

Introduction to retinal straylight

1. Basics of retinal straylight

What is retinal straylight?

We know that disturbances to the eye media may cause vision loss of small detail. This can be determined with visual acuity assessment using a letter chart. But eye media disturbance can do much more harm, because it may cause light scattering, resulting in a veil of straylight over the retinal image. The patient complaints may include hazy vision, increased glare hindrance, loss of contrast and color, etc. These problems are much enhanced if visual function is already low from retinal pathology, such as in macular degeneration or glaucoma.

In an ideal eye there would be no light scattering at all, but because the eye media are not optically ideal, there will always be some light scattering. This light scattering reduces the contrast of the image projected on the retina, thus decreasing the quality of vision (see Figure 1). In short, more straylight means worse vision.

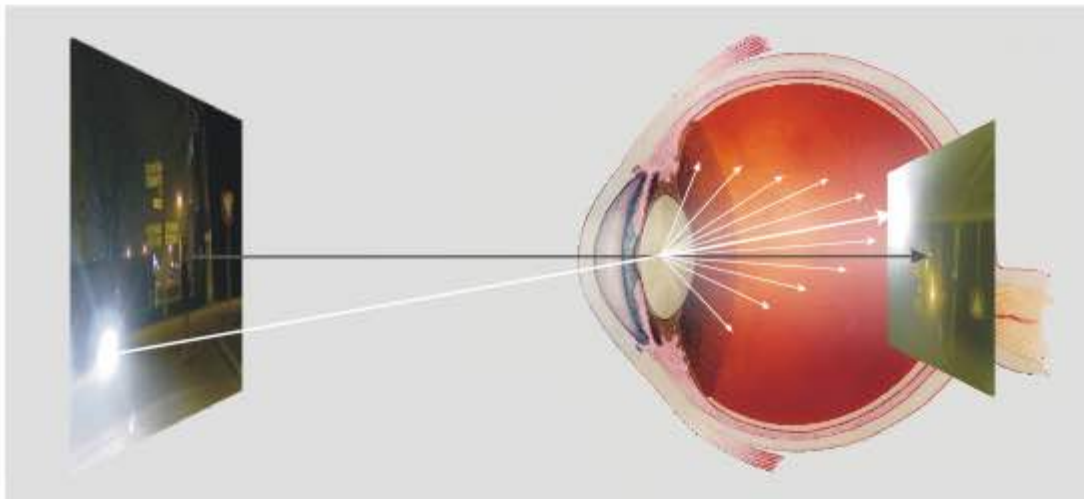


Figure 1: Visualization of retinal straylight. The optical components of the eye form an image of the outside world (left picture) on the retina (right picture). In the case of such a street scene, the picture on the retina is much degraded. Street objects are much less visible compared to the original picture. This is caused by the fact that part of the light coming from the car headlight is scattered in all forward directions (represented by the white arrows in the figure), projecting a veil of light over the retinal image which causes a decrease in the contrast of this image. This veil of light is called straylight.

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 $\log(s)=1.47$. Normal visual acuity would be around 1.5, and a normal straylight value would be around $\log(s)=0.87$, so 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.

Refraction type blur
visual acuity ≈ 0.4

$\approx$ Normal eye

Increased Straylight
 $\log(s)\approx 1.47$

Signs in the NORI elevator



Against-the-light face recognition



Driving at night



Office illumination



Figure 2: Comparison between Refraction type blur (visual acuity around 0.4) and early straylight disturbance ($\log(s)$ around 1.47), for different daily life situations.

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).

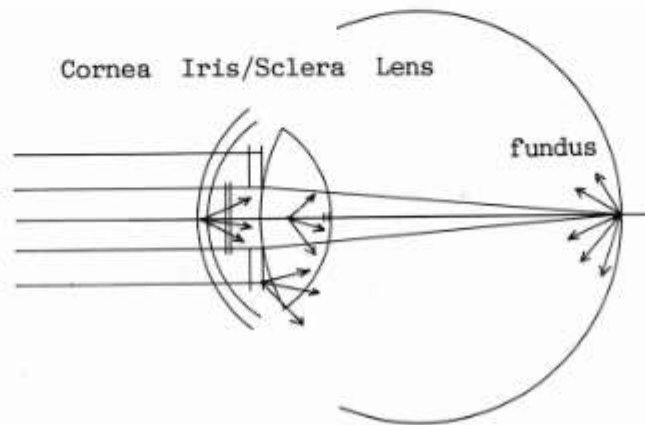


Figure 3: Primary sources of intraocular straylight: corneal scatter, iris and sclera transparency, lens scatter, and fundus scatter.

For a young, healthy, Caucasian eye, the total amount of straylight is, roughly speaking, for 1/3 caused by the cornea, for 1/3 by the lens, and for 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 (which 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 ageing of the eye lens.
- The **fundus** does not absorb all the light, so part of the light that reaches the retina will be reflected backwards 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

- **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 2 above). Why should patients be allowed cataract surgery only on the basis of visual acuity loss?

- Most **corneal disturbances** as *e.g.* 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.
- 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.
- 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.
- **Turbidity in the vitreous** can cause large increases in straylight, often also without much effect on visual acuity.

2. Measurement of retinal straylight

What is the result of a (C-Quant) straylight measurement?

The amount of straylight in an eye is expressed in one number, called the straylight parameter, s . This parameter determines the ratio between the “unwanted” scattered light, which causes the retinal contrast reduction, and the “wanted” non-scattered light, which forms the retinal image of the visual scene you are looking at. For reasons that have to do with the way human perception works, it is more convenient to use the logarithm of s , denoted as $\log(s)$. A higher $\log(s)$ value means more straylight and thus worse vision.

What straylight values are to be expected?

Population studies in the past have shown that the average $\log(s)$ value for young, healthy eyes is around 0.85. Above 40 years of age this value starts to increase to 1.2 at 70 yrs and 1.4 at 80 yrs (see Figure 4 for well-controlled healthy eyes). In the true population much more increased values can be found. Figure 5 gives results of a European multi-center study among people driving automobiles. A young, healthy, non-Caucasian eye may have a value as low as 0.6, whereas a cataract may cause the $\log(s)$ value to hit 2.0 or more.

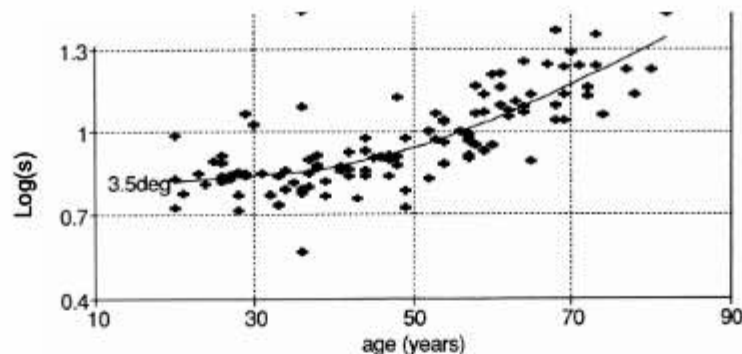


Figure 4: Log(s) values as a function of age, in a normal, well-controlled healthy population.

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 ten-fold increase in straylight.

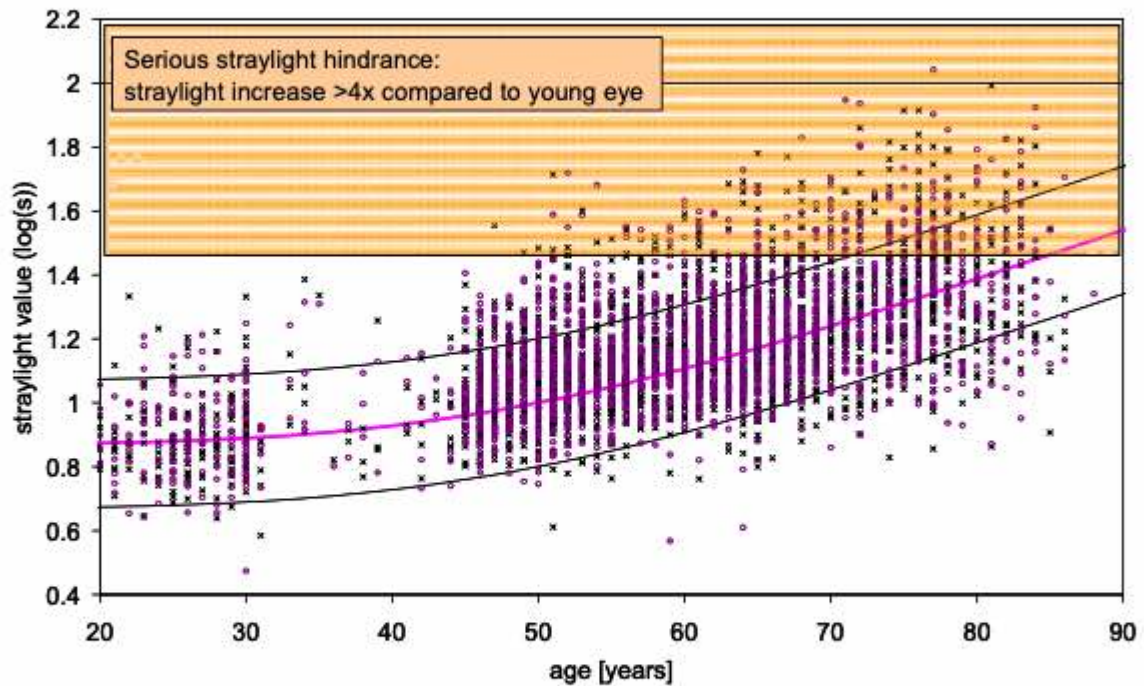


Figure 5: Log(s) values as a function of age for a population of European drivers.

What is the reliability of a straylight measurement?

A strong point of the (C-quant) Straylight Meter is the fact that it measures the straylight as the subject actually sees it (and is disturbed by it). But, because it is a psychophysical technique, reliability of individual measurements needs to be checked (as with visual field measurements). So, a reliability parameter (ESD) was designed that predicts the accuracy of an individual measurement. In the C-Quant a limit value of $Esd \leq 0.08$ 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. Because 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 non-scattered light (which is the light that forms the image on the retina) is increased, and by the same amount. So 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.

3. Relation between straylight measurement and other tests

Straylight and 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 to 90 degrees), whereas visual acuity is determined by light deflections over small angles (<0.1 degree, more commonly known as aberrations). Moreover, the physical processes that cause these light deflections are different for the two angular domains. Therefore, changes in the 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 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 7 for the large European driver study.



Figure 6: ETDRS Visual Acuity

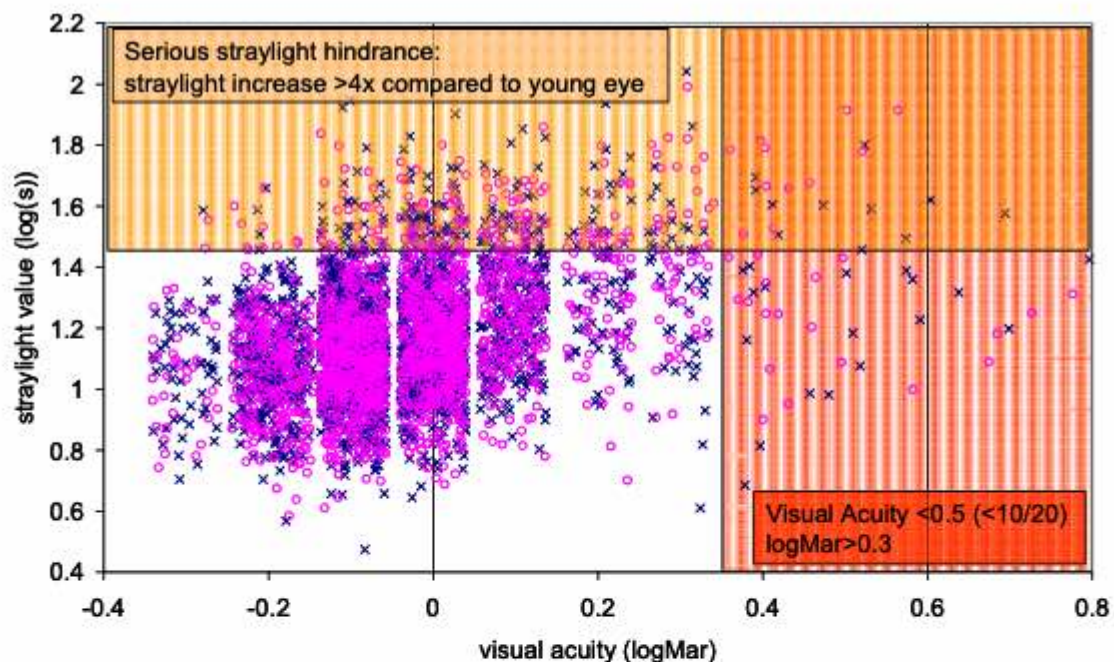


Figure 7: Straylight value as a function of visual acuity for a European driver population. Log(s) values > 1.47 and visual acuities < 0.5 ($\log\text{MAR} > 0.3$) are considered serious visual impairments. A lot more individuals in this population are impaired by increased straylight than by decreased visual acuity. Only a very small subgroup suffers from both impairments.

Straylight and contrast sensitivity

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



Figure 8: Pelli-Robson Contrast Sensitivity Chart.

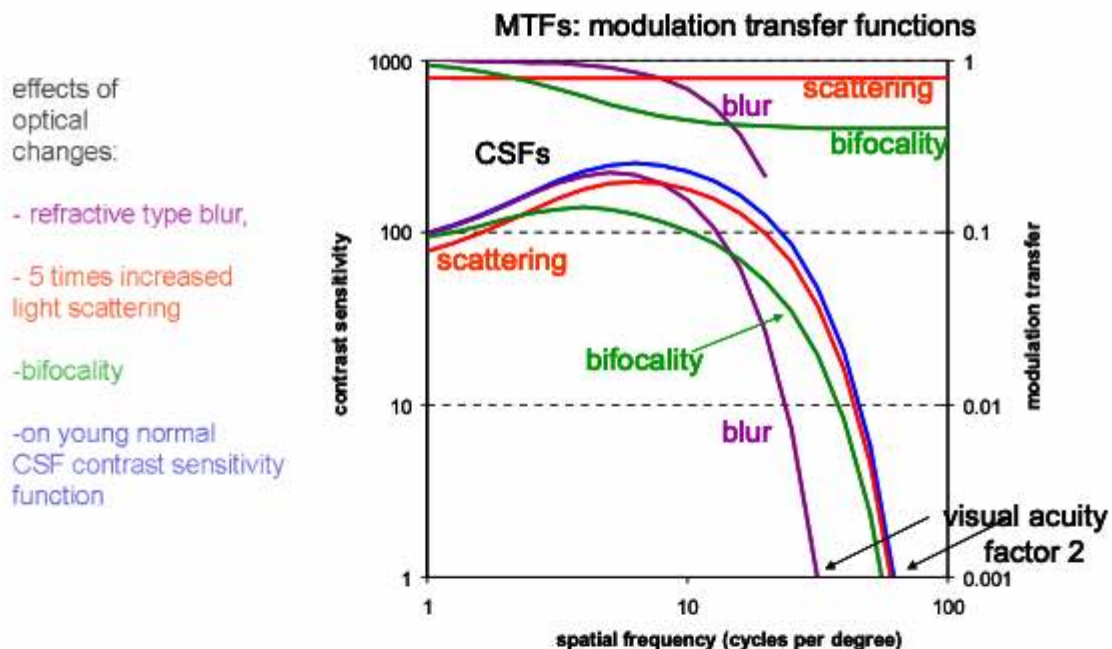


Figure 9: Effects of optical changes on the contrast sensitivity function.

Straylight and 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 2). But the point to make here is that in our normal surroundings huge intensity differences exist. Because of 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. So 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.



Figure 10: Rodenstock Nyktotest.

Straylight and slitlamp based examination

With so-called objective measurements using backward light scatter, such as those based on the slitlamp examination principle (e.g. digital slitlamp, Scheimpflug system, Lens Opacity Meter, LOCS), it is possible to assess opacities of the optical media of the eye. 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 slitlamp and the amount of straylight.

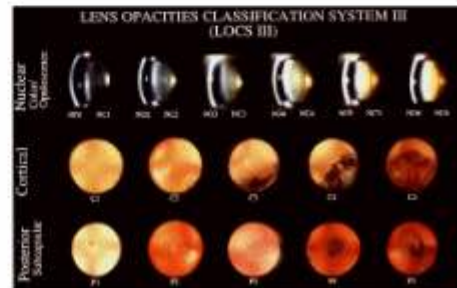


Figure 11: Lens Opacities Classification System (LOCS) III.

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 slitlamp examination. Second, with the slitlamp you look at the 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. The C-Quant Straylight Meter does exactly that.

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 straightforward quantitative 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. It may strongly depend on the individual subject which of these complaints are mentioned, or even what words are used to describe the complaints. 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, but 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.

Additional information

This document is intended as an introduction to retinal straylight. More thorough references related to this subject can be found in the separate document “C-Quant literature overview”. For additional information, please contact:

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