





# Straylight As The Result Of Refractive Correction

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**Purpose:** To investigate the effect of refractive correction on straylight.

**Patients and methods:** Straylight values were measured with the C-Quant (Oculus Optikgeräte, GmbH, Wetzlar, Germany) in 1) near-emmetropic eyes (n=30) with various negative powered refractive lenses and in 2) myopic eyes (n=30) corrected with prescribed eyeglasses and contact lenses. The straylight measurements in each group were compared in the different conditions.

**Results:** In the near-emmetropic group, a significant effect (p<0.001) of each added negative diopter was found to increase straylight values with 0.006 log-units. In the second group, no significant correlation with type of correcting lens was found on straylight values.

**Conclusion:** Refractive correction with high minus power (contact) lenses result in subtle increase of straylight values. These changes are relatively small and do not lead to visual disability in a clinical setting.

**Keywords:** straylight, contact lenses, eyeglasses, glare, light scatter, refractive error

## Introduction

The prevalence of refractive errors, in particular myopia, is increasing worldwide.<sup>1-4</sup> Patients with (high) refractive errors, who have inadequate vision with spectacles and are contact lens intolerant, may choose for refractive correction by laser surgery or intraocular lens (IOL) implantation. But correction of refractive errors, even when leading to excellent visual acuity, may, however, not necessarily lead to complete patient satisfaction if vision is tinged by troublesome glare. Since the beginning of the twentieth century, it is known that straylight has great effect on the quality of vision.<sup>5-7</sup> The International committee on illumination (CIE) has defined disability glare as “the effect of straylight in the eye whereby visibility and visual performance are reduced.”<sup>7</sup>

Straylight is the result of forward intraocular light scatter on the retina. For each beam of light that reaches the eye, the light is scattered to some extent by imperfections of optical media, before it reaches the retina.<sup>5,8,9</sup> In every eye, this mechanism is responsible for an amount of straylight in the presence of a (bright) light source. Normal values of straylight will induce limited visual disability effects, but an increase in straylight can lead to symptoms that affect the quality of vision seriously. These symptoms include halos and loss of contrast, but also blurred vision, decreased color vision, and difficulty in face recognition.<sup>5</sup>

Many clinical studies have evaluated the pre- and post-operative effect on straylight after refractive surgery. The results were consistent: post-operative straylight values in myopes after laser-assisted in situ keratomileusis (LASIK)/ laser-assisted epithelial keratomileusis (LASEK)<sup>10-14</sup> or after phakic intraocular lens (pIOL) implantation<sup>15,16</sup>

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were on average slightly lower than pre-operative straylight measurements. Assumptions were made that these improvements are the result of ill-tolerated contact lenses pre-operatively.<sup>13,15,16</sup> Another factor that might have played a role in these findings is the effect of change in retinal image size due to correction of the refractive error. For example, after pIOL implantation in high myopic eyes, visual acuity may increase 1 or more lines due to image magnification effects.<sup>15,17,18</sup> Labuz et al<sup>19</sup> demonstrated differences in elevated straylight as the result of multifocal contact lens wearers. Van der Meulen et al<sup>20</sup> showed increased straylight during rigid contact lens wear, possibly as a result of deposits on the contact lens, but the degree of refractive error was not taken into account.

The effect of different degrees of refractive correction on retinal straylight, with its concomitant effect on retinal image size, has not yet been investigated and remains unclear. We therefore want to examine if different refractive corrections, resulting in different retinal image sizes, have an effect on straylight values.

## Materials And Methods

### Subjects

This study involves two study groups with an age range of 18–35 years: 1) a near-emmetropic group (n=30 eyes of 15 subjects), defined as having a spherical refractive error between –1.00 and +1.00 dioptres (D) and a cylindrical refractive error not exceeding –2.00 D. 2) A myopic group (n=30 eyes of 15 subjects) with a spherical refractive error of at least –6.00 D and a cylindrical refractive error not exceeding –2.00 D. Subjects with a history of ocular pathology, cataract, corneal opacities, visual acuity of <0.2 Snellen or epilepsy, were excluded. The participants were recruited and assessed at the Leiden University Medical Center (LUMC) in the Netherlands between May 2013 and October 2014. The study was conducted in accordance with the Declaration of Helsinki and approved by the medical ethical committee of the LUMC. All participants provided written informed consent.

### Straylight Measurements

Straylight values were measured using the compensation comparison-based Oculus C-Quant (Oculus Optikgeräte, GmbH, Wetzlar, Germany). This method for assessing straylight has been described in detail in the literature and has been thoroughly validated.<sup>6,17,18,21,22</sup> The amount of straylight is quantified by means of the straylight parameter *s*, given logarithmically as log(*s*). All measurements

were performed in identical light conditions. The test was repeated to obtain 2 reliable measurements for each condition. The mean of the 2 measurements was used for analysis. The reliability outputs of the measurement were chosen as follows: an estimated standard deviation of ≤0.08 and a shape factor Q of ≥0.5.<sup>17,21</sup>

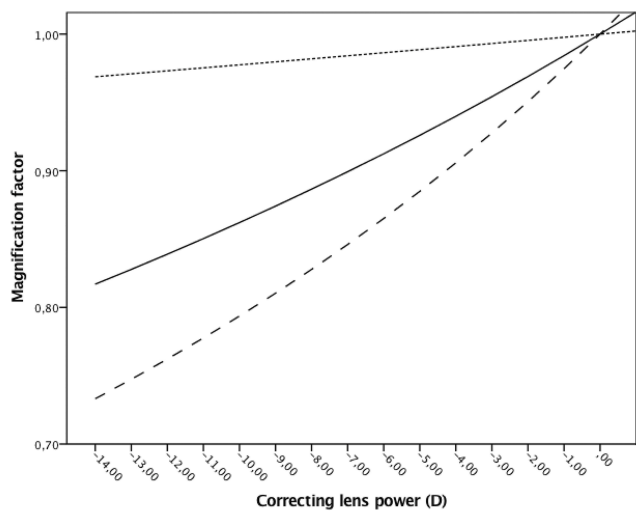
### Study Design

For each study group, we used a different approach to change refractive correction. In the first group, 1) the near-emmetropic group, straylight values were measured under 5 conditions: with a trial lens (provided by the manufacturer of the C-Quant) with a spherical power of (a) –14.00 D, (b) –10.00 D, (c) –6.00 D, (d) –4.00 D and (e) without any correction. Right and left eye were tested alternately. Between every measurement a pause of 30 s was given. Relative magnification of the different retinal image sizes was calculated with the standard spectacle magnification formula (1) for values for spectacle magnification.<sup>23</sup>

$$SM = 1/1 - (t/n)D_1 * 1/1 - hD \quad (1)$$

Where: SM = Spectacle magnification; t = thickness of the lens in meters; n = refractive index of the lens material; D<sub>1</sub> = the base curve or front surface power of the lens in diopters; h = the vertex distance +3 mm, converted to meters; and D = actual power of the lens in diopters.

In the second group, 2) the myopic group, straylight values were measured under 3 conditions: with correction by (a) trial lens, (b) spectacles and (c) contact lens. The same standard formula (1) was used to determine the image magnification resulting from different vertex distance *a* under the various test conditions: (a) *a*=0.026 m (trial lenses), (b) *a*=0.016 m (spectacles) and (c) *a*=0.003 m (contact lenses). In Figure 1, the lens magnification factor is plotted as a function of different refractive lens powers. Prior to straylight measurements, autorefractometry (Topcon KR 8900 Ref, Tokyo, Japan), corneal topography (Oculus Pentacam HR, Wetzlar, Germany), axial length (Lenstar LS 900 Haag-Streit, Koeniz, Switzerland) and slitlamp examination were performed. Best-corrected visual acuity (BCVA), own-spectacle-corrected visual acuity and contact-lens-corrected visual acuity (if applicable) were determined by ETDRS assessment (logMAR units). Trial lenses and prescribed spectacles were thoroughly cleaned before examination and new contact lenses were used. Only non-tinted spectacles with no macroscopic scratches and refractive index of 1.67 were used.



**Figure 1** Calculated magnification factor as a function of refractive correction power in diopters (D) for thin contact lenses (dashed line), spectacles (solid line) and trial lenses (interrupted line).

In case spectacles were worn, a vertex distance of 16 mm was maintained.

### Statistical Analysis

Statistical analysis was performed using SPSS statistics software version 23 (IBM). Descriptive statistics, including means, standard deviations, proportions, and frequency distributions, were generated for subject characteristics. Bland–Altman analysis was performed and 95% limits of agreement (LoA) were estimated by mean difference  $\pm 1.95 \times$  standard deviation (SD) of the difference. Data are expressed as the mean  $\pm$  SD. The normality of data was checked with the Kolmogorov–Smirnov test. Means, standard deviations and boxplots were used to visualize the data. A linear mixed model with random intercept was used to examine the relationship between straylight values and the different test conditions. We chose this statistical model in order to deal with the potential correlation of repeated measures of right and left eye. The correlation between straylight and the various test conditions was tested with a linear as well as a quadratic function. Our primary variable and all the possible variables were implemented in a model. We compared all the possible combinations by removing the variables with the highest p-value  $>0.05$  once at a time to create the best fit model (backward selection). In addition, each variable was tested individually in separate models on having an effect on straylight measurements. The model with the minimum value for Akaike’s information criterion (AIC) was identified as the optimal

model for the specific outcome measure. To evaluate the normal distribution of the final models, residual scatter plots and histograms were used. Statistical significance was defined as a p-value of less than 0.05.

Power calculations were made to determine the sample size. A significance level (adjusted for sidedness) of 0.025, a power of 90% and a standard deviation of the difference of 0.1 provided a minimum sample size of 13 patients for each group to satisfy valid conclusions. We included 15 patients in each group to meet the required sample size, allowing for dropouts.

## Results

### Characteristics Of The Participants

The characteristics of the study groups are shown in Table 1.

### Straylight Results

The repeatability of the straylight measurements was very good in both groups and comparable with previous

**Table 1** Characteristics Of The Near-Emmetropic (A) And Myopic Study Group (B)

<b>A.</b>				
<b>Near-emmetropic population</b>	<b>Mean</b>	<b>SD</b>	<b>N</b>	<b>%</b>
Male eyes			16	53
Female eyes			14	47
Age (years)	23.3	4.3		
SE refraction (D)	0.16	0.6		
Blue/green iris colour			18	60
Brown iris colour			12	40
<b>B.</b>				
<b>Myopic population</b>	<b>Mean</b>	<b>SD</b>	<b>N</b>	<b>%</b>
Male eyes			4	13
Female eyes			26	87
Age (years)	23.2	2.8		
SE refraction (D)	-8.78	1.69		
BCVA (logMAR)	-0.07	0.11		
VA with own spectacles (logMAR)	-0.06	0.12		
VA with contact lens (logMAR)	-0.10	0.11		
Keratometry mean (D)	43.7	1.17		
Axial length (mm)	26.8	0.77		
Pupil size (mm)	3.45	0.59		
Blue/green iris colour			18	60
Brown iris colour			12	40
Rigid contact lens			2	7
Soft contact lens			28	93

**Abbreviations:** SD, standard deviation; SE, spherical equivalent; D, diopters; BCVA, best-corrected visual acuity; VA, visual acuity.

reports,<sup>17,18,22,24</sup> with repeated measures standard deviations of 0.068 and 0.056 log-units for the near-emmetropic and myopic groups, respectively, also shown in Bland–Altman plots (Figure 2).

The measured straylight values are shown in Table 2 and with boxplot analysis (Figure 3). The mean baseline straylight value of the near-emmetropic group (measurements without trial lens, therefore no altering of retinal image size) is 0.91 log-units. In the myopic group, the mean baseline straylight value (measurements with contact lens, therefore minimal altering of retinal image size) is 0.97 log-units. Comparison of baseline straylight values between the near-emmetropic and myopic group shows no significant difference (Mann–Whitney significance 0.133/Independent sample *T*-test  $p=0.062$ ).

1) In the near-emmetropic group the refractive correction, with its concomitant image size altering effect, had a significant effect ( $p<0.001$ ) on the  $\log(s)$  straylight value. None of the other parameters tested (eye, age, SE and iris pigmentation) had significant effect on straylight. For more details see Table 3A.

2) In the myopic group the different refractive corrections had no significant effect on retinal straylight values ( $p=0.150$ ). There was no significant difference between the different test conditions, ie, trial lenses, soft contact lenses and spectacles. None of the other parameters (eye, age, SE, keratometry, iris pigmentation, AL, pupil size) had significant effect on straylight. For more details see Table 3B.

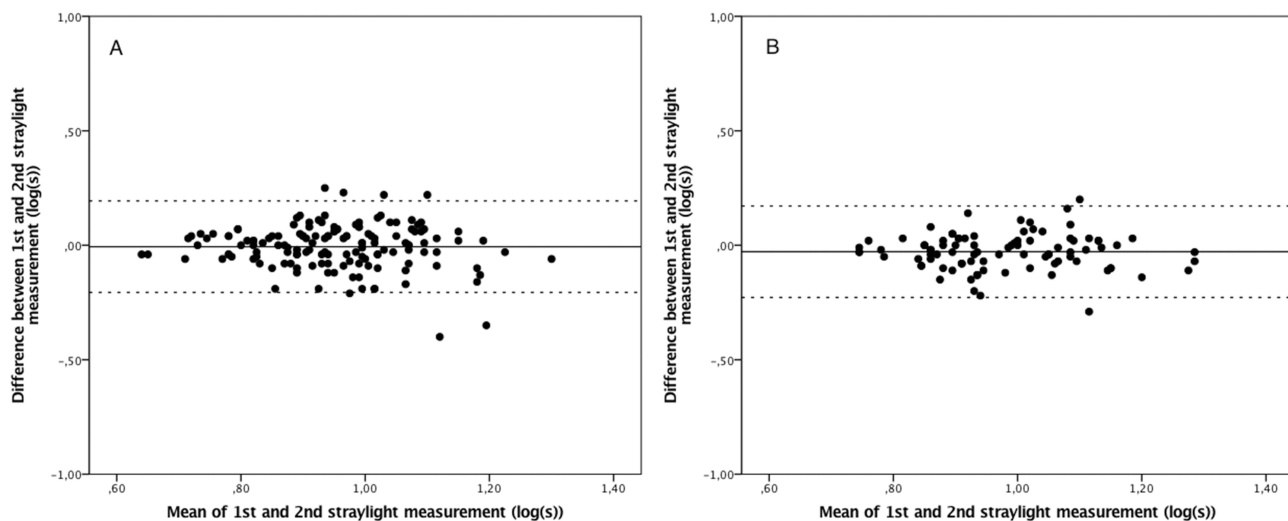
**Table 2** Measured Straylight Values At Different Conditions Of Retinal Image Size For The Near-Emmetropic (A) And Myopic (B) Eyes

A.			
Trial lens (D)	Mean $\log(s)$	SD	N
0	0.91	0.14	30
-4	0.96	0.12	30
-6	0.92	0.11	30
-10	0.99	0.10	30
-14	0.99	0.11	29
B.			
Condition	Mean $\log(s)$	SD	N
Own glasses	0.98	0.15	30
Trial lens	0.99	0.11	30
Contact lens	0.97	0.11	30

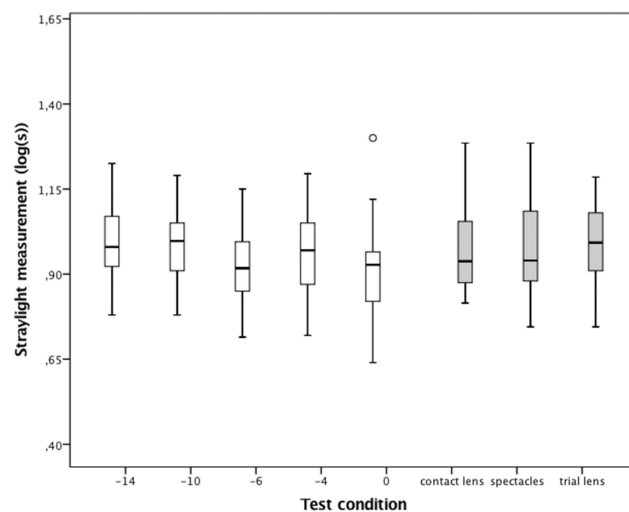
**Abbreviations:** D, diopters; SD, standard deviation.

## Discussion

The main conclusion is that the effects of glasses and soft contact lenses, including the degree of refractive error it corrects, on straylight are modest and all the measurements were below 1.47  $\log(s)$  which is the threshold for serious hindrance. In the first (near-emmetropic) group, a significant effect was found of the different powers of lenses, which must partly be attributed to the known effects of scatter angle (image size), but our hypothesis is that accommodation might also play a role in this finding. During accommodation the crystalline lens takes on a more spherical shape, and lens thickness increases with 0.045 mm for every diopter of added accommodation stimulus.<sup>24</sup>



**Figure 2** Bland–Altman plots for the first and second straylight measurement differences with 95% limits of agreement (LoA) in the (A) near-emmetropic group and the (B) myopic group. Solid line: mean, dashed line: upper and lower LoA.



**Figure 3** Boxplot of the straylight values measured by C-Quant in log-units ( $\log(s)$ ) for the 30 near-emmetropic eyes (white) and the 30 myopic eyes (gray) under the different test conditions.

To our knowledge, we are the first to describe the effects of glasses on straylight. The effect of contact lenses on straylight, however, has been described by van der Meulen et al.<sup>20</sup> They demonstrated straylight values of 0.934  $\log(s)$  during soft contact lens wear in a study

**Table 3** Associations Of Mean Straylight Values And Possible Predictor Variables Generated By Linear Mixed Models In The Near-Emmetropic Study Group (A) And The Myopic Study Group (B)

A.			
Variable	Estimate	95% CI	P-value
Intercept	0.911	+0.853 to +0.969	<0.001
Lens power	0.006	+0.004 to +0.008	<0.001
Eye	-0.017	-0.039 to +0.004	0.118
Age	-0.006	-0.022 to +0.010	0.445
SE	0.008	-0.078 to +0.093	0.861
Iris pigmentation	0.062	-0.051 to +0.175	0.259
B.			
Parameter	Estimate	95% CI	P-value
Intercept	2.556	+0.821 to +4.292	0.005
Lens type spect/ctl	-0.129	-0.298 to +0.040	0.130
Trial/ctl	-0.233	-0.514 to +0.048	0.102
Magnification	-1.617	-3.404 to +0.170	0.075
Eye	-0.035	-0.071 to +0.005	0.053
SE	-0.028	-0.058 to +0.003	0.073
Iris pigmentation	-0.016	-0.115 to +0.082	0.721
K mean	0.026	-0.015 to +0.067	0.204
Age	-0.011	-0.032 to +0.011	0.297
Axial length	-0.003	-0.062 to +0.057	0.924
Pupil size	0.017	-0.074 to +0.109	0.699

population with normal eyes, comparable to 0.938  $\log(s)$  after removal of the lens. The straylight values of our myopic study population are slightly higher, probably due to the refractive power of the lens. Rigid contact lenses<sup>20</sup> and multifocal contact lenses<sup>19</sup> have also shown some slightly elevated straylight values, possibly as the result of other underlying mechanisms, such as deposits on the contact lens or diffractive effects, respectively. Therefore, these results cannot be compared with our findings, as we only used soft contact lenses in our study.

Although some studies have shown that age and iris pigmentation<sup>9,17,18,25-28</sup> can have significant effect on straylight values, in the present study, age, iris pigmentation, and all the other tested parameters were not significant. Probably, the fact that age is not significant in our study population is caused by a selection effect because we only selected subjects between 18 and 35 years of age. May be the pigmentation spread was not sufficient either in our small cohort.

What might explain the differences between the near-emmetropic and myopic study group? The first thing we should consider is the accommodation effect as described earlier. Second, a possible effect of the contact lenses used in the study as myopic participants' own contact lenses were used for visual correction and contact lenses have previously been shown to influence straylight values.<sup>20,29,30</sup>

Another factor that may be considered is that data of the near-emmetropic eyes group may have resulted in better statistical power due to more straylight measurements and greater range of magnification factor. However, if we exclude the data generated by test conditions with trial lenses of powers -14 D and -4 D, resulting in a similar number of observations as in the myopic group, a clearly significant effect remained ( $p < 0.001$ ).

## Conclusions

The effect of the degree and the method of correction, including eyeglasses and soft contact lenses, of refractive correction on straylight are modest and clinically irrelevant. The small effects found, might partly be attributed to known effects of scatter angle (image size), but accommodation might also play a role in this finding. Further, in-depth studies in this issue need to be pursued.

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## Disclosure

Dr van den Berg developed the method to assess straylight. This is licensed by the Royal Academy to Oculus for the C-Quant instrument. Dr van Rijn was supported by Opthec b. v., Stichting Blindenhulp, and by the ANVVB and LSBS foundations through Uitzicht. The funding organisations provided unrestricted grants and had no role in the design or conduct of this research. The authors report no other conflicts of interest in this work.

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