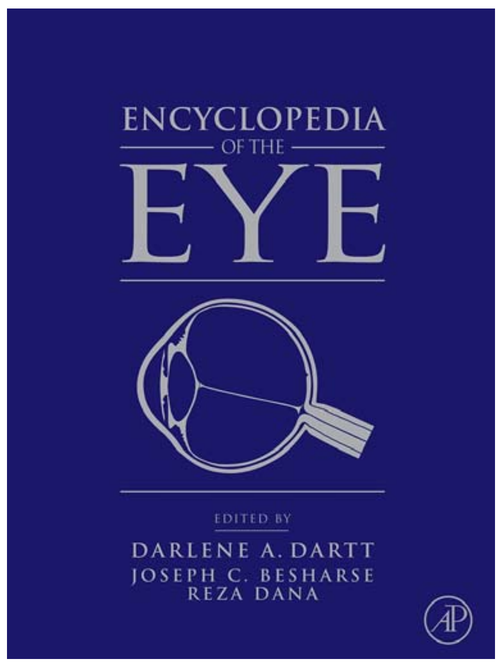

van den Berg T J T P, Franssen L and Coppens J E Ocular Media Clarity and Straylight. In: Darlene A. Dartt, editor. Encyclopedia of the Eye, Vol 3. Oxford: Academic Press; 2010. pp. 173-183.

O

Ocular Media Clarity and Straylight

T J T P van den Berg, L Franssen, and J E Coppens, Netherlands Institute for Neuroscience of the Royal Netherlands Academy of Arts and Sciences, Amsterdam, The Netherlands

Glossary

Angle – In ophthalmology, it is usually measured in degrees (or °) and minutes of arc (or ′). A full circle encompasses 360°, and 1° = 60′. The horizontal human visual field encompasses ± 100°. The scientific standard for angle is the radian, with 2π = 360°.

***Commission internationale d'Eclairage* CIE, or International committee on illumination** – International standards committee with representative bodies in virtually all larger countries, acknowledged by ISO.

Disability glare – The effect of straylight on the eye whereby visibility and visual performance are reduced. Disability-glare sensitivity and straylight can be used synonymously according to CIE definition. Discomfort glare is glare that produces discomfort. It does not necessarily interfere with visual performance or visibility.

Glare – The effect produced by a luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort (discomfort glare or psychological glare), or loss in visual performance and visibility (disability glare or physiological glare).

Light scatter – The physical effect of irregular material on the transmission of light, whereby part of the light is deflected. Most often scattering by isolated (often optically independent) and small irregularities is considered, resulting in straylight. Sometimes the word scatter is used for small-angle light spreading resulting from large-scale refractile aberrations.

Point-spread function or PSF – The (effective) distribution of light in the eye, deriving from an ideal point source of light, and delivering the unit amount of light to the eye. Properly defined, the PSF integrates to unity. When expressed with the visual angle θ as an independent variable, the functional (as seen) PSF equals $L_{eq}(\theta)/E_{bl}(\text{ster}^{-1})$, with $L_{eq}(\theta)$ the equivalent luminance (as seen), and E_{bl} the illuminance on the eye deriving from the point source.

Steradian – The unit for solid angle, shortened to ster. or sr. A half sphere encompasses 2π steradian.

Straylight – The outer part of the functional PSF of the human eye. As practical limits, values 1–100° are used. It is quantified by means of the straylight parameter $s(\theta)$, defined by $s(\theta) = \theta^2\ \text{PSF}(\theta) = \theta^2\ L_{eq}(\theta)/E_{bl}$. As for most eyes, the dependence on θ is weak, $s(\theta)$ is often shortened to s.

Straylight meter – An instrument for performing a psychophysical test to determine the straylight parameter. The psychophysical tests aim to establish the equivalent luminance L_{eq} deriving from a glare source with calibrated E_{bl} value. Originally, only threshold tests were employed, but more recently, equivalence is established by means of counter-phase flicker, as used in the current, only commercial, instrument (C-Quant by Oculus).

Introduction

Disturbances to the eye media may cause vision loss of several different types. With visual-acuity assessment using a letter chart and other means, the smallest detail that can be resolved is established. With the contrast sensitivity test, testing is extended to include not only the smallest distances, but also differences over somewhat larger distances, typically up to a few tenths of a degree. However, eye-media disturbance can also degrade vision because it may cause light scattering. This results in a veil of straylight over the image, strongly depending on the presence of brightness differences as typical in most visual scenes. The complaints

Encyclopedia of Eye (2010), vol. 3, pp. 173-183

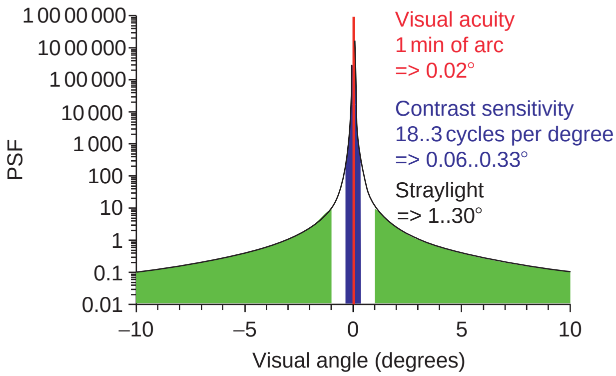

Figure 1 Point-spread function (PSF) of the normal human eye according to the standard formulated for the CIE in 1999. When the eye looks at a point source, the actual light distribution spreads out over the full retina. Different domains of this distribution are indicated, dominating different aspects of visual function. The PSF has steradian^{-1} as unit, and integrates to unity (steradian to be used as variable of integration).

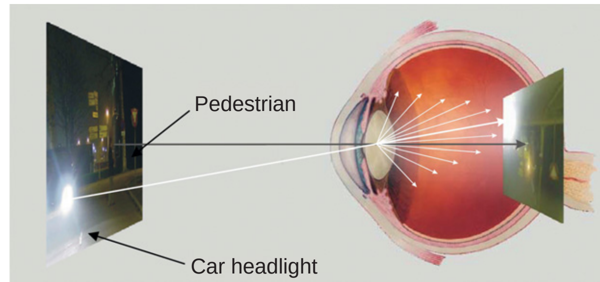

Figure 2 Visualization of retinal straylight. The optical components of the eye form an image of the outside world (left picture) on the retina (right picture). In the case of such a street scene, the picture on the retina is much degraded because part of the light coming from the car headlight is scattered in all forward directions (white arrows in the figure), projecting a veil of light over the retinal image. This veil of light is called straylight. Actually, the left picture simulates what a normal eye would see, and the right picture, what would be seen with an early cataract.

may include hazy vision, increased glare hindrance, loss of contrast and color, etc. These problems are much worsened if visual function is already low from retinal pathology, such as in macular degeneration or glaucoma.

It has long been realized that 20/20 is not enough. Contrast sensitivity was added to better assess full quality of vision. However, contrast sensitivity also was not enough. This can be understood on the basis of the large dynamics of the human eye, as illustrated in Figure 1. Figure 1 shows the point-spread function (PSF) of the normal human eye (for the average Caucasian at 62 years of age), according to the standard observer defined by the *Commission internationale d'Eclairage* (CIE). It gives the light distribution that follows from a point source of light. It shows that a point source does not project on the retina as a point, but strongly spreads out. This spreading of light is caused by several essentially different optical errors of the eye. The PSF dictates the effects of imperfect eye optics on vision. This has been studied over the years in many publications.

Different domains can be identified in the PSF. Ideally, light distribution should only be the central peak up to 1 min of arc, shown in red. The optically ideal PSF is called the Airy pattern, resulting from the fundamental diffractive properties of light, with a central disk extending to 1.22 × wavelength/pupil diameter. With a wavelength of 550 nm, and a pupil diameter of 4 mm, gives 1.2 min of arc for the central disk to become zero (this would be minus infinity in Figure 1 because of the logarithmic scale). However, actual eyes show aberrations causing this central peak to widen. This is the reason why Figure 1 does not show the very steep decline toward minus infinity at 1.2′. The most central area dominates visual acuity. The next area goes on to 10 min of arc (the blue area), which dominates contrast sensitivity (6 cpd corresponds to 5 min of arc band width). However, the light spreading continues over the full retina. The light spreading over 60 min of arc (1°) and more is called straylight. Every area of this PSF is important for quality of vision.

Straylight

Small-angle disturbances to the eye media may cause vision loss of small detail, determined with visual acuity assessment using a letter chart or contrast sensitivity. But how does the light scattered over larger distances affect vision? The light scattered results in a veil of straylight over the retinal image (see Figure 2). The patient's complaints may include hazy vision, increased glare hindrance, loss of contrast and color, etc. If concomitant retinal pathology exists, as macular degeneration, retinal dystrophy, or glaucoma, the problems experienced from straylight are much aggravated, calling for extra attention on straylight in such patients.

It is important to realize that the effect of straylight on vision is totally different from the effect of decreased visual acuity on vision. This is illustrated in the following examples, produced with known realistic means. Daily-life scenes were photographed under three conditions: normal, with a blurring lens, and with a light-scattering filter in front of the camera lens. The blurring lens simulates decreased visual acuity of about 0.4; the scattering filter simulates increased light scattering of around $\log(s) = 1.5$ (see Figure 3). Normal visual acuity would be around 1.5, and a normal straylight value would be around $\log(s) = 0.9$; therefore in both cases, the image is deteriorated by a factor of 4. These pictures illustrate that, in certain daily-life circumstances, increased light scattering has a much stronger effect on the quality of vision than decreased visual acuity.

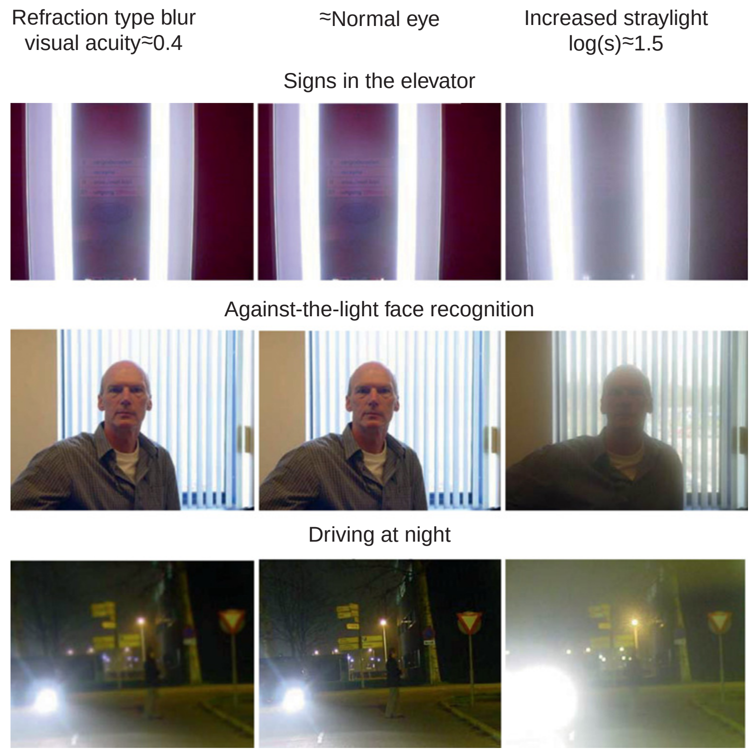

Figure 3 Comparison between refraction type blur (visual acuity around 0.4) and early straylight disturbance (log(s) around 1.5), for different daily-life situations.

History

Since the beginning of the twentieth century, the importance of retinal straylight for visual function has been recognized by several investigators. Cobb introduced the concept of equivalent veiling luminance (L_{eq}) as an apt way to define retinal straylight. Disability glare/retinal straylight, as defined by the CIE, is now quantified by means of this concept of equivalent luminance, that is, the (external) luminance that has the same visual effect as the glare source at some angular distance. Holladay and Stiles applied this concept in their measurements and formulated a disability glare formula, which has been widely used. Nowadays, retinal straylight can also be introduced as the outer skirt of the PSF, outside say, 1°. Since retinal straylight is defined in a functional sense by L_{eq}, the comparison with the PSF only holds if the PSF is also defined in the functional sense. Retinal straylight causes a veiling luminance over the whole retina that adds to the retinal projection of the visual scene, thereby reducing the contrast of the retinal image. Important overview papers were written by Vos. In 1999, a standard was proposed to the CIE (see Figure 1) for the normal eye, including age and pigmentation effects.

The first attempts to measure intraocular straylight by means of equivalent luminance involved two types of threshold measurements: thresholds in the presence of a distant glare source and those in the presence of a homogeneous background luminance. From such a series of measurements, the equivalent luminance could be derived, defined as the luminance giving identical thresholds as the glare source (equivalent veil method). This method did not gain practical use, such as in clinical or driver-licensing applications, because it was quite elaborate. As a result, variation was quite large between the older studies. However, the method continued to be used in experimental applications. Some approximate alternatives were designed to circumvent the measurement load. As even more easy-to-use alternatives, the so-called glare testers were introduced, which usually consisted of a visual acuity or contrast sensitivity test, with and without a glare source presented at some angular distance in the visual field. As a result of issues with glare testers, a standard way of glare measurement was never adopted.

To improve on this situation, a dedicated psychophysical method was designed, called the direct compensation (DC) method. In short, this method works as follows: A bright ring-shaped light source around a (dark) test field is presented flickering. Due to intraocular scatter, part of the light from the bright ring-shaped source will be projected on the retina at the location of the test field, inducing a (weak) flicker in the test field. To determine the exact amount of straylight, variable counterphase compensation light is presented in the test field. By adjustment of the amount of compensation light, the flicker perception in the test field can be extinguished. In this way, the straylight modulation caused by light scattered from the glare source is directly compensated. In 1990, this technique was implemented in a small portable device, called straylight meter. Apart from the group of Van den Berg, this led to studies notably by the groups of Elliott, Kooijman, Schallhorn, and Alexander. However, outside the laboratory it proved to be a difficult technique. In 2003, a better psychophysical approach was defined, called compensation comparison (CC), and implemented in a commercial instrument, by the German firm Oculus, called C-Quant (see Figure 4). The essential difference was that this new approach is suitable for random subjects and for routine clinical use. Moreover, the CC approach enables control over the reliability of the assessment.

Figure 4 The C-Quant instrument from Oculus for measuring the amount of straylight in patient eyes.

Normal Eyes

Figure 5 shows the age dependence of straylight in the normal population. Straylight/disability glare increases with age A by a factor

$$\left[1 + \left(\frac{A}{D}\right)^4\right],$$

where D is the age at which the amount of straylight doubles. Values for D were found to be between 62.5 and 70 years. This age dependence was later implemented in a more extensive model including pigmentation as a second parameter. The model was further refined, including age-dependency formulas of different levels of complexity, applicable in different angular-validity domains. This led to a proposal to the CIE for a standard glare observer in 1999, which was accepted as the CIE standard a few years later.

Angular dependence is classically described with the Stiles–Holladay approximation (proportionality to angle^{-2}), holding relatively well between 1° and 30°. As this approximation also holds for aging eyes, including cataracts and other conditions, for most applications, a measurement at one angle suffices. As a consequence, the PSF multiplied with θ^2 (the definition of the straylight parameter s) is more or less constant between 1° and 30°.

Pigmentation of the eye was found to be of importance for quality of vision. Blue-eyed Caucasians were found to have 0.1–0.4 log units higher straylight values compared to pigmented non-Caucasians, depending on angle. This pigmentation dependence is partly caused by variations in transmission of light through the ocular wall. For dark-brown eyes of pigmented individuals, transmission

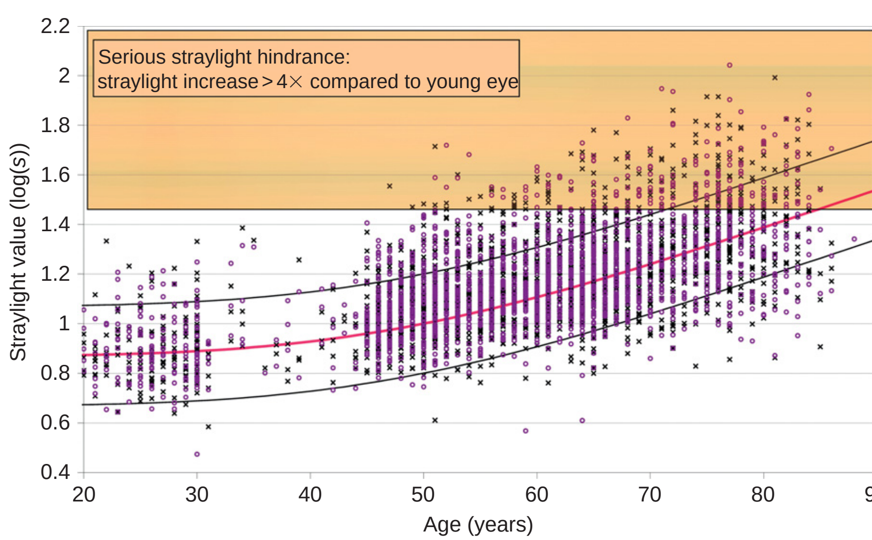

Figure 5 Log(s) values at 10° as a function of age for a population of European drivers. Keep in mind that, because of the logarithmic scale, a 0.3 increase in the log(s) value means in fact a doubling of the amount of straylight, and a log(s) increase of 1 means a tenfold increase in straylight.

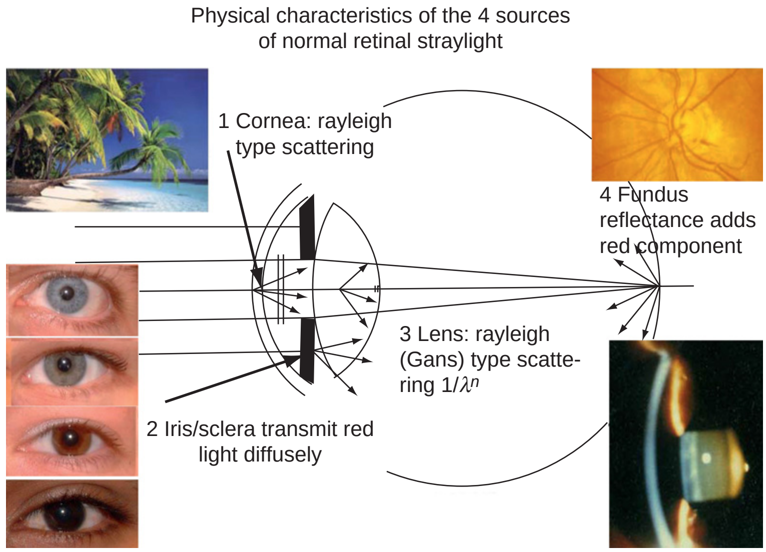

Figure 6 Primary sources of intraocular straylight in the normal eye: corneal scatter, iris, and sclera transparency, lens scatter, and fundus scatter.

was found to be orders of magnitude lower than that for blue-eyed individuals. Furthermore, variations in fundus reflectance are also partly responsible for pigmentation dependence of straylight. In albinism and other defects to pigmentation, the effects can be much stronger. Figure 6 gives an overview of the sources of straylight in the normal eye.

Wavelength dependence of straylight is important as a clue to what processes in the eye might cause straylight. A strong inverse wavelength dependence would signify scatter in the optical media to originate from particles of sizes in the same range as, or smaller than, the wavelength of light. (Like the blue of the sky originates from light scattering by very small irregularities in the air, which is called Rayleigh scatter.) However, depending on pigmentation, eye-wall transmittance and fundal reflections may introduce a straylight component with a wavelength dependence of the opposite sign (red dominant), negating the wavelength dependence from small particle scatter as identified in the lens and cornea.

Sources of straylight in the normal eye at young age are to about equal amounts, the cornea, the lens, and the pigmentation-dependent part. At older age only the lens component changes considerably, so as to dominate the other two, especially if (early) cataract develops. Often, straylight increase is the first complaint, before visual acuity changes.

Cataract

Cataract dependence of straylight was measured in patients with cortical, nuclear, or posterior subcapsular cataract. When compared to visual acuity, on average, the posterior subcapsular type showed the largest straylight increase, but individual results varied considerably. In all cataract types, straylight was often found to be increased considerably while visual acuity was still good; however, in other patients, the reverse was also possible. The important conclusion for ophthalmological practice is that straylight must be taken into account for just assessment of visual problems from cataract, and the decision for cataract surgery.

The angular dependence was found to be about the same for the different cataract types. The behavior was found to be similar to normal (extreme) aging, and it was concluded that, at least with respect to straylight, cataract can be modeled as early aging of the crystalline lens. Light-scattering filters that could be used to simulate the straylight characteristics of cataract were defined (used to create Figure 2). Straylight values after cataract surgery were found to be significantly decreased compared to preoperative values, but still about a factor of 2 above expected (best) levels. The reason is not yet resolved but may partly be due to the intraocular lenses or preclinical forms of posterior capsule opacification (PCO).

Cornea

The cornea proved to be a particularly sensitive organ for straylight increase. In experimentally hydrophilic contact-lens-induced corneal edema on average, a 10% corneal swelling induced a 50% increase in straylight. Variability in this relationship was speculated to be due to changes in the epithelium caused by the contact lens. After contact lens removal, individual straylight values decreased linearly with time, on a similar timescale as the decrease in corneal swelling. Straylight scores in established contact-lens wearers were found to be significantly greater than in age-matched normals. Rigid gas permeable (RGP) contact lenses were shown to induce more straylight than hydrophilic contact lenses. Subclinical corneal edema seemed to be prevalent in some subjects.

Pathological conditions of the cornea may variably induce increased light scatter, strongly depending on the type of disease. In central crystalline dystrophy, straylight was found to be much increased while visual acuity was relatively well preserved. Alternatively, in posterior polymorphous dystrophy, straylight was not increased, even with impaired visual acuity. In macular and also lattice dystrophy, straylight and visual acuity were affected in a similar way. For deep lamellar endothelial keratoplasty (DLEK) and penetrating keratoplasty (PK), small differences on average between pre- and postoperative straylight values were found. Here the effects of habitual glasses must be mentioned. They were found to induce, as a rule, less straylight than is already present in the eye. The speculative conclusion is that the glass wearer has a tolerance against straylight from his glasses in dependence on his natural level. Higher straylight levels induce him to clean his glasses.

Since the introduction of laser refractive surgery, much concern has been expressed with respect to straylight problems regarding this type of corneal surgery. In radial keratotomy (RK), mean straylight increases by a factor of 1.4 (0.15 log units) in eyes with 4-mm-sized pupils and a factor of 2 (0.3 log units) for 8-mm-sized pupils. These values may be considered as functionally significant increases, but increases of a factor of 6 (0.8 log units) were also found. Studies on photorefractive keratectomy (different varieties are known by acronyms such as PRK, laser-assisted *in situ* keratomileusis (LASIK), and laser-assisted sub-epithelial keratomileusis (LASEK)) provided a less-clear picture. It is well known that a clear haze in the cornea or interface debris as result of the procedure gives subjective complaints, but with the advancement of techniques, these are not often seen. The emerging picture seems that in most cases, straylight does not increase, but that in 5–20% of the cases, depending on the study, significant straylight increase is found, without, in many cases, clear clinical signs.

Forward and Backward Scatter

Straylight reflects the effects of forward light scatter in the eye media. Several methods exist to assess the condition of the eye media using backward light scatter. In fact, the basic ophthalmological tool to evaluate the eye media (the slit lamp) is based on back scatter. Other examples are Scheimpflug slit-image photography, lens opacity meter, and lens opacities classification system (LOCS). One may wonder whether backward light scatter faithfully reflects the functional effect of light scatter in the eye, which is determined by forward light scatter. To address this question, *in vitro* measurements of light scatter in human donor lenses were performed, which showed that backward and forward light scatter are dominated by different light-scattering processes. In correspondence with these *in vitro* studies, patient studies on the comparison between different measures of backward light scatter and forward light scatter showed very variable results. It must be noted here that we consider forward scatter not in a very closely forward direction, but over angles of more than 1°. For more closely forward angles (smaller than 1°) we approach the domain that can be captured with other techniques, such as double-pass and wavefront-sensing approaches.

CIE Standard Observer

As mentioned above, the CIE has adopted standards for the glare of the normal observer. The CIE equations are given here. The total glare function proposed by Vos and Van den Berg (as eqn [8] in the CIE report) does actually give the complete PSF. It reads:

$$\mathrm{PSF} = [L_{\mathrm{eq}}/E_{\mathrm{gl}}]_{\mathrm{total}} = \left[(1-0.08)(A/70)^4\right] \left[\frac{9.2\times10^6}{[1+(\theta/0.0046)^2]^{1.5}} + \frac{1.5\times10^5}{[1+(\theta/0.045)^2]^{1.5}}\right] + [1+1.6(A/70)^4]\left\{\left[\frac{400}{1+(\theta/0.1)^2} + 3\times10^{-8}\times\theta^2\right] + p\left[\frac{1300}{[1+(\theta/0.1)^2]^{1.5}} + \frac{0.8}{[1+(\theta/0.1)^2]^{0.5}}\right]\right\} + 2.5\times10^{-3}\times p[sr^{-1}],$$

where θ is the glare angle in degrees, A the age in years, and p a pigmentation factor ($p = 0$ for very dark eyes, $p = 0.5$ for brown eyes, and $p = 1.0$ for blue–green-eyed Caucasians).

Figure 1 shows the angular course of this function for $A = 62$ years and $p = 1$. Note that the total dynamics of the PSF span a range of about 10^9, or 1 000 000 000. Due to this enormous range, the differences for the various conditions appear to be very subtle, whereas, in fact, they are functionally very significant. These differences are more clearly represented when the curves are presented in terms of the straylight parameter s by multiplication of the PSF with θ^2. In this way, the approximate $1/\theta^2$ angular dependence is removed, so as to allow a better view of differences, see Figure 7.

For practical purposes, the CIE 1999 total glare equation is relatively complicated. Therefore, some simplified equations were formulated. The most simple (given as eqn [9] in the CIE report) version of a disability glare formula seems to be the classic Stiles–Holladay equation, in which the

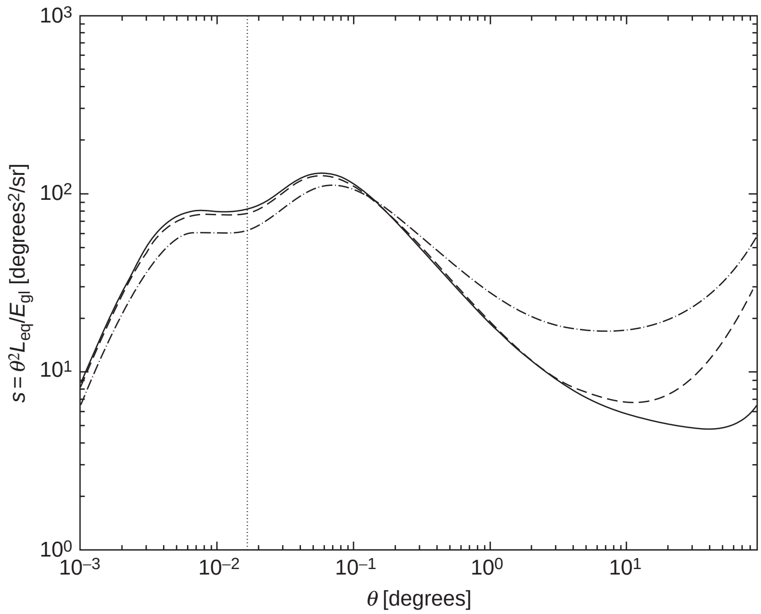

Figure 7 The CIE 1999 total glare function (PSF) multiplied by θ^2 to represent it in terms of the straylight parameter for a 35-year-old negroid (continuous line), a 35-year-old blue–green eyed Caucasian (dashed line), and a 80-year-old blue–green eyed Caucasian (dash–dotted line). The vertical dotted line indicates 1 min of arc. This is customarily assumed to be the smallest detail that can be resolved by an eye having a visual acuity of 1.

constant is multiplied by an age factor. It was called the age-adapted Stiles–Holladay equation:

$$\mathrm{PSF} = \left[L_{eq}/E_{gl}\right]_{\mathrm{S-H,agead}} = \left\{1 + [A/70]^4\right\}10/\theta^2$$

which has a validity domain that runs from 3° to 30°. As it is evident that the Stiles–Holladay equation falls short in particular below 1°, the following equation, the simplified glare equation (eqn [10] in the CIE report[131]), may serve in a more extended angular domain:

$$\mathrm{PSF} = \left[L_{eq}/E_{gl}\right]_{\mathrm{simpl}} = 10/\theta^3 + \left\{1 + [A/62.5]^4\right\}5/\theta^2,$$

which has a validity domain from 0.1° to 30°. To also cover the very large angle domain, more terms of the total glare equation should be taken into account; this is the general glare equation (eqn [11] in the CIE report):

$$\mathrm{PSF} = \left[L_{eq}/E_{gl}\right]_{\mathrm{gen}} = 10/\theta^3 + \left[5/\theta^2 + 0.1 \times p/\theta\right] \cdot \left\{1 + [A/62.5]^4\right\} + 2.5 \times 10^{-3} \times p,$$

which has a validity domain that stretches from 0.1° all the way up to the very limit of the field of view, somewhere around 100°.

Relation between Straylight and Other Test Outcomes

Visual Acuity

There is only a weak relation between straylight and visual acuity. This is because straylight is determined by light scattering over larger angles (1–90°), whereas visual acuity is determined by light deflections over small angles (<0.1°, more commonly known as aberrations). Moreover, the physical processes that cause these light deflections are different for the two angular domains. Therefore, changes in one domain do not necessarily mean changes in the other domain. For example, putting a +2 dpt trial lens in front of a subject's eye will definitely change the subject's visual acuity, whereas his/her straylight value will stay precisely the same. On the other hand, putting a fog filter in front of the subject's eye will show a dramatically increased straylight value, whereas visual acuity will hardly decrease. This independence is also illustrated in the practical population by Figure 8 for a large European-driver study.

Contrast Sensitivity

This is the subject of much misunderstanding. Contrary to what is often believed, straylight affects normal contrast sensitivity only very weakly. It is true that straylight reduces the contrast of the image of the outside world that is projected on the retina. Hence, increased straylight means lower contrast sensitivity. Only the decrease in contrast sensitivity is much smaller than the increase in straylight. This is illustrated in Figure 9. Five times increased light scattering lowers the contrast sensitivity function by only 20%; a very small amount, especially when compared to the contrast-lowering effect of blur (decreased visual acuity) or a bifocal implant or contact

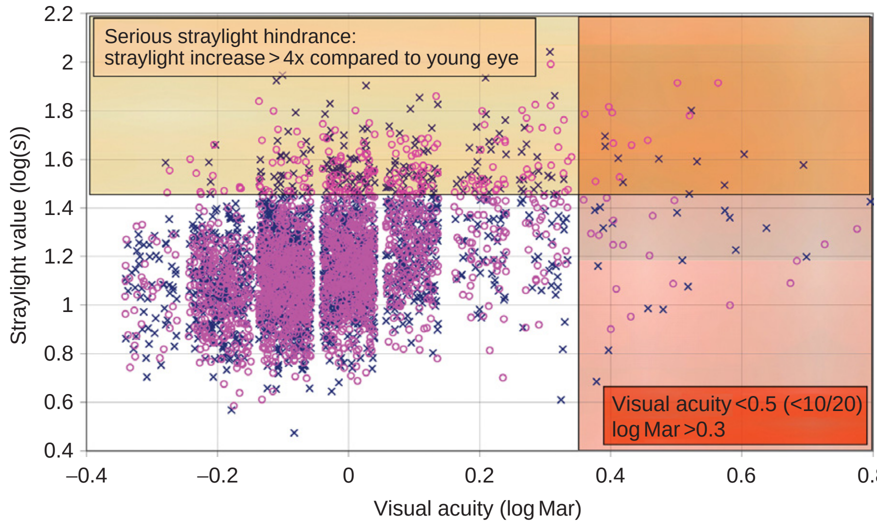

Figure 8 Straylight value as a function of visual acuity for a European driver population. Log(s) values > 1.47 and visual acuities < 0.5 (log MAR > 0.3) are considered serious visual impairments. A lot more individuals in this population are impaired by increased straylight than by decreased visual acuity. Only a very small subgroup suffers from both impairments.

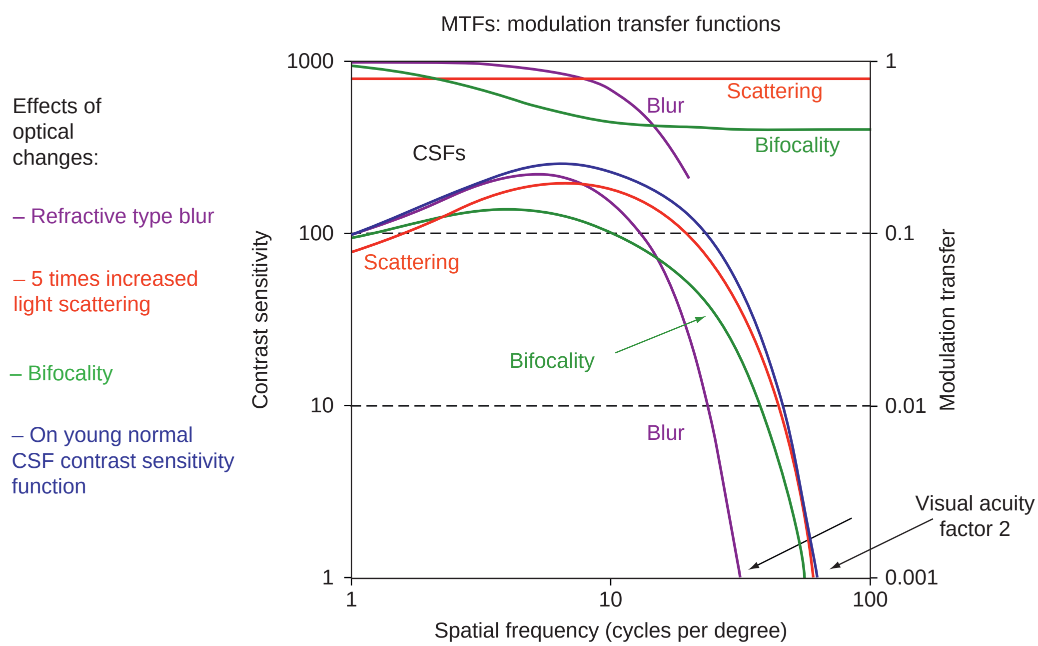

Figure 9 Effects of optical changes on the contrast sensitivity function.

lens. In other words, contrast sensitivity cannot be used as a valid means to assess the amount of straylight.

Glare Sensitivity

Maybe a reason for the misunderstanding is that it is still true that one of the most important effects of straylight is reduction of contrast sensitivity (see the examples in Figure 3). But the point to make here is that in our normal surroundings, huge intensity differences exist. Due to straylight, high-intensity areas influence effective contrasts and, as a consequence, effective contrast sensitivity in low-intensity areas. A better correlation between straylight and contrast sensitivity may be found when contrast sensitivity is measured with a glare source next to the measurement chart. But in that case, differences between subjects will also depend on differences in contrast sensitivity that already exist without the glare source. Therefore, the parameter that would best relate to the straylight value is the decrease in contrast sensitivity caused by the glare source. There have been attempts to measure glare sensitivity in both ways with so-called glare testers. The Rodenstock Nyktotest, depicted in Figure 10, is an example of the first type (plain contrast sensitivity measurement with a glare source at the side). The second type is in fact a straylight measurement, but in an indirect, and therefore less accurate, way. In theory, it is a valid measurement, which may seem to relate more to all-day real-life circumstances, but in practice, the results appeared to be unreliable and could not be related to the patients' complaints.

Straylight and Slit-Lamp-Based Examination

Using backward light scatter, such as those based on the slit lamp examination principle (e.g., digital slit lamp, Scheimpflug system, lens opacity meter, LOCS), it is possible to assess opacities of the optical media of the eye. Figure 11 gives the LOCS III classification chart developed by Chylack and coworkers. These opacities are partly responsible for the amount of light scattering in the eye, so there may be a relation between the degree of opacity as observed with the slit lamp and the amount of straylight. However, this will not be a one-to-one relation for two reasons. First, as already mentioned, the opacities account for only a part of the total light scattering. For example, the transparency of the iris and sclera, as well as the amount of light reflected from the fundus, are not assessed by the slit lamp examination. Second, with the slit lamp one looks at light that is scattered back from the optical media. This is not the light that reaches the retina, which is the light that is scattered in forward direction. Studies showed that no direct relation exists between the forward and backward scatter. Therefore, it makes more sense to measure the amount of forward scatter, as this is what the patient actually sees and is bothered by.

Figure 10 Rodenstock Nyktotest.

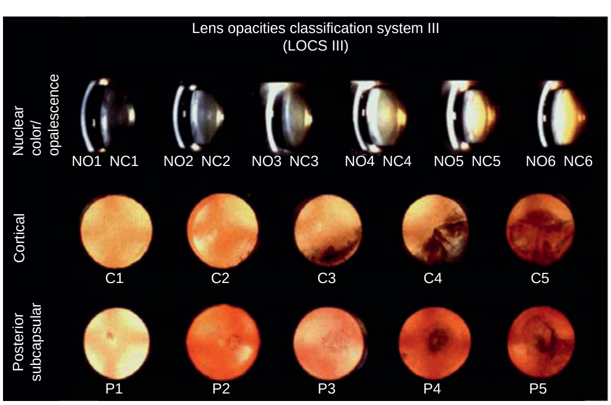

Figure 11 Lens opacities classification system (LOCS) III.

Straylight and Patient Complaints

Patient complaints from increased straylight may be voiced in a variety of ways. It is important to note that straylight defines a functional condition of the eye in a physical way, and the patient complaints will not always correspond with equal precision. As listed above, complaints may include hazy vision, increased glare hindrance, loss of contrast and color, halos around bright lights, and difficulties with against-the-light face recognition. The complaints mentioned or even the words used to describe them may strongly depend on the individual subject. Moreover, it must be mentioned that in the field of glare a particularly subjective type of patient response has been identified, called discomfort glare. As opposed to disability glare, which is the functional effect of glare, discomfort glare is a description of subjective glare. Complaints may be expressed in terms of discomfort, annoyance, fatigue, and even pain. On average, increased disability glare will also lead to more discomfort; however, in some cases, such as with the nowadays-abundant blue-light high-intensity discharge (HID) car headlamps, people might be severely annoyed by light sources that have only a moderate functional glare effect.

Frequently Asked Questions

What Are the Causes of Retinal Straylight?

The amount of retinal straylight is different for each individual, and may even be different for the two eyes of one individual. It depends on age, pigmentation, pathologies, such as cataract, and may change due to human interventions such as refractive surgery.

Normal eye

Within the eye, there are four major sources that contribute to the total amount of straylight: the cornea, the iris and sclera, the eye lens, and the fundus (see Figure 3). For a young, healthy, Caucasian eye, the total amount of straylight is, roughly speaking, 1/3 caused by the cornea, 1/3 by the lens, and 1/3 by the iris, sclera, and fundus. These ratios change with age and pigmentation:

- Corneal light scatter is more or less constant with age, but may increase as an unwanted side effect of refractive surgery.
- The iris and sclera are not completely opaque. Depending on the level of pigmentation, some of the light falling on the iris and sclera will be transmitted and contribute to the false light that reaches the retina. This contribution will be low for pigmented non-Caucasians (who have brown eyes), but might be considerable for lightly pigmented blond Caucasians with blue eyes.
- Light scattering by the crystalline lens increases with age, especially when people develop a cataract, which in terms of straylight can be seen as an accelerated aging of the eye lens.
- The fundus does not absorb all the light, so part of the light that reaches the retina will be reflected backward and scatter to different locations on the retina, thus contributing to the total amount of straylight. The amount of this scattered light is pigmentation dependent.

Important causes of increased retinal straylight

Some of the major causes for increase in retinal straylight are:

1. *Early cataract.* If cataract starts to develop, the earliest complaints often are from increased straylight, such as increased glare hindrance when driving at night. In fact, most often the first effect of cataract is that patients stop driving at night. Other complaints may include hazy vision, loss of contrast and color, halos around bright lights, and difficulties with against-the-light face recognition (see examples in Figure 3). Why should patients be allowed cataract surgery only on the basis of visual acuity loss?
2. *Corneal disturbances.* Most corneal disturbances as, for example, in corneal dystrophies cause strong increase in straylight. In some cases, visual acuity can be remarkably maintained while straylight deterioration is strong, such as in corneal edema.
3. *Refractive surgery.* In refractive surgery, there is a chance of haze in the cornea. Visual acuity hardly suffers, but complaints from straylight such as glare are of considerable concern.
4. *Contact lenses.* As a rule, contact lenses cause straylight to increase. Deposits or scratches can often be identified as a major cause of increased straylight, but if the cornea reacts to improper (use of) contact lenses, straylight increase can be huge.
5. *Turbidity in the vitreous.* This can cause large increases in straylight, often also without much effect on visual acuity.

What is the Reliability of a Straylight Measurement?

The CC method as implemented in the C-Quant straylight meter measures straylight as the subject actually sees it (and is disturbed by it). However, because it is a psychophysical technique, reliability of individual measurements needs to be checked (as with visual-field measurements). Therefore, a reliability parameter (estimated standard deviation (ESD)) was designed that predicts the accuracy of an individual measurement. In the C-Quant, a limit value of ESD ≤ 0.08 is used. In the large European-driver study an overall accuracy of 0.1 log units was found. These accuracies are more than sufficient compared to the effects to be measured (see above).

Does Pupil Size Affect the Straylight Measurement?

This subject is the cause of a lot of misunderstanding. As more glare is experienced at night, one might think that straylight is stronger at night. This may be believed to be caused by a larger pupil size. Indeed, the amount of straylight is higher because of the larger pupil, but also the nonscattered light (which is the light that forms the image on the retina) is increased, and by the same amount. Therefore, the straylight value will not change (the ratio stays the same). However, this is only true in general. On an individual basis, an increase as well as a decrease might happen, depending on the location-dependent scattering properties of the eye. For example, a patient with a centrally located lenticular opacity may get a lower straylight value with larger pupil size. In other words, to assess straylight hindrance at night, it is not needed as a rule to dilate the patient's eye when using the C-Quant.

See also: Acuity; Contrast Sensitivity; Refractive Surgery.

Further Reading

Aslam, T. M., Haider, D., and Murray, I. J. (2007). Principles of disability glare measurement: An ophthalmological perspective. *Acta Ophthalmologica Scandinavica* 85: 354–360.
Cervino, A., Montes-Mico, R., and Hosking, S. L. (2008). Performance of the compensation comparison method for retinal straylight measurement: Effect of patient's age on repeatability. *British Journal of Ophthalmology* 92: 788–791.
Cobb, P. W. (1911). The influence of illumination of the eye on visual acuity. *American Journal of Physiology* 29: 76–99.

de Waard, P. W., IJspeert, J. K., van den Berg, T. J. T. P., and de Jong, P. T. (1992). Intraocular light scattering in age-related cataracts. *Investigative Ophthalmology and Visual Science* 33: 618–625.
de Wit, G. C. and Coppens, J. E. (2003). Straylight of spectacle lenses compared with straylight in the eye. *Optometry and Vision Science* 80: 395–400.
de Wit, G. C., Franssen, L., Coppens, J. E., and van den Berg, T. J. T. P. (2006). Simulating the straylight effects of cataracts. *Journal of Cataract and Refractive Surgery* 32: 294–300.
Elliott, D. B. and Bullimore, M. A. (1993). Assessing the reliability, discriminative ability, and validity of disability glare tests. *Investigative Ophthalmology and Visual Science* 34: 108–119.
Elliott, D. B., Fonn, D., Flanagan, J., and Doughty, M. (1993). Relative sensitivity of clinical tests to hydrophilic lens-induced corneal thickness changes. *Optometry and Vision Science* 70: 1044–1048.
Franssen, L., Coppens, J. E., and van den Berg, T. J. T. P. (2006). Compensation comparison method for assessment of retinal straylight. *Investigative Ophthalmology and Visual Science* 47: 768–776.
Stiles, W. S. and Crawford, B. H. (1937). The effect of a glaring light source on extrafoveal vision. *Proceedings of the Royal Society of London. Series B, Biological Sciences* 122: 255–280.
van den Berg, T. J. T. P. (1995). Analysis of intraocular straylight, especially in relation to age. *Optometry and Vision Science* 72: 52–59.
van den Berg, T. J. T. P., Hagenouw, M. P. J., and Coppens, J. E. (2005). The ciliary corona: Physical model and simulation of the fine needles radiating from point light sources. *Investigative Ophthalmology and Visual Science* 46: 2627–2632.
van den Berg, T. J. T. P., van Rijn, L. J., Michael, R., et al. (2007). Straylight effects with aging and lens extraction. *American Journal of Ophthalmology* 144: 358–363.
Vos, J. J. (1984). Disability glare – a state of the art report. *Commission International de l'Eclairage Journal* 3(2): 39–53.
Vos, J. J. and van den Berg, T. J. T. P. (1999). Report on disability glare. *CIE collection* 135: 1–9.

Relevant Website

http://www.cie.co.at – Commission internationale d'Eclairage CIE, or International committee on illumination.