Normal Values for the Size of a Halo Produced by a Glare Source

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ABSTRACT

PURPOSE: To determine the size of a halo in the visual field induced by bright light in healthy eyes of all ages using the Vision Monitor (MonCv3; Metrovision, Pérenchies, France) and to assess the repeatability of the method.

METHODS: Measurements were made in the right eyes of 147 healthy subjects (mean age: 48.2 ± 16.2 years) who were classified into six age groups. Using the Vision Monitor, optotypes of low luminance were presented at a distance of 2.5 m. The visual angle subtended by the radius of the halo was calculated in minutes of arc (arc min). The repeatability of the method was determined in a subset of 37 subjects older than 50 years by calculating the Bland–Altman coefficient of repeatability.

RESULTS: The mean radius of the halo was 111.6 ± 39.8 arc min. Halo radius started to increase significantly from the age of 50 to 59 years. The relationship between halo radius and age ($r = 0.65$; $P < .0001$) was described by fitting a power function to the data. Halo size was independent of gender. The coefficient of repeatability of the method was ±44 arc min.

CONCLUSIONS: Halo size increases with age following a power model. The normal halo size values provided could help clinicians distinguish between normal or abnormal glare problems. The intersession repeatability observed for halo size measurement indicates this method could be useful for assessing visual impairment caused by glare.

[*J Refract Surg.* 2013;29(9):618-622.]

Light from a bright glare source in the visual field is scattered onto the retina. This scattered intraocular light reduces the contrast and visibility of the target's foveal image and leads to disability glare.[1,2] Around the image of the glare source, the viewer perceives a blurred glowing circle called a disk halo where an object cannot be clearly seen.[3] This type of halo is caused by scattering of small particles or small localized variations in the index of refraction of the ocular tissues. Other types of halo exist, each with a different physical cause. Ring halos are usually caused by diffractive scattering by peripheral portions of the crystalline lens fibers acting as a diffraction grating (lenticular halo)[4] and sometimes by a phenomenon in which the basal cells of the corneal epithelium form a diffraction grating in situations of corneal edema (Sattler's veil).[5] Disk halos can also be the result of refractive aberrations due to the transition zone between ablated and non-ablated cornea within the pupillary area following laser refractive treatment.[6]

Measuring the size of a glare source-induced halo has been proposed as an objective method of quantifying quality of vision in subjects such as those with night vision problems following refractive surgery,[7,8] with cataract[9] or multifocal intraocular lenses,[10-12] and those wearing spectacles or contact lenses.[13]

Several methods and testing protocols have been developed to measure halo size.[9,10,13,14] However, methodological limitations such as the subjectivity involved in determining the limit of a diffuse halo on a screen in the absence of a target image with only the glare source makes the findings of such studies difficult to interpret. We propose that a method capable of determining the area of the visual field across which visual

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Submitted: January 18, 2013; Accepted: May 2, 2013

Supported by a grant from Banco Santander-Universidad Complutense de Madrid.

The authors have no financial or proprietary interest in the materials presented herein.

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doi:10.3928/1081597X-20130819-03

targets such as letters cannot be seen will avoid the subjectivity of methods in which a subject is required to precisely locate the margins of a halo. In addition, if the method is sufficiently repeatable, this will allow real clinical changes to be distinguished from naturally occurring measurement variability.

It is widely accepted that light scattered in the direction of the retina (retinal straylight) increases with age[15-18] and cataract,[19] reducing an individual's quality of vision (eg, while driving at night or viewing a person against a bright background). However, so far the literature lacks halo size data for large populations covering all ages, the limits that could be considered normal, and to what extent halo size increases with age. We believe there is a need for this type of information for comparisons with data obtained in patients who have undergone refractive surgery or older adults who complain of glare.

This study was designed to establish normal values for the size of a disk halo in the visual field in a large number of healthy eyes of subjects aged 20 to 79 years using the Vision Monitor device (MonCv3; Metrovision, Pérenchies, France). The repeatability of the method was also assessed.

PATIENTS AND METHODS

Patients

The study was conducted at the Faculty of Optics and Optometry, Complutense University, Madrid, Spain. Measurements were obtained in the right eyes of 147 healthy subjects: 59 men and 88 women with a mean age of 48.2 ± 16.2 years (range: 20 to 77 years). The study sample was stratified into six age groups. The age bands established and the total number of subjects in each age group were: 20 to 29 years (n = 28); 30 to 39 years (n = 17); 40 to 49 years (n = 25); 50 to 59 years (n = 31); 60 to 69 years (n = 34); and 70 to 79 years (n = 12).

In each eye, we determined visual acuity and subjective refraction and conducted a slit-lamp and ophthalmoscopic examination. Inclusion criteria were uncorrected distance visual acuity of at least 20/25 and refractive error no greater than ±3.75 diopters (D) sphere or ±1.50 D cylinder. Exclusion criteria were posterior subcapsular cataract, cortical or nuclear opacities greater than LOCS III classification grade 2, diabetic retinopathy, glaucoma, amblyopia, retinal vascular disease, or any other retinal abnormality. Subjects were also excluded if they were aphakic, pseudophakic, or had undergone refractive surgery.

The tenets of the Declaration of Helsinki were adhered to and full approval for the study was obtained from our institution's review board. Subjects were first informed about the study protocol before giving their consent to participate.

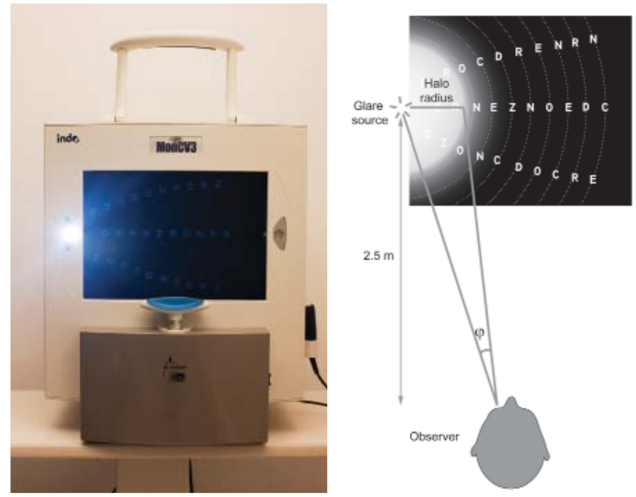

Figure 1. Measuring halo size. (Left) Vision Monitor (MonCv3; Metrovision, Pérenchies, France). (Right) Diagram showing how the visual angle produced by the radius of the halo is determined (φ) in the left eye. It is noteworthy that in this study the right eye was measured.

Halo Size Measurement

Halo size was measured using the Vision Monitor (**Figure 1**). This commercial instrument has two white circular light sources (LEDs) on each side to generate glare. Each glare source has a single luminance of 200,000 cd/m^2 and forms a visual angle of 3.8 degrees from the center of the monitor at a distance of 2.5 m. At this distance, illuminance on the eye by the glare source was 7 lux as measured using a FlexOptometer Radiometer/Photometer UDT (Gamma Scientific, San Diego, CA). The right source was chosen to test right eyes. This off-axis light source illuminated the patient's eye and produced stray intraocular light reducing the contrast of a foveal target. The effects of scatter were enhanced through the use of low luminance optotypes presented over a dark background. Three luminance levels can be used: 1, 5, and 100 cd/m^2. According to the manufacturer, the 5 cd/m^2 level is suitable for normal individuals, the 1 cd/m^2 level for individuals whose visual performance is above average, and the 100 cd/m^2 level for individuals with impaired visual performance. In this study, the test was performed using a letter luminance level of 5 cd/m^2. This level is at the upper end of the mesopic range, the luminance ratio (Lmax-Lmin)/Lmin for this level being 40.7.

Optotypes were arranged in three radial lines of letters appearing from the periphery toward the glare source (see **Figure 1**). Each line contained 10 letters forming 10 rings at intervals of 33 minutes of arc (arc min) at a distance of 2.5 m. Each letter subtended 15 arc min corresponding to a decimal visual acuity of 0.33 (Snellen 20/60). Two different combinations of letters were used. Letter size was 20/60 (Vision Monitor's only available size).

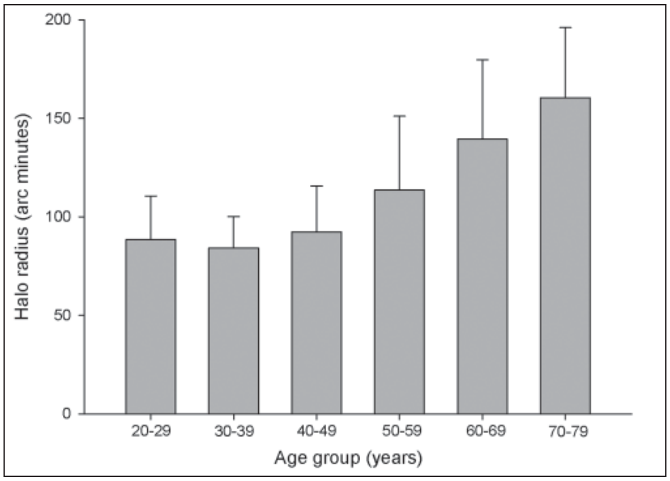

Figure 2. Mean halo radius across age groups. Vertical lines indicate the standard deviation.

The subject was seated 2.5 m from the monitor with the head positioned using a chinrest aligned with the center of the monitor. The subject was instructed to cover the left eye and to view the optotypes during simultaneous illumination of the eye with the glare source. The subject was told not to look directly at the light source to avoid a retinal after-image. Thereafter, the subject read each line starting from the side opposite to the light source (ie, optotypes were read from the periphery toward the glare source until a letter could not be identified). The subject was encouraged to read each letter despite being unsure. Letters not identified in each line were recorded and the test result was calculated as the average distance from the glare source for the three lines. This distance was taken as the radius of the halo. Next, the visual angle formed by the radius of the halo was calculated in minutes of arc (**Figure 1**). Before testing, the subject was allowed to dark adapt for 5 minutes and pupil size was measured using a Colvard pupillometer. Monocular testing took place in a dark room with best spectacle correction.

Reliability of the Halo Measurement Method

Inter-session repeatability of halo size measurements obtained using the Vision Monitor was determined in a subset of 37 subjects: 17 men and 20 women (mean age: 60 ± 5.1 years, range: 50 to 79 years). We selected subjects older than 50 years because older adults complain more of disability glare and halos than younger individuals.

Halo size measurements were made by the same examiner in two sessions 1 week apart, always using the same series of letters. In the second session, the examiner was blind to the first set of measurements.

Statistical Analysis

Halo size variability among the six age groups was compared by analysis of variance. Fisher's least significant difference procedure was conducted as a post hoc test to determine which means were significantly different for each of the six age groups. Mean halo sizes in men and women were compared using the Student's *t* test. All statistical tests were performed using the software package Statgraphics Centurion Version XVI (STATPOINT Technologies, Warrenton, VA). Significance was set at a *P* value less than .05.

The link between halo size and age was modeled by fitting a power function to the data using SigmaPlot 11 (Systat Software Inc., Chicago, IL).

The Bland–Altman method[20] was used to determine the repeatability of halo size measurements made with the Vision Monitor using the Analyse-it for Microsoft Excel program Version 2.0 (Microsoft Corporation, Redmond, WA). The variables determined were the mean difference between measurements made in the first and second sessions, the standard deviation of differences, the coefficient of repeatability (coefficient of repeatability = ±1.96 × standard deviation of differences), and the limits of agreement at the 95% level (mean difference ± coefficient of repeatability). The paired *t* test was also used to establish the significance of the differences observed.

RESULTS

Halo Size in Healthy Participants

Mean halo radius was 111.6 ± 39.8 arc min (range: 66.0 to 220.0 arc min) for a luminance level of 5 cd/m^2. **Figure 2** shows mean halo radii and their standard deviation bars for each age group. A significant effect of age group on halo size was detected (F = 18.62, $P < .00001$). Thus, there was a mean halo radius difference of 72 arc min between the youngest (88.4 ± 22.1 arc min) and oldest (160.4.± 35.5 arc min) age groups. A post hoc analysis using the Fisher's least significant difference procedure was conducted to identify means that differed significantly among the age groups. The first three age groups returned similar mean halo radius values (20 to 29 years: 88.4 ± 22.1 arc min; 30 to 39 years: 84.1 ± 16.0 arc min; 40 to 49 years: 92.4 ± 23.1 arc min), whereas the remaining three groups differed among each other (50 to 59 years: 113.5 ± 37.5 arc min; 60 to 69 years: 139.4 ± 40.2 arc min; 70 to 79 years: 160.4 ± 35.5 arc min) and with respect to the remaining groups. Thus, halo size increased gradually from 50 to 59 years onward.

A power model was fitted to the halo size data plotted against age (**Figure 3**). Significant positive correlation was found between halo radius and age (r = 0.65; $P < .0001$). Halo size increased rapidly beyond the age of 50 years.

The mean halo radius was 112.1 ± 40.6 arc min for women and 107.4 ± 36.7 arc min for men; no significant gender difference emerged (t = 0.499, $P = .62$). The

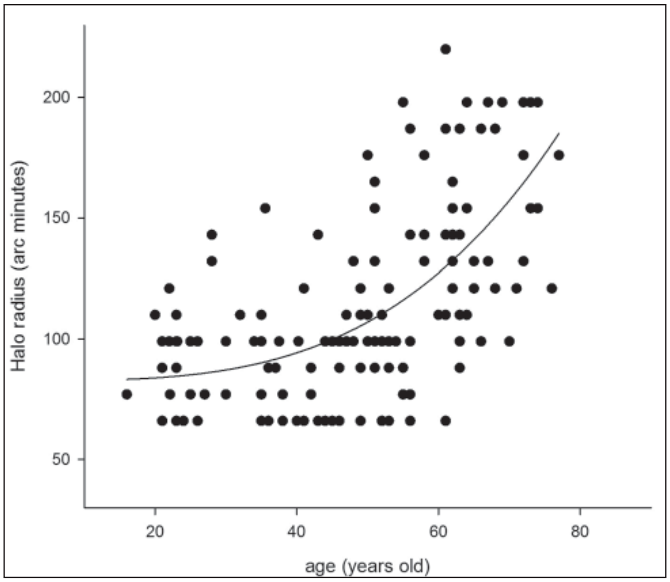

Figure 3. Halo radius according to age.

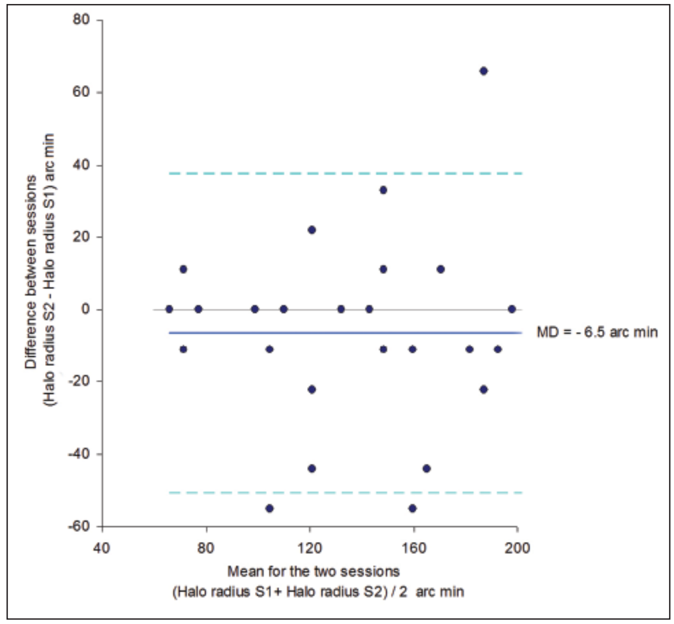

Figure 4. Repeatability of the Vision Monitor (MonCv3; Metrovision, Pérenchies, France) for halo radius measurements displayed as a Bland–Altman plot. The dotted lines indicate the lower and the upper 95% limits of agreement (S1: session 1, S2: session 2).

mean and range of pupil diameters measured using the Colvard pupillometer under low luminance conditions were 5.4 ± 1.0 and 3 to 8 mm, respectively.

Repeatability of Halo Size Measurements

Mean halo radii and their standard deviations obtained in the repeatability study were 100 ± 43 and 93.4 ± 41.6 arc min for the first and second sessions, respectively. Differences in the scores obtained in these two sessions did not vary significantly ($P > .05$). **Figure 4** shows the Bland–Altman plot for the repeatability of the Vision Monitor measurements. The mean difference between the two sets of measurements was -6.5 arc min, the coefficient of repeatability was ±44 arc min, and the limits of agreement at the 95% level were -50.7 to 37.6 arc min.

DISCUSSION

This study establishes a normative database for glare source-induced halo size in a large, normal, non-clinical population using the Vision Monitor. Our findings indicate that the size of a halo produced by a glare source somewhere in the visual field increases significantly across the lifespan of individuals with healthy eyes. We detected an increase of 72 arc min between our youngest and oldest age groups. Specifically, there appears to be no significant change in halo size until approximately the age of 50 to 59 years, when halo size starts to increase (**Figures 2-3**). A significant power relationship between halo radius and age was detected that was able to explain 42% of the variance. Consistent with the increase in halo size noted here, reports in the literature on aging indicate that even in the absence of ocular disease, normal age-related changes in disability glare occur due to increased intraocular scatter and these changes also follow a power model.[16,17] Retinal straylight has been shown to increase with the fourth power of age in healthy eyes.[1,15,21] In our study, halo size increased with age to the power of 3.33. This increase in halo size with age could be due to changes in the transparency of the ocular media.

Using the Vision Monitor we were able to establish the limit in the visual field at which the subject was unable to identify the optotypes. Because of the halo, these optotypes were below the contrast threshold. For the subject under test, identifying letters is easier than trying to mark on the score the limit of a diffuse halo produced by a central glare source, which has to be viewed by the subject. In previous studies, the task for the subject has been to report when a red spot touched the edge of a possible halo at a 2 m distance.[7,10] Alternatively, the subject had to place a marker at the outer limit of the halo using a computer mouse at a 1 m distance.[13] The main shortcoming of these methods is that if the subject does not see a defined halo or does not understand what a halo is, identification of the margin of the halo could be difficult. Further, each subject might delimit the halo in a different way. In other studies, the subject has had to detect small peripheral luminous stimuli that are presented briefly around a central high-luminance stimulus. A light distortion index was then obtained as an index of the halo.[14,22,23]

Differences in methodology, luminance of the glare source, distance, and measurement units make it difficult to compare the findings of the few studies that have examined halo size. In some studies, halo size has been reported as its radius (mm) at 30 cm.[9,24] In others, halo size values are given in square degrees (sqd).[7,13] Thus, in LASIK patients younger than 50 years, mean preoperative halo size was 1.97 ± 1.20 sqd.[7] Bearing in mind the different measurement method, mean halo size in our subjects younger than 50 years was 6.9 ± 0.4 sqd. However, when a central glare ring source was used at a distance of 1 m, the halo size reported was 61.3 ± 6.5 sqd in emmetropic subjects.[13] In view of these results, there seems to be a need for a standard method of halo size measurement. A limitation of the halo approach is that it has no gold standard definition, although the underlying process is the point spread function.

Knowing the repeatability of an instrument allows clinicians to distinguish true clinical changes from measurement variability. To the best of our knowledge, the current study is the first to evaluate the repeatability of halo size measurements obtained using the Vision Monitor device in healthy eyes of subjects older than 50 years. Our data suggest that when an examiner takes repeated halo size readings in healthy eyes of subjects older than 50 years of age over time, changes of more than 44 arc min (ie, approximately one ring) can be considered clinically significant. The mean difference between the two test scores (-6.5 arc min) was not significantly different from zero in both statistical and clinical terms, indicating that fatigue or training did not significantly affect the test scores.

The results of our study add to the literature on glare by providing normal halo size values for each age obtained using the Vision Monitor. In clinical practice, this could be of help when assessing symptoms in patients who complain of glare and halos such as those with cataract or patients undergoing refractive surgery or the implantation of multifocal intraocular lenses. Knowing the repeatability of the method used to determine halo size will help the clinician distinguish an abnormal halo size leading to impaired vision.

AUTHOR CONTRIBUTIONS

Study concept and design (CP-A, MCP); data collection (CP-A, MJP-C); analysis and interpretation of data (BA, AB, MCP); drafting of the manuscript (BA, AB, MCP); critical revision of the manuscript (CP-A, MJP-C)

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