The Influence of Age-Related Cataract on Blue-on-Yellow Perimetry

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Purpose. The influence of cataract on the blue-on-yellow visual field is unknown. The aim of the study was to compare the effect of age-related cataract on the normal blue-on-yellow (B-Y), yellow-on-yellow (Y-Y) and white-on-white (W-W) visual field.

Methods. Forty normal subjects (age range, 60 to 81 years) randomly performed B-Y, Y-Y, and W-W perimetry using a modified Humphrey Field Analyser 640 (HFA) (Program 24-2). Twenty age-matched patients with cataract underwent the same testing paradigm. Cataract was classified using the LOCS II system. Ocular media absorption was measured with the HFA by determining the difference in scotopic sensitivity to 410-nm and 560-nm stimuli. Forward light scatter was measured by the direct compensation technique of van den Berg. Unweighted mean deviation (MD), short-term fluctuation, and corrected pattern standard deviation indices were calculated for each patient with cataract for each of the three stimulus combinations.

Results. Cataract produced an adverse effect on the MD (i.e., a more negative MD) in all patients for each of the three stimulus combinations. The magnitude depended on the degree and type of cataract and was highly correlated with forward light scatter. The attenuation in sensitivity was greatest for the B-Y and W-W stimulus combinations; the B-Y field was preferentially affected by posterior subcapsular cataract and the W-W field by anterior cortical cataract.

Conclusions. Cataract predominantly causes a general reduction in B-Y sensitivity. Caution therefore needs to be exercised in the interpretation of the B-Y visual field in patients in whom glaucoma and cataract coexist.

Furthermore, B-Y loss may indicate visual field progression before that of standard perimetry.5,6 In addition, SWS loss has been recorded in patients with ocular hypertension1,2,4,6 and is thus an early indicator of nerve fiber bundle damage.4 Short wavelength sensitivity loss has also been noted in retinal diseases, such as retinitis pigmentosa9 and age-related maculopathy.10

Cataract is thought to cause visual degradation by three mechanisms: image blur, decreased retinal illumination, and veiling glare. Theoretical considerations in normals11,12 and in patients with glaucoma,13,14 studies using induced light scatter,14-17 and comparison of the visual field after cataract extraction and intraocular lens implantation18,19 suggest that cataract produces a general deficit across the W-W field that is exacerbated by the use of smaller stimulus sizes.11,12 The reduction in sensitivity confounds the interpretation of the glaucomatous visual field in that it contaminates any diffuse loss that may also occur in glaucoma and also produces a flattening or underestimation of focal loss.15

Recently, it has been shown that forward light scatter...
ter induced in the young normal eye by scattering particles placed in front of the eye preferentially reduced B-Y perimetric sensitivity compared to the corresponding Y-Y and W-W control stimuli. However, the effect on the B-Y visual field of forward light scatter resulting from age-related cataract is unknown. The aim of this study, therefore, was to determine the effect of cataract and cataract type on the B-Y perimetric profile.

METHODS

Sample
The sample consisted of a group with age-related cataract and a normal age-matched control group. The group with cataract was composed of 20 subjects (age range, 60 to 82 years; median, 74.3 years; mean, 5.7 years) conforming to rigid inclusion criteria: intraocular pressure of less than 22 mm Hg, normal optic nerve head appearance, no family history of glaucoma or diabetes, no history of ocular disease or trauma, no neurologic history, no systemic medication known to influence the visual field, and no known congenital color vision anomaly. The distance spherical refractive error in the examined eye ranged from +5.00 D to -8.00 D sphere, and the maximum power of the cylinder was -3.00 D. The visual acuities ranged from 6/6 to 6/36. Cataract was classified by the LOCS II system. The technique is a simple subjective method for grading lens opacities in vivo using slit lamp biomicroscopy and has been shown to be valid and repeatable. The group consisted of seven subjects with anterior cortical cataract, seven with nuclear cataract, and six with posterior subcapsular cataract.

The normal age-matched control group was composed of 40 subjects (age range, 60 to 81 years; mean age, 69.6 years; SD, 6.5 years). Twenty subjects were between 60 and 69 years of age (mean, 64.2 years; SD, 3.5 years), and 20 were between 70 and 81 years of age (mean, 75.3 years; SD, 3.3 years). The subjects conformed to inclusion criteria identical to those in the group with cataract, with the exception that corrected visual acuity was 6/9 or better in each eye and nuclear sclerosis was minimal (< NI) as classified by LOCS II. Informed consent was obtained from each subject. The research followed the tenets of the Declaration of Helsinki, informed consent was obtained from all subjects after the nature and possible consequences of the procedure had been fully explained, and the study was approved by the Aston University Human Science Ethical Committee.

Perimetry
Data were collected over two visits. Perimetry was undertaken with a modified Humphrey Field Analyser 640. At the first visit, the designated eye of each subject was examined with Program 24-2 for each of three stimulus combinations. All tests for a given subject were completed within a maximum period of 2 weeks. A size V blue stimulus was used for compatibility with other studies, the larger stimulus increased the dynamic range of the perimeter and was in accord with the greater isolation reported for a 2° diameter stimulus. A size V Y-Y stimulus was used as an MWS-LWS control, and a size III white stimulus on a 10 cd/m² background was used because it is the clinical standard. The modifications necessary for B-Y and Y-Y perimetry have been described in detail elsewhere and comprised an increased maximum available stimulus luminance of 5079 cd/m² (16,000 asb), the addition of a high-intensity background illumination system, and the use of appropriate stimulus and background filters. The yellow adapting background was produced by the use of a Schott (Mainz, Germany) OG530 filter transmitting above 500 nm. The background luminance was 330 cd/m². The blue stimulus comprised a broadband blue OCLI (Santa Rosa, CA) dichroic filter that transmitted wavelengths below 475 nm. The broadband blue stimulus was used additionally to enhance the dynamic range of the perimeter. This combination of stimulus and background filters at 200 cd/m² has been shown to achieve at least 1.4 log units of SWS isolation out to 30° eccentricity. Because the background luminance was 330 cd/m², the degree of isolation recorded was likely to be 1.4 log units, if not higher. The yellow control stimulus was achieved with a Schott yellow OG530 filter transmitting above 500 nm.

The perimetric sensitivities for the B-Y, Y-Y, and W-W stimuli were each calculated in log units relative to the maximum stimulus intensity of the given stimulus. Calibration of the given stimulus and background was undertaken with an LMT L1003 photometer (Lichtmesstechnik GMBH, Berlin, Germany). The maximum stimulus luminance of the blue OCLI filter was 275 cd/m² (865 asb) and that of the yellow OG530 filter 4029 cd/m² (12658 asb). The dB output from the Humphrey Field Analyser (HFA) was corrected for the attenuation in stimulus luminance by the respective stimulus filter and for the increase in luminance of the yellow background. All data were normalized relative to the maximum stimulus luminance of the yellow stimulus filter, which yielded a measurement range of 2.94 log units.

The order of tests was randomized between subjects to minimize order effects. Appropriate refractive correction was used for the viewing distance of the perimeter bowl. Fixation losses were less than 20%, and the incidence of false-negative and false-positive responses was minimal for all subjects. The efficiency of the Heijl-Krakau blind spot measuring technique to detect fixation loss in B-Y perimetry was reduced because of the reduction in the maximum luminance.
of the blue stimulus. However, the reliability of the blind-spot measuring technique is questionable even in conventional W-W perimetry.55 Fixation was constantly monitored with the video monitor. Extensive rest periods were given within and between tests to minimize fatigue effects.58,59 In the normal group, the designated eye was selected at random, and in the group with cataract, the designated eye was determined by cataract type and severity. Natural pupils were used throughout. Mean and standard deviation pupil size were measured on the HFA monitor and corrected for the magnification of the monitor. In the group with cataract, they were: 3.3 mm (SD 0.3), 3.3 mm (SD 0.3), and 4.2 mm (SD 0.6) for the B-Y, Y-Y, and W-W stimulus combinations, respectively. In the normal group, they were: 3.2 mm (SD 0.5), 3.2 mm (SD 0.5), and 4.1 mm (SD 0.5), respectively. A repeated measures analysis of variance (ANOVA) with the group as a between-subjects factor, stimulus combination as a within-subjects factor, and age as a covariate revealed that pupil size for the W-W combination was significantly larger than for either the B-Y or Y-Y combinations (P < 0.001); the differences in pupil size between the group with cataract and the normal group did not reach statistical significance.

Those subjects in each group not experienced in standard W-W or B-Y perimetry received training in the appropriate techniques on at least two sessions before the start of the study, thereby minimizing potential learning effects.56-58

Ocular Media Absorption

At the second visit, measurements were undertaken of ocular media absorption and forward light scatter. The degree of ocular media absorption was assessed using the technique of Sample et al.55 The procedure was used because it is the currently accepted psychological method with the HFA for correcting the results of B-Y perimetry for ocular media absorption.5-8 It involved the measurement of two scotopic thresholds of equal sensitivity to rhodopsin, i.e., 410 nm and 560 nm at 15° eccentricity in each quadrant along the 45° and 225° meridians using a size V stimulus presented for 100 msec. The measured differences in scotopic sensitivity are attributed to wavelength-dependent absorption by the ocular media. Fixation was assessed through the video monitor using an infrared light source (Osram, Middlesex, UK) mounted in the perimeter bowl. The infrared reflected off the bowl surface and illuminated the eye. A red filter (Cinelex 406 red: Strand Lighting, Middlesex, UK) was positioned over the light-emitting diode fixation target to preserve dark adaptation. The difference between the two thresholds was scaled according to the crystalline lens of the "standard observer" of Norren and Vos54 and to the transmission characteristics of the blue OCLI filter. To account for the broadband characteristics of the OCLI filter, an average media density was calculated across all wavelengths in 10-nm intervals from 400 nm to 470 nm.

Light Scatter Assessment

The degree of intraocular forward light scatter was measured using the straylight meter of van den Berg.56,57 The center of a 1°-diameter dark target surrounded by an annulus with an outer radius of 2° and a luminance of 30 cd m⁻² is fixated, and a yellow glare source consisting of light-emitting diodes (maximum wavelength, 570 nm; half width, 30 nm) flickering at 8 Hz and arranged in a circular display is separately presented at one of each of three different angles (3.5°, 10°, and 28°). Because of forward light scatter, flicker is seen in the central dark area. The luminance modulation of a counterphase flickering light is adjusted to cancel the resulting central 8-Hz flicker. The null point was measured by reducing the luminance modulation of the flickering light until no flicker was perceived. The straylight parameter at each angle was taken as the mean of six measurements. The light scatter measurements were taken after the measurement of ocular media absorption.

Analysis

The B-Y data were individually corrected for ocular media absorption by adding the absorption value to the B-Y sensitivity at each stimulus location. The two stimulus locations immediately above and below the blind spot were omitted from the analysis. The mean sensitivity (MS) was calculated for each of the two normal groups at each of the remaining 52 Program 24-2 stimulus locations for each of the three stimulus conditions (B-Y, Y-Y, and W-W). The attenuation of perimetric sensitivity for each patient with cataract for each of the three stimulus conditions was then expressed relative to the normal values by the use of the unweighted visual field indices mean deviation (MD) and corrected pattern standard deviation (CPSD) calculated using the sign convention of Heijl et al.57 whereby a negative MD represented an abnormal field. The MD expresses the deviation in the height of the measured visual field from that recorded in normal subjects of the same age, whereas the CPSD represents the deviation in shape of the measured field from that of the normal and is corrected for the effect of the short-term fluctuation.

The straylight parameters for each of the three glare angles was averaged for each normal subject.56 and the results were expressed as a group mean for the 20 subjects in each of the two age groups. The difference between the straylight parameter of each patient with cataract and that of the mean of the corresponding age-matched normal group was then calculated. This latter procedure provides a measure of the isolated cataract straylight parameter (ICSP).56
Cataract and Blue-on-Yellow Perimetry

TABLE 1. Group Mean MS and SF for the Three Stimulus Combinations for Each of the Two Age Groups of Normal Subjects

<table>
<thead>
<tr>
<th>Stimulus/Background Combination</th>
<th>60–69 Years</th>
<th>70–81 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MS</td>
<td>SF</td>
</tr>
<tr>
<td>B–Y</td>
<td>2.03 (0.25)</td>
<td>0.15 (0.04)</td>
</tr>
<tr>
<td>Y–Y</td>
<td>1.07 (0.11)</td>
<td>0.12 (0.04)</td>
</tr>
<tr>
<td>W–W</td>
<td>2.80 (0.19)</td>
<td>0.12 (0.08)</td>
</tr>
</tbody>
</table>

Values are expressed in log units. One log unit is equivalent to 10 dB. One standard deviation is given in parentheses. MS = mean sensitivity; SF = short-term fluctuation.

RESULTS

Normal Group

Group mean MS and group mean short-term fluctuation (SF) for each of the three perimetric stimuli for each of the two age groups are given in Table 1. The corresponding group mean ocular media absorption and the group mean straylight parameter are given in Table 2.

Group With Cataract

Group mean MDs, SFs, and CPSDs of the cataract group are given in Table 3 and indicate that the visual field recorded in the presence of cataract was depressed relative to the normal for all three stimulus combinations. The MDs were greater than the CPSDs by a factor of between 2 and 2.5 times.

The B–Y MDs plotted against the Y–Y MDs are shown in Figure 1 (top). The B–Y MDs were more negative (i.e., of lower sensitivity) than for those of the Y–Y stimulus combination, indicating that cataract has a more profound effect on the SWS profile than on the control MWS–LWS profile. The adverse effect on the B–Y profile increased with increasing cataract severity. The size III W–W MDs against the Y–Y MDs are shown in Figure 1 (middle). The W–W MDs were more negative (i.e., of lower sensitivity) than those of the Y–Y size V stimulus combination, indicating that cataract has a more adverse effect on the W–W stimulus combination. This effect was also more pronounced as the severity of the cataract increased. The corresponding graph for the W–W and B–Y MDs (Fig. 1, bottom) showed no consistent trend.

The ICSP as a function of the MD for each of the three perimetric stimulus combinations is shown in Figure 2. The regression slope was constrained to pass through the origin because, in the normal eye, the MD and the ICSP would theoretically be expected to be zero. However, even when the regression line was unconstrained, it passed very close to the origin for each of the stimulus combinations. Of the three MDs, the B–Y MD was most affected by forward light scatter (r = 0.84) (Fig. 2, top) and the YY MD the least.

The MDs for each of the three stimulus combinations as a function of individual cataract type and severity are shown in Figure 3. Anterior cortical cataracts caused a greater reduction in sensitivity for the W–W stimuli (top), whereas posterior subcapsular cataracts caused a greater reduction in sensitivity for the B–Y combination (bottom). The degree of attenuation increased with increase in the LOCS II classification of cataract severity for all three types of cataract.

The B–Y CPSD plotted against the Y–Y CPSD is shown in Figure 4 (top). The B–Y CPSD was greater than that of theYY CPSD, although the magnitude of both CPSDs was small. The W–W CPSD was greater than that of the YY, particularly for anterior cortical cataract and for increasing severity of cataract (Fig. 4, bottom).
FIGURE 1. (top) Y-Y MD against B-Y MD as a function of cataract type and severity. (middle) W-W MD against Y-Y MD as a function of cataract type and severity. (bottom) W-W MD against B-Y MD as a function of cataract type and severity. Cataract type and severity is classified by LOCS II, whereby increase in severity is denoted by an increase in the Roman numeral. ■ = anterior cortical cataract; ▲ = posterior subcapsular cataract; □ = nuclear cataract. A negative MD represents a reduction in sensitivity. A slope of unity representing equality between the two given MDs is illustrated for reference. 1 log unit = 10 dB.

middle). The corresponding graph for the B-Y and W-W CPSDs tended toward a slightly greater reduction in the W-W CPSD for the more severe cataracts (Fig. 4, bottom). The CPSD correlated poorly with the ICSP for the B-Y (r = 0.08) and W-W (r = 0.12) stimulus combinations and moderately with the Y-Y stimulus combination (r = 0.60).

The SF correlated poorly with the ICSP for all three stimulus combinations: of the three SFs, the B-Y SF was most affected by forward light scatter (r = 0.22).

DISCUSSION

This study demonstrates that cataract has a profound effect on the visual field, primarily resulting in a general reduction in sensitivity across the field. These findings are in accord with other studies.12,38 The attenuation of the W-W and Y-Y response can be attributed to the reduction in luminance contrast between stimulus and background. Forward light scatter merges stimulus and background, with consequent loss of stimulus contrast. Greater attenuation of the B-Y stimulus combination, compared to the Y-Y stimulus (Fig. 1, top), can be explained on the basis of the chromatic content of the stimulus. In addition to the loss of luminance contrast, the B-Y stimulus also exhibits a change in chromaticity toward that of the yellow background. Effectively, the stimulus becomes less blue and more yellow. An alternative explanation for the greater attenuation of the B-Y response might be that of a preferential scattering of short wavelength stimuli, especially because our straylight measurements were based on medium wavelengths. However, studies of the normal, elderly, and cataractous eye suggest that light scatter is independent of wavelength.39,40

The attenuation of the W-W response, in comparison to that of the Y-Y response (shown by the distribution of data points above the slope of unity in Fig. 1, middle) involves consideration of both stimulus size and background luminance, along with the associated reduction in pupil size for the Y-Y stimulus combina-
Cataract and Blue-on-Yellow Perimetry

FIGURE 2. (top) B-Y MD against the isolated cataract straylight parameter averaged for the three glare angles. The two slopes represent the linear regression line determined by least squares, the broken line indicates the best fit of the data, and the continuous line that constrained to pass through the origin at \( x = 0, y = 0 \). (middle) The corresponding function for the YY stimulus combination and (bottom) for the W-W stimulus combination.

The effect of light scatter is known to be more pronounced for smaller perimetric stimuli.\(^{11,12}\) This provides a convenient explanation for the greater attenuation of the W-W sensitivity. It seems unlikely that attenuation in sensitivity at the higher background luminance (and smaller pupil size) would be any less than that observed at the lower luminance (W-W) stimulus combination. The selective attenuation of the smaller stimulus is analogous to the effect of cataract on contrast sensitivity for sinusoidal gratings where stimuli of medium and high spatial frequencies are preferentially affected.\(^{41}\) Alternatively, the greater attenuation of W-W sensitivity could be due to the fact that the sensitivity of the white stimulus was not corrected for media density, despite the fact that white contains a measure of blue light. However, given the evidence for greater attenuation of small stimuli by light scatter,\(^{11,12}\) we think it is this factor that dominates the findings.

It is clear that the effect of cataract type on MD is dependent on the stimulus configuration used. The B-Y MD is greater for posterior subcapsular cataract, whereas anterior cortical cataract has a preferential effect on the W-W MD. This phenomenon can be explained on the basis of pupil size. At high bowl luminances, as used for the B-Y stimulus, the pupil will constrict around any centrally located opacity such as a posterior subcapsular cataract, with severe consequences for visual performance. Alternatively, at lower background luminances, the larger pupil size will cause peripheral anterior cortical opacities to produce their maximal effect. The impact on the visual field of cataract progression will also be governed by the interaction of cataract type and pupil size.

Previous studies with the Octopus automated perimeter (Interzeag AG, Schlieren–Zurich, Switzerland) have shown that the attenuation of the perimetric profile because of forward light scatter increased with an increase in eccentricity in the normal and the cataractous eye, i.e., the visual field preferentially steepened in the periphery.\(^{13,14}\) A repeated measures ANOVA using the Greenhouse–Geisser correction for the assumption of compound asymmetry, with age as a covariate and stimulus combination and eccentricity as within-subjects factors, showed that in the present study, overall, the perimetric attenuation from
The adverse effect on the MDs for the three stimulus combinations increased as a function of the LOCS II severity classification and as a function of the isolated cataract straylight parameter. The pupil size for the straylight measurements would have been larger than the pupil size for the perimetry. Because, as has been shown, the effect of cataract on the outcome of the visual field is dependent on pupil size, the discrepancy in the pupil sizes between the two measurements is likely to have reduced the correlation between the straylight function and the visual field indices. If the pupil size had been artificially maintained at the same level for both measurement procedures, the apparent agreement would have been still higher. The correlation between the LOCS II classification and the isolated cataract straylight parameter was only moderate ($r = 0.49$). The LOCS system is a measure of back scatter. Indeed, previous studies have shown only limited agreement between measures of back scatter and those of forward scatter.36,42

The finding of a predominantly general reduction in sensitivity in age-related cataract for the W-W and B-Y sensitivity profiles has ramifications for the detection and follow-up of primary open-angle glaucoma in the presence of cataract. The extent to which diffuse loss is a component of glaucomatous damage is equivocal,65-66 W-W field loss is thought to be more localized in normal-tension glaucoma47,49 and more diffuse in high-tension glaucoma.50 The reduction of B-Y sensitivity in glaucoma also appears to exhibit diffuse and localized components.4 In addition, patients with raised intraocular pressure and normal W-W fields demonstrate diffuse reductions in B-Y sensitivity.51 Clearly, there is a need to separate optical attenuation from that caused by neural attenuation. Unless this is achieved, forward light scatter will falsify the B-Y perimetric profile in the glaucomatous eye by confounding the diffuse loss due to neural damage and, by artificially depressing the hill of vision, will lead to
Cataract and Blue-on-Yellow Perimetry

The SF has been shown to be higher in B-Y perimetry than in conventional W-W perimetry.\textsuperscript{52} Indeed, for the present study, a repeated measures ANOVA with age as a covariate, group as a between-subjects factor, and stimulus combination as a within-subjects factor showed that the B-Y SF was higher than that for the Y-Y or W-W stimulus combinations in the group with cataract and the normal group ($P = 0.003$). The SF for all three stimulus combinations was higher in the cataract group ($P = 0.02$), and this difference increased with increase in age ($P = 0.03$).

Recently, a commercially available upgrade to the Humphrey Field Analyzer was introduced that uses a 440-nm narrow band stimulus filter and a bowl luminance of 100 cd m$^{-2}$. The precise nature of the outcome of forward scatter on these different stimulus parameters is difficult to predict from the present study. With respect to the background luminance, the qualitative nature of the selective B-Y attenuation shown in Figure 1 (top) would not be expected to change because the reduction in background luminance applies equally to the B-Y and Y-Y stimulus combinations. However, the magnitude of the selective B-Y attenuation at the lower bowl luminance, together with any effects arising from the difference in transmission characteristics of the stimulus filter, remains unknown.

Clearly, there is a need to establish a comprehensive normative data base for B-Y perimetry. Such a data base would have to account for the different mechanisms of diffuse loss. The results of the current study suggest that with prior knowledge of the degree of forward light scatter and of ocular media absorption for a given patient, the perimetric profile could be corrected for the effects of optical attenuation. The analysis for abnormality could then be undertaken using the total and pattern deviation probability techniques applicable to conventional W-W perimetry.\textsuperscript{53,54} However, the difficulty inherent in W-W perimetry, namely, that of separating any neural diffuse loss from the focal loss, would remain.\textsuperscript{55,56} Alternatively, the optical component could be ignored because the reduction in perimetric sensitivity from forward light scatter

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4.png}
\caption{(top) Y-Y CPSD against B-Y CPSD as a function of cataract type and severity. (middle) W-W CPSD against Y-Y CPSD as a function of cataract type and severity. (bottom) W-W CPSD against B-Y CPSD as a function of cataract type and severity. The cataract type and severity classification is that contained in the legend of Figure 1. A slope of unity representing equality between the two given CPSDs is illustrated for reference. 1 log unit $\approx 10$ dB. Note that the scaling on the abscissa is different from that in Figure 1.}
\end{figure}
and to short wavelength absorption is similar at all stimulus locations across the visual field. The sensitivity at a given location could then be analyzed on an intraindividual basis, for example, by comparison with the sensitivity at the mirror image location in the opposite hemisphere.\textsuperscript{17–20} Such an approach would accept that the depth, severity, or both of any focal loss would be reduced by the general reduction in sensitivity caused by cataract; however, it would be in the knowledge that focal loss in B-Y perimeter, whatever its true depth, precedes that in W-W perimeter.\textsuperscript{1–8} The advent of B-Y perimeter is unquestionably an exciting prospect; nevertheless, the influence of such factors as ocular media absorption and forward intraocular light scatter, and their interaction with the given stimulus parameters, necessitates caution in the interpretation of the glaucomatous visual field in the presence of age-related cataract.

Key Words
automated perimeter, color, cataract, light scatter, glaucoma

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