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# Retinal stray light originating from intraocular lenses and its effect on visual performance

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*Document Version*
Publisher's PDF, also known as Version of record

*Publication date:*
2016

Link to publication in University of Groningen/UMCG research database

*Citation for published version (APA):*
van der Mooren, M. H. (2016). *Retinal stray light originating from intraocular lenses and its effect on visual performance*. [Thesis fully internal (DIV), University of Groningen]. Rijksuniversiteit Groningen.

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# Chapter 3

# Rostock Glare Perimeter:

# A distinctive method for Quantification of Glare

*Reprinted from Optometry and Vision Science, Vol. 90, Meikies D, van der Mooren M, Terwee T, Guthoff RF, Stachs O, Rostock Glare Perimeter: A distinctive method for Quantification of Glare, Pages 1143-1148 Copyright © 2013, with permission from American Academy of Optometry(Wolters Kluwer Heath, Lippincott Williams & Wilkins)*

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http://dx.doi.org/10.1097/OPX.0b013e318295a720.

*This study was supported by a grant from the Dutch government IS062031 and INT111017 and German grant REMEDIS. Presented in part at the 2009 annual meeting of the Association for Research in Vision and Ophthalmology (ARVO), Fort Lauderdale, Florida.*

## ABSTRACT

**Purpose.** Disability glare induced by headlights of oncoming cars has been associated with reduced quality of vision. This study aimed at developing the Rostock Glare Perimeter to quantify dysphotopsia effects under simulated realistic conditions.

**Methods.** Sixty phakic subjects of different ages were dazzled by a bright light source centered at a projection screen 3.30m away from the subject’s eye. Using a projected marker moving outward from the screen center with angular steps of 0.25° in 12 directions, the area where the subject cannot distinguish the white spot from the glare effects of the light source was determined. A corresponding mean radius in a field angle relative to the subject’s eye was defined as a measure for disability glare. Monocular and binocular measurements were performed, and a separate repeatability and reproducibility study was executed to determine the precision of the Rostock Glare Perimeter.

**Results.** A significant mean positive correlation of disability glare with age ($r = 0.534$, $p < 0.001$) was found. The disability glare ranged from 0.33° to 1.8°, and a strong ($r = 0.93$, $p < 0.0002$) binocular summation effect was found. The repeatability and reproducibility limit of the Rostock Glare Perimeter method is 0.14° for 95% confidence interval.

**Conclusions.** The Rostock Glare Perimeter method is sensitive to detect age-related disability glare differences and to find binocular summation for disability glare in a healthy population for small field angles with high angular resolution. These findings suggest that the Rostock Glare Perimeter method is a helpful device to quantify symptoms of glare.

***Key Words.*** *disability glare, quality of vision, visual assessment, dysphotopsia, binocular summation*

Various approaches were developed to objectively quantify the severity of disability glare,[1-3] for example, a ''halometer,''[4] a ''glaremeter,''[5] and a ''stray light meter.''[6] Other devices measure reduced contrast sensitivity, for example, the Brightness Acuity Tester (Marco Ophthalmic, Inc., Jacksonville, FL),[7] or high- or low-contrast visual acuity, for example, the Berkeley Glare Test,[8] with and without a glare source at different angular distance in the visual field. The latest development is the C-Quant (OCULUS Optikgeräte GmbH, Wetzlar, Germany), an instrument for the measurement of retinal straylight based on a compensation comparison method using an 8-Hz flickering annulus as stimulus.[9] To evaluate the subjective perception, also scores such as subjective glare ratings[5] or questionnaires with photographs illustrating pertinent optical phenomena, for instance, the one developed by Aslam,[10] have been used. Glare is, beside reduced visual acuity, a significant condition for patients with cataract. Previous investigations showed increased glare sensitivity even in eyes with beginning opacity of the lens.[11] However, also, after uneventful cataract surgery, some of the patients suffer from dysphotopsia effects to the extent that they revert to the preoperative condition; in some cases, the symptoms may even be more severe.[12] According to their own testimony, subjects with multifocal lenses generally enjoy improved visual acuity, and they are less prone to need spectacles than subjects with monofocal lenses.[13] Visual acuity being comparable members of the former group enjoy better near vision and a greater depth of field.[14] Multifocal lenses, however, are generally known for reducing the contrast sensitivity in low-contrast conditions and for causing optical phenomena often described as halos.[15-19] Besides cataract surgery, also all refractive correction procedures are of interest for the evaluation of disability glare. Standardized measurement of such optical phenomena, simulating realistic conditions encountered by the patients in daily life, however, is not yet feasible and should be pursued as a long-term objective of this project. This article describes the Rostock Glare Perimeter for investigating disability glare, based on the everyday situation where a person in the dark-blinded by the headlights of an oncoming vehicle-is unable to see less brightly lit objects, such as pedestrians on the side of the road.

## METHODS

### Description of the Rostock Glare Perimeter

The subject sits at a distance of 3.30 m from a projection screen with a central cold light source with fiber optics of 2 mm diameter (LQ1100; LINOS, Göttingen, Germany). The illuminance is 0.65 lux at the level of the eye, and the subject gazes at this light source during the examination as illustrated in Figure 1. The light from the central light source was geared to the middle between the eyes, so that it reached each eye around an angle of 0.5°. A software tool produced a black background projected onto the screen by a projector (Mitsubishi HC4900, Mitsubishi Electric Europe B.V., Ratingen, Germany) with a luminance of less than 0.01 cd/m$^2$ on an area of 1.12 m (height) x 1.50 m (width).

Furthermore, the software provided on the screen a white marker, stepwise moving outward from the center at a speed of 0.25°/s. The geometry of the marker was a square with an angular size of 0.09° and a luminance of 22 cd/m$^2$. In a random sequence, this spot moved sequentially in one of a total of 12 directions. As soon as the subject was able to differentiate the marker from the halo of the dazzling light source, he or she was instructed to announce this verbally. The respective distance to the central light source was recorded. In the next step, the direction was changed at random. In the end, 12 directions in equal distances were investigated, each with a total of three repetitions per monocular and binocular measurement. Because the measured blind area is assumed to be circular, it has a defined radius. This radius on the projection screen is translated into a certain field angle relative to the subject's eye. In the context of this study, this angle in degrees is used as a measure for disability glare. During the entire investigation, the pupil size was measured using the Plusoptix S04 PowerRef II (Plusoptix GmbH, Nuremberg, Germany). It was installed 1 m in front of the subject's eyes, below eye level, so that it did not cover the concerning parts of the screen. This device also allowed monitoring the subject's fixation of the central light source. Light levels were detected by the photometer Tek Lumicolor (Tektronix, Köln, Germany). Measurements were performed in a room with scotopic lighting conditions (< 0.01 cd/m$^2$). Refraction errors of the subjects tested with Snellen acuity were corrected with glasses in a trial frame. To obtain comparable test results, each subject was given a glass in front of each eye, even if it was emmetropic. A dark adaptation of at least 5 min was performed before every measurement.

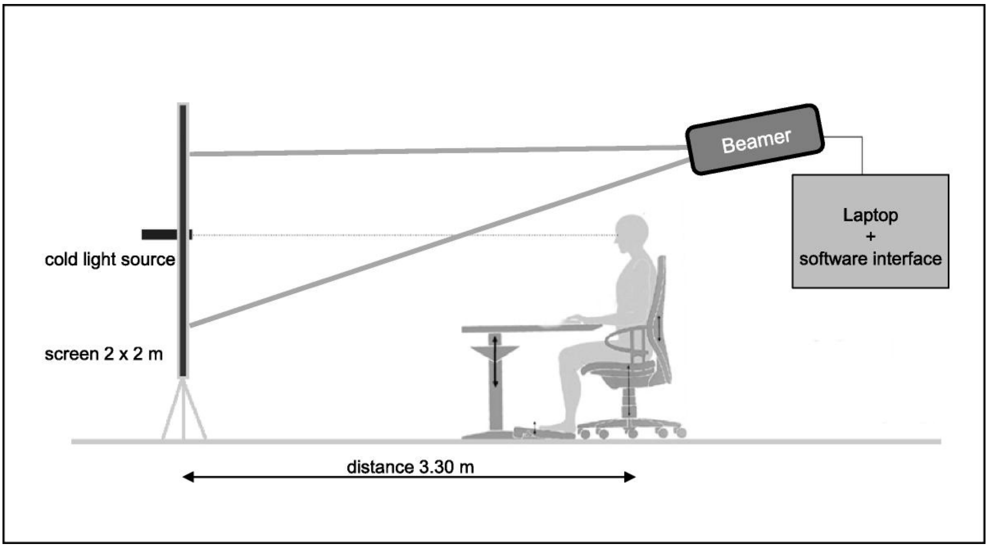
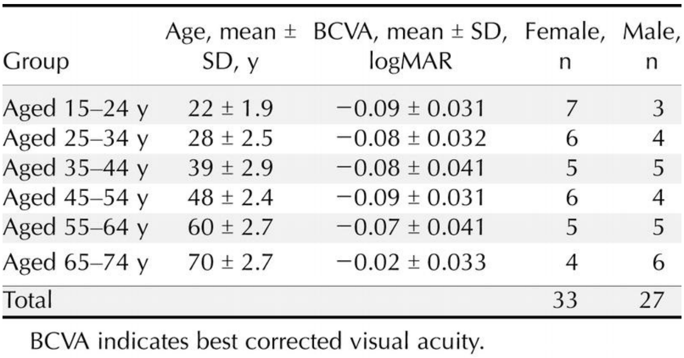


*Figure1. Experimental setup of the Rostock Glare Perimeter: a subject is sitting 330 cm from a screen with a central cold light source (0.65 lux at eye level); a beamer projects a marker (size of 0.09°, luminance of 22 cd/m$^2$) on the screen, stepwise moving outward with a speed of 0.25°/s.*

**Subjects**

Sixty phakic subjects of different age groups were investigated. There were 33 female and 27 male subjects selected and divided into six age groups of 10 subjects according to the demographic overview from Table 1. Inclusion criteria were best corrected distance visual acuity of at least 0.0 logMAR and an ophthalmologic uneventful medical history. Cataract patients were excluded by slitlamp microscopy.

**TABLE 1.** Characterization of subjects examined by Rostock Glare Perimeter



| Group | Age, mean ± SD, y | BCVA, mean ± SD, logMAR | Female, n | Male, n |
|---|---|---|---|---|
| Aged 15–24 y | 22 ± 1.9 | −0.09 ± 0.031 | 7 | 3 |
| Aged 25–34 y | 28 ± 2.5 | −0.08 ± 0.032 | 6 | 4 |
| Aged 35–44 y | 39 ± 2.9 | −0.08 ± 0.041 | 5 | 5 |
| Aged 45–54 y | 48 ± 2.4 | −0.09 ± 0.031 | 6 | 4 |
| Aged 55–64 y | 60 ± 2.7 | −0.07 ± 0.041 | 5 | 5 |
| Aged 65–74 y | 70 ± 2.7 | −0.02 ± 0.033 | 4 | 6 |
| Total | | | 33 | 27 |

BCVA indicates best corrected visual acuity.

**Study Design**

Evaluation study procedures were performed in accordance with the ethical standards of the Declaration of Helsinki, and informed consent was obtained from all participants before their inclusion in the study. The subjects were examined by monocular and binocular disability glare testing, so all together each subject was examined three times. The pupil diameter was recorded during all examinations. They were asked to assess their subjectively perceived disability glare by ‘‘subjective glare rating’’[5] using a scale between 0 and 3. Grade 0 indicates no glare symptoms at all, grade 1 means minor symptoms, grade 2 indicates moderate symptoms, and grade 3 stands for severe symptoms. The repeatability and reproducibility study was performed with three trained inexperienced operators, and in total, four subjects were measured three times on the right eye. The subjects were familiar with vision tests, and each operator measured three subjects.

**Statistical Analysis**

The measured monocular and binocular disability glares were statistically described and were analyzed for normal distribution at 5% significance level. Only nonparametric tests such as the Mann-Whitney *U*test and Spearman correlation analysis were used for this purpose, since a Gaussian distribution could not be presumed, which will be foreclosed later on using the Kolmogorov-Smirnov test. Disability glare was also analyzed for correlation with maximum pupil diameter, subjective glare rating, age, and gender.

Disability glare was exponentially fitted with age, and standard t test was applied for age-corrected gender comparison. Pearson coefficients were calculated to determine the level of correlation for the age fit. The presence of binocular summation was analyzed by equating the binocular disability glare with the quadratic summation of the monocular outcomes. Furthermore, Pearson coefficient was calculated to determine the level of correlation. The monocular disability glare values were subtracted from each other, and the difference distribution was analyzed for symmetry by calculating the average and skewness. The within-operator (repeatability) and inter-operator (reproducibility) limits were calculated for 95% confidence interval using analysis of variance. The repeatability and reproducibility limit was calculated by quadratic summation of the within-operator limit and the inter-operator limit.

## RESULTS

For the right eye, the disability glare ranged from 0.39° to 1.78°with a median value of 0.69°, and for the left eye, the disability glare ranged from 0.40° to 1.85° with a median value of 0.76°. The binocular disability glare ranged from 0.33° to 1.58° with a median value of 0.59°.The Kolmogorov-Smirnov test revealed with high probability ($p < 0.001$) that the disability glare of all eyes measured by Rostock Glare Perimeter is showing a non-Gaussian distribution. In conjunction with this study, neither the maximum pupil diameter nor the subjective glare rating showed a significant correlation with disability glare, as depicted in Table 2. The monocular and binocular outcomes for three subjects with similar binocular disability glare and different subjective glare rating are displayed in Figure 2. Binocular disability glare ($r = 0.62$) and monocular disability glare ($r = 0.48$) showed median age dependence and is illustrated by the binocular result in Figure 3. The correlation between binocular disability glare and age had a power of 99% for $p = 0.05$. Among male subjects, disability glare obtained by binocular measurement (0.76° ±0.33°) was higher than among female ones (0.58° ± 0.19°), but when corrected for age, there was no statistically significant difference. Binocular disability glare could be predicted with high probability ($r = 0.93$, $p < 0.0002$) from the quadratic summation of the monocular disability glare outcomes divided by √3 found by the least square method. The predicted versus the observed binocular disability glare is displayed in Figure 4. The monocular disability glare difference between the right eye and the left eye was found to be symmetric (skewness of 0.068) and centered (mean of 0.01°). With a power of 90% ($p = 0.05$), the binocular disability glare (0.66° ± 0.27°) was lower than monocular disability glare (0.81° ± 0.30°). The result of the precision study for the within-operator limit is 0.13°, and for the inter-operator limit, it is 0.05°.The repeatability and reproducibility limit for the Rostock Glare Perimeter method is 0.14°.

**TABLE 2** Additional parameters and their correlation with disability glare

| | Mean ± standard deviation of DG, ° | Coefficient of correlation, r | Probability, p |
|---|---|---|---|
| Maximum pupil size, mm<br>6.2 ± 1.0 | 0.81 ± 0.30 (monocular DG) | −0.088 | 0.341 |
| Subjective glare rating<br>1.0 ± 0.7 | 0.66 ± 0.27 (binocular DG) | 0.039 | 0.766 |

DG, disability glare.

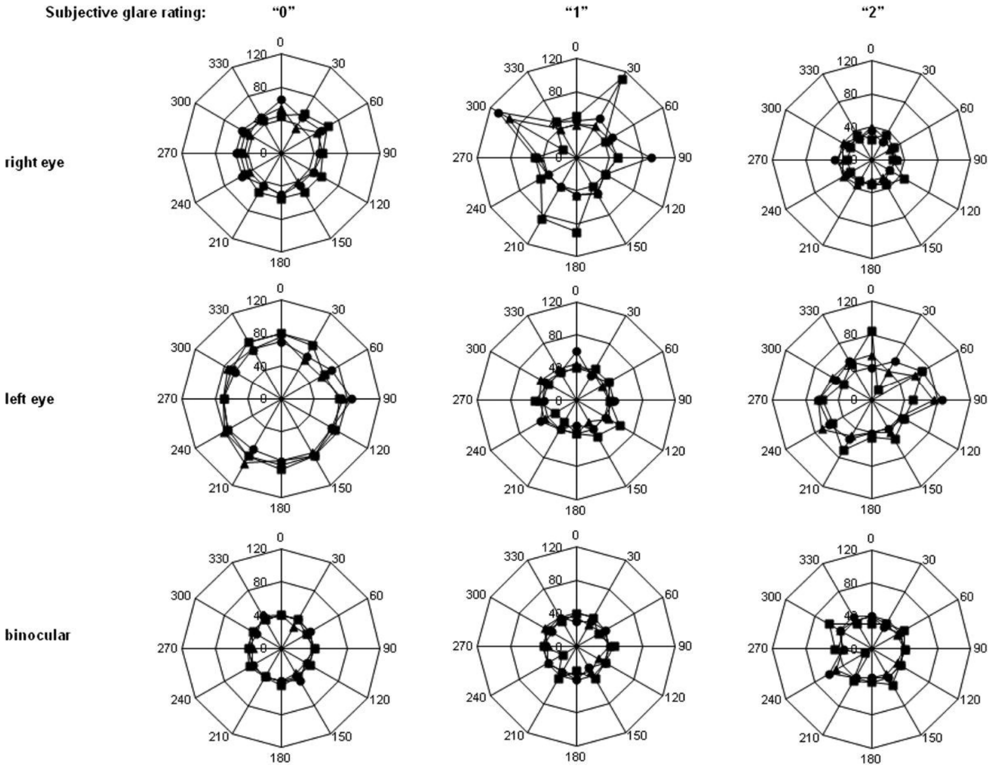


*Figure 2. Three examples of Rostock Glare Perimeter outcomes (monocular and binocular) in subjects with subjective glare ratings of ''0,'' ''1,'' and ''2'': despite different subjective glare ratings, binocular disability glare is similar. In most cases, binocular disability glare is lower than monocular disability glare. The three circles in each graph illustrate the three repeated measurements per session. On the radial axis, the distance to the central light source is plotted in pixel on the user interface of the Blackscreen software.*

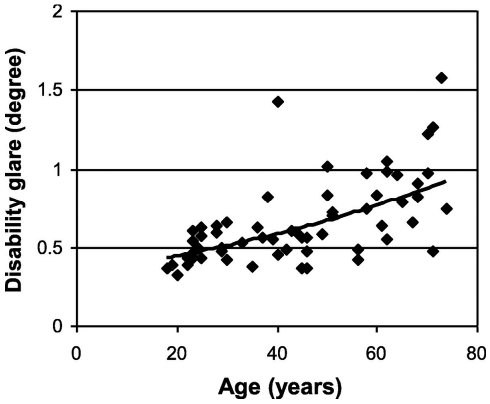


*Figure 3. Correlation between age and binocular disability glare (r = 0.62).*

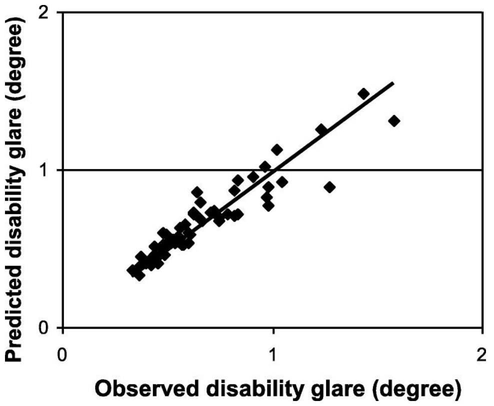


*Figure 4. Predicted versus observed binocular disability glare (r = 0.93): predicted binocular disability glare calculated by the quadratic summation of monocular disability glare divided by √3.*

## DISCUSSION

The Rostock Glare Perimeter simulates a realistic glare situation that is daily encountered on dark roads with oncoming traffic. A bright light source imitates realistic light levels[20] (0.65 lux at eye level) during night driving and a projected light spot simulates a roadside pedestrian yielding low field angle outcomes. The experimental setup is spacious, so assessment of disability glare is possible under far monocular and binocular visions, which is close to reality. As shown in this investigation based on the phakic population, there is a mean positive correlation between age and disability glare, what can be the most probable reason for non-normal disability glare distribution. Roughly, it was found that the binocular field angle at age 75 years is with a factor of 2 larger than that for a young person. The age-related increase of the density and inhomogeneity of the natural lens alone intensifies the light scattering effect and thus also increases disability glare, which is a common finding.[21,22] As expected, our study did not detect any correlation between pupil size and disability glare. Pupil size affects the retinal illuminance caused by the stimulus and the glare source equally. The minimal correlation between the objectively measured disability glare and the self-evaluation by subjective glare rating might be attributed to interindividual differences in the processing and interpretation of stimuli and sensitivity tolerance. This brings about a certain risk of underestimating the degree of visual impairment by glare, for instance, in traffic situations. Because the individual subjects are not necessarily aware of disability glare, as evidenced by the nonexisting correlation with the subjective glare rating in this study and also found, for example, by Ehmer et al.,[23] nighttime traffic brings about additional hazards that might be elucidated by the Rostock Glare Perimeter.

Binocular disability glare was predicted by the quadratic summation of the monocular disability glare values divided by $\sqrt{3}$. A pure optical summation would yield a factor of $\sqrt{2}$, and our outcome suggests the presence of a neural component for the further suppression of disability glare. The binocular summation factor for disability glare is of the same magnitude as found in other studies when investigating the binocular summation for visual acuity and contrast sensitivity. The precision of the Rostock Glare Perimeter was expressed in repeatability and reproducibility limit and was not directly compared with other methods because the setup is distinct for the type of stimulus to be detected. Besides, most methods use a glare source at various fixed field angles, and in the Rostock Glare Perimeter method, the field angle is an outcome. Some of the drawbacks of the Rostock Glare Perimeter may include increasing fatigue during investigation with time, plus the aspect that the motion of the marker also complicates its detection. This affects the fixation ability because the subject - more or less unconsciously - tends to scan the screen to find the marker. Furthermore, sometimes, reflecting light from the spectacles could influence the recognition of the marker. Some of these aspects were mitigated through measuring each meridian three times. This is confirmed through the results of the monocular difference distribution, which is symmetric and centered. Assuming that the healthy phakic population has, on average, the same quality for disability glare in the right and left eyes, it is concluded that the subject fixation was, on average, in line with the center of the screen. Although the option of an out-to-in strategy for marker presentation may have simulated a night driving situation better, we have chosen the in-to-out strategy for marker presentation to shorten the measurement procedure and because marker alignment is easier and it also avoids after-image effects. Advantages of the Rostock Glare Perimeter are that the speed, luminance, and size of the marker and the illuminance of the glare source are adaptable. Note that the chosen settings (speed = 0.25°/s, L = 22 cd/$m^2$, size = 0.09°) are optimal for contrast detection.[24] When the marker size of 0.09° is back calculated to a spatial frequency of 5.8 cycles per degree or a visual acuity of 0.7 logMAR, it is evident that all subjects were limited by acuity detection and not by acuity resolution. Future investigations are planned on varying the illuminance of the cold light source, the marker size, and the marker luminance to study the impact on the field of view that the subjects would need. The application of a computer-recorded user response may help facilitate the execution of all these new experiments. The Rostock Glare Perimeter is a new method of quantifying glare problems under simulated realistic conditions. It is evidently sensitive enough to detect age-dependent differences and to find binocular summation for disability glare in subjects with healthy eyes for small field angles with high angular resolution. This makes it possible to use this approach for the assessment of the visual quality in refractive and cataract surgery, which may lead to improved refractive correction procedures and optical designs of intraocular lenses.

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