Retinal Straylight as a Function of Age and Ocular Biometry in Healthy Eyes

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PURPOSE. To determine the dependency of straylight on ocular biometry.

METHODS. This prospective study included 518 eyes of 277 volunteers of diverse ethnic backgrounds with healthy eyes of various iris colors. The eyes had retinal straylight tested using a commercial psychophysical device. Ocular axial length and refraction were also measured with an ocular biometer and an autorefractometer, respectively.

RESULTS. The measured retinal straylight was validated by comparing data with the age model described in the literature as \( \log(s) = P_1 + \log[1 + (\text{age}/65)^4] \), where \( P_1 \) is the logarithm of the average straylight for the eyes of a newborn. The data agreed well with this model, although \( P_1 \) was slightly higher (0.931 vs. 0.87). When this model was subtracted from the measured straylight values, a quadratic increase was found in the function of axial length, \( Y: \log(s) = 0.931 + \log[1 + (\text{age}/65)^4] + (0.01089L^2 - 0.4820L + 5.330) \). A similar model was defined for the spherical equivalent refraction \( SE \). This corresponds to an increasing amount of straylight for increasing degrees of myopia. No correlation was found with keratometry and corneal astigmatism or with iris color.

CONCLUSIONS. Retinal straylight increases not only with age, but also with axial length. Further study is needed to identify the causes of this dependency. (Invest Ophthalmol Vis Sci. 2010; 51:2795–2799) DOI: 10.1167/ iovs.09-4056

Ocular straylight is a parameter that is relatively new in clinical practice after being studied for many years in experimental settings. It concerns the part of the incident light that is scattered by the ocular media and does not participate in the normal image formation on the retina. Instead, this light creates a more or less homogeneous haze over the retinal image. To be more precise, two forms of ocular light scattering can be distinguished: forward scattered or retinal straylight (i.e., light scattered in the direction of the retina) and back-scattered light (i.e., light leaving the eye after being scattered, as seen during slit lamp investigation). No clear relationship can be defined between the two forms of scattered light, as they may have different causes.1,2

Pathologic conditions such as cataract,3,4 corneal edema,5 Fuchs’ corneal dystrophy, and vitreous floaters are known to increase retinal straylight considerably, which may lead to symptoms such as loss of contrast sensitivity, disability glare, and halos. These phenomena reduce a patient’s quality of vision in everyday life—for example, while driving at night and in recognizing a person against the background of a light source—but have only a very limited effect on visual acuity, as measured during an ophthalmic examination.5

Retinal straylight has been shown to increase with the fourth power of age, after 45 years in healthy eyes.6,7 Furthermore, the literature reports higher values in eyes with light iris colors than in those with dark iris colors because of fundus reflectance and the translucency of the iris and eye wall.8 Especially in albino patients, light iris color causes considerably increased straylight, partially due to backscattered light originating from the choroid that is not absorbed because of the absence of retinal pigment.

Disregarding the influence of iris color and ethnicity, retinal straylight \( s \) can be modeled as follows:

\[
\log(s(\text{age})) = P_1 + \log \left[ 1 + \left( \frac{\text{age}}{P_2} \right)^{P_3} \right] \tag{1}
\]

where \( P_1 = 0.87 \) is the logarithm of the average straylight in a newborn’s eyes (base), \( P_2 = 65 \) is the age that retinal straylight, \( s \), doubles; and \( P_3 = 4 \) is the power. This increase to the fourth power of age was found to be valid for a range of scattering angles.6

We studied the influence that ocular refraction and axial length may have on retinal straylight and formulates a new straylight model taking age, ocular biometry, and iris color into account. The data were collected in the framework of Project Gullstrand, a European multicenter study conducted to determine the correlation between ocular biometry and several psychophysical tests in the general population, as well as determining what levels of visual quality are tolerable before they affect a patient’s quality of life. One of the parameters included in Project Gullstrand is retinal straylight.

As in the general population, only a limited number of people have very long eyes, a group of pre-LASEK patients was also included in an effort to increase the statistical power of the correlation study between biometry and retinal straylight. Including them may introduce a slight bias in biometry values compared with the general population.

SUBJECTS AND METHODS

Subjects

This prospective work includes 518 eyes (257 right and 261 left) of 277 subjects (90 male and 198 female) recruited from the personnel of the Antwerp University and the Antwerp University Hospital (\( n = 189 \)), as well as from a group of patients who were pre-LASEK (\( n = 88 \)). Any subjects with a history of ocular surgery, amblyopia, early cataract,
TABLE 1. Subject Data

| Subject, n | 277 |
| Male/female | 86/191 |
| Subject ethnicity | Caucasian 268, Non-Caucasian 9 |
| Age, y | 39.7 ± 13.2 (8.5, 78.0) |
| Eyes, n | 518 |
| Right/left eyes | 257/261 |
| SE refraction, D | −1.5 ± 2.9 (~10.75, 8.4) |
| Axial length, mm | 25.9 ± 1.3 (19.85, 28.70) |

* Mean ± SD (range).

corneal haze, corneal scars, or systemic diseases (e.g., diabetes, systemic macula diseases) were excluded, as well as pregnant women and hard contact lens wearers. As Project Gullstrand aims to describe the general population, no additional selection criteria were used.

This study adhered to the tenets of the Declaration of Helsinki and received ethics committee approval (Ref. nr. 7/6/24). Signed informed consent was obtained from the participating subjects.

Methods

The retinal straylight measurements in this study were obtained with a commercial version of the compensation comparison technique proposed by Van den Berg9,10 (C-Quant; Oculus Optikgeräte, Wetzlar, Germany). This method has been described in full detail in the literature9,10 and has been thoroughly validated.11,12 It provides a measure for the straylight parameter log(s), as well as an estimation of the fit quality Q of the psychometric function and a repeated-measures estimated SD (Esd).13 In the following, only measurements with an Esd parameter below 0.08 and a measurement quality parameter Q above 0.5 were included. Each measurement was performed under spherical equivalent correction of the patient’s refraction by means of added lenses.

Furthermore, we performed axial length measurements with an ocular biometer (IOL Master, ver. 2; Carl Zeiss Meditec, Jena, Germany), which it gradually increased. On average, the data appeared to be higher than the values given by model 1 (solid line in Fig. 1), particularly in the age range of 20 and 40 years. If these eyes are divided as a function of their spherical equivalent (SE) refraction, the young adult eyes with high straylight correspond with higher myopia values (data series with SE < −3 D) and with higher hyperopia to a lesser degree (series with SE > +1 D). It must be noted that because of the inclusion of prerefractive patients in the study population, there was an overrepresentation of young, medium myopic eyes.

To validate our data with the literature, parameters P1, P2, and P3 of model 1 can be estimated by means of a least-squares fit. For this purpose, only the 189 emmetropic eyes in this group (i.e., eyes with SE refractions between −1 and +1 D) were considered, eliminating any possible influence of the SE refraction.

Fitting all three parameters P1, P2, and P3 of model 1 to these data gives a coefficient of determination of r^2 = 0.531. If instead we choose P3 = 4, as is proposed in the literature, and fit P1 and P2 to the data, we find r^2 = 0.321. Finally, if only parameter P1 is fitted and the values P2 = 65 and P3 = 4 proposed in the literature are used, r^2 = 0.319 is found (Table 2). As there did not seem to be large differences in coefficient of determination between these three models and to avoid overfitting of the data, we decided to use the single-parameter model in the following, with P1 = 0.931.

RESULTS

Subjects

In 613 of the 659 eyes included in this work, a straylight measurement of acceptable quality (i.e., Esd parameter below 0.08 and a measurement quality parameter Q above 0.5) was obtained. Axial length, anterior biometry, and autorefractometer measurements were also available for 518 of these eyes and have been included in this study. The population data of these subjects are given in Table 1.

Retinal Straylight as a Function of Age

The retinal straylight log(s) is shown as a function of age in Figure 1. Straylight remained constant until the age of 45, after which it gradually increased. On average, the data appeared to be higher than the values given by model 1 (solid line in Fig. 1), particularly in the age range of 20 and 40 years. If these eyes are divided as a function of their spherical equivalent (SE) refraction, the young adult eyes with high straylight correspond with higher myopia values (data series with SE < −3 D) and with higher hyperopia to a lesser degree (series with SE > +1 D). It must be noted that because of the inclusion of prerefractive patients in the study population, there was an overrepresentation of young, medium myopic eyes.

TABLE 2. Parametric Fit of the Straylight as a Function of Age in 190 Emmetropic Eyes

<table>
<thead>
<tr>
<th>3 Fit Parameters</th>
<th>2 Fit Parameters</th>
<th>1 Fit Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base P1, 0.960 ± 0.015</td>
<td>0.938 ± 0.014</td>
<td>0.931 ± 0.009</td>
</tr>
<tr>
<td>SL-doubling age P2, 66.0 ± 1.7</td>
<td>66.5 ± 2.4</td>
<td>(65)</td>
</tr>
<tr>
<td>Power P3, 5.59 ± 0.90</td>
<td>(4)</td>
<td>(4)</td>
</tr>
<tr>
<td>r^2</td>
<td>0.331</td>
<td>0.321</td>
</tr>
</tbody>
</table>

SE refraction between −1 and +1 D.

FIGURE 1. Retinal straylight log(s) as a function of age. The different series indicate different amounts of spherical equivalent refraction. Dashed lines: 95% confidence interval with respect to the model.
Retinal Straylight as a Function of Ocular Biometry

In an effort to estimate the influence of the SE refraction, we defined base-and-age-corrected straylight (or BAC straylight) as the difference between the measured straylight and model 1 with the parameters given in the last column of Table 2. When the BAC straylight is plotted as a function of SE (Fig. 2a), a decrease in straylight is seen with increasing SE. Fitting a linear function to these data results in $r^2 = 0.105$, while fitting it to a parabola results in $r^2 = 0.137$, with $P < 0.0005$ for the quadratic component, which justifies the use of a quadratic fit.

By combining this weak parabolic relationship in the function of SE with the age model 1 and performing a least-squares fit of the entire group of 518 eyes for $P_1$, we find the linear and the quadratic coefficients:

$$\log[s(\text{age}, \text{SE})] = 0.931 + \log\left[1 + \left(\frac{\text{age}}{65}\right)^4\right] + (0.0024 \cdot \text{SE}^2 - 0.0072 \cdot \text{SE} + 0.0125) \quad (2)$$

leading to a coefficient of determination of $r^2 = 0.265$.

Alternatively, the BAC straylight $s$ is found to increase as a function of the axial length $L$. Fitting a parabola to these data produces a coefficient of determination of $r^2 = 0.159$ ($P < 0.0005$ for the quadratic component; Fig. 2b), whereas a linear fit results in $r^2 = 0.122$. Combining this parabolic relationship with the age model 1 gives the following equation:

$$\log[s(\text{age}, L)] = 0.931 + \log\left[1 + \left(\frac{\text{age}}{65}\right)^4\right] + (0.01089 \cdot L^2 - 0.4820 \cdot L + 5.330) \quad (3)$$

leading to the coefficient of determination is $r^2 = 0.285$. A comparison of the $r^2$ values for models 1, 2, and 3 is given in Table 3, both for the entire population and for the subpopulation of 191 emmetropic eyes. Note that the coefficient of determination $r^2$ for the age model is much smaller for the entire group than when only emmetropic subjects were included, because of the large number of ametropic individuals included in our population.

No correlation was found between the BAC straylight and keratometry (Fig. 2c; $r^2 = 0.010$), or with astigmatism ($r^2 = 0.003$). No significant difference was found when the BAC straylight of 334 eyes with with-the-rule astigmatism larger than $-0.5$ D was compared to 33 eyes with against-the-rule astigmatism larger than $-0.5$ D (unpaired t-test, $P = 0.470$). A correlation was found between SE and $L$ ($r^2 = 0.643$).

![Figure 2](image)

Table 3. Coefficient of Determination of the Parametric Fit to the Straylight as a Function of Age, SE Refraction, and Axial Length

<table>
<thead>
<tr>
<th>Model</th>
<th>All Eyes</th>
<th>Emmetropic Eyes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age model</td>
<td>0.038</td>
<td>0.319</td>
</tr>
<tr>
<td>Age and SE model</td>
<td>0.265</td>
<td>0.308</td>
</tr>
<tr>
<td>Age and L model</td>
<td>0.285</td>
<td>0.328</td>
</tr>
<tr>
<td>Eyes, n</td>
<td>518</td>
<td>189</td>
</tr>
</tbody>
</table>
Influence of Eye Color

To study the influence of iris color on straylight, we study a subgroup of 560 eyes for which the eye color was recorded. They were divided in blue (n = 156), green (n = 66), brown (n = 111), and black (n = 27). Most of the black eyes belonged to non-Caucasian subjects. To conform to the literature,\(^7\) numerical values were assigned to each eye color to account for iris pigmentation (blue: \(C = 1.2\); green: \(C = 1.0\); brown: \(C = 0.5\); black: \(C = 0.0\)). These values can be used to include iris color in the form of a linear term added to model 3.

Performing the least squares fit of \(P_1\), the linear and quadratic coefficients of the SE refraction, and the linear coefficient of eye color \(C\) gives the following:

\[
\log [s(\text{age},L,C)] = 0.931 + \log \left[ 1 + \left( \frac{\text{age}}{65} \right)^4 \right] \\
+ (0.01085 \cdot L^2 - 0.4820 \cdot L + 5.330) + 0.021 \cdot C \quad (4)
\]

which leads to a coefficient of determination of \(r^2 = 0.331\), almost the same as for model 3, in which the eye color term was not included (\(r^2 = 0.315\)), and much higher than the age model 1 (\(r^2 = 0.171\)).

Deviations from the Model Descriptions

Figure 3 gives the average and SD of the BAC straylight in the function of SE refraction calculated over 2 D bins. The average values underwent a parabolic increase with increasing ametropia, as was described in model 2. The SD, on the other hand, remained constant for the SE refraction range considered, which was confirmed with a Levene test \((P = 0.837)\). The SD taken over the entire group with respect to the SE model 2 is 0.14 log units.

DISCUSSION

When interpreting the results presented in this work, it must be noted that due to the inclusion of subjects who were pre-LASEK the present study might be biased and not fully representative for the general population. However, including these subjects increases the statistical power of the influence of axial length on retinal straylight.

Looking only at the 189 emmetropic eyes and comparing these data with the age model 1 shows that an increase in the number of fitted parameters barely increases the quality of the fit (Table 2). From this, it follows that the parameter values of model 1 established in the literature\(^4\) are suitable to describe the age-related increase in retinal straylight in this data set as well. The only exception is \(P_1\), for which the slightly higher value of 0.931 was found to be more appropriate. Speculatively, this may be the result of small calibration differences or differences in spectral distribution of the light used between the compensation comparison device used in the literature\(^4\) and the one that we used (C-Quant; Oculus), or differences between the populations studied. In the earlier study, active drivers were recruited, which may have caused a slight bias.

If the entire population is considered, a weak but significant quadratic dependency on the SE is found that becomes apparent only after the age model 1 is subtracted from the measured straylight data (Fig. 2a). This result suggests that including linear and quadratic terms of the axial length into the straylight model may improve it and provide a better fit of the measurements obtained in this study. This possibility is confirmed by the coefficient of determination \(r^2\) of model 2, which is substantially higher than that of age model 1 (Table 3). The use of the spherical equivalent is justified, since corneal astigmatism has been shown not to have any influence on BAC straylight (\(r^2 = 0.003\)).

Given that \(L\) plays a major role in ocular refraction (\(r^2 = 0.643\)), it is not surprising that a similar relationship was found between BAC straylight and \(L\) (Fig. 2b).

In light of these findings, the retinal straylight, and SE data from a previous population study\(^4\) were analyzed further by one of the authors (TvdB) in a way similar to the present study (model 2). These data also showed a significant quadratic increase with SE, albeit by less than half of that found in the present study.

When describing data by means of a model, it is important to indicate how well the measured data follow the model. The SD of the BAC straylight was found to be constant with SE refraction, at about 0.14 log units (Fig. 3), which is higher than the 0.10 used for the population reference in the C-Quant device. This difference in SD may be because, in that study,\(^4\) an average of two repeated measures was used to calibrate the C-Quant, whereas in the present study only one measurement per eye was used. Moreover, in the latter study only subjects with clear lenses were selected as a reference for the C-Quant device, whereas the Gullstrand study did not impose such a criterion.

On first examination, no systematic deviations from the models are apparent in Figures 2a and 2b, but the random deviation is sizeable compared with the repeated measures SD of the test (0.07 log units). This finding suggests that there may be other ocular parameters that have an influence on retinal straylight, such as backscatter from the fundus, crystalline lens thickness, and variations in lens clarity.

Contrary to what is described in the literature,\(^7\) iris pigmentation did not appear to have a noticeable influence on the straylight measurements in this data set. This discrepancy may partly be due to the higher SD in the present data compared with that in the literature, resulting in an insufficient statistical power to detect a significant effect.

One candidate would be the refraction-corrected image size \(I\), which increases as a function of axial length \(L\). Smaller image sizes would produce smaller test patterns on the retina, which results in a test angle that is smaller than the 7° test angle of the C-Quant. A 15% decrease in image size would result in a test angle of 6.1°, which corresponds with a straylight increase of 0.01 log units (calculated using the wide angle straylight models for the standard observer published by the CIE\(^1\)). Similarly smaller straylight decreases are found for increases in image size. As the range of axial lengths in our populations corresponds with a range of image sizes between ±15%, this effect causes straylight changes of −0.007 to +0.01 log units. How-
ever this is an order of magnitude too small to explain the observations in Figure 2.

Thus, the source of the dependency of straylight measurements on $SE$ is unclear at this point and, despite the obvious improvement in statistical fit and coefficient of determination with respect to model 1, only a fraction of the variation in retinal straylight is explained by these new models.

We are pursuing this issue in further studies. One strong candidate for the increase in straylight could be contact lens use at larger refractive errors. However, variation in crystalline lens size and clarity must also be considered.

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References