mean deviation [MD] and loss variance [LV]) for a conventional staircase procedure and the TOP algorithm were high, as assessed on a moderately sized group with mixed disease states. Other investigators have found similarly high correlations.7,8 However, studies have found significantly reduced values for LV when compared with conventional staircase strategies,9-10 which suggests that the TOP strategy underestimates the depth of focal defects.

The spatial resolution of the TOP strategy has not yet been investigated thoroughly. It has been noted that the borders of deep scotomata are less distinct with TOP,4,5,7 which likely reflects the spatial averaging inherent in the procedure. Although spatial averaging techniques have been advocated by some researchers to reduce test variability11 and thereby improve the ability to monitor progression,12 others have found that the ability to detect progression of small defects is masked by spatial averaging.13 Because of the relatively complex rules used by TOP, the nature of any spatial averaging in the technique is unlikely to be as simple as that from the post hoc techniques investigated in previous studies.11-13

This article examines the performance characteristics of the TOP procedure, using computer simulations. In particular, this article examines the spatial resolution of TOP, given that the procedure makes extensive use of linear spatial interpolation when determining sensitivity estimates. Simulation studies are advantageous, in that the sensitivity and response characteristics of the simulated observer are known precisely and can be manipulated systematically, which cannot be done in conventional perimetric studies. Although simulation studies using the TOP algorithm have been performed previously,3 the details of the simulation technique used are unclear. In particular, it is unknown whether the influence of response variability was incorporated into the observer response model. In addition, only a few summary indices from these simulations were presented,3 which may not be sufficiently sensitive to demonstrate systematic trends in the TOP data.

**Methods**

Tendency-Oriented Perimetry

In the TOP procedure, the visual field is divided into four overlapping submatrices (Fig. 1). The procedure commences by assuming that the initial sensitivity estimate for each location is half the age-expected sensitivity value (Fig. 2a).7 Stimuli from the first submatrix are presented, and the responses recorded (Fig. 2b); a “seen” response is recorded as +1/6 of the age-expected sensitivity at the location, and an “unseen” response is recorded as −1/6 of the age-expected sensitivity. Threshold estimates are then adjusted by the average response value, based on a $3 \times 3$ window centered on the point in question (Fig. 2c). Testing then continues for points from the second submatrix, with responses recorded as $\pm 1/6$ of the age-expected sensitivity. Threshold estimates then are adjusted, based only on the average responses from the second submatrix, again using a $3 \times 3$ window. Responses from
the third and fourth submatrices are similarly recorded as $\pm \frac{3}{16}$ and $\pm \frac{1}{16}$ of the age-expected sensitivity, respectively, and sensitivity estimates adjusted as outlined previously.

Simulation Details

The pattern of visual field locations simulated was as given in Figure 1, which is identical with that used in TOP perimetry.4 For simplicity, the sensitivity of the visual field was assumed not to change with eccentricity. As the starting values and step sizes in the TOP technique are all relative to the expected normal sensitivity for each test location, the absolute test sensitivity is of limited importance. Also, the effects presented in the Results section are large, compared with eccentricity-related changes in sensitivity, and are unlikely to be altered by the incorporation of eccentricity-related effects into the simulation. Furthermore, the calculations in the TOP algorithm occur over a $3 \times 3$ window, rather than the whole visual field, and so the assumption that sensitivity does not change with eccentricity is more closely met over this small window. The advantage of assuming a constant sensitivity across the visual field, however, is that it allows the effect of the TOP algorithm to be compared between multiple points without normalization (e.g., Fig. 6) and makes the relatively complex workings of the TOP algorithm more easily understood.

The average sensitivity of the visual fields (before the incorporation of any field defect) was 30 dB and was randomly varied between simulated fields with a Gaussian distribution of 1.5 dB SD, consistent with the values expected in normal Octopus perimetry.14 Visual field defects were simulated by reducing the sensitivity of points within a given region by between 0 and 30 dB, with all points in the defect reduced by identical amounts. Therefore, for a given field, the sensitivities of all normal locations were identical, as were the sensitivities of all abnormal locations. The blind spot was not incorporated into the visual field, because it is not clear how the TOP algorithm is implemented in this area.

The subject’s response to a stimulus was generated with a cumulative Gaussian psychometric function, the mean of which was centered on the sensitivity value described earlier. The SD of the cumulative Gaussian was 1.1 dB, which is equivalent to that expected from normal observers.15 (The interquartile range reported by Spry et al.15 is...
The median was used as the measure of central tendency. The spread of the data was quantified by the 10th and 90th percentiles, which corresponds to ±1.28 SD for normally distributed data. Two global indices for the analysis of the visual field were calculated: mean deviation (MD) and loss variance (LV). These indices were calculated using the formulas given by Bebie,\textsuperscript{20} with MD being equal to Bebie's mean defect, but of opposite polarity (i.e., reduced sensitivity = negative MD). Therefore

\[
MD = -\left(\frac{1}{7}\sum_{i=1}^{7} z(i)\right); \quad z(i) = m(i) - x(i)
\]  \hspace{1cm} (1)

(1) where \(m(i)\) is the normal sensitivity at location \(i\), and \(x(i)\) is the measured sensitivity. Loss variance was calculated as follows

\[
LV = \frac{1}{T-1} \sum_{i=1}^{T} [z(i) - MD]^2
\]  \hspace{1cm} (2)

The index MD provides a measure of uniform loss or loss involving a large fraction of the visual field, whereas the index LV provides a measure of local irregularity.

### Results

#### Single Defective Point

Figure 3 plots the true sensitivity of a single defective point in one of the four submatrices, versus the TOP estimate of sensitivity (circles). For an ideal thresholding strategy, data should fall along the 45° solid line in each panel. TOP sensitivities for the defective points typically stratified into one of two values, with normal sensitivities of 30 dB returned for shallow defects and subnormal sensitivities returned for deeper defects. The minimum sensitivity returned by TOP increased as the submatrix number increased, and the "knee" in the bistratified line moved to the right.

The solid and dashed lines show the median sensitivity of normal points surrounding the defective point, as schematically represented in the lower right corner of each panel. When the sensitivity estimate for the defective point became abnormal, the sensitivity estimate of the surrounding normal points typically was reduced also below the nominal average sensitivity of 30 dB. The magnitude of the sensitivity reduction was not uniform for all surrounding points in most cases.
Two Contiguous Defective Points

Figure 4 shows the plot of the true sensitivity of a pair of defective points versus the TOP estimate of sensitivity (circles and squares), for pairs of points located as in the schematic diagrams. A stratification of TOP sensitivity estimates occurred that showed a pattern similar to that in Figure 3. The minimum sensitivity estimate typically was lower, however, for two contiguous points than a single defective point. The estimated sensitivity of normal points surrounding the defective points (solid and dashed lines) was reduced when the sensitivity estimate for the defective points decreased. Simulations were also run for two diagonally contiguous points, and returned similar results (data not plotted); points on submatrices 1 and 2 reached a minimum plateau at 16 and 19 dB, respectively, and points on submatrices 3 and 4 reached a minimum plateau at 24 and 28 dB, respectively.

The data set shown in the top left-hand panel of Figure 4 was further analyzed to determine the effect of the TOP strategy on global indices of the visual field, with the results shown in Figure 5. The TOP algorithm provided a good estimated of the true MD (Fig. 5, top), but provided a poorer estimate of LV that was typically less than the true LV (Fig. 5, bottom).

Four Contiguous Defective Points

Figure 6 plots the true sensitivity of a cluster of four defective points versus the TOP estimate of sensitivity. The TOP algorithm returned lower sensitivities than for the smaller defects described previously, although sensitivities still reached a plateau for very deep defects. The estimated sensitivity of normal points surrounding the defective points (solid and dashed lines) decreased as the sensitivity estimate for the defective points decreased.

The summary indices for the data presented in Figure 6 are given in Fig. 7 and show that the TOP algorithm provided a good estimate of the true MD (Fig. 7, top). Estimated values of LV (Fig. 7, bottom) tended to plateau and so underestimated the true LV when defects were deep, which is consistent with the plateau in the sensitivities values seen in Figure 6.

Nine, and Greater, Contiguous Defective Points

Figure 8 plots the true sensitivity of a cluster of nine defective points versus the TOP estimate of sensitivity. The stratification seen previously (Figs. 3, 4) was absent, and sensitivity estimates continued to decrease as the true sensitivity of the defect decreased. A large spread in the sensitivity estimates for each of the defective points was evident, however, with the difference in sensitivity between the point in the center of the defect (triangles) and the edge of the defect reaching up to 14 dB. The estimated sensitivity of normal points surrounding the defective points (solid and dashed lines) reduced as the sensitivity estimate for the defective points decreased.

The summary indices for the data presented in Figure 8 are given in Fig. 9, and show that the TOP algorithm provided a good estimate of the true MD (Fig. 9, top). The prediction of the true LV (Fig. 9, bottom) was improved when compared with the case in which only two (Fig. 5) or four (Fig. 7) points in the field were abnormal, although LV still was underestimated when defects were deep.

A similar pattern was seen with a defect of 18 contiguous points arranged in an arcuate pattern (Fig. 10). Large varia-
tions in sensitivity still occurred between individual points within the defect (Fig. 10, bottom), and LV was systematically reduced for deep defects (Fig. 10, top).

Effect of False-Positive and False-Negative Responses

Figure 11 shows the effect of false responses on the global indices MD (Fig. 11, top) and LV (Fig. 11, bottom), for a defect of four points. False-positive responses had little influence on the median MD or LV, although variability was increased at high LVs. In contrast, false-negative responses moved both the MD and LV away from the values returned from a reliable observer (circles), and increased the variability in both indices.

DISCUSSION

The results of these simulations showed that the TOP strategy has poor spatial resolution characteristics. Sensitivity estimates for small defects showed a characteristic bistratification (Figs. 3, 4), with the depth of the defect typically being underestimated. Sensitivities were estimated with greater fidelity as defect size increased (Figs 6, 8, 10), although quite large defects of nine contiguous points were required before sensitivity estimates reaching 0 dB were achieved. It has been observed clinically that local absolute (0 dB) defects are missed by TOP. The sensitivity estimates for normal points surrounding the defect were reduced, consistent with the “blurring” of defects noted clinically.

Figure 3 shows that the depth of defect and the knee in the bistratified data were determined, in part, by the submatrix in which the defect was located. This can be explained through a close examination of the TOP rules. For example, in the top left panel of Figure 3, a “no” response in submatrix 1 should be recorded only when the sensitivity in the defect is below approximately 15 dB (half the age-expected sensitivity, and the starting point of the TOP procedure), and so sensitivities stratify based on whether the initially presented point was seen or not seen. All subsequent responses, being outside the area of loss, will proceed identically, regardless of the depth of the defect. Similarly, a “no” response would be expected in submatrix 2 only when the sensitivity in the defect declines below 22.5 dB (half the age-expected sensitivity + 7.5-dB step; see Fig. 2). This corresponds to the location of the knee in Figure 3, bottom right. A defect in submatrix 4 is completely missed (Fig. 3, top right), because a “no” response is expected even in areas of normal sensitivity, in that the test stimulus in submatrix 4 is nominally subthreshold (8/16 + 3/16 + 5/16 + 7/16 = 17/16 of normal sensitivity). Because the TOP step size decreases as each submatrix is tested, the depth of the estimated defect becomes shallower the higher the number of the submatrix in which the defect is located. In addition, the impact of false responses would be expected to be greatest in the earliest stages of the TOP algorithm when low-numbered submatrices are being tested, and it is for this reason that patients responding incorrectly early in the test are advised to have the test repeated.

FIGURE 7. Comparison of the true mean deviation (MD) versus the TOP estimate of MD (top) and comparison of the true loss variance (LV) versus the TOP estimate of LV (bottom), for the data presented in Figure 6. Linear regression equations for the data were $y = 0.94x - 0.19$ (top) and $y = 0.46x + 6.34$ (bottom). All other details are as described in Figure 5.

FIGURE 8. True sensitivity of a defective point (abscissa) versus TOP sensitivity estimate (ordinate) for a cluster of nine abnormal points. For clarity, some symbols have been laterally displaced (squares by -0.5, triangles by +0.5, and diamonds by +1) and error bars are not plotted. The Cartesian coordinate for the top left point in the defect was $(4, 5)$. Other details are as described in Figure 3.
The situation becomes slightly more complex as contiguous defect points appear in the field (e.g., Fig. 4), although the general pattern still holds: Defective points in low-numbered submatrices return deeper defects than those in higher-numbered submatrices, with the knee in any stratification moving to higher sensitivities when defective points are in higher-numbered submatrices. The presence of stratification in the sensitivity values demonstrates that TOP is insensitive to change in the true visual field when defects are small. Because of this, it may be expected that the ability of TOP to monitor progression of visual field defects is compromised, despite previous work suggesting that TOP has similar variability characteristics to a conventional staircase strategy.7

In all the simulations described in this article, the TOP algorithm provided a good estimate of MD. As this index is relatively insensitive to the localized visual field defects used in this evaluation, this result suggests that TOP provides appropriate sensitivity estimates of the normal areas of visual field. This dependence of the MD results on normal sensitivity is seen in Figure 5, where MD estimates are roughly symmetrically distributed above and below zero and are dependent on the variation in the sensitivity of the normal visual field (30 ± 1.5 dB) built into the simulation procedure, rather than the depth of the simulated defect. In contrast, the prediction of LV was less accurate and tended to underestimate the true LV when defects were deep (Figs. 5, 7, 9). This result agrees with the significant reduction in LV found in some clinical studies.8–10 The index LV is more predictive of focal losses in sensitivity within the visual field, and so the underestimation of LV is consistent with the underestimation of defect sensitivity depth typically seen in TOP (Figs. 3, 4, 6). This underestimation was preserved in the presence of substantial false-positive responses (Fig. 11).

As expected, the performance of the TOP algorithm was poorest when defects were deep and well demarcated, because this is when surrounding sensitivity is poorly predictive of local sensitivity. Although modifications to the spatial averaging used in TOP have been proposed to produce better spatial localization of sharp scotomata,7 these appear to be based on anatomic predictions made from the distribution of retinal ganglion cell nerve fibers and so would be expected to be of advantage primarily in diseases affecting these layers, such as glaucoma. In contrast, neurologic and chorioretinal lesions may cause deep, localized defects with a pattern of loss unrelated to the nerve fiber layer distribution in the retina.

In summary, the results of these simulations suggest that the TOP algorithm has a number of anomalies in its ability to both spatially localize defects and faithfully estimate sensitivity. Sensitivity of a defective point (abscissa) versus TOP sensitivity estimate (ordinate) for the same defect. Symbols are as described in the legend for Figure 8, ignoring submatrix numbers, with the circle showing the top left corner of the defect in both cases. For clarity, some symbols are horizontally displaced by an amount provided in Figure 8.
sensitivity in the area of small- (Figs. 3, 4) and moderate-sized defects (Fig. 6) typically was overestimated, and the estimated sensitivity of normal surrounding areas decreased by a variable amount. The estimated sensitivity of a defect also depended on its absolute position within the field, with different TOP submatrices returning different sensitivity estimates. Given that threshold static automated perimetry should faithfully estimate the top horizontal position of the true MD or LV, error bars give the 10th and 90th percentiles. *Dashed lines* median data when FP or FN 10%. The error bars for the end-points of the solid lines (triangles) are displaced horizontally by 0.2 units (top) and 2 units (bottom), for clarity.

**Figure 11.** Comparison of the true mean deviation (MD) versus the TOP estimate of MD (top) and comparison of the true loss variance (LV) versus the TOP estimate of LV (bottom), for various false-positive (FP) and false-negative (FN) response rates. The defect was a cluster of four points, as described in Figure 6. *Circles* indicate the median for the solid lines (triangles) are displaced horizontally by 0.2 units (top) and 2 units (bottom), for clarity.

### References


8. Takada S, Matsumoto C, Okuyama S, Iwagaki A, Otori T. Comparing the sensitivity of normal surrounding areas decreased by a variable amount. The estimated sensitivity of a defect also depended on its absolute position within the field, with different TOP submatrices returning different sensitivity estimates. Given that threshold static automated perimetry should faithfully estimate the top horizontal position of the true MD or LV, error bars give the 10th and 90th percentiles. *Dashed lines* median data when FP or FN 10%. The error bars for the end-points of the solid lines (triangles) are displaced horizontally by 0.2 units (top) and 2 units (bottom), for clarity.

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