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Importance of pathological intraocular light scatter for visual disability

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Abstract. For healthy eyes intraocular light scatter was investigated several decades ago. For pathological eyes, however, little is known. As clinical test several techniques have been proposed but none has gained general acceptance. A disadvantage of these tests was that quantities were estimated that related only indirectly to the amount of light scatter. We propose a method that gives a direct estimate of the light scatter.

We studied patients with cataract, corneal dystrophy, iris and fundus hypopigmentation, etc. A remarkable finding was that visual acuity correlates rather weakly with the amount of scatter. Since, however, the amount of scatter causes a considerable loss of visual function, the results show that for these patients the visual acuity test gives a rather limited impression of their visual handicap. More attention to the problems associated with intraocular light scatter is needed.

Introduction

Intraocular light scatter is the phenomenon that part of the light reaching the retina does not partake in normal image formation. Rays originating from a certain point in space are converged by the refracting surfaces of the eye to the focal area in the eye. Some of the rays are dispersed to other areas by optical imperfections of the eye which may be multiple. This occurs especially in pathological states, such as cataract, corneal dystrophy, floating particles in the chambers etc. These dispersed rays, we may assume, are distributed all over the retina, but with decreasing density at distances further away from the original focal area. Through this effect, the retinal light distribution in any visual environment is composed of two parts: the image of the external world based on the focused rays, superimposed upon a more or less homogeneously distributed background caused by the dispersed rays. As a result contrast is lost in the image of interest. The severity of this contrast loss depends on the illuminance ratio between background and image. The extreme situation is represented by the classical glare condition: strong light somewhere in the visual field while a weakly lit object has to be observed. Depending on the distance between glare source and object this situation can lead to complete blinding. The typical situation is blinding by oncoming traffic at night.

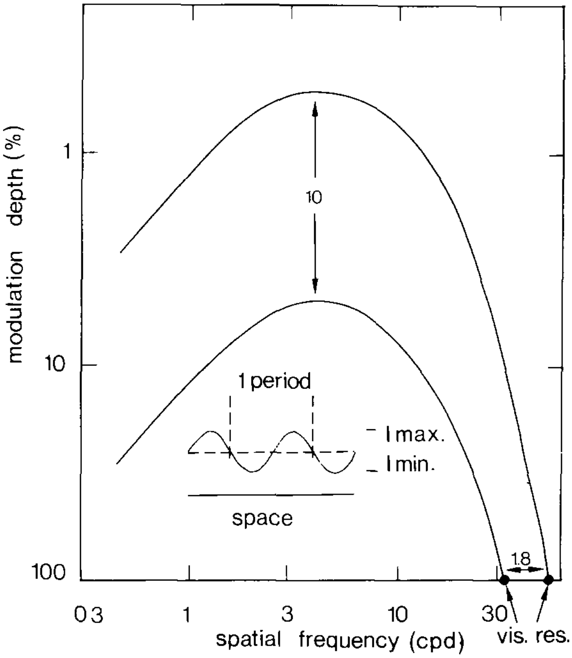

Figure 1. Spatial Contrast Sensitivity Function (CSF or Spatial Transfer Function, STF). Vertically the threshold modulation depth for sinusoidal gratings is plotted. Modulation depth is defined as $(I_{max} - I_{min})/(I_{max} + I_{min})$. Horizontally the spatial frequency of the sinusoidal grating is plotted defined by 1/(the length of one period) in cycles per degree (cpd). This curve holds approximately for our experimental conditions at 200 cd/m^2 but depends on pupil size, field size, colour etc. The high frequency tail falls off 4 log units per log unit of spatial frequency, which is a mean value found in literature. This figure is intended to demonstrate that losses of contrast (sensitivity) are associated with much smaller losses of spatial resolution (visual acuity), which is determined by the 100% end of the curve.

More moderate situations are encountered in daily life where less extreme luminance differences in the visual field exist. The loss of contrast may, however, even then form a serious handicap. This loss of contrast cannot be derived from a test of visual acuity. Visual acuity depends largely on the light distribution over short distances, i.e. on the focal area of the optics of the eye, which may or may not be disturbed by the same processes that cause the light scatter. In as far as visual loss is caused by loss of contrast it tends to underestimate the seriousness of the contrast loss (Figure 1).

For more or less complete documentation of contrast loss we must realize that contrast sensitivity depends on the spatial distance over which the contrast extends. This is investigated nowadays by means of the spatial transfer function (Figure 1). Horizontally the spatial frequency (= reciprocal of spatial distance) is plotted and vertically the contrast sensitivity expressed as threshold modulation depth. For the situation considered here we may assume that the retinal illuminance in the area of interest does not change because of the light scatter: if the mean luminance is about constant over the whole visual field including the area of interest, as much light is scattered towards that area as is scattered away from that area. So only the modulation depth changes, not the retinal illuminance. As a result the whole spatial transfer function drops. Since visual acuity correlates with the 100% point located at the steepest portion of this curve, visual acuity drops much less than contrast sensitivity; in this example a factor of 1.8 against 10.

The importance of intraocular light scattering has long been recognized. For healthy eyes it has been the subject of extensive studies (see Vos et al., 1976 and Vos, 1983). For pathological eyes no comparable studies have been performed quantifying the angular distribution of the scattered light. On the other hand several techniques have been proposed for practical use that give at least some indication of the amount of scatter. For instance Wolf (1960) designed an apparatus to test the threshold intensity for a Landolt C target in the presence of a glare source. Aulhorn and Harms (1970) introduced a glare tester that more or less stimulated a traffic situation. More recent examples are Paulsson and Sjöstrand (1980), Le Claire et al. (1982) and Van der Heijde et al. (1985). None has, however, gained general acceptance (Sekuler et al., 1983). They all give indirect information from which the amount of scatter must be deduced on the basis of sometimes complicated theoretical assumptions. We have designed a method that estimates the amount of scatter directly for each angular distance tested. The results are compared with the visual acuity in a number of patients.

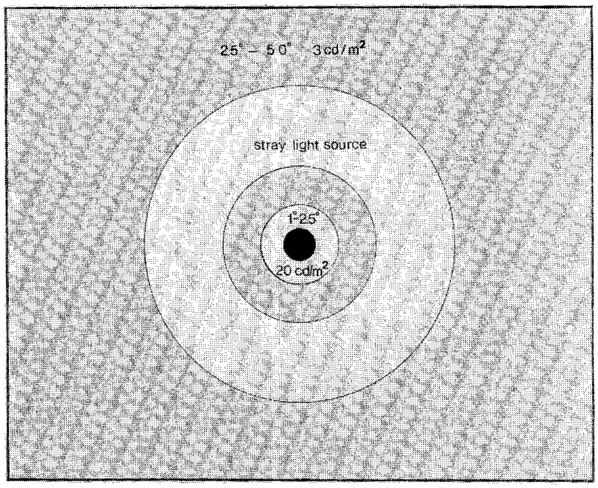

Figure 2. Spatial configuration of the field. In the center only, an adjustable compensation light is present of the same colour as the stray light source, but flickering in counterphase. It is surrounded by a high intensity white annulus and a low intensity large surround. One of the stray light sources is depicted which is at a mean distance of 7 degrees from the center.

Methods

The subject with his head in a chin rest fixes with one eye the center of a circular arrangement of fields (Figure 2). A stray light source can be presented at four distances from the center. The distance from the center to the middle of the annuli ranges from 3.75 to 30 degrees. The stray light source is interrupted periodically at about 8 Hz. As a result flicker is observed in the central area due to the scattered light. In the central field an adjustable counterphase flickering light can be turned on. The patient's task is to minimize or abolish the flicker perception by adjusting the luminance of this light by means of a one turn dial. This luminance L is by definition identical to the equivalent luminance describing the scatter function. In Figure 3 the quantity $L\phi^2/E$ is plotted. E is a calibration factor, ϕ^2 is added for mathematical elegance. See for the theory Vos (1983). The $20\,cd/m^2$ intermediate ring is present to suppress the perception of stray light flicker in the area adjacent to the test field.

Results and discussion

At present 18 patients have successfully performed the test; most of them for both eyes and for all three colours red, white and green; each at all four eccentricities of the stray light source. Their ages ranged between 10 and 92 years. 4 Patients failed the test. The daignoses included 11 cataracts, 7 corneal dystrophies and 4 others. In Figure 3 the results are depicted for white light and the two extreme eccentricities 3.75 and 30 degrees. The scatter index $L\phi^2/E$ is plotted against visual acuity, both on a logarithmic scale.

If we wish to connect VA and scatter in the way outlined in the introduction (Figure 1), we must realize that the surrounding field of the optotypes plays an essential role here. Often only the direct surroundings of the optotypes are brightly lit up to 1–3 degrees distance. Thus the areas tested for scatter in our experiment do not as a rule contribute to VA decrease. Instead the focal area of the optics of the eye and the scatter from the direct surroundings determine VA. Turning the argument around, we may say that VA estimates the amount of blurring over short distances, and we might wonder in how far VA could be used to predict the amount of scatter over longer distances.

Figure 3 tells us that VA correlates rather badly with scatter over more then 3 degrees. To start with, Figure 3 shows that scatter may be increased significantly in patients who have no appreciable VA loss (VA = 1). These patients are, however, already handicapped for an activity like night driving. With moderate VA loss (VA = 0.8) scatter can be increased 20-fold, confronting the patient with a very serious handicap. Although our selection of patients is limited, the results show quite clearly that VA can be very inadequate to estimate the importance of turbidity in the eye.

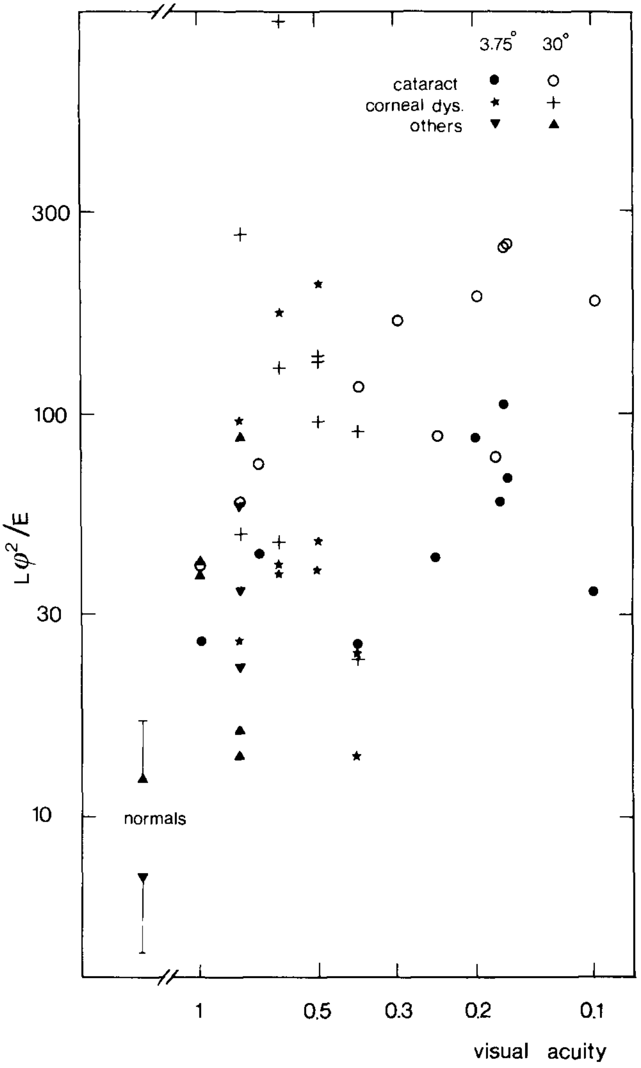

Figure 3. Relation between decimal visual acuity (horizontally) and strength of the light scatter (vertically) over 3.75 and 30 degrees. Data are plotted for 11 cataractous eyes, 10 corneal dystrophic eyes and 5 other pathological eyes. Not all eyes were measured at 3.75 degrees scatter distance.

In order to visualize the visual loss experienced by the patient we determined spatial contrast sensitivity functions. For each spatial frequency we asked the patients whether they could see sinusoidal gratings that were presented at different modulation depths in a stepwise procedure. On the basis of the patients' responses the threshold modulation depths were estimated for each of two conditions: there was either a dark surround or a large

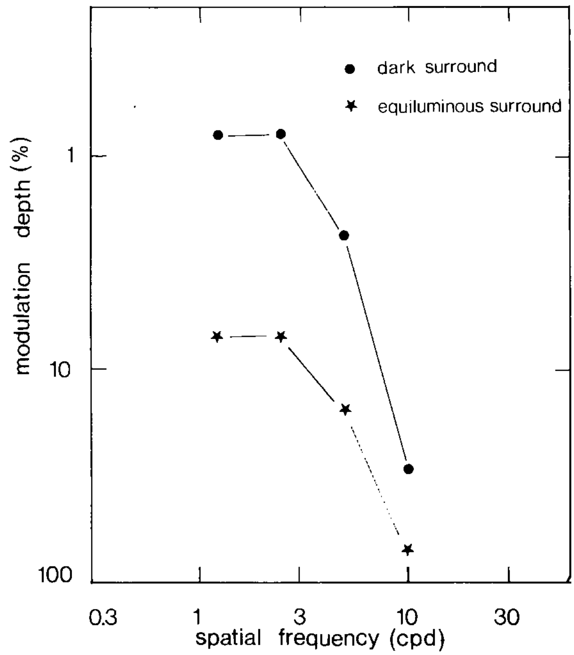

Figure 4. Effect of equiluminous surround on contrast sensitivity in the case of an eye with high scatter. The spatial contrast sensitivity function of this patient has dropped considerably, especially for high spatial frequencies, because of his crystalline corneal dystrophy (Delleman and Winkelman, 1968). With an equiluminous surround, which is a normal condition in daily life, he suffers additionally a great loss of contrast sensitivity.

equiluminous surround around the 3 degree diameter test field. The example given in Figure 4 represents a patient with 20-fold increase in scattered light. We see that contrast sensitivity loss amounted to a factor of 10. So, even if lighting conditions are far from extreme, this patient is seriously invalidated by scattered light. This stresses the conclusion that, in cases of turbidity of the media, evaluation of the visual acuity sometimes yields a gross overestimation of the nature of the visual world of the patient (Hess and Woo, 1978; Hess and Garner, 1977).

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