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Visual Optics: 2

SaB   10:45am–12:25pm
Mesa Ballroom A/B

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University of California, Berkeley

Discussants:	SaB1	Nancy J. Coletta, *University of Houston*
	SaB2	Jay M. Enoch, *University of California, Berkeley*
	SaB3	Pierre Simonet, *University of Montreal, Canada*
	SaB4	Larry N. Thibos, *Indiana University*

Letter Imaging through Light Scattering Eye Media in the Absence and Presence of Glaring Light

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In cataractous eyes, part of the incoming light is directly transmitted through the optical media and, part is scattered or absorbed by opacities in the lens. Wide angle, diffusively scattered light results in a veiling luminance, which mainly reduces contrast in the retinal image. Several investigators have pointed out that the standard visual acuity (VA) test is insufficient in detecting increased intraocular light scattering, the latter giving rise to glare problems. This circumstance has been the main reason for suggesting glare testing as a standard clinical procedure in the evaluation of cataractous eyes but yet no standard glare method has been widely adopted. In this work I analyse a glare test method in which one determines the smallest size of fixed contrast letters that the patient can identify. The test is performed with and without glare sources in the field of view. The Allergan Humphrey Auto Refractor model 570 (HAR 570) is an example of a glare tester utilizing this method. In addition to the standard VA-test, using letters at a high contrast (of about 1), it also presents letters of different sizes at a contrast of about 0.07. During testing, glare sources at a mean glare angle of about 2° may also be added to the field of view.

Theory

The retinal image is given by convolving the geometrical intensity function of the imaged object with the normalized point-spread function (PSF) of the eye, $i(\theta)$ (dimension: cd/lm). Here $i(\theta)$ is divided into two separate parts: the first part specifying resolution, $i_r(\theta)$, and the second part specifying scattering, $i_s(\theta)$:

$$\int_{2\pi} \left(i_s(\theta) + i_r(\theta) \right) d\Omega = 1 \qquad (1),$$

where θ denotes the planar scattering angle and $d\Omega$ the steric angle differential. The fraction of scattered light is:

$$k = \int_{2\pi} i_s(\theta) \, d\Omega \qquad (2).$$

If the resolution of the eye were determined by the pupil diameter only (diffraction limited), $i_r(\theta)$ would have been the well known Airy function.

Here instead, $i_r(\theta)$ is approximated by a Gaussian, with a fixed angular width, θ_r of 0.5' (min of arc):

$$i_r(\theta) = \frac{1-k}{\pi \cdot \theta_r^2} e^{-\left(\frac{\theta}{\theta_r}\right)^2} \qquad (3).$$

The scatter function of a cataractous eye, $i_s(\theta)$, is individual and in principal unknown until measured. In this study I assume that $i_s(\theta)$ also has a Gaussian distribution.

$$i_s(\theta) = \frac{k}{\pi \cdot \theta_s^2} e^{-\left(\frac{\theta}{\theta_s}\right)^2} \qquad (4).$$

The scattering angle (θ_s) gives the angular spread of scattered light and is assumed to be much larger than the angle of resolution ($\theta_r \ll \theta_s$).
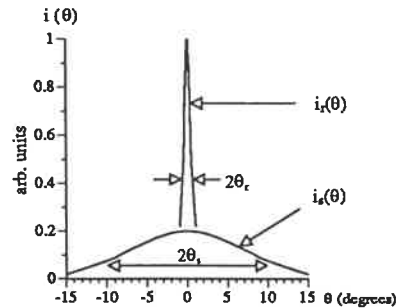

Figure 1. Illustration of the normalized point-spread function, $i(\theta)$.

A section of the retinal image of a Landolt's C opening (angular width: δ) under a few different imaging conditions is schematically illustrated in Figure 2. The case when diffraction and scattering effects can be neglected, i.e. when $\delta \gg \theta_r$ and $k=0$, is shown in Figure 2a. The retinal image contrast is then (Michelson's definition of contrast):

$$c_0 = \frac{I_b - I_t}{I_b + I_t} \qquad (5),$$

where I_b = background intensity and I_t = Landolt's C stem intensity. Still without light scatter (k=0) but with significant diffraction effects ($\delta \approx \theta_r$) the contrast reduces to:
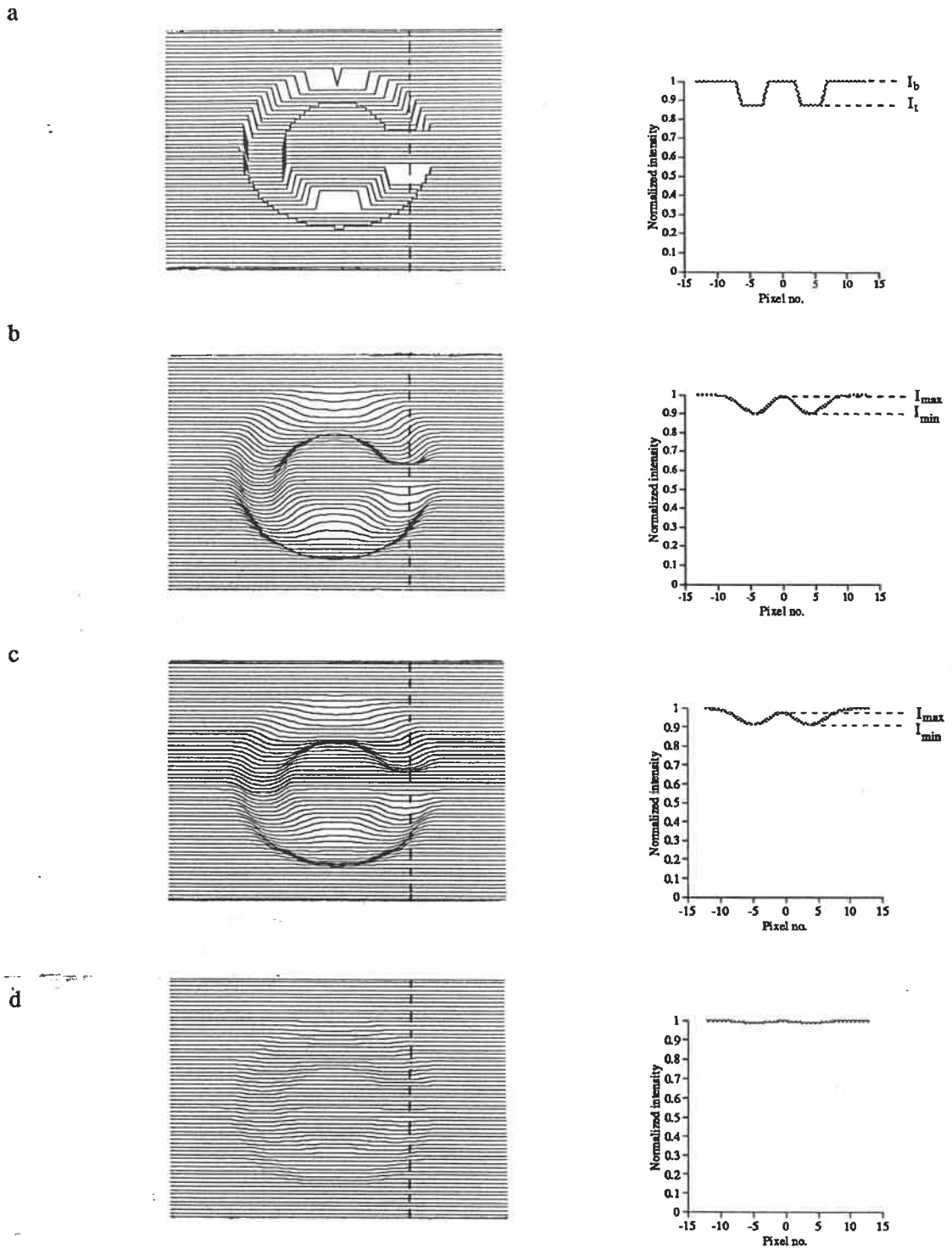
a

b

c

d

Figure 2. Left column: Landolt's C images under four different imaging conditions, a) the case when diffraction and scattering effects can be neglected ($\delta >> \theta_r$ and $k=0$), b) without light scatter ($k=0$) but with significant diffraction effects ($\delta \approx \theta_r$), c) significant diffraction effects ($\delta \approx \theta_r$) and light scattering lens ($k>0$), d) significant diffraction effects ($\delta \approx \theta_r$), light scattering lens ($k>0$) and glare sources in the field of view. Right column: sections through the Landolt's C opening along the broken lines.

$$c_1 = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (6),$$

where I_{max} and I_{min} are the calculated maximum and minimum intensities in the target area as shown in Figure 2b. The case of a light scattering lens ($k>0$) is shown in Figure 2c. Qualitatively, the target area loses light intensity due to scattering out from it and gains intensity due to scattering into it from the surrounding:

$$c_2 = \frac{I_{max}(1\text{-}k) - I_{min}(1\text{-}k)}{I_{max}(1\text{-}k) + I_{min}(1\text{-}k) + 2I_b k} \quad (7).$$

Figure 2d shows the situation with glare sources added. Both the target area and its close surrounding gain the scattered intensity I_s which is proportional to the glare source intensity Ig. The resulting retinal contrast is:

$$c_3 = \frac{I_{max}(1\text{-}k) - I_{min}(1\text{-}k)}{I_{max}(1\text{-}k) + I_{min}(1\text{-}k) + 2I_b k + 2I_s} \quad (8).$$

To simulate the experimental conditions the calculations were performed with glare source geometry and intensity as used in the HAR 570 test set up. Both lettercontrasts, c_0 (0.07 and 1), and sizes, δ (0.7', 1.0', 1.25', 1.5', 2', 2.5', 3', 4', 5', 10'), were chosen identical to the mentioned test. The diffraction limited retinal image intensities (an example of which is shown in Figure 2b) were numerically calculated in a computer by convolving the geometrical image intensity as given by Figure 2a with the resolving part of the PSF: $i_r(\theta)$. This calculation yielded numerical values of I_{max} and I_{min}, which were used in equations (7) and (8), the latter including lens scattering effects and the presence of glare sources. The parameter I_s in equation (8) was evaluated through the integral:

$$I_s = I_g \int_{\Omega_g} i(\theta) \, d\Omega \quad (9),$$

where I_g is assumed to be constant over the steric angle Ω_g subtended by the glare sources and where θ is the planar angle between the point of integration and the target.

The retinal image can thus be estimated as described above, and for a given δ it is determined by c_0, k, and θ_s. What minimum retinal image contrast is then needed for identification of the Landolt's C opening? I used the results of Campbell and Green [J Physiol, 1965] (Figure 3), who measured the neural contrast sensitivity for sinusoidal patterns, having reasonably well known contrast, which were directly generated on the retina. For simplicity, the Landolt's C opening profiles in Figure 2 were regarded as roughly a period of a sinusoidal pattern and, Figure 3 was used to directly obtain the contrast threshold for a given δ.
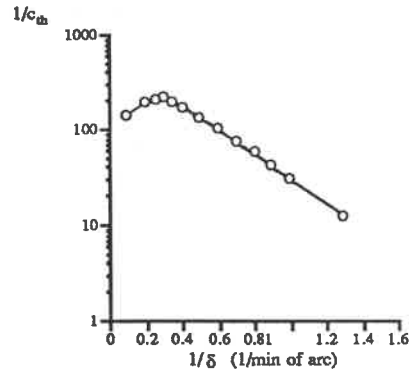

Figure 3. The neural contrast sensitivity function used in the evaluation of the calculated retinal images. The data points are taken from Campbell and Green .

Simple experiments

To study the usefulness of the above derived theory five young test subjects, with excellent visual acuity (VA>20/15) and without evidence of any optical opacities, went through both VA and glare testing. A standard VA-chart and a HAR 570 glare tester were used. In order to simulate cataracts, the test subjects wore light scattering glasses, the scattering properties of which had been measured previously [Beckman et al, Optom Vis Sci, 1992].

Results

First the case with no light scattering was studied. With the two chart contrasts, c_0, 0.07 and 1, the corresponding letter sizes δ, yielding retinal contrasts equal to the threshold value c_{th}, were calculated as described in the previous section. The obtained angular sizes were 1.1' for $c_0 = 0.07$ ($c_2 = c_{th} = 0.014$) and 0.7' for $c_0 = 1$ ($c_2 = c_{th} = 0.056$). The corresponding measured mean δ values obtained with the five test subjects (wearing no light scattering glasses) were: 1.25' and 0.7' respectively. For the $c_0 = 0.07$ test the smallest chart letter size was 1.25' and all five test subjects could indeed identify all letters of that size. (The second smallest letter size of the same contrast was 1.5'.) In the high contrast letter case the data ranged from 0.625' to 0.77'. Hence in this case the agreement between calculations and measurements is good.

Next the influence of light scattering in the absence of glare was studied. The curves in Figures 4a and b show the calculated threshold widths δ_{th}, as a function of the scatter strength, k, for the two chart contrasts 0.07 and 1, respectively. Three measured data points in both figures are also shown, obtained with and without the two light scattering glasses. Note in Figure 4b, which simulates a standard VA measurement that δ_{th} appears to be only weakly dependent on k for k ≤ 0.8. This is in agreement with results obtained from clinical studies. Further, the measured data points are in fair agreement with the calculations.
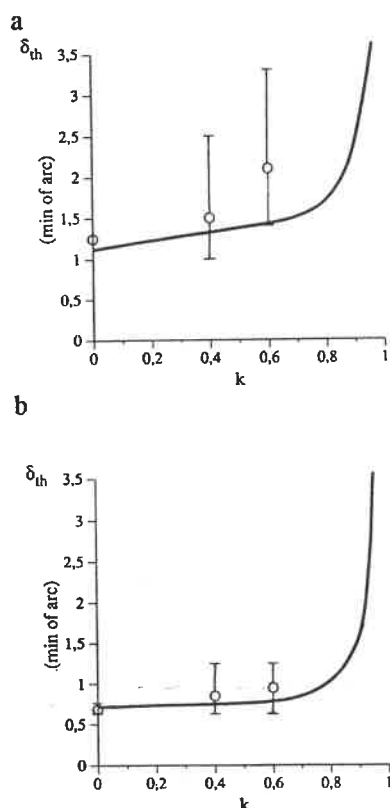
a

b

Figure 4. *The curves show calculated letter size at identification threshold δ_{th}, as a function of scattered intensity fraction k, without glare sources in the field of view. Circles show measured mean values, data spread indicated. a) Chart letter contrast: 0.07. b) Letter contrast: 1.*

In Figure 5 calculations with glare sources included are shown. In this case the scattering angle of the cataractous eye θ_s, is of importance, contrary to the case when there are no glare sources present. The glare disturbance is most pronounced when $\theta_s \approx \theta_0$, i.e. when the mean angle between the point of observation and the glare sources approximately equals the scatter

angle of the cataractous eye. Particularly, in the low contrast case ($c_0 = 0.07$) glare disturbance occurs at much lower k-values with glare sources present than without (cf. Figures 4a and 5a). Since the light scattering glasses do not have a Gaussian scattering distribution a direct comparisson with the calculations is not meaningful.
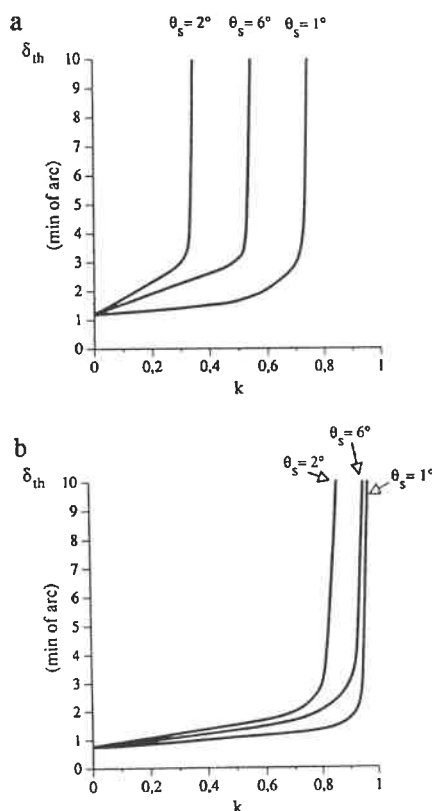
a

b

Figure 5. *The curves show calculated letter size at identification threshold δ_{th}, as a function of scattered intensity fraction k, with glare sources in the field of view, and for a few different scattering angles θ_s. a) Chart letter contrast: 0.07. b) Chart letter contrast: 1.*

Conclussion

The analysis shows that VA is quite insensitive even to substantial lens turbidity provided that the light is diffusively scattered and that glare sources are not present in the field of view. Even with glare sources in the field of view VA is rather insensitive to eye turbidity. However, if the letter contrast is reduced the sensitivity increases. In the "light" of this study, the mentioned absence of a simple relationship between VA and glare measurements found by others is not surprising.

Part of this work was presented at the Biomedical Optics Europe meeting in Budapest, Hungary, September, 1993.