Twenty one eyes with primary open angle glaucoma were tested with standard (white stimulus-on-white background) and color (blue stimulus-on-yellow background) visual fields over a range of 6–26 mo. There was no significant increase in threshold between the initial and final standard fields overall or by quadrant ($P < 0.188$, overall field). A significant increase in mean log thresholds for all areas of the color visual field ($P < 0.019$, overall field) was found. Of the 21 patients, nine worsened by >0.2 log units, two improved by >0.2 log units, seven worsened by <0.2 log units, and three improved by <0.2 log units. When these same patients were matched to 21 normal eyes by age, lens density, and acuity they showed significantly reduced thresholds throughout their color visual fields ($P < 0.023$). Whereas normal age-related increases in threshold for the short-wavelength system are only 0.10 log units per decade ($n = 88$), 10 glaucomatous eyes with increases of 0.14–0.75 log units were found within only 26 mo. The authors conclude that color visual fields may indicate significant change in visual function before it is apparent on standard visual fields. Invest Ophthalmol Vis Sci 33:2068-2071, 1992

Current clinical methods for assessing visual fields in eyes with primary open angle glaucoma may not show sensitivity loss until a considerable number of retinal ganglion cells have atrophied. Histopathologic evidence has indicated damage primarily to cells with larger optic nerve fibers; M cells, which project to the magnocellular layers of the lateral geniculate nucleus; and possibly a subset of P cells, which have large fibers projecting to the parvocellular layers. The latter probably project from ganglion cell “on-centers” that handle inputs from short-wavelength sensitive cones and have cell bodies that are approximately 50% larger than those handling middle and long-wavelength cone inputs. This may explain why several investigators have found significant deterioration of short-wavelength sensitivity in eyes with primary open angle glaucoma.

From the Department of Ophthalmology, University of California at San Diego. This work was supported in part by NEI grant EY-08208. Submitted for publication: July 19, 1991; accepted December 2, 1991. Reprint requests: Pamela A. Sample, Department of Ophthalmology, 0946, University of California at San Diego, La Jolla, CA 92093-0946.

It was necessary to rule out significant progression of color visual fields for detecting progressive visual field damage in primary open angle glaucoma.

Materials and Methods. Standard and color visual fields were obtained on a Humphrey (San Leandro, CA) visual field analyzer, model 620, using program 24-2. We previously reported the modifications necessary to obtain color visual fields with a blue stimulus and yellow background. The goal of these modifications is to isolate the short-wavelength sensitive mechanisms. The key components are a bright yellow background (80.9 cd/m²), a short-wavelength test flash (440 nm), a large diameter stimulus (1.8°), a stimulus duration of 200 msec, and correction of the results for lens density.

Subjects were 21 normal control eyes and 21 eyes with primary open angle glaucoma. Values in parentheses denote mean ± standard deviation. The two groups were matched for acuity (20/22.38 ± 3.75 for normals, 20/23.33 ± 7.80 for glaucomas), age (66.05 ± 10.01 normals, 65.67 ± 10.34 for glaucomas), and lens density (0.85 ± 0.42 for normals, 0.74 ± 0.48 for glaucomas). The glaucoma eyes were tested twice over a range of 6–26 mo (13.43 ± 5.39). One eye was selected randomly for study in each subject. Eyes with pupil diameters of less than 3 mm were excluded.

All eyes had a complete ophthalmologic examination, including best-corrected visual acuity, slit-lamp biomicroscopy, applanation tonometry, and diluted funduscopy. All subjects were optimally refracted for all tests. Subjects with ocular pathology other than primary open angle glaucoma, a history of congenital color vision loss, or ocular surgery were excluded from the study. Only those having intraocular pressures less than 21 mmHg, normal optic nerve heads, normal visual fields, and no family history of glaucoma were included in the normal group. Patients with primary open angle glaucoma exhibited glaucomatous optic nerve head abnormalities, characteristic standard visual field loss, and intraocular pressure exceeding 24 mmHg on at least two occasions. Differences in mean log threshold between groups, and between initial and final tests on glaucoma eyes were evaluated using analysis of variance. A $P$ value of less than 0.05 was considered significant.

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in color visual field loss resulting from increasing lens density or increasing age during the time period of the tests. To obtain an index of lens density for each eye, we employed a previously described and validated procedure.\(^9\) Values of lens density are reported in units relative to 0.00 lens density on the lens density index, the value for a clear lens. Higher values correspond to increasing opacity of the lens. A one unit change on the index is equivalent to a 0.1 log unit change in lens density. Eyes with a lens density index of 1.50 or more were excluded from study. Color visual field results were corrected for lens density by our usual method.\(^7\) To assess expected change in color visual field sensitivity with age, we evaluated 88 normal eyes ranging in age from 19–78 yr using procedures identical to those described above.

This project was approved by the Human Subjects Committee at the University of California, San Diego. The nature of the procedures was fully explained and informed consent was obtained from each subject.

**Results.** Eyes with primary open angle glaucoma (n = 21) showed significant defects on color visual fields when compared to age- and lens density-matched normal eyes (n = 21). The mean log threshold values in apostilbs for each visual field location were: superior nasal—glaucoma, 1.32 ± 0.64 and normal, 1.68 ± 0.40, \(P < 0.036\); superior temporal—glaucoma, 1.34 ± 0.52 and normal, 1.64 ± 0.36, \(P < 0.040\); inferior nasal—glaucoma, 1.57 ± 0.52 and normal, 1.89 ± 0.38, \(P < 0.030\); and inferior temporal—glaucoma, 1.59 ± 0.04 and normal, 1.82 ± 0.30, \(P < 0.049\). For the overall field, values were: glaucoma, 1.46 ± 0.48 and normal, 1.75 ± 0.33, \(P < 0.023\). These results are consistent with those reported previously.\(^7\)

In addition to showing significant color visual field defects when compared to normal eyes, the glaucoma eyes also had more extensive deficits on color visual fields than on standard fields (Figure 1 shows results from two eyes, one with early and one with moderate standard visual field loss). After excluding fixation and two locations associated with the blind spot, the remaining 52 locations for all fields were analyzed according to Anderson’s criteria.\(^10\) That is, points were considered abnormal if they fell within a cluster containing three or more points 0.5 log units or more below those for age- and lens density-matched normals, two or more contiguous points 0.8 log units below, or one isolated point at least 1.0 log unit below. These criteria were chosen over other recommended guidelines because they are widely used in clinical practice. An average of six additional visual field loca-

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**Fig. 1.** Examples of overlapping visual field losses on both the initial and final exams found for two eyes, with the color visual field loss being more extensive. Each location corresponds to one of 52 visual field locations on the Humphrey program 24-2, but the scale is condensed to accommodate the data.
tions met these criteria for the initial color field (26.83 ± 20.53 locations) when compared to the initial standard field (20.53 ± 19.71), and seven additional locations were included for the final color field (30.56 ± 20.13) compared to the final standard field (23.05 ± 19.34). Fifty eight percent of the 21 glaucoma eyes showed more than three additional defective visual field locations (19.9 ± 12.24) on their color fields, 14% showed more than three fewer, and 28% were essentially the same (within ± 3 locations) on standard and color fields. Although color field loss was more extensive, the general field location of the defects overlapped for the two types of visual fields (Fig. 1).

Finally, comparison of initial fields with those done later indicated significantly more progression of loss on the color visual fields than seen on standard fields (Figs. 1–2). No significant differences were noted at any visual field location between initial and final standard fields (Table 1). Color visual fields were significantly poorer on retest (Table 1) for three of four quadrants: superior nasal (P < 0.046), superior temporal (P < 0.018), and inferior temporal (P < 0.015), as well as overall (P < 0.019). The results for the inferior nasal field were not significant (P < 0.110).

The progression noted for the glaucoma eyes was much greater than that due to normal aging (Figure 3). Whereas normal eyes evidenced a change of 0.10 log units per decade (simple regression, r = −0.372, P < 0.001), including ages 60–78 yr (n = 29), we found 10 glaucomatous eyes with increases of 0.14–0.75 log units within only 26 mo.

**Discussion.** There is mounting evidence that color visual fields successfully differentiate between normal and glaucoma eyes, and that color fields show deficits in suspect eyes when standard fields remain normal. In addition, we now show that color visual fields indicate more extensive damage across the retina than evidenced by standard visual fields, and that color visual fields show progressive loss sooner than standard fields for eyes with primary open angle glaucoma. A larger sample size and continued long-term follow up should indicate the value of this procedure in clinical diagnosis and management of glaucoma.

One advantage of color visual fields is the ability to take lens density into account. This also is a disadvantage because the lens density index value must be obtained prior to each color field. Although the test is simple to implement and easily accepted by patients, the required half hour of dark adaptation is time con-

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**Table 1.** Log threshold (mean ± standard deviation) and statistical results for standard visual fields and color visual fields at various visual field locations

<table>
<thead>
<tr>
<th>Field location</th>
<th>Initial</th>
<th>Final</th>
<th>P value</th>
<th>Initial</th>
<th>Final</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior nasal</td>
<td>2.04 (±0.98)</td>
<td>1.95 (±1.00)</td>
<td>0.178</td>
<td>1.18 (±0.80)</td>
<td>1.02 (±0.78)</td>
<td>0.046</td>
</tr>
<tr>
<td>Superior temporal</td>
<td>2.18 (±0.67)</td>
<td>2.17 (±0.64)</td>
<td>0.849</td>
<td>1.28 (±0.63)</td>
<td>0.99 (±0.60)</td>
<td>0.018</td>
</tr>
<tr>
<td>Inferior nasal</td>
<td>2.30 (±0.58)</td>
<td>2.35 (±0.71)</td>
<td>0.559</td>
<td>1.54 (±0.59)</td>
<td>1.40 (±0.61)</td>
<td>0.110</td>
</tr>
<tr>
<td>Inferior temporal</td>
<td>2.41 (±0.36)</td>
<td>2.31 (±0.45)</td>
<td>0.078</td>
<td>1.58 (±0.51)</td>
<td>1.37 (±0.34)</td>
<td>0.015</td>
</tr>
<tr>
<td>Overall</td>
<td>2.23 (±0.61)</td>
<td>2.19 (±0.61)</td>
<td>0.380</td>
<td>1.39 (±0.58)</td>
<td>1.22 (±0.57)</td>
<td>0.019</td>
</tr>
</tbody>
</table>

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*Fig. 2.* Individual eye differences in log threshold for the initial test minus the log threshold for the final test for the overall visual field. Standard field differences are indicated by a cross. Color visual field differences by a dot. The solid lines denote the usual range of intertest variance of ±0.3 log units.
Fig. 3. Mean log threshold for the overall visual field for 88 normal eyes, ranging in age from 19 to 78 years. The solid line denotes the result of a simple regression, $R = -0.10$ per decade.

Assuming. Shorter dark adaptation times are not accurate, especially with older individuals. A new and rapid method for assessment that can be used for interpretation of color visual fields is desirable, but until this is possible a half hour is a small amount of time for ensuring accurate interpretation of field results and detection of progressive field loss.

We conclude that color visual fields provide substantially more information about the functional changes in vision associated with glaucoma than do standard visual fields. Hence, they may have an important role for diagnosing and detecting progressive functional change in glaucoma.

Key words: glaucoma, color visual fields, visual fields, progression, aging

References