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VISUAL EFFICIENCY OF SCATTERING AND FLUORESCENCE IN THE HUMAN EYE LENS

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ABSTRACT

Recent data in the literature on psychophysically determined *in vivo* intraocular straylight, and on *in vitro* fluorescence of the eye lens are analyzed. From the psychophysical straylight data, light scattering changes in the lens due to normal aging and age-related cataract formation are derived in physical terms. The intensities of these light-scattering changes prove to follow approximately $c\theta^p$ (θ=scatter angle) with $p \approx -2$ and c dependent on age and cataract. Both p and c are in accordance with recent *in vitro* studies on light scattering using donor lenses. Fluorescence of the lens causes light with wavelengths of 420 nm and lower to be in total visually much more effective: by a factor of 2.7 to 6.8 at 400 nm, and a factor of 71 to 151 at 380 nm. Because fluorescence adds a homogeneous veil to the point spread function, for some visual effects (e.g., glare) the increase can be (much) larger.

Keywords light scattering and fluorescence; human lens; aging; glare; stray light.

1 INTRODUCTION

Intraocular straylight can be quantified psychophysically, as it is important for (hindering) visual function. In principle it can be of the elastic type (no change in wavelength) or of the inelastic type (fluorescence with wavelength increase). Straylight has been found to depend on several eye tissues, including the lens. This paper is devoted to isolating from some of recent studies the contribution of the human eye lens to functionally relevant straylight. For this, psychophysical data as well as *in vitro* data on physical light scattering and fluorescence by donor eye lenses will be used.

The optically relevant structures of the human eye include cornea, aqueous, lens, vitreous, and the eye wall. Their combined effect on the optical quality of the eye may be assessed by the retinal point-spread function (PSF). The PSF is defined as the light distribution resulting from a point source, in the present case assumed to be in best focus. Usually the PSF is normalized by setting its integral to unity. However, the amount of light reaching the retina is also important. The fraction of light from a point source transmitted in total (over all forward directions) by the eye media is called *total transmittance*, T. The fraction of light transmitted within a cone of limited top half angle α (on the order of 1 deg) around the zero direction is called *direct transmittance*, T_α. The differences between T and T_α are due to nonzero values of the PSF for angles larger than α. The skirt of the PSF may be phenomenologically referred to as ''straylight,'' meaning that this light is astray, with no physical interpretation attached. Several physical phenomena may contribute to it. Whereas aberrations and diffraction have the greatest effect at very small angles (<15 min[1]), at larger angles straylight (>0.15 deg[2]) is often assumed to be dominated by light scattering, but diffraction[3] or fluorescence[4] may also contribute.

2 STRAYLIGHT DATA

For understanding straylight effects on visual function, one would be interested in the functional PSF, i.e., the PSF according to psychophysical measurements. This may be different from the optical PSF because of the directional sensitivity of the photoreceptors. The (functional) straylight part of the PSF rather than the central part has been the subject of many older studies. Cobb[5] introduced the concept of ''equivalent luminance'' L_{eq} for quantification of straylight. L_{eq} is an external luminance that is perceptually equivalent to the entoptic straylight. With PSF=L_{eq}/E_{gl}, E_{gl}=illuminance on the eye (gl for glare), the above-mentioned normalization is obtained. This can easily be verified if a homogeneous full field is considered. Many authors have measured straylight using this concept (see review in Ref. 6; more recent examples can be found in Refs. 7 and 8). As a rule, in straylight studies, wavelengths are so large that fluorescence does not play a role.

In order to achieve higher measurement accuracy, the ''direct compensation method'' was designed for measurements between a 2.5 and 35 deg scattering angle.[9] In this method, the straylight source is presented flickering. Then observable

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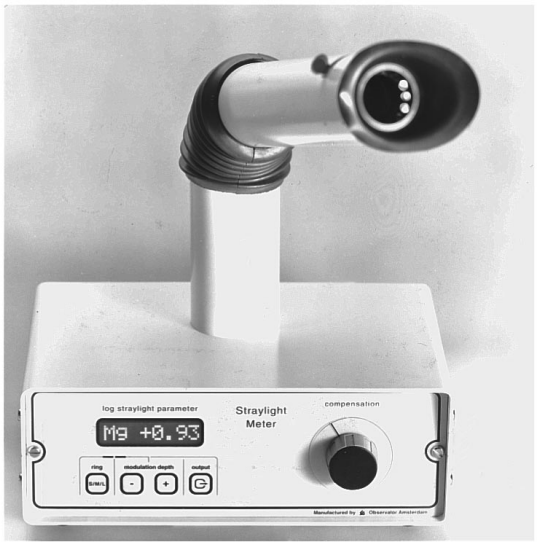

Fig. 1 Entoptic straylight at 3.5, 10, and 28 deg can be determined with the straylight meter depicted in this photograph, employing the direct compensation method.

flicker is obtained elsewhere in the visual field because of straylight. This flicker can be nulled by presentation of a spot of light flickering in counterphase. This method is implemented[10] in the straylight meter (Figure 1) with a measurement accuracy between 0.05 and 0.1 log units, depending on experience in administration of the test. Independent tests were performed.[11–13]

The direct compensation method as realized in the straylight meter works as follows: A ring-shaped (radius 3.5, 10, or 28 deg) straylight source consisting of LEDs modulates at a frequency of 8 Hz with an adjustable modulation depth. The central field is a dark circular field of 1 deg radius. This is surrounded by a bright ring-shaped field, the separation annulus. Due to intraocular straylight, the modulation of the straylight source can be perceived in the dark central field as a weak flicker, although physically no light emanates from there. If an adjustable amount of counterphase light is presented in the central field, one can obtain an apparently silent (i.e., nonflickering) central field. In this way the light straying intraocularly from the straylight source is compensated for. The light presented in the central field is used as the ''measuring stick'' to measure the amount of straylight.

An advantage of the compensation principle is that the retina (and all higher neuronal signal transfers) is used only to judge a zero condition. Light reaching the fovea from the central test field adds optically to the straylight. The retina must signal only the presence or absence of modulation in the combined light. The neuronal part of the visual system is used as a ''null instrument.'' Thus, in principle, the outcome cannot be influenced by disturbances on retinal and/or higher processing levels. Also, the adaptational state of the retina is inconsequential. However, measurement uncertainty can increase if neuronal behavior is disturbed.

In the straylight meter, the modulation depth of the straylight source can be changed in steps of 0.2 log units between 100 and 2.5%. This allows the strength of the straylight flicker to be adjusted to accommodate the flicker sensitivity of the patient. By definition, the compensating luminance modulation in the central field is equal to the ''equivalent'' luminance L_{eq} modulation of the straylight. With E_{gl} as the illuminance modulation on the patient's eye caused by the straylight source, the ratio L_{eq}/E_{gl} defines the normalized PSF. To be precise, the quantity measured with the straylight meter (or any other method) does not equal true L_{eq}/E_{gl}, but rather L_{eq}/E_{gl} divided by the integral of L_{eq}/E_{gl} taken over the test field. This denominator integral is less than unity. It is about 0.9 for a 1-deg radius test field for the healthy young eye. For older and/or pathological eyes, it might become lower. Yet, it is not always necessary to correct for this. If one is interested in the functional effects of straylight (contrast loss in a target), one needs the ratio between target luminance and straylight equivalent luminance. This is precisely what L_{eq}/E_{gl} as measured with the straylight meter gives (for a target of 1-deg radius). This might be called ''effective'' L_{eq}/E_{gl}. If the denominator integral is much less than unity, effective L_{eq}/E_{gl} can become quite high. As a result, the measured value of L_{eq}/E_{gl} might seem to be inconsistent with the normalization of the PSF.

For θ>1 deg PSF declines roughly proportional to θ^{-2}, i.e., if the angle is doubled, the PSF decreases by approximately 0.6 log units. In order to make better use of the high measurement accuracy, we write PSF=$s(\theta)\theta^{-2}$. $s(\theta)$ is called the *straylight parameter*. $s(\theta)$ is much less strongly dependent on θ, and shows differences among individuals more clearly.[14] It also shows more clearly the deviations from the θ^{-2} dependence, the true PSF being steeper for θ<10 deg,[2,8] and more shallow for θ>10 deg.[15]

In normal young eyes, an important part of the straylight comes from the lens.[8] With normal aging, straylight increases,[8,15,16] predominantly because of increased light scattering in the lens,[17] approximately according to $s(\theta)\sim 1+(\text{age}/70)^4$. The standard deviation of interindividual differences in homogeneous age groups is between 0.1 and 0.2 log units.[10,15] With the formation in the lens of age-related cataracts, straylight further increases.[17,18] Such data can be used to derive estimates for light scattering by the lens. It must be taken into account that lightly pigmented eyes have more intraocular straylight because less light is caught in the pigment granules.[19]

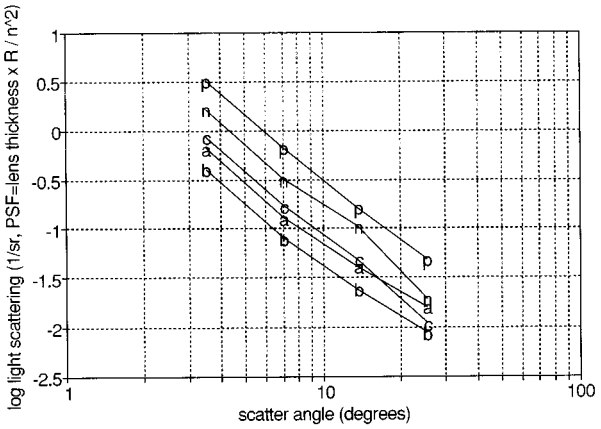

Fig. 2 Log straylight intensity as function of scatter angle for (b) young, normal, well-pigmented subjects; for (a) the increase as result of aging until 70 years; and for the increase due to age-related cortical, (c), nuclear, (n), and posterior, (p), subcapsular cataracts.

3 Derivation of Lenticular Light Scattering

For Figure 2, data were analyzed from Ref. 17 in which log [$s(\theta)$] for different ages and for groups with early age-related cataracts is presented (see especially Figure 4 in Ref. 17). Three types of cataracts were studied: cortical (c), nuclear (n), and posterior subcapsular (p).

Although straylight can sometimes be very disturbing because of the glare it induces, in all except dense cataracts, we must realize that its optical intensity is rather weak. Correspondingly, single scattering dominates, and the total straylight reaching the retina is the algebraic sum of straylights originating from the different sources mentioned earlier. If scattering intensifies because of pathology, multiple scattering can become important.[20] In case of cataracts, this stage is reached only in very advanced cases. For the present discussion, the different sources can be treated independently. Also, light losses due to absorption in the eye media can be neglected. Since both experimental quantities L_{eq} and E_{gl} are measured outside the eye, light absorption in the eye media does not affect their ratio.

The data in Figure 2 were derived as follows: From Ref. 17 population means for log [$s(\theta)$] can be derived for (1) normal, young, and well-pigmented eyes; (2) the same at 70 years of age; (3) early cortical cataract eyes; (4) early nuclear cataract eyes; (5) early posterior subcapsular cataract eyes; and (6, 7, and 8) for the respective noncataractous, age, and pigmentation-matched groups. The differences in $s(\theta)$ between (1) and (2) may represent pure lenticular aging effects, if one disregards aging effects in other light-scattering parts of the eye. The differences in $s(\theta)$ between (3) and (6), between (4) and (7), and between (5) and (8) may represent pure cataract light scattering of the respective types. If the light used to determine $s(\theta)$ is more or less monochromatic, these differences $\Delta s(\theta)$ can be directly transformed into radiometric units[21]:

$$\Delta PSF(\theta) = \Delta s(\theta) / \theta^2 = R(\theta) d / n^2 \quad (1/sr), \tag{1}$$

with $R(\theta)$ the Rayleigh ratio for the respective lens material, d the thickness of the respective lens material layer, n the refractive index of the vitreous[22] (1.336), and sr the steradian. The Rayleigh ratio is the common radiometric standard to define light scattering in a volume V. It is defined as $R = Ir^2 / I_0 V$, with I the scattered irradiance at a distance r and incident irradiance I_0.[23] Often, the light used to determine $s(\theta)$ is nonmonochromatic, and weighted averaging using the spectral sensitivity curve of the eye would be needed to correct (1). For example, in the straylight meter the light has a 570-nm peak emission and 30-nm half width at half height. Since foveal viewing is used, the relevant eye sensitivity curve is the V_λ curve with a 555-nm peak and 50-nm half width at half height. On the other hand, with such values the deviation from monochromaticity is not very important.

In Figure 2 log [$\Delta s(\theta)/\theta^2$] is depicted for (a) the 70-year age effect, (c) the early cortical cataract effect, (n) the early nuclear cataract effect, and (p) the early posterior subcapsular cataract effect. Also depicted is (b) the result for young, normal, well-pigmented eyes (group 1 above). It must be realized that this last result is not a difference, and that other light-scattering parts of the eye, especially the cornea, probably contribute in this case.[8] However, in well-pigmented eyes, contributions from the eye wall are minimal.[19] Also in (a), other parts of the eye might contribute if their scattering depends on age. This might in particular be true for the pigmented structures of the eye, since pigmentation decreases with age. Pigmentation-dependent scattering is strongest at larger angles.[19] That may explain why curve (a) bends slightly upward at larger angles.

It seems remarkable that all the functions for lens and cataract alike follow more or less the same course. However, this is supported by *in vitro* light-scattering studies in normal lenses from donor eyes.[20,21] Scattered intensity proved to follow an approximate power law as in Figure 2:

$$\log[R(\theta) d / n^2] \approx \log(c\,\theta^p) = \log(c) + p\ \log(\theta), \tag{2}$$

with for 602 nm the power $p = -2.20 \pm 0.20$[20,21] and log (c) between 0.43 and 1.83, depending on cataract severity[21] (angular domain 3.5 to 28 deg). Figure 2 shows that this corresponds closely to the *in vivo* findings (effective wavelength about 560 nm) with p between −2.14 and −1.96, and log (c) between 0.60 and 1.67. It must be noted, however, that the two lens sets are not fully comparable. It was also found that normal light scattering in the nucleus, including normal aging changes, had

somewhat lower powers, and of course relatively low c values.[21] Perhaps this also contributes to the slightly lesser slope of the (a) and (b) curves in Fig. 2.

4 FUNCTIONAL EFFECT OF LENTICULAR FLUORESCENCE

Fluorophores in the human lens transform (visually barely effective) shortwave light into visually more effective light. This is because the emitted wavelengths are longer than the wavelength of the exciting light (Stoke's rule). This effect has long been realized.[4,24,25] Fluorescence may be assumed to add a uniform component to the retinal point spread function, but is strongly dependent on wavelength. It adds to the uniform component already present due to the translucence of the eye wall.[19,26]

A typical UV source is the so-called black light (a UV-emitting low-pressure mercury lamp, used at parties and discos). A black light not only causes fluorescent effects on clothes and other objects, but also fills our entire visual field with nondescript light. This light might be assumed to originate from the fluorescence of the lenses of our eyes. Since fluorescence is essentially isotropic, the light seems to have no origin. Also on other occasions fluorescence interferes with vision.[25] Night driving may become a new problem area since at present the automobile industry is considering the introduction of UV headlights to make traffic objects visible by their fluorescence. Because the CIE (Commission Internationale de l'Eclaizage) luminous efficiency function is very low for UV (phakic eyes), UV headlights supposedly give no glare problems from oncoming traffic. But small fields, of say 1 deg radius,[22] were used to derive the CIE luminous efficiency curve. Within 1 deg only 0.015% of isotropic radiation into the forward half space would be collected. Since fluorescence is isotropic, the luminous efficiency curve could seriously underestimate the total visual effect of UV, that is, the total as it is collected over the full retina.

In a study using intact donor eye lenses, absolute values for fluorescence intensity behind the lens were measured.[27] Such data can be used to estimate the visual effects of lens fluorescence.[25] The study verified that fluorescence causes isotropic straylight, as opposed to elastic lenticular light scattering. If Eq. (2) were applied to straylight from fluorescence, the power p would be zero.

In Figure 3, the results of this study[27] are used to derive visual effects. Three lenses were studied; they were 28 years of age (excitation wavelength 400 nm), 69 (380, 400, and 420 nm), and 22 years (380, 400, and 420 nm). The results for the 28-year lens were virtually identical to the 400-nm results for the 22-year lens, causing the corresponding data points in Figure 3 to be hardly discriminable. For each age-wavelength combination, the emission spectrum was measured. From each of these spectra the total amount of emitted quanta per excitation quantum (quantum efficiency, Q.E.) was derived; it is given as filled squares in Figure 3. The older lens had 0.3–0.5 log units higher Q.E. than the two younger lenses. Note that only half of the emitted quanta enters the eye and was accordingly taken into account in the following derivation of visual efficiency.

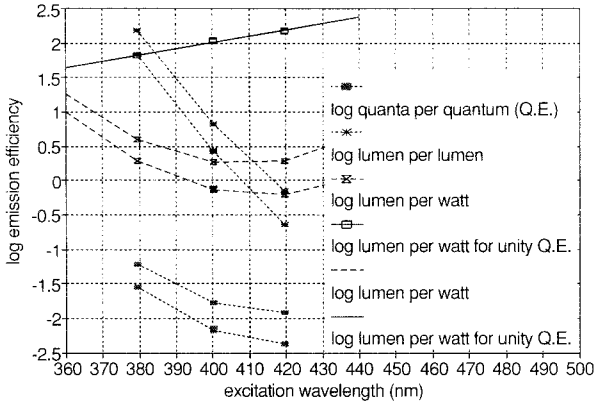

Fig. 3 Shortwave light excites fluorescence in the lens with efficiencies as depicted here in different units. Of each pair of curves, the lower holds for ages 22 or 28 years and the upper for 69 years. The hourglasses show much larger luminous efficiencies (lumens per watt) than the CIE values of 0.027, 0.27, and 2.8 lumens per watt at, respectively, 380, 400, and 420 nm.

Each of the emission spectra was weighted with the CIE photopic luminous efficiency spectrum corrected for lens transmission[22] to arrive at equivalent lumens entering the eye. Total equivalent lumens per excitation watt are given as hourglasses in Figure 3. Whereas the Q.E. is not very high with values around −2 log units, the lumens per watt are about 2 log units higher. This results mainly from the fact that around the peak of the emission spectrum (480 to 500 nm) CIE photopic efficiency is 100 to 200 lumens per watt. The values obtained at 400 nm are 0.7 and 1.8 lumens per watt (Figure 3). These values are clearly higher than the CIE value of 0.27 lumens per watt at 400 nm. At 380 nm, the results are 1.9 and 4.0 lumens per watt compared with the CIE value of 0.027. At 420 nm, the results are 0.6 and 2.0 compared with the CIE value of 2.8. The ratios between these results and the CIE values are depicted in Figure 3 with stars (lumen per lumen).

The open squares in Figure 3 give the ratio between lumens per watt and Q.E. This quantity proved to be virtually the same for the two younger lenses and the older lens. A rather precise linear relationship with wavelength seems to hold (solid line), which might allow for some extrapolation. The behavior of the other quantities is more complex. The quantity of importance for visual function (lumen per watt) was fitted with a quadratic model (dashed line), but extrapolation must be applied with more caution.

These results indicate that fluorescence is visually important at excitation wavelengths of 420 nm and

less. For the intact eye, a correction must be made because of light losses in the cornea. However, this correction is small; it is less than 0.1 log unit at 380 nm.[28] Above 420 nm, the luminous efficiency of the excitation light itself is largest. For the young eye stimulated with 380 nm light however, fluorescence adds a visually effective stimulus that is larger by 1.85 log unit (a factor of 71) than the 380-nm light itself. At 400 nm, the addition is larger by 0.43 log unit (a factor of 2.7). At 420 nm, the addition is smaller by 0.66 log unit (a factor of 0.22). For the older eye, the additions were more than twice as large: for 400 nm, they were 0.83 log unit (a factor 6.8); for 380 nm, 2.18 log unit (a factor of 151); and for 420 nm, −0.15 log unit (a factor of 0.71). It must, be realized that these figures are based on the luminous efficiency function. However, this function is invalid for old eyes. The sensitivity of old eyes to short wavelengths is much lower. So, in fact for old eyes, the ratio of luminous effect between the direct light and the fluorescence it causes can be much larger. For example, for this 69-year-old eye, at 380 nm, log (transmittance)=−4.96, whereas for young eyes, log (transmittance)=−2.61.[22] The difference in visual effect between 380-nm light and its fluorescence for this eye would be 2.17+4.96 − 2.61=4.52 log units (a factor of 33,000).

To evaluate the importance of this added light, the following comparison may help. It is based on a model for the point spread function.[29] Realize that the added light is homogeneously distributed over the retina, whereas the normal light follows the PSF. The PSF has a high peak and declines with angle up to 90 deg. If the PSF is compared with a homogeneously distributed light of some other origin (fluorescence), the two may cross at some point. For homogeneous light that is larger than the PSF by 2, 1, or 0 log units, crossing takes place at 0.92, 2.2, and 6.4 deg, respectively. Taking as an example the above value for 420 nm (the addition is 0.66 log unit smaller), at angles larger than 10 deg the PSF for 420-nm light is increased by a factor of 2.7 on account of fluorescence. From the functional point of view (glare, contrast sensitivity, etc.), this is a serious deterioration of the PSF and hence of vision. The deterioration increases sharply with decreasing wavelength (and increasing age).

These results can be used to understand the literature[30] on UV-induced glare. The effect of illuminating the eye with approximately 1.5 W/m^2 at 365 nm on test results with letter charts of different contrasts was studied for normal subjects of different ages. A significant change was found only at the lowermost contrast of 11% (a luminance of 100 cd/m^2). Changes increased from 0.00625 logMAR (a factor of 0.99) for 21 to 30-year-old subjects to 0.04167 logMAR (a factor of 0.91) for subjects 71 years and older,[30] but with large uncertainty intervals. From Figure 3 at 365 nm for the transformation of watts to lumens, values of 0.8 or 1.1 log can be read, but note that this involves extrapolation. Thus, 1.5 W/m^2 corresponds to 10 or 20 lumens/m^2 in the plane of the pupil. Since fluorescence is a homogeneous veil, the same veil would result from observing a homogeneous stimulus field emitting the same amount of lumens per square meter. Such a field would have a luminance of 3 or 6 cd/m^2. So, application of the UV light must have resulted in a 3 or 6% reduction in contrast. In view of this, the very small changes in logMAR can be understood.

REFERENCES

1. P. Artal, M. Ferro, I. Miranda, and R. Navarro, ''Effects of aging in retinal image quality,'' *J. Opt. Soc. Am. A* **10**, 1656–1662 (1993).
2. J. J. Vos, J. Walraven, and A. van Meeteren, ''Light profiles of the foveal image of a point source,'' *Vision Res.* **16**, 215–219 (1976).
3. G. C. Simpson, ''Ocular haloes and coronas,'' *Br. J. Ophthalmol.* **37**, 450–486 (1953).
4. Y. le Grand, *Recherches sur la fluorescence des milieux oculaire,* Instituto de biofisica Universidade do Brasil (1948).
5. P. W. Cobb, ''The influence of illumination of the eye on visual acuity,'' *Am. J. Physiol.* **29**, 76–99 (1911).
6. J. J. Vos, ''Disability glare—a state of the art report,'' *Comm. Int. de l'Eclairage J.* **3**, 39–53 (1984).
7. B. R. Wooten and G. A. Geri, ''Psychophysical determination of intraocular light scatter as a function of wavelength,'' *Vision Res.* **27**, 1291–1298 (1987).
8. G. Westheimer and J. Liang, ''Influence of ocular light scatter on the eye's optical performance,'' *J. Opt. Soc. Am.* A **12**, 1417–1424 (1995).
9. T. J. T. P. van den Berg, ''Importance of pathological intraocular light scatter for visual disability,'' *Doc. Ophthalmol.* **61**, 327–333 (1986).
10. T. J. T. P. van den Berg and J. K. IJspeert, ''Clinical assessment of intraocular straylight,'' *Appl. Opt.* **31**, 3694–3696 (1992).
11. D. B. Elliott and M. A. Bullimore, ''Assessing the reliability, discriminative ability and validity of disability glare tests,'' *Invest. Ophthalmol. Vis. Sci.* **34**, 108–119 (1993).
12. D. Yager, C. L. Liu, N. Kapoor, and R. Yuan, ''Relations between three measures of ocular forward light scatter and two measures of backward light scatter,'' in *Technical Digest on Noninvasive Assessment of the Visual System* **3**, 174–177 (1993).
13. Z. Butuner, D. B. Elliott, H. V. Gimbel, and S. Slimmon, ''Visual function one year after excimer laser photorefractive keratectomy,'' *J. Refract. Corneal Surg.* **10**, 625–630 (1994).
14. T. J. T. P. van den Berg and J. K. IJspeert, ''Intraocular straylight, studied using the direct compensation technique,'' *Comm. Int. de l'Eclairage* **1**, 83–84 (Part 1, Div. 1) (1991).
15. J. K. IJspeert, P. W. T. de Waard, T. J. T. P. van den Berg, and P. T. V. M. de Jong, ''The intraocular straylight function in 129 healthy volunteers; dependence on angle, age and pigmentation,'' *Vision Res.* **30**, 699–707 (1990).
16. W. K. Adrian, ''Grundlagen der physiologischen and psychologischen Blendung und ihre numerische Darstellung,'' *Lichttechnik* **27**, 312–319 (1975).
17. T. J. T. P. van den Berg, ''Analysis of intraocular straylight, especially in relation to age,'' *Optom. Vision Sci.* **72**, 52–59 (1995).
18. P. W. T. de Waard, J. K. IJspeert, T. J. T. P. van den Berg, and P. T. V. M. de Jong, ''Intraocular light scattering in age-related cataracts,'' *Invest. Ophthalmol. Vis. Sci.* **33**, 618–625 (1992).
19. T. J. T. P. van den Berg, J. K. IJspeert, P. W. T. de Waard, ''Dependence of intraocular straylight on pigmentation and light transmission through the ocular wall,'' *Vision Res.* **31**, 1361–1367 (1991).
20. T. J. T. P. van den Berg and J. K. IJspeert, ''Light scattering by donor lenses,'' *Vision Res.* **35**, 169–177 (1995).

21. T. J. T. P. van den Berg, ''Depth dependent forward light scattering by donor lenses,'' *Invest. Ophthalmol. Vis. Sci.* (in press) (1996).
22. G. Wyszecki and W. S. Stiles, *Color Science*, Wiley, New York (1982).
23. H. C. van de Hulst, *Light Scattering by Small Particles*, Dover Publications, New York, (1983).
24. C. Hess, ''Pathologie und Therapie des Linsensystems,'' in *Graefe-Saemisch Handbuch der gesamten Augenheilkunde Teil II*, Verlag van Wilhelm Engelmann, Leipzig (1911).
25. R. A. Weale, ''Human lenticular fluorescence and transmissivity, and their effects on vision,'' *Exp. Eye Res.* **41**, 457–473 (1985).
26. T. J. T. P. van den Berg, J. K. IJspeert, P. W. T. de Waard, and F. Meire, ''Functional quantification of diaphany,'' *Doc. Ophthalmol.* **75**, 239–246 (1990).
27. T. J. T. P. van den Berg, ''Quantal and visual efficiency of fluorescence in the human eye lens,'' *Invest. Ophthalmol. Vis. Sci.* **34**, 3566–3573 (1993).
28. T. J. T. P. van den Berg and K. E. W. P. Tan, ''Light transmittance of the human cornea from 320 to 700 nm for different ages,'' *Vision Res.* **33**, 1453–1456 (1994).
29. J. J. Vos and T. J. T. P. van den Berg, ''The large angle course of the disability glare function and its attribution to components of ocular scatter,'' submitted (1996).
30. D. B. Elliott, K. C. H. Yang, K. Dumbleton, and A. P. Cullen, ''Ultraviolet-induced lenticular fluorescence: intraocular straylight affecting visual function,'' *Vision Res.* **13**, 1827–1833 (1993).