Straylight Effects with Aging and Lens Extraction

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- PURPOSE: To assess possible gains and losses in straylight values among the population to consider straylight as added benefit of lens extraction.
- DESIGN: In this cross-sectional design, data from a multicenter study on visual function in automobile drivers were analyzed.
- METHODS: On both eyes of 2,422 subjects, visual acuity (logarithm of the minimum angle of resolution [logMAR] in steps of 0.02 log units), straylight on the retina (psychophysical compensation comparison method), and lens opacity (slit-lamp scoring using the Lens Opacities Classification System III [LOCS III] system) were determined. Three groups were defined: 220 pseudophakic eyes, 3,182 noncataractous eyes (average LOCS III score, <1.5), and 134 cataractous eyes (average LOCS III score, >3.0).
- RESULTS: Noncataractous straylight values increases strongly with age as: log(s) = constant + log(1 + (age / 65)k), doubling by the age of 65 years, and tripling by the age of 77 years. Population standard deviation around this age norm was approximately 0.10 log units. The cataract eyes (in this active driver group) had relatively mild straylight increase. In pseudophakia, straylight values may be very good, better even than in the noncataract group. Visual acuity and straylight were found to vary quite independently.
- CONCLUSIONS: Lens extraction holds promise not only to improve on the condition of the cataract eye, but also to improve on the age-normal eye. Lens extraction potentially reverses the strong age increase in straylight value, quite independently from visual acuity. (Am J Ophthalmol 2007;144:358–363. © 2007 by Elsevier Inc. All rights reserved.)

QUALITY OF VISION LOSS BECAUSE OF EYE MEDIA disturbances is limited not only to visual acuity effects, but also to other effects such as caused by straylight. Straylight is the known cause of disability glare.1–3 Light scattering in the eye’s optical media causes a veil of straylight over the retina. This leads to deleterious visual effects such as glare while driving at night, hindrance from a low sun during daytime, facial recognition problems, reports of haziness of vision, color and contrast loss, etc. Straylight increases with age in the perfectly healthy eye, but much more so with disturbances to the optical media, such as cataract.1,2,4,5 The typical straylight-dependent symptoms are thought to occur quite independently from visual acuity–associated symptoms. To understand the patient’s visual handicap more fully, straylight assessment is needed in the clinic.

As a logical consequence, the question must be raised whether straylight should be used as additional functional entry criterion for surgical lens replacement. This has become a realistic option with the recent introduction of a clinically useful assessment method called compensation comparison and a commercial instrument based on that method (C-Quant; Oculus GmbH, Wetzlar, Germany). To answer this question, data are needed on this presumed independence between visual acuity and straylight. Second, if raised straylight levels are to be used as entry criterion, we need to ascertain what kind of straylight values can be expected after surgery. Third, a reference database must be established for straylight values in the aging population, because the earlier studies5 were not based on the improved methodology and used much smaller populations. These three questions were examined in the present study. This knowledge is presented and discussed as the basis for an adjustment of the decision process in cataract extraction with straylight as added functional criterion.

METHODS

PARTICIPANTS WERE RECRUITED AMONG DRIVERS IN A wide area around five participating clinics in Amsterdam, Salzburg, Tübingen, Barcelona, and Antwerp as part of a study on the prevalence of visual function deficits in the European driver population. Subjects belonged to one of the following age groups: 20 to 30 years, 45 to 54 years, 55 to 64 years, 65 to 74 years, and 75 years of age and older. Subjects had to possess a valid class 1 driving license and to consider themselves active drivers. All subjects underwent a battery of ocular tests. Details about the full study protocol and the prevalence values will be published.
elsewhere (see also www.glare.eu). Relevant for the present paper are: 1) best-corrected visual acuity, measured with the Early Treatment of Diabetic Retinopathy Study (ETDRS) chart (logarithm of the minimum angle of resolution [logMAR] scale)\(^6,7\) according to the modified ETDRS protocol\(^8\), 2) all subjects provided a brief medical and ophthalmologic history to an ophthalmologist, 3) a slit-lamp examination of the anterior segment and funduscopy of the optic nerve head and macular region were performed without pupillary dilation, and 4) the condition of the lens was scored using the Lens Opacities Classification System III (LOCS III) classification system.\(^9\) Results are given for both eyes, classified as either pseudophakic, no cataract (average LOCS III score, <1.5), or cataract (average LOCS III score, >3.0). This resulted in 220 pseudophakic eyes, 3,182 noncataractous eyes, and 134 cataractous eyes, with LOCS III assessment lacking in 285 of the phakic eyes. It must be noted that the LOCS III system was not applied precisely because it was not possible for practical reasons to dilate the eyes. This may have resulted in underestimation of LOCS III scores. Because in the present study different groups were compared on the basis of this same scoring, little error will result, but the population data cannot simply be compared with other studies that do use dilation. In total, eight eyes had undergone refractive surgery and 36 eyes had other corneal problems at presentation. Fifty-three subjects reported dry eyes. These eyes were not removed from the study. They did not seem to be present preferentially in either one of the above-mentioned groups.

Straylight was measured, using a computerized straylight meter, according to the compensation comparison principle described elsewhere (van den Berg TJTP, et al. IOVS 2005;46:ARVO E-Abstract 4315).\(^10–13\) Values were expressed as \(\log(\text{straylight parameters})\). Higher values indicate more straylight and more sensitivity to glare. This test also gives an assessment of the reliability of the test outcome, specified as the expected standard deviation. Only reliable measurements defined as expected standard deviation < 0.1 log units were included in the data analysis, resulting in an actual repeated measures standard deviation of 0.08 to 0.07 log units on average. Each eye was measured twice and the results were averaged. In short, the compensation comparison method is based on the direct compensation method,\(^2,14\) which involves presenting a flickering ring to the subject. Because of light scattering in the eye, part of the flickering light from this ring also reaches the center of the retinal projection of this ring. Because of that, the subject perceives a (faint) flicker in the center of the ring. When counterphase modulating light is presented at the centre, this straylight flicker can be silenced. The amount of counterphase modulating light needed for silencing directly corresponds to the strength of retinal straylight in the respective individual. A two-alternative forced choice procedure was developed to determine the amount of compensation light needed, including a measure for the reliability of the test outcome. This approach, called compensation comparison, was implemented in a home-built system, but recently a market instrument (C-Quant) was manufactured by Oculus GmbH (van den Berg TJTP, et al. IOVS 2006;47:ARVO E-Abstract 1220). In the present study, straylight was measured at 10 degrees scattering angle on average (ring size, seven to 14 degrees; see reference 5), but in the C-Quant, the average angle is 7 degrees (ring size, five to 10 degrees; see reference 5).

RESULTS

FIGURE 1 SHOWS THE STRAYLIGHT VALUES AS A FUNCTION of age for each of the three groups: pseudophakic (open circles), no cataract (closed points), and cataract (crosses). It must be noted that in particular, the cataract group cannot be considered unbiased because this was an active driver population, presumably experiencing relatively mild straylight levels, or else the individuals might have stopped driving or had their cataract removed. It seems safe to assume that true population straylight levels before cataract surgery are on average more than the values of this group. More interesting is the behavior of the normal and pseudophakic groups. The normal group shows the general behavior that is very well known from literature, that is, an increase with age to the power of \(4.0^{1.5}15\) In accordance, a model function was drawn in Figure 1 with the formula:

\[
\log(\text{straylight parameters}) = \log(s) = C + \log(1 + (\text{age}/65)^4)
\]

It was found earlier\(^5\) that the age dependency is the same for different scattering angles. In case straylight is expressed by means of the straylight parameter \(s\), also the constant \(C\) is relatively independent of scattering angle (10 degrees in the present experiment). That is, straylight expressed by means of the straylight parameter can be described approximately for all angles using only this equation. In Figure 1, the constant \(C\) is 0.90, and from the angular dependency studies,\(^5\) it follows that for the 7-degree angle as used in the C-Quant, a correction of 0.03 log units needs to be made, resulting in \(C = 0.87\). Note that \(C\) is the asymptotic value for \(\log(s)\) at low age, effective at less than, say, 40 years of age. The dashed lines in Figure 1 correspond to the 95% confidence interval (CI) of \(\pm 0.20\) log units. This analysis shows that, on average, straylight remains relatively unchanged at up to 40 years of age. It doubles in noncataractous eyes by the age of 65 years and triples by the age of 77 years as compared with the young eye.

Most interesting are the straylight findings in pseudophakia. Figure 1 shows data from a large number of pseudophakic eyes with straylight values well below the lower 95% CI line. That is, they not only have improved
as much as expected compared with the cataract level (often more than the upper 95% CI line), but also compared with the normal level (in between the 95% CI lines). These eyes could be called super normal for their age (with respect to straylight). However, there are also eyes with age-normal values and a few above-normal values in the pseudophakic group as follows: above age normal, 10%; age normal, 46%; and below age normal, 44%. As opposed to the normal group, the straylight values for the pseudophakic group is not very dependent on age: for the normal group, the age model of Equation 1 corresponds to a slope of 0.15 log units per decade. Regression analysis of the data of the pseudophakic group results in a slope of 0.03 log units per decade (r = 0.10; straight line in Figure 1). Note that the age range is relatively small for the pseudophakic group, so that a more complicated function as for the normal group (Equation 1) cannot be justified.

Figure 2 shows the same straylight data compared with the best-corrected visual acuity (r = 0.34 for all data; r = 0.23 for the normal group). The horizontal line in Figure 2 gives the level where straylight has increased four-fold (0.6 log units) as compared with the average young eye. Many instances are seen where such increase occurs in the presence of good visual acuity. Better-than-normal straylight values can be found in pseudophakic eyes. This was confirmed recently by Nuijts and associates and by ourselves studying eyes within a few months after cataract surgery (personal communication). The explanation may be simple. The older lens is an important source of straylight, even the clearest old lens. In fact, studies have suggested that the lens is the dominant factor in the normal increase in straylight with age, as illustrated in Figure 1 for the normal group. If the lens is removed, straylight may be expected to drop to levels of the young. In fact, Figure 1 shows that indeed, some old eyes, but not all, regain the clarity of youth after their lens is removed. And it seems a fascinating perspective to try to reach that goal of super vision for a larger improvement in straylight can be achieved with cataract surgery, and 3) the new straylight assessment method shows about the same normative data as older studies. Figure 2 shows that most of the variation in visual acuity and straylight is independent of each other, although the correlation was significant. Note that the repeated-measures standard deviation of the straylight values was approximately 0.075 log units in the present study. This finding underlines a notion well known in the clinic that visual acuity often is insufficient to understand the patient’s symptoms. Figure 2 shows many instances of more than four-fold straylight increase, in the presence of good (logMAR, approximately 0.0) visual acuity. A four-fold increase in straylight can be considered a serious handicap, as one can imagine knowing the hindrance one experiences already before the age of 40 years from a low sun or other against-the-light viewing conditions.

DISCUSSION

THE THREE MAJOR CONCLUSIONS ARE 1) STRAYLIGHT AND visual acuity vary rather independently, 2) significant

FIGURE 1. Graph showing straylight values as a function of age for each of the three groups: pseudophakic (open circles; with regression line), no cataract (closed points), and cataract (crosses).
proportion of the pseudophakic eyes. But better understanding of the processes involved is needed.

Some higher straylight values in the pseudophakic group may be caused by the occurrence of (early forms of) after-cataract, or other disturbances that were not diagnosed during the multicenter study. In particular, vitreous turbidity may have an important impact on straylight (studies under way). Of new concern is laser surgery, sometimes leading to increased straylight levels. It seems unlikely that this was an important factor for the present study, but it may affect population data in future. Also, the straylight effects of IOLs themselves are unknown. It seems clear that much more information is needed than was available in the present study. Questions that need to be addressed include potential differences between monofocal and multifocal IOLs, material differences between IOLs, the time since IOL implantation, gradation of capsular fibrosis, etc.

From the point of view of the physiology of the human lens, the changes with age are well known. The lens starts to change its color from crystal clear at the age of 20 to 25 years to slight yellow, up to brown at more than 65 years of age. The lens grows over the course of a lifetime and thus creates more and more optical distortions. The anatomic layers of the crystalline lens from the embryonic stage to the adult may be one of the causes of light scattering in the eye. While knowing this, it is clear why pseudophakic people may gain super vision after lens extraction. The IOLs implanted in the eye does not have lamellae, its color is crystal clear, and its dimensions are 10% in width (anteroposterior axis) when compared with the human lens. This fact may explain the super-normal results of pseudophakics for their age with respect to straylight. The normal physiology also makes clear the relation of the increase in straylight values with age. A separate issue is pupil size. We studied pupil size effects in healthy eyes and found effects to be small. In eyes with cataract or other disturbances to the optical media, pupil size effects may be larger. This should be studied in future.

Figure 2 shows independence between best-corrected visual acuity and straylight to exist to a large degree. In this population, some comorbidity such as amblyopia and age-related macular degeneration may play a role in visual acuity, but most variation probably can be attributed to the lens. Assuming comorbidity (of the retina) to play a minor role in this population, the question arises how it can be understood that these two aspects of lens behavior (i.e., straylight and visual acuity effects) can be so independent. The answer may lie in the specific character of optical disturbances in the lens. It must be noted here that for proper understanding of the functional effects (effects in the projection on the retina), the scale of the optical disturbances is of utmost importance. In optical in vitro studies on the lens, it was found that straylight is caused by irregularities, with sizes on the order of the wavelength of visible light. The proteins in the eye lens long have been

![Graph showing straylight data compared with the best-corrected visual acuity for each of the three groups: pseudophakic (open circles), no cataract (closed points), and cataract (crosses). The horizontal line gives the level where straylight has increased four-fold as compared with the average young eye. The vertical line gives the much-used limit for driver licensing: logarithm of minimum angle of resolution (logMAR) > 0.3 (decimal visual acuity < 0.5).]
considered an important source of light scattering, especially when aggregates form.\textsuperscript{18–21} Examination of optical scattering from donor lenses has been used to estimate the size of these sources, which was found to be approximately 0.7 μm in radius.\textsuperscript{22–25} The scatter seen from donor lenses was consistent with the perceived scatter in vivo (i.e., retinal straylight).\textsuperscript{23,25} A morphologic search by Gilliland and associates and by Costello and associates led to the identification of candidate particles for forward light scattering in human lenses.\textsuperscript{26–28} Visual acuity, however, is dominated by processes of a completely different scale, that is, refractive errors and wavefront aberrations. Refractive errors are disturbances that have a scale in the millimeter range, and (higher order) wavefront errors have a scale in the 100-μm range. It thus may not be surprising that the two types of changes in the lens are so independent. However, further study on this topic is needed. To avoid misunderstanding, this issue does not relate to the amount of the aberration to the wavefront, but to the size of the processes causing the aberration. The aberration to the wavefront is much smaller than 100 μm. The spatial extent of the processes causing the aberrations measured is much larger, if only because of the limitation set by the sampling distance of the measurement. In particular, the lenslet arrays in case of Hartmann-Shack (H-S) usually have interlens distances on the order of 100 μm. Straylight, however, is caused by processes with a size on the order of 1 μm.

As a practical consequence of this study, straylight must be considered an independent source of symptoms. Apart from this general point, it must be stressed that glare sensitivity after cataract surgery is addressed infrequently. For proper patient information, it is essential to know what the patient can expect after cataract surgery. This counts especially in surgery for mild or early cataract, but also for advanced cataract.


REFERENCES

Biosketch

Thomas (“Tom”) J. T. P. van den Berg, PhD physicist, studied the visual system all his scientific life. He entered The Netherlands Ophthalmic Research Institute (recently merged into The Netherlands Institute for Neuroscience) in 1974 to work on functional aspects of the eye, in particular in the fields of glaucoma and optics. Heading the Ocular Signal Transduction Department, Dr van den Berg studied straylight in the human eye and developed measurement methods that have recently become clinically available.