Vision through cataracts

R. Hess and G. Woo*

Contrast thresholds for a range of different spatial frequencies were compared with "acuity" tests for 10 subjects with unioocular senile cataract. The results indicate that the magnitude and extent of the intra–resolution limit abnormality vary dramatically in cataract subjects and that, for some subjects, vision is abnormal for objects of all sizes. This finding indicates that the present acuity evaluation of vision with cataracts is inadequate because, in some cases, it grossly overestimates the nature of the visual world of the cataract patient.

Key words: contrast sensitivity, spatial frequency, senile cataract, visual acuity, optical filtering, intraocular scattering

In the clinical environment visual function has been traditionally assessed by estimating the smallest-sized, high-contrast object capable of being resolved. This procedure measures only the limit of vision, and one has to make an assumption about the relationship between relative visibility and object size within the resolution limit. Such an assumption is valid, for example, when the visual abnormality is due to or can be equated with dioptric defocus because, in this case, the extent and magnitude of the intra–resolution limit abnormality are intuitively appreciated and can be quantitatively predicted.

Recently it has been suggested that the intra–resolution limit abnormality resulting from conditions in which substantial intraocular scattering occurs cannot be modeled by dioptric defocus loss because, in the former case, vision for large objects (e.g., low-spatial-frequency gratings) is affected more than would be predicted from the abnormality measured for small objects (e.g., high-spatial-frequency gratings). Furthermore, it was found that when low spatial frequencies are disproportionately affected more than high frequencies, vision is much more dramatically restricted. This result led to the suggestion that visual assessment of cases in which intraocular scattering occurs should involve not only measurement of the limit of resolution (acuity assessment) but also the quality of vision for object sizes within the resolution limit (intra-resolution limit assessment).

The general notion of the need for supplementing the present "acuity" assessment of vision in which scattering occurs has been recognized by Miller et al., who suggested measuring glare recovery. The contrast-threshold function is an ideal candidate for evaluating relative visibility for object sizes within the resolution limit because it allows measurement of contrast thresholds for a wide range of object sizes (spatial frequencies) while maintaining a fixed level of light adaptation. With the use of this test, assumptions are not necessary concerning the nature of the intra–resolution limit abnormality, since this can be directly measured. If the visual loss has a purely optical basis, then this test measures the contrast transfer characteristics of the eye's optics.

In the present investigation, the prediction that cases involving substantial intraocular...
scattering have a disproportionate low-frequency visibility abnormality and therefore visual function is being grossly overestimated by present acuity tests was evaluated. Contrast-threshold measurements for a wide range of spatial frequencies were compared with acuity measurements (letter and grating acuity) for a sample of subjects with senile cataracts. In order to eliminate the considerable intersubject variability of absolute contrast threshold from the description of the visual abnormality due to cataract, only subjects with uniconal cataract were selected for testing. In this way each subject acted as his own control, the normal eye's response representing a baseline from which the response of the fellow cataractous eye could be accurately compared.

Apparatus, method, and subjects

**Contrast thresholds.** Vertical sinewave gratings of variable frequency and contrast were generated on the screen of a specially constructed 40 by 30 cm video monitor (P4 phosphor) by the method of Robson. The screen's mean luminance was set to 80 cd/m², and contrast was modulated about this luminance and adjusted by the subject with an 80-position switched logarithmic attentuator connected to a digital voltmeter. The oscilloscope surround-area was illuminated by indirect lighting to approximately that of the screen's mean luminance. The video monitor's frequency response and contrast linearity were measured with a PIN photodiode, and contrast testing was confined to within the linear contrast region and the flat frequency-response region of these respective curves. The viewing distance was varied from 57 cm, for spatial frequencies up to 2 c/degree, to 456 cm for higher spatial frequencies. The grating field size therefore varied from 40 by 30 degrees to 5 by 3.7 degrees. Subjects were carefully refracted for ametropia and viewing distance, and natural pupils were used. For the subjects tested, the pupil diameters ranged from 2 to 3.5 mm, and for each subject pupil diameters were equal between eyes. The method of adjustment (staircase tech-
Figs. 3 and 4. Contrast sensitivity functions for two representative subjects with unilocal senile cortical (C) cataracts. In the lower frame, the response of the normal eye (o) is compared to that of the fellow cataractous eye (*). In the upper frame, the ratio of these two responses (a) is plotted and compared with that predicted from defocus aberration (dashed sloping line). Fig. 3. Low-frequency, contrast sensitivity is normal. Fig. 4. Contrast sensitivity is depressed for all spatial frequencies (p < 0.001).

Technique) was used by the subject to set thresholds, each data point representing the average of three readings. To establish valid comparisons that were uncontaminated by time-dependent threshold variation, the procedure was such that each eye was alternately compared for each spatial frequency (point-to-point comparison). An eye patch was used to occlude the eye not being tested.

Letter acuity. Letter acuity was measured with single Landolt C's (approximately 100% contrast), and frequency-of-seeing data were probit-analyzed to obtain a more accurate 50% threshold. Each letter size was presented eight times. The mean luminance and testing conditions were identical to those already described for the contrast-threshold measurements.

Subjects. Subjects were selected from the files of the departmental clinic according to very strict guidelines, so that only subjects who had a purely optical (cataract) basis for their visual loss (i.e., with no neural component) were selected. The selection guidelines were as follows: (1) unilocal cataract, (2) good observer, (3) no history of general medical illness, (4) full normal ocular history prior to cataract formation combined with no sign of any degenerative or other neural abnormality in the good eye after cataract formation, and (5) no other optical or oculomotor abnormality. The criteria for a normal eye (i.e., unilocal cataract) were as follows: no ophthalmoscopically visible cataract formation within the pupillary region, no associated ocular abnormality, and normal visual acuity. The cataracts were classified as cortical or nuclear depending upon the site of the major opacity.

Results

The sinewave contrast threshold function which represents the contrast necessary for threshold detection over a 2½ log unit range of spatial frequency was measured for the normal and fellow cataractous eye of 10 subjects with unilocal cataract. The results could not be described by a single family of visual loss functions. Recent results concern-
Fig. 5. Summary of the contrast attenuation results for the 10 uniacular senile cataract subjects tested. These results, which were derived from contrast sensitivity functions, have been separated into two groups depending upon the extent of the intra-resolution limit abnormality. The low-frequency attenuation (right) is statistically significant and repeatable (p < 0.001). The senile cataracts have been divided into cortical (C) and nuclear (N).

ing optical and neural abnormalities suggest that an obvious and most useful classification can be based upon the presence or absence of low-frequency involvement. According to this criterion the results from this limited sample were found to fall generally into one or other of two discrete response categories; an example of each of these is seen in Figs. 1 and 2 for nuclear cataracts and Figs. 3 and 4 for cortical cataracts.

In the lower portion of each of these figures the normal eye’s response (unfilled symbols) is compared with the response of the fellow cataractous eye (filled symbols). The ratio of these responses, which represents the contrast attenuation due to the cataract, is plot-
ACUITY RATIO (cataract/normal eye)

Fig. 6. The acuity ratio (cataract/normal acuity) for single Landolt C's (o) and gratings (∗) is plotted against the magnitude of the low-spatial-frequency (average for 0.12 and 0.24 c/degree) abnormality (ratio of cataract/normal eye). An insignificant correlation exists between these two parameters for the 10 subjects tested, and the results exhibit a dichotomous behaviour (see text).

Fig. 1 typifies a response in which there is a frequency-dependent loss of contrast with normal low-frequency vision remaining. This result, which represents the largest acuity loss for the subjects tested, can be considered in general terms to be similar to dioptric defocus in that there is a range of low frequencies (large bars) for which vision is normal and the contrast loss at high frequencies can be approximately modeled, in this case, by that predicted from dioptric defocus. The dashed line in Figs. 1 to 4 denotes the predicted contrast loss (approximated slope of high-frequency fall-off) which was computed (autocorrelation computations of the pupil function) for a schematic eye (2 mm pupil) exhibiting 0.16 wavelengths of primary spherical aberration. Because defocus degradation can be easily simulated, this represents a convenient reference plane for appreciating the type of high-frequency contrast degradation due to cataract. Fig. 2 illustrates a response in which there is a frequency-dependent loss of contrast for high spatial frequencies combined with a constant low-frequency depression. This low-frequency depression is statistically significant (p < 0.1%). Figs. 3 and 4 show similar results for two subjects with predominantly cortical opacities. For one subject (Fig. 3) the intra-resolution limit abnormality is restricted to only high spatial frequencies, whereas for the other subject (Fig. 4) contrast detection is abnormal at all spatial frequencies. In both cases the high-frequency contrast loss is much more gradual than would occur from defocus.

The contrast-loss functions due to cataract for the ten subjects tested are displayed in Fig. 5. These results have been separated into two categories depending upon whether the intra-resolution limit abnormality is restricted to high-medium frequencies or affects all spatial frequencies. The results show that two distinctly different types of intra-resolution limit abnormalities occur, either the visual abnormality is restricted to high frequencies or it involves all spatial frequencies. Close inspection of the results shows that these two abnormalities have no correlation with the question of whether the cataract is cortical or nuclear and that for a complete picture of the type of intra-resolution limit abnormality one has to know the following values: the cut-off acuity, slope of the high-frequency fall-off, and the magnitude of the low-frequency abnormality. It would seem that all these factors can vary independently, and so more extensive results are required before their interrelationships are known. One interpretation of the present results is that as a cataract develops, optical aberrations and narrow-angle scattering are the major contributors to visual loss. When scattering becomes isotropic, vision for all frequencies will be affected equally, and so the contrast-loss function undergoes a predominantly vertical shift. A longitudinal study using the present technique to monitor the visual loss during the course of cataract formation should be able to test this suggestion. The interrelationship of these three factors may vary from one cataract to another, and to
Fig. 7. Photographs of an image formed by an artificial eye (3 mm diameter pupil) for three conditions of viewing. In-focus (A), defocus (B), and diffuse imagery (C) are compared. The defocus and diffusing filters had identical acuity (high-frequency) responses, and all conditions were equated for the same total diffuse transmission. The diffuser, which affects low frequencies as well as high frequencies, produces a more visually debilitating result than the equivalent defocus (see text).

this extent each cataract will be unique and require individual assessment.

What is certain from the present results is that the type and extent of the intra-resolution limit abnormality (whether all or just a limited band of frequencies are affected) cannot be detected by measurement of acuity. The presence of the two response groups in Fig. 5 would not have been appreciated from conventional acuity tests. This point is more clearly seen in the results of Fig. 6 in which the acuity abnormality (ratio of cataract eye's acuity to normal eye's acuity) for letters and for gratings is plotted against the magnitude of the low-frequency abnormality. The letter acuity results were obtained after probit analysis of frequency-of-seeing data for single Landolt C detection. The grating acuity results were obtained by extrapolation to the abscissa of the individual high-frequency contrast-threshold results. These results were replotted on semi-log coordinates and fitted by linear regression.

The results show that there is no significant correlation ($r = 0.1; p > 0.1$) between the magnitude of the low-frequency abnormality and either the letter or grating acuity abnormality. There is however a good correlation ($r = 0.7$) between acuity (grating or letter) and magnitude of the low-frequency abnormality within the low-frequency-abnormality group, although for the sample size this correlation coefficient is not significant ($0.1 > p > 0.05$).

**Discussion**

The main finding of this investigation is that visual loss for subjects with senile cata-
ract cannot be described by a single visual-loss function because, for some subjects, vision for low frequencies (large bars) is disproportionately depressed. It is in the finding of this significant low-spatial-frequency abnormality that the present results differ from those of a previous study on simulated cataract. In this respect visual loss from all cataracts cannot be thought of or assessed in terms of contrast loss from dioptric defocus. Because the presence or absence of a low-frequency contrast abnormality is not correlated with the degree of high-frequency degradation (Fig. 6), present acuity tests will not be able to detect this extra intra-resolution limit abnormality.

The fact that contrast threshold are elevated for low spatial frequencies has important visual significance. Because the cause of this threshold elevation has a purely optical basis, it can be predicted that contrast perception in the suprathreshold region will be depressed by the same ratio. This luxury of being able to go from threshold results to suprathreshold predictions may not be valid if the visual loss has a neural basis. In the case of neural loss, threshold may be affected without any significant suprathreshold consequence if the abnormality occurs after the contrast gain-setting mechanism. It is only when the abnormality has a purely optical basis that suprathreshold prediction must hold, since the abnormality must occur before the neural contrast gain-setting mechanism. It is for this reason that the results in Fig. 5 have been expressed as a contrast ratio. These results therefore represent the suprathreshold contrast matching functions for cataracts and allow estimation of the perceptual world of the cataract subject at any contrast level.

The previous finding on optical depression of contrast perception at low spatial frequencies has a very debilitating visual effect is further supported by the results of optical filtering (Fig. 7). In this figure a complex visual scene has been optically filtered by a diffuser (consisting of 5 μm diameter spherical particles in liquid media) in Fig. 7, C, and a defocus lens in Fig. 7, B, giving identical high-frequency degradation (equal acuity for 3 bar military test target). The optical set-up for this filtering consisted in photographing the image formed by an artificial eye (3 mm diameter pupil). Each optical filter was placed as close as possible to the anterior lens surface of the artificial eye, and each filter was luminance-matched for total forward diffuse transmittance. The diffuser, unlike the defocus lens, affects low spatial frequencies and can be seen to produce more severe visual degradation than the "equivalent defocus." Similarly, cataract subjects who exhibit low-frequency visual abnormalities may have much greater visual loss under everyday conditions than would be indicated by our acuity assessment.

These results add to our present appreciation of the type of vision that a cataract patient experiences and may have an important bearing upon the question of when to refer the patient for removal of the cataract. It is suggested that the assessment of the visibility of large objects (e.g., low-spatial-frequency gratings) be used in the clinical environment to supplement the present acuity evaluation of vision for cataract subjects. These cataract findings raise the more general question as to how any residual visual function should be assessed for occupational or legal needs. Is the present acuity evaluation and visual field requirement adequate to define "blindness" or partial sightedness? Assessment and specification of the intra-resolution abnormality, combined with an understanding of its suprathreshold consequences, should allow a much more adequate definition of legal blindness. When the visual loss has a purely optical basis as, for example, in cataract, visual assessment should involve measurement of the visibility of large objects as well as the limit of resolution. When this is done, the suprathreshold contrast-matching function is automatically known, and contrast perception at any suprathreshold level can be calculated.

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REFERENCES

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