Interocular comparison of contrast sensitivities in glaucoma patients and suspects

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SUMMARY Glaucoma affected the ability to detect low-contrast, flickering patterns ('DRC' measurement). DRC patterns were foveally viewed, of low spatial frequency, and flickering at 8 hertz. Interocular comparisons were performed in control subjects, in ocular hypertensives, and in glaucoma patients with asymmetric damage. Interocular differences in DRC tended to be of greater magnitude in the glaucoma patients than in the ocular hypertensive patients or control subjects. In the glaucoma patients DRC was consistently lower in the eye with the greater field defect than in the other (more normal) eye. In patients with optic disc asymmetry DRC was lower in the eye with the more abnormal disc. Treatment asymmetries did not appear to play a significant role in these relationships. When examined by interocular comparisons DRC showed no consistent relationship to Snellen visual acuity or to level of intraocular pressure at the time of DRC testing.

The early stages of glaucomatous visual damage are generally detected outside of the central 5-10° of the visual field. As long as Snellen acuity remains good, it is ordinarily assumed that vision in the central field has not yet been affected by the disease process. However, we have found¹ abnormalities of central vision in glaucoma patients who had normal Snellen acuities. These abnormalities occurred in a variable named the 'dynamic response coefficient' or DRC, which is based on the contrast required for the detection of flickering patterns. Two types of stimuli, a homogeneous flickering field, and a counterphase flickering grating of low spatial frequency, were presented on a centrally fixated screen 4° of visual angle in diameter. The mean contrast sensitivity of these 2 stimuli (defined as the DRC) was consistently lower in glaucomatous than in normotensive eyes. Thus there appeared to be a relationship between central retinal performance, as measured by the DRC, and the more peripheral visual field defects detected by Goldmann kinetic perimetry.

Glaucomatous damage commonly occurs in one eye earlier than in the other. We examined *interocular* DRC differences in patients with asymmetrical

Table 1 Subject groups

Group*	Number of subjects	Age (years)	
		Mean	(SD)
(1) POAG	17	52	(18)
(2) OHT	19	46	(17)
(3) Control	16	52	(23)

*POAG = Primary open-angle glaucoma patients. OHT = Ocular hypertensive patients.

glaucoma in order to explore further the sensitivity and specificity of this new test of foveal vision in glaucoma.

Materials and methods

SUBJECTS

Three groups were studied. These were: (1) 17 patients with primary open-angle glaucoma (POAG) chosen for asymmetric damage to visual fields and optic discs; (2) 19 ocular hypertensive (OHT) patients; and (3) 16 control subjects (Table 1). The mean ages of the control and POAG groups were 52 years and of the OHT group was 46 years. The patient groups were defined by the same selection criteria used in our previous report¹ and included some of those patients. Patients and control subjects

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with ocular pathology other than glaucoma, or with any neurological disorder, were excluded from the study. In all cases Snellen visual acuities were 6/12 or better, and all except 2 of the total of 104 eyes had acuities of 6/9 or better.

Each of the glaucoma patients and ocular hypertensives had had intraocular pressure (IOP) readings of 22 mmHg or higher on 2 or more occasions. Goldmann dynamic perimetry showed normal fields bilaterally in the OHT group. In the POAG group the glaucomatous defect was restricted to one eye in 13 patients. The other 4 had field defects in both eyes, more severe in one than in the other. Six of the 13 POAG patients with uniocular visual field damage had only mild defects. These were: constriction of the central field in 3 eyes; an early, relative paracentral scotoma in 2 eyes; and a superior nasal depression in one eye. The other 7 patients had more severe defects. These were: nasal step with central constriction in one eye; Bjerrum scotoma with central constriction in 3 eyes; Bjerrum scotoma with paracentral scotoma and nasal defect in one eye; and sector defect in one eye. Of the 4 patients with visual field damage in both eyes 1 showed only mild defects, consisting of central constrictions, more severe for one eye than for the other. The others showed, in addition to enlarged blind spots, paracentral scotoma (1 eye), Bjerrum scotoma (4 eyes), peripheral nasal step (1 eye), and nasal constriction (2 eyes).

PSYCHOPHYSICAL TESTING

The stimulus was presented to central vision on an oscilloscope screen that subtended 4° of visual angle.¹ The mean luminance of the screen remained constant throughout each test session. The mean luminance level was 6 foot-lamberts (20.6 cd/m²) for 2 of the control subjects, and for 10 of the OHT and 4 of the POAG patients; for the rest the level was 40 foot-lamberts (137 cd/m²). As this difference had no apparent effect on results of the interocular comparisons, it will not be referred to again in this report.

The psychophysical testing method has been described previously.¹ The DRC test employs 2 stimulus conditions: 'diffuse flicker' and 'counterphase flicker'. In the diffuse flicker condition the subject viewed a blank, evenly illuminated screen. Its luminance changed abruptly back and forth between 2 levels at a rate of 8 hertz. In the counterphase flicker condition the stimulus was a grating pattern of dark and light bars with a sinusoidal luminance profile and a spatial frequency of 1.2 cycles per degree. That is, the 4-degree stimulus-field contained 5 cycles of the sinusoidal grating pattern, which means there were 5 dark bars and 5 light bars

on the screen at a given moment. This is a relatively coarse grating. It was temporally modulated at a rate of 8 hertz: 16 times per second the pattern reversed, i.e., each dark bar changed abruptly into a bright one, and vice versa.

While mean luminance remained constant during each test, contrast was varied. Contrast is defined as the ratio of the difference between peak and mean luminance of the test screen to its mean luminance, or equivalently, as $(L_{\max} - L_{\min}) / (L_{\max} + L_{\min})$, where $L_{\max}$ is the highest level of luminance in the test pattern, and $L_{\min}$ is the lowest.

The contrast thresholds of each subject were measured both for the diffuse flickering field and for the counterphase grating, as will be described, and used to derive the corresponding contrast sensitivities.

Contrast thresholds were determined by a method of 'constant stimuli'. The flickering stimulus was presented at a given contrast level for a duration of 4-6 seconds and the subject was asked whether or not he saw the pattern (flicker or grating). Then the contrast was changed and the stimulus was presented again. Between presentations the subject looked at a blank screen with luminance matched to that of the test screen. Each contrast change was made at random, either upwards or downwards, and by an increment of 2 decibels (db) or some multiple of 2 db. The first few presentations were used to bracket the threshold, and the subsequent presentations were restricted to a 10 db interval containing the threshold. In general, 4 independent replications were performed at each of the discrete contrast levels within this interval. The contrast threshold for diffuse flicker was the minimum contrast at which the subject detected the flicker on about half of the presentations. The reciprocal of this threshold was the contrast sensitivity to diffuse flicker. The contrast threshold for the counterphase flickering grating was the minimum contrast at which the subject detected the bar pattern on about half the presentations, and the grating contrast sensitivity was the reciprocal of this latter contrast threshold. Each such sensitivity determination took about 4-5 minutes.

The average of the diffuse flicker contrast sensitivity and the counterphase grating contrast sensitivity has been named 'dynamic response coefficient' or DRC.¹ The DRC may be viewed as a crude estimate, obtained at a temporal modulation frequency of 8 hertz, of the low spatial frequency end of the foveal contrast sensitivity curve. DRC was measured on a logarithmic scale in decibels. If the DRCs of the 2 eyes differ by 6 db, then the contrasts required by one eye are double those required by the other.

Results

In the glaucoma patients with asymmetric visual field damage DRC differences between the right and left eye tended to be larger than in the ocular hypertensives or the control subjects (Fig. 1). Although many from the latter 2 groups had interocular DRC differences as large as 2 db, only 1 from each had a difference as large as 3 db. None of the control or OHT interocular differences was as large as 4 db, but more than half the POAG interocular differences were of this magnitude or larger ($P < 0.01$, chi square).

The direction of the DRC asymmetry was then examined in relation to the direction of asymmetry of 4 other variables: field loss (Fig. 2, 1st column); optic disc morphology (2nd column); visual acuity (3rd column); and intraocular pressure (IOP) (4th column). In the patients with unilateral visual field loss the direction of field-loss asymmetry was obvious. In patients with visual field losses in both eyes the criteria were as follows. It was assumed that the eye with the more constricted field, and/or with more and/or larger scotomata, and/or with scotomata that more closely encroached upon the foveal part of the field, is the one with the greater visual field damage. Further, one eye was considered more abnormal than the other with respect to optic disc morphology (2nd column) if its cup/disc ratio was greater than the other eye's by 0.2 or more, with respect to visual acuity (3rd column) if its

Fig. 1 Size distributions of interocular DRC differences for each group. Height of each bar signifies the number of patients or control subjects (see key) having an interocular difference within the range specified beneath it ('2-4' means '2 or more but less than 4'). DRC signifies dynamic response coefficient (see text). $|\Delta DRC| = |DRC(OD) - DRC(OS)|$ is the absolute value of the difference between DRC of right eye and DRC of left eye. OHT signifies ocular hypertensive patients; POAG, primary open-angle glaucoma patients.

Snellen acuity ratio was less than the other eye's by 0.2 or more, and with respect to intraocular pressure (last column) if its applanation tension exceeded the other eye's by 2 mmHg or more.

In Fig. 2 the ordinate, ΔDRC , signifies the amount by which DRC of the eye showing greater abnormality in one of these other variables deviates from DRC of the fellow eye, that is, $\Delta DRC = (DRC \text{ of more abnormal eye}) - (DRC \text{ of fellow eye})$. In the glaucoma patients DRC was lower in the eye with the greater glaucomatous visual field damage. The consistently negative values of ΔDRC in the first column of Fig. 2 signify that the eye with more field

Fig. 2 Relations of DRC interocular differences to interocular differences in 4 other variables. Filled triangles represent interocular differences of primary open-angle glaucoma (POAG) patients, open circles of ocular hypertensive (OHT) patients. The ordinate, ΔDRC , is interocular difference of DRC in db. DRC is defined in the text. A difference of 6 db would mean that the mean contrast sensitivity to 8 Hz flicker of one eye was twice that of the other. In each column a point below zero (negative ΔDRC) signifies that the eye with the greater defect of the type specified at the top of that column had a lower DRC than the other eye; a point above zero (positive ΔDRC), on the other hand, signifies that the eye showing more of the specified defect had a higher DRC than the other. See text for additional explanation.

loss nearly always had a DRC level less than its fellow eye ($P < 0.001$ by sign test). The eye with the more abnormal optic disc was similarly compared to its fellow eye (Fig. 2, second column); the DRC was never higher and was usually lower in the eye with the more abnormal optic nerve head ($P < 0.001$ by sign test).

The relations of DRC to 2 other variables were examined in the same way. Interocular DRC differences were not significantly associated with interocular differences in Snellen visual acuity. The eye with poorer Snellen acuity might have a DRC either higher or lower than its fellow eye. This is shown in the third column of Fig. 2, where Δ DRC is in some instances above and in others below zero. Similarly, the IOP measured at the time of the DRC test does not appear to be a main determinant of DRC, since the DRC of the eye with the higher pressure was in some instances above and in others below that of the fellow eye (Fig. 2, fourth column).

The observed pattern of interocular differences in DRC could not be accounted for by pharmacological effects at the time of testing. Of the 17 POAG patients the majority were receiving either no glaucoma medication (7 patients) or the same medication in both eyes (5 patients). There were only 5 instances in which one eye was receiving drug therapy different from the other. Three were unilateral POAG patients who used epinephrine drops in the eye with the glaucomatous visual field damage (their Δ DRC magnitudes were 4.0, 4.5, and 5.5 db). The remaining 2 were unilateral POAG patients who used multiple medications, with pilocarpine only in the eye *without* visual field damage (Δ DRC magnitudes were 2 and 15 db); for these 2 patients the visually more normal but pilocarpine-medicated eye had a smaller pupil and lower retinal illumination than the glaucomatous eye. Nevertheless, in these as in all except 1 of the other POAG patients DRC was lower in the eye with greater glaucomatous visual field damage.

Discussion

Interocular DRC disparities ($|\Delta$ DRC|) tended to be larger in the asymmetric POAG patients than in control subjects. Interocular disparities are common in POAG, and increased magnitudes of asymmetry are sometimes clues to pathology. Interocular differences in IOP are often abnormally large in glaucoma patients.² In diagnosing glaucoma, optic disc asymmetry^{2,3-6} or afferent asymmetry of pupillary response⁷ may be significant even in the absence of definite glaucomatous defects. It may be that DRC asymmetry can be included as another such diagnostic sign of POAG. It remains to be

seen whether abnormally large interocular DRC disparities will occur in glaucoma patients who do not otherwise manifest clinical asymmetry.

The interocular DRC differences of OHT patients were indistinguishable from those of control subjects (Fig. 1). This suggests that imminent POAG in OHT patients may not be signalled by increased magnitudes of DRC asymmetry. Or else one could assume that none of the ocular hypertensive patients we tested will develop glaucoma. At this point we have no evidence that interocular DRC differences will have predictive value. Only long-term follow up of OHT patients can provide such evidence. Further, even if DRC asymmetry sometimes warns of impending asymmetric glaucomatous damage, continued DRC *symmetry* will not be reassuring, since early glaucomatous damage may occur symmetrically.

Our most important finding has to do with the directions rather than the magnitudes of interocular differences. Apparently there is a specific association of DRC depression with glaucomatous visual field and optic nerve head defects. A similar association had already been demonstrated in a different manner by intergroup comparisons of POAG patients with control subjects.¹ Because the observed DRC interocular differences do not seem to depend on the IOP differences prevailing at the time the DRC test is performed, we infer that (within the observed range of IOPs) DRC depression probably reflects the chronic more strongly than the acute effects of raised IOP.

Further, both our previous report and this one provide evidence that the DRC losses in the glaucoma patients are not attributable simply to aging. Age does affect contrast sensitivity, and aging is associated with a contrast sensitivity loss at low spatial frequencies. This was reported by Atkin and his colleagues¹ and established recently by Sekuler and collaborators.⁸ The loss in glaucoma, however, exceeds the loss due simply to age by a factor of 3, as was shown by comparing contrast sensitivity at low spatial frequencies in glaucoma patients and age-matched controls.¹ Clearly the present finding of a *within-subject* interocular association between glaucomatous changes and DRC loss provide another demonstration of this specificity of the DRC test.

The association of DRC depression with changes in the optic nerve head and visual field in patients without loss of acuity or other evidence of foveal dysfunction means that early glaucoma affects foveal as well as peripheral vision. Apparently these foveal changes in glaucoma can be detected by DRC when they are not detected by kinetic perimetry or by Snellen visual acuity measurements. Still, we are

far from sure that this procedure will prove to be the most sensitive and specific psychophysical technique for detecting early foveal changes in glaucoma. The DRC test measures the detectability of coarse targets flickering at 8 hertz. Tyler⁹ recently reported that many patients with glaucoma have not only peripheral but also foveal contrast sensitivity losses to flickering targets. He confirmed the magnitude of the losses in glaucoma that we had reported¹ at a flicker rate of 8 hertz. However, he also found that losses commonly occur at temporal frequencies substantially above 8 Hz, and their magnitudes appear to be greater at the higher temporal frequencies. It remains to be seen whether contrast sensitivity studies that include a range of temporal frequencies above 8 Hz can generate a test of greater clinical usefulness than the 8 Hz test we have been employing.

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References

- 1 Atkin A, Bodis-Wollner I, Wolkstein M, Moss A, Podos S. Abnormalities of central contrast sensitivity in glaucoma. *Am J Ophthalmol* 1979; **88**: 205-11.
- 2 Kraus H. Ocular hypertension and glaucoma. *Recent Advances in Glaucoma*. New York: Springer, 1977: 277.
- 3 Armaly MF. Cup/disc ratio in early open angle glaucoma. *Doc Ophthalmol* 1969; **26**: 526-33.
- 4 Fishman RS. Optic disc asymmetry. A sign of ocular hypertension. *Arch Ophthalmol* 1970; **84**: 590-4.
- 5 Krupin T, Podos SM. The glaucomas: classification and synthesis. In: Heilmann K, Richardson KT, eds. *Glaucoma: Conceptions of a Disease*. Stuttgart: Thieme, 1978: 348-69.
- 6 Spaeth GL. Morphological damage of the optic nerve. In: Heilmann K, Richardson KT, eds. *Glaucoma, Conceptions of a Disease*. Stuttgart: Thieme, 1978: 145.
- 7 Kohn AN, Moss AP, Podos SM. Relative afferent pupillary defects in glaucoma without characteristic field loss. *Arch Ophthalmol* 1979; **97**: 294-6.
- 8 Sekuler R, Hutman LP, Owsley CJ. Human aging and spatial vision. *Science*, in press.
- 9 Tyler CW. Notch loss of temporal frequency sensitivity in glaucoma and ocular hypertension. *Invest Ophthalmol Visual Sci*, in press.