Contrast sensitivity in the presence of a glare light
Theoretical concepts and preliminary clinical studies

L.-E. Paulsson and J. Sjöstrand

A method is presented for quantitative measurements of the glare effect of light scattered in the ocular media. The contrast sensitivity function is measured with a television display system. A bright light source is introduced into the field of vision, and the resultant decrease in contrast sensitivity is measured. It is further used to calculate a scattering factor which is a direct measure of the intraocular light scattering. The scattering factor shows a marked increase in patients with early cataracts even if their visual acuity is not affected.

Key words: contrast sensitivity, glare light, intraocular light scattering

The commonly used visual acuity tests measure only the spatial resolution of very fine targets at high contrast. This resembles the situation in technical optics 20 to 30 years ago, when it was common to describe the quality of an optical system, e.g., a camera lens, in terms of its ability to resolve fine details—its resolving power. Since then it has been found necessary to use a more extensive description of the optical properties of a lens, and the modulation transfer function (MTF) is now in common use. The MTF describes the transformation of contrast vs. spatial frequency of an optical system. Lately the same concept has been introduced into the field of visual optics. In recent years, several investigators have used contrast sensitivity vs. spatial frequency as a description of visual performance under various experimental and clinical conditions (for review see refs. 3 to 5).

In a recent study of vision through cataracts, Hess and Woo have demonstrated impairment of contrast sensitivity in cataract subjects. The contrast sensitivity function when measured under ordinary illumination, however, gives only limited information relevant to the impairment of vision in daily life caused by intraocular light scattering. In order to enhance the effects of light scattering on the contrast sensitivity, we tried to measure the decrease in contrast sensitivity when a bright light source is introduced into the visual field.

This procedure was tried on six patients who performed well on the standard visual acuity test and who showed only moderate decrease in the normal contrast sensitivity test, but who complained about visual impairment, especially at work. Their disabilities clearly showed up as extreme suppressions of their contrast sensitivity in the presence of a glare light. Only patients with incipient posterior subcapsular cataracts were selected for the study presented here. Five normal subjects were included as controls.
Fig. 1. Definitions of optical parameters. Television screen luminances = \( L_{\text{max}}, L_{\text{min}}, \) and \( L_0 \); spatial frequency at TV screen = \( \frac{r}{x \cdot 180} \); \( r = \text{test distance} \); \( x = \text{cycle length} \); \( I = \text{glare light intensity} \); glare illumination = \( E = \frac{1}{r^2} \); equivalent veiling luminance = \( L_{\text{eq}} \).

**Material and methods**

**Subjects.** Five normal controls (age 30 to 61 years, visual acuity 1.0 to 2.0) without evidence of ocular disease and six patients with various degrees of posterior subcapsular cataracts (age 46 to 68 years, visual acuity 0.5 to 1.5) took part in the study. Refractive errors were corrected optimally for the test distance, and natural pupil was used.

**Apparatus.** A pattern of light and dark vertical bars with a horizontally sinusoidal light distribution was generated electronically and displayed on a black and white TV screen as described by Sjöstrand and Frisén. The screen was masked with white cardboard to subtend a 1 x 1° angle at the eye when viewed at a distance of 5 m. The mask, which subtended 4 x 4°, was illuminated to approximately the same space average luminance as the TV screen. The spatial frequency was varied between 0.7 and 38 cy/deg and the pattern contrast (defined as the modulation \( M = \frac{(L_{\text{max}} - L_{\text{min}})}{(L_{\text{max}} + L_{\text{min}})} \), where \( L_{\text{max}} \) and \( L_{\text{min}} \) denote the maximum and minimum luminances of the sinusoidal pattern, respectively) was varied in steps in the range 0.65 to 0.0007. The steps were individually calibrated with a photometer at low frequencies. The space average luminance of the TV screen \( L = \frac{(L_{\text{max}} + L_{\text{min}})}{2} \) was 135 cd/m² independent of both contrast and frequency. A small 110 cd incandescent lamp, the glare light, was placed to the right of the TV screen at distances corresponding to 1.7°, 3.4°, or 5.4° from the center of the TV screen.

The TV screen and the ambient light gave an illumination of 5.1 lux falling towards the patient. This was increased by 12.7 to 17.8 lux when the glare light was on. Only 5.4 lux of the increase falls directly from the lamp into the eye; the rest is a result of an increase in the ambient illumination.

**Procedure.** The contrast sensitivity (reciprocal of contrast threshold) was determined monocularly by raising the contrast from a subthreshold level at a selected spatial frequency until a pattern was just visible to the patient. Sixteen frequencies were explored twice in a random order. Thereafter the contrast sensitivity function was determined in the presence of the glare light. The entire procedure was repeated for at least one distance (1.7°) between the lamp and the center of the TV screen and in a few cases for all distances indicated above. In those cases where the effect of the glare light was too small to be conveniently measured, neutral density filters (transmission 0.1 or 0.01) were placed immediately in front of the screen. The TV screen luminance was thereby reduced to \( L = 13.5 \) or 1.35 cd/m², respectively.

**Theory.** It is possible to describe the light scattering properties of the ocular media as an equivalent veiling luminance \( L_{\text{eq}} \) (cd/m²), expressed as a fraction \( \eta = L_{\text{eq}}/E \), where \( E \) (lux) is the direct illumination onto the eye from the glare light source and \( \eta \), which is a function of the angle \( \theta \) between the object (the center of the TV screen) and the light source and which has the dimension (1/steradian), is a characteristic measure of the intracocular light scattering. The relevant parameters are illustrated in Fig. 1.

Let \( M_1 \) and \( M_2 \) denote the contrast modulation presented at the TV screen at the detection threshold without and with the glare light.

Let \( M'_1 \) and \( M'_2 \) be the resultant contrast modulation on the retina. Because of the conservation rule for luminances, the equivalent veiling lumi-
Assuming a constant relationship between $M$ and $M'$, e.g., $M'_i = k \cdot M_i$ we can write
\[
M'_i = k \cdot \frac{L_{\text{max}} - L_{\text{min}}}{2L} = k \cdot M_i
\]
and
\[
M'_2 = k \cdot \frac{1}{2(L + L_{\text{eq}})} = k \cdot \frac{L_{\text{max}} - L_{\text{min}}}{2L} \cdot \frac{1}{1 + L_{\text{eq}}/L} = k \cdot \frac{M'_2}{1 + L_{\text{eq}}/L}
\]

If we assume that psychophysical effects such as adaptation and pupil size can be neglected, we may set the threshold values equal $M'_2 = M'_1$, and we obtain
\[
k \cdot M'_1 = k \cdot \frac{M'_2}{1 + L_{\text{eq}}/L}
\]
\[
L_{\text{eq}} = L \cdot \left( \frac{M'_1}{M'_1 - 1} \right)
\]

The light scattering factor $\eta$ can then be expressed as
\[
\eta = \frac{L}{E} \left( \frac{M'_2}{M'_1} - 1 \right)
\]

In order to work within the contrast range of the TV, it was necessary to adjust the ratio $L/E$ by adjusting $L$ by means of neutral density filters. In our studies $L/E = 25$ was found useful for the cataract patients whereas $L/E = 2.5$ or 0.25 was needed to get reliable results for the normal subjects.

**Results**

Compared to controls, most of the cataract subjects had a loss of contrast sensitivity in the high- and/or middle-frequency range as seen in Fig. 2, with normal contrast sensitivity in the low-frequency range. In other cataract patients an impairment of the contrast sensitivity function was found over the whole frequency range in agreement with the findings detailed in ref. 6.

Typical contrast sensitivity curves for one normal and one cataract patient are given in Fig. 2. In the presence of a glare light the normal subject (visual acuity 1.0) showed an insignificant decrease in contrast sensitivity with $L/E = 25$, whereas the contrast sensitivity was markedly decreased in the patient with incipient cataract (visual acuity 1.0). With $L/E = 2.5$ some sensitivity loss was found even for the normal. In both cases the glare light source was positioned 15 cm (1.7°) from the center of the TV screen.

It was observed for many of the subjects that decrease in contrast sensitivity in the presence of the glare light was most distinct at low and medium frequencies. At high frequencies the decrease was less pronounced. The scattering factor was therefore calculated as an average value at five frequencies in the range 2 to 7 cd/deg. The results are summarized in Tables I and II. In a few cases the measurements were extended to larger angles ($\theta = 3.4^\circ$ and $5.2^\circ$). These results are also included in Tables I and II.

**Discussion**

Our study demonstrates that the quality of vision that a patient with cataract experiences
Table I. Summary of contrast sensitivity decrease for normal subjects in the presence of a glare light

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age</th>
<th>Visual acuity</th>
<th>L/E</th>
<th>Contrast sensitivity decrease ( \frac{M_2}{M_1} )</th>
<th>( \eta = \frac{L}{E} \left( \frac{M_2}{M_1} - 1 \right) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>2.0</td>
<td>25</td>
<td>1.98</td>
<td>1.46</td>
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<tr>
<td></td>
<td>2.5</td>
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<td></td>
<td>3.34</td>
<td>2.7</td>
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<td>0.25</td>
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<td>22.5</td>
<td>5.4</td>
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<tr>
<td>2</td>
<td>32</td>
<td>1.5</td>
<td>25</td>
<td>1.46</td>
<td>1.46</td>
</tr>
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<td></td>
<td>2.5</td>
<td></td>
<td></td>
<td>2.07</td>
<td>2.7</td>
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<td>0.25</td>
<td></td>
<td></td>
<td>24.1</td>
<td>5.8</td>
</tr>
<tr>
<td>3</td>
<td>52</td>
<td>1.0</td>
<td>25</td>
<td>1.22</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td></td>
<td></td>
<td>2.24</td>
<td>3.1</td>
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<tr>
<td></td>
<td>0.25</td>
<td></td>
<td></td>
<td>12.5</td>
<td>2.9</td>
</tr>
<tr>
<td>4</td>
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<td>1.0</td>
<td>25</td>
<td>1.23</td>
<td>1.23</td>
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<td>2.5</td>
<td></td>
<td></td>
<td>3.78</td>
<td>7.0</td>
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<td>0.25</td>
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<td></td>
<td>17.5</td>
<td>4.1</td>
</tr>
<tr>
<td>5</td>
<td>61</td>
<td>1.0</td>
<td>25</td>
<td>1.36</td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td></td>
<td></td>
<td>3.37</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td></td>
<td></td>
<td>18.2</td>
<td>4.3</td>
</tr>
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</table>

Luminance of the TV was \( L \) \((\text{cd/m}^2)\), and the flux upon the eye from the light source \( E = 5.4 \) lux. The angular distance between the center of the TV screen and the light source was \( \theta = 1.7^\circ \).

* Expressed as a ratio of the contrast threshold with (\( M_2 \)) and without (\( M_1 \)) a glare light source.

† Change in threshold contrast was in these cases too small to provide useful results, due to the stepwise variations of \( M_1 \) and \( M_2 \). The smallest steps were 58%. The averaging over 5 frequencies (2 to 7 cy/deg) partially smoothes out the steps.

cannot be assessed by visual acuity tests alone. In spite of clinically normal visual acuity (1.0 or 20/20) a marked impairment of contrast vision can occur due to intraocular light scattering. Using a similar grating pattern without a glare light, Hess and Woo have compared acuity tests with contrast thresholds for patients with unilocular senile cataract. They found evidence for two types of contrast sensitivity loss in cataract patients, one group with impairment over the whole frequency range and another with spared low-frequency vision. These results indicate that the visual impairment varies among cataract patients with the same visual acuity.

Many of the patients in the present study complained about visual problems in daily life. Most of them performed well on the standard visual acuity test and met the legal requirements for a driving license.

By slit-lamp microscopy and ophthalmoscopy it was in all cases possible to find lens cataracts of various degrees; those reported here were all of the posterior subcapsular type. The obvious drawback with slit-lamp microscopy or ophthalmoscopy is the lack of a quantitative estimate possible to relate to the degree of visual impairment.

One attempt to quantify the slit-lamp observations was made by Wolf and Gardiner, who suggested the use of a photometer to measure the luminance of the slit-lamp image in the lens.

By such arrangements it is possible to measure the amount of light which is scattered in the near-backward direction, i.e., out of the eye. The vision is, however, mainly affected by light scattered in the forward direction, toward the retina. The ratio of forward scattering to backward scattering is largely dependent on the size and distribution of the scattering elements. The backscattered light may therefore not give relevant information concerning the visual impairment of cataract patients. We have in the present paper used the retina itself as a photometer for measuring the intraocular forward light scattering. The use of sine-wave contrast sensitivity and the fact that the measured threshold values always appear as ratios in the formulas greatly reduce the influence of subjective factors.

Some idea of the accuracy of the method
Table II. Summary of contrast sensitivity decrease for patients with posterior capsular cataract in the presence of a glare light.

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age</th>
<th>Visual acuity</th>
<th>$\theta$ (degrees)</th>
<th>Contrast sensitivity decrease ($M_2/M_1$)</th>
<th>$\eta = \frac{L(M_2/M_1)}{E(M_1 - 1)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>46</td>
<td>1.0</td>
<td>1.7</td>
<td>21.9</td>
<td>523</td>
</tr>
<tr>
<td>7</td>
<td>46</td>
<td>0.7</td>
<td>1.7</td>
<td>32.0</td>
<td>775</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.4</td>
<td>9.37</td>
<td>174</td>
</tr>
<tr>
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<td></td>
<td>5.2</td>
<td>4.8</td>
<td>95</td>
</tr>
<tr>
<td>8</td>
<td>56</td>
<td>1.5</td>
<td>1.7</td>
<td>1.73</td>
<td>—c</td>
</tr>
<tr>
<td>9</td>
<td>58</td>
<td>1.0</td>
<td>1.7</td>
<td>7.26</td>
<td>157</td>
</tr>
<tr>
<td>10</td>
<td>66</td>
<td>0.5</td>
<td>1.7</td>
<td>2.15</td>
<td>—c</td>
</tr>
<tr>
<td>11</td>
<td>68</td>
<td>0.7</td>
<td>1.7</td>
<td>2.37</td>
<td>34.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.4</td>
<td>1.38</td>
<td>9.5c</td>
</tr>
</tbody>
</table>

Luminance of the TV ($L$) was 135 cd/m² and the flux upon the eye from the light source was $E = 5.4$ lux. The angular distance between the center of the TV screen and the light source was $\theta L/E = 25$.

*Expressed as a ratio of the contrast threshold with ($M_2$) and without ($M_1$) a glare light source.

In this case a test with $L = 13.5$ cd/m² ($L/E = 2.5$) was made which gave $M_2/M_1 = 38$ and $\eta = 92.5$.

See second footnote to Table I.

and of the validity of the assumptions made in the Theory section can be obtained by comparison with the previous studies on retinal light profiles from point sources. Most of these studies were summarized by Vos et al., who gave an empirical relation of $\eta$ vs. $\theta$.

$$\eta = \frac{I_{\text{win}}}{E} = \frac{K}{(\theta + 0.13)^{a}} \quad (0.15^\circ < \theta < 8^\circ)$$

where $K = 29$ and $a = 2.8$ for the normal eye. This relation gives $\eta = 5.4$ for $\theta = 1.7^\circ$.

For the normal subjects we found as an average $\eta = 4.9$ for the same $\theta$. The small material and the uncertainty in $\theta$ due to the large TV screen (1°) may fully account for the difference.

The exponent for the $\theta$-dependence ($a$) was determined for the most advanced cataracts and was found to be in the range 2.0 to 2.6. This shows that the dependence of $\eta$ on $\theta$ does not change very much from the normal ($a = 2.8$) in the case of posterior subcapsular cataracts. The $\theta$-dependence has also earlier been found to be constant with age and between individuals. The large $\eta$’s for the cataract patients (range 34 to 775) can thus be ascribed mainly to an increase of the proportionality factor (K). Therefore it seems possible to use the value of $\eta$ at a single specified angle $\theta$ as a convenient measure of the intraocular light scattering.

For our normal subjects we found that the frequency of the contrast sensitivity peak was shifted toward higher frequencies when the glare light was switched on. The shift was in the range 0 to 40%, with a mean value of 12%. The total light flux falling upon the eye changed from 5.1 lux to 17.8 lux, i.e., 3.1 times (0.5 decade) more. De Valois et al. have studied the contrast sensitivity at different target luminances, and from their results we find a shift of 26% toward higher frequencies when the target luminance is increased by one decade. Our data shows an increase of about 24% per decade of total light flux, indicating that the adaptation may merely be a function of total light flux than of target luminance.

The shift in peak frequency may be responsible for the observed differences between the contrast sensitivity decrease at high and low frequencies. The error which is introduced by this shift is probably partly canceled at low frequencies by a simultaneous shift upward. By using the data from ref. 11, we estimate that the total error in $\eta$ due to adaptation would be about 5% to 15%.

It should be noted that we have not paid...
any attention at the present stage to the color differences between the TV screen and the incandescent lamp. The effect of this still remains to be explored.

In conclusion we propose a relatively simple and clinically useful method for determining the degree of visual impairment due to intraocular light scattering. The method may prove useful in vision tests for occupations with high demands on visual ability, perhaps including car driving.

It may also be valuable for detecting pre-stages of cataract in patients occupationally exposed to potential cataractogens, e.g., infrared and microwave radiation. The method may in its present stage be too cumbersome for routine tests, but the concepts outlined may be useful as a starting point for further work, especially as contrast sensitivity measurements become more and more used.

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REFERENCES


