Relationship between halo size and forward light scatter

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ABSTRACT

Purpose To determine the relationship between the size of a halo induced by a glare source and forward scatter or visual acuity (VA) in healthy eyes.

Method Measurements were made in the right eyes of 51 healthy individuals of mean age 29.3±7.5 years. Halo radius was measured using the Vision Monitor and low luminance (1 cd/m^2) optotypes 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). Forward scatter or, straylight, was measured using the compensation comparison technique. Best-corrected distance VA was measured using high contrast (HC) (96%) and low contrast (LC) (10%) Bailey-Lovie logMAR letter charts under photopic (85 cd/m^2) and mesopic (0.15 cd/m^2) luminance conditions.

Results Mean halo radius was 202±43 arc min (3.4 ±0.7°) and mean retinal straylight was 0.95±0.12 log units. Mean photopic distance HC-VA and LC-VA were −0.02±0.06 and 0.12±0.09 logMAR, respectively. Mean mesopic distance HC-VA and LC-VA were 0.35 ±0.11 and 0.74±0.11 logMAR, respectively. Forward stepwise regression analysis revealed that halo radius was significantly correlated with straylight (r=0.45) and mesopic LC-VA (r=0.48), but not with photopic HC-VA and/or LC-VA and mesopic HC-VA.

Conclusions In healthy eyes, the larger the halo size induced by a given glare source, the greater the forward-scatter (straylight) and worse the mesopic LC-VA. Halo size seems to be independent of photopic HC-VA or LC-VA and mesopic HC-VA.

INTRODUCTION

When a strong light source is presented in the field of view, forward-scattered light in the eye produces a veiling light over the retina, reducing retinal contrast and inducing disability glare[1 2] and disk halos.[3] Light scattering reduces optical image quality in patients with cataract,[4 5] or following cataract surgery,[6] corneal refractive surgery[7] or keratoplasty.[8] This effect has been attributed to modifications in ocular media transparency and/or the regularity of the optical surfaces of the ocular system. In these patients, quality of vision can be reduced, for example, while driving at night and in recognising a person against the background of a light source. Among other photic phenomena or night vision disturbances, halos produced by a glare source may be reported, and halo size measurements are available in the literature for patients with night vision problems following refractive surgery,[9–11] with cataract[12] or those implanted with an intraocular lens.[13–15] Methods and testing protocols for quantifying halo and night vision disturbances differ and different outcomes have been reported.[12–14 16 17] One of the most recently developed tests measures the angular radius of the area where the patient cannot distinguish white spots moving (in 12 directions) outward from the bright light source centred on a projection screen.[18] Other visual tests based on Halo V.1.0 software quantify discrimination capacity through a disturbance index under low illumination, and have been used to evaluate patients with keratitis and age-related macular degeneration[16] or after myopic LASIK surgery.[19] In these tests, peripheral luminous stimuli presented at different positions have to be discriminated with respect to a central high-luminance stimulus on a monitor screen.

Despite these reports, few investigations have addressed halo size, and most clinical outcomes related to glare are expressed in terms of straylight determined using a C-Quant straylight meter.[20] A recent study has provided normal disk halo radii across a wide age range, and described the repeatability of halo radius measurements made using the Vision Monitor device.[17] In healthy eyes, disk halos are mainly caused by light scattered by small particles or small localised variations in the refraction index of the ocular tissues. Straylight is also caused by the scattering of light entering the human eye.[21] Further, in healthy individuals, straylight and halo radius have been shown to increase with age following a power model function including a rapid increase beyond the age of 45 years.[17 22 23] However, the relationship between these two measurements is scarcely known. One study has correlated the luminous distortion index (LDI), formerly referred to as halo phenomena, and retinal straylight measures in post-LASIK eyes.[24] Other authors report high correlation between the disturbance index, as a measure of halo size, and the Strehl ratio (commonly used to estimate overall optical quality considering ocular aberrations and intraocular scattering) in patients undergoing LASIK surgery.[19] However, to better characterise the aetiology and variability of disk halos, the relationship between halo size and straylight needs to be determined in healthy patients younger than 45 years of age to avoid the effects of age on both these variables.

Visual acuity (VA, high-contrast letters tested under photopic conditions) is still the most common primary outcome measure used to assess visual performance after cataract or refractive surgery. However, retinal image quality has been shown to correlate better with VA tasks of lower contrast and lower luminance than the task of photopic high-contrast (HC)-VA.[25] The impact of small changes in retinal image quality in healthy eyes is best reflected by a corresponding change in low-contrast (LC)-VA under dim illumination conditions (mesopic).[26] Thus, it would be interesting if we could establish the extent to which halo size is related to such VA tasks as opposed to the conventional VA task. Indeed, most patients who complain of seeing halos report a good VA.

This study was designed to determine the relationship between the size of a halo induced in the visual field by a bright light and straylight or photopic and mesopic HC-VA and LC-VA in healthy young individuals.

METHODS

Persons

This study was conducted at the Faculty of Optics and Optometry, Universidad Complutense de Madrid, Madrid, Spain. Measurements were obtained in the right eyes of 51 healthy persons, 22 men and 29 women, of mean age 29.3±7.5 (20–43 years). Only right eyes were examined because it has been established that in phakic individuals with no eye disease, the right and left eyes show no differences in glare (halo).[18]

In each eye, we determined VA and subjective refraction and conducted a slit-lamp and ophthalmoscope examination. Inclusion criteria were a best-corrected distance VA (CDVA) of at least 20/25, and a refractive error no greater than ±4.00 D sphere or ±1.50 D cylinder. Patients were required to perform normally in an ophthalmologic examination. They were excluded if they had a systemic or eye disease or had undergone refractive surgery.

The guidelines of the Declaration of Helsinki were adhered to, and full approval for the study was obtained from our institution's review board. Informed consent to participate was obtained from each person.

Halo radius

Halo radius was measured using the Vision Monitor at a distance of 2.5 m (MonCv3, Metrovision, France). The method has been described extensively.[17] Briefly, the right light source illuminates the patient's right eye and produces stray intraocular light reducing the contrast of a foveal target. In this study, the test was performed using a letter luminance level of 1 cd/m^2. Optotypes were arranged in three radial lines of letters appearing from the periphery towards the glare source. Each line contains 10 letters forming 10 rings at intervals of 33 arc min at a distance of 2.5 m. Each letter subtends 15 arc min corresponding to a VA of 20/60. It should be noted that this method only measures a section of the halo and, therefore, only gives an estimation of halo size. Although halos reported by using other methods may not be perfectly circular,[16 18] a good approximation is to assume that halo area is circular in normal circumstances and has a defined radius.

Before testing, the patient was allowed to dark adapt for 5 min. Monocular testing took place in a dark room with best spectacle correction. For the test, the patient was seated 2.5 m from the monitor with the head aligned, using a chinrest, with the centre of the monitor. The patient was instructed to cover the left eye and to view the optotypes during simultaneous illumination of the eye with the glare source. The patient was instructed not to look directly at the light source to avoid a retinal after-image. Thereafter, the patient read each line starting from the side opposite to the light source, that is, optotypes were read from the periphery towards the glare source until a letter could not be identified. The patient 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 arc min.

Straylight

Scattered light on the retina was measured using the C-Quant straylight metre (Oculus Optikgeräte, Wetzlar, Germany) according to the psychophysical compensation comparison method described elsewhere.[20] Values were expressed as straylight logs; the higher the value the greater the straylight and sensitivity to glare. Only eyes providing straylight measurements of acceptable quality (ie, a repeated measures SD parameter, Esd, lower than 0.08 and a measurement quality parameter, Q, higher than 1.0) were included.

Visual acuity

Best-CDVA was measured monocularly using high-contrast (96%) and low-contrast (10%) Bailey-Lovie logMAR letter charts under photopic (85 cd/m^2) and mesopic (0.1 to 0.2 cd/m^2) luminance conditions at a distance of 4 m. Patients were encouraged to guess letters, even if they were unsure. Each letter read correctly on each line was given a score of 0.02 log units. In these charts, a loss of one line of letters corresponds to a logMAR increase of 0.1.

The chart was externally illuminated with a halogen lamp behind a screen connected to a potentiometer to adjust the exact voltage needed to reach the adequate mesopic luminance level with the room lighting turned off. This setup provides uniform luminance over the chart. For photopic conditions, normal room lighting was left on. In both cases, measures of luminance for the tests were obtained using a MAVO-SPOT 2 USB luminance meter (Gossen Lighting Control). The patient was first tested under mesopic conditions allowing at least 10 min to dark-adapt before the test. After this procedure, acuity testing was continued at photopic luminance levels.

Statistical analysis

The Kolmogorov–Smirnov test was used to check the normal distribution of each of the parameters. Linear regression was used to analyse the individual relationship between halo radius and straylight, and between halo radius and each independent VA variable. The relative contributions of straylight and VA variables to explaining halo radius variance were determined by forward stepwise regression analysis. Significance was set at an α value of 0.05.

All statistical tests were performed using Statgraphics Centurion Version XVI software.

RESULTS

Mean halo radius was 201.6±42.7 arc min (range 121–297 arc min or 2–5°) for a letter luminance level of 1 cd/m^2. The last three letters along each radius (furthest from the glare source) could be seen by all the patients. Mean straylight was 0.95 ±0.12 log units (range 0.64–1.21 log units). No significant effect of age on halo radius and straylight was observed in our study sample. A significant positive correlation was observed between halo radius and straylight (r=0.45; p=0.001; R^2=20%), such that the higher the level of retinal straylight, the larger the halo size (figure 1).

Under photopic conditions, mean best-corrected HC-VA and LC-VA were −0.02±0.06 and 0.12±0.09 logMAR, respectively, (20/19 and 20/26 Snellen means, respectively). Halo radius increased slightly as photopic VA worsened (a higher logMAR value indicates a worse VA). A significant positive correlation

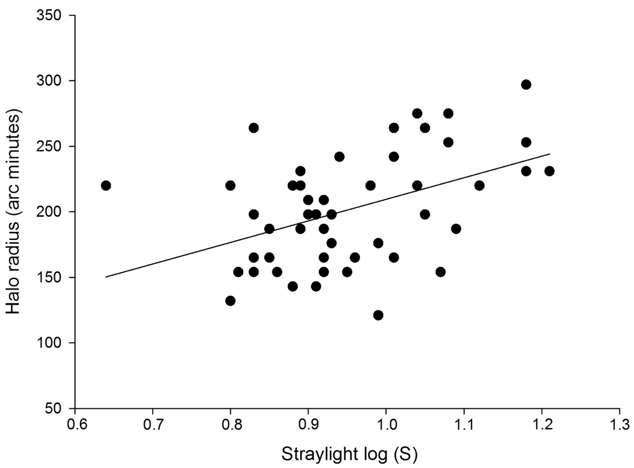

Figure 1 Halo radius (arc minutes) according to log straylight in healthy eyes (halo radius=44.99+164.55×log (s)).

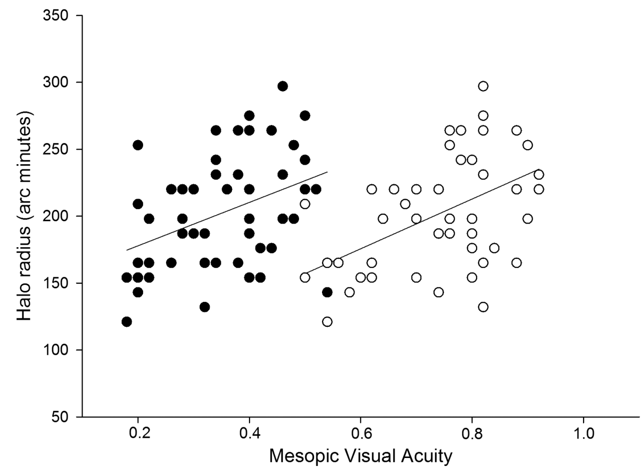

Figure 3 Halo radius (arc minutes) according to mesopic VA (logMAR) measured using high-contrast (●) and low-contrast (○) letter charts in healthy eyes (halo radius=145.40+162.32×HC-VA and halo radius=64.19+185.78×LC-VA, respectively). HC, high contrast; LC, low contrast; VA, visual acuity.

was detected between halo radius and photopic HC-VA (r=0.29; p=0.0358; R^2=8.7%) and LC-VA (r=0.33; p=0.0206; R^2=11%) (figure 2).

Under mesopic conditions, mean best-corrected HC-VA and LC-VA were 0.35±0.11 and 0.74±0.11 logMAR, respectively (20/45 and 20/110 Snellen means, respectively). Halo radius increased with worsening mesopic VA. Halo radius was positively correlated with mesopic HC-VA (r=0.40; p=0.0033; R^2=16%) and LC-VA (r=0.48; p=0.0003; R^2=23.8%) (figure 3).

Independent variables for multiple linear regression were identified by forward stepwise regression. Halo radius was independently correlated with straylight (p=0.0105) and with mesopic LC-VA (p=0.0036). Results indicated that halo size could be predicted from a linear combination of straylight and mesopic LC-VA (halo radius=−24.63+147.56×LC-VA +122.62×log (s), R^2 value=33%, F=11.08, p=0.0001). By contrast, photopic HC-VA and LC-VA and mesopic HC-VA showed no significant association with halo size.

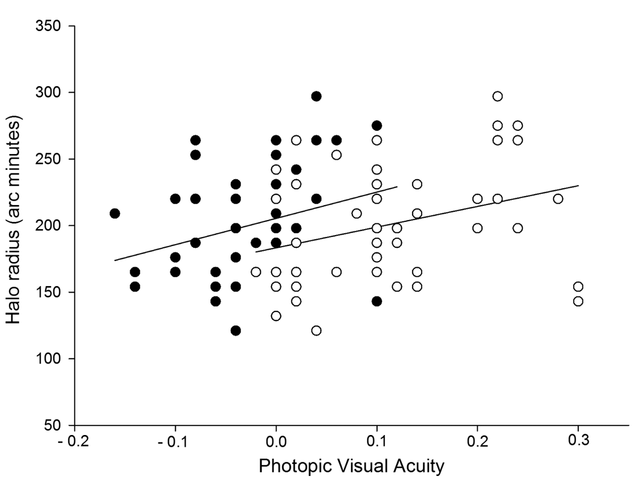

Figure 2 Halo radius (arc minutes) according to photopic VA (logMAR) measured using high-contrast (●) or low-contrast (○) letter charts in healthy eyes (halo radius=205.46+197.44×HC-VA and halo radius=183.28+155.53×LC-VA respectively). HC, high contrast; LC, low contrast; VA, visual acuity.

DISCUSSION

Numerous studies have addressed visual performance and the optical quality of the visual system after cataract or refractive surgery, yet few investigations have examined halo size as an outcome. In this study, we show how disk halo radius correlates with the better-known outcome measure of straylight. The effect of forward light scatter on halo radius was exacerbated using a strong glare source and letters of low luminance (1 cd/m^2) presented over a dark background. The mean halo radius obtained in the healthy eyes younger than 45 years of age was 3.4°, which is approximately twice the value obtained for this age group using letters of higher luminance (5 cd/m^2).[17] Mean straylight was 0.95±0.12 log units, and this is in line with reported baseline values.[22 23] We noted that larger disk halo radius values were significantly related (r=0.45, p=0.001) to greater straylight levels. In normal eyes, the light distribution of the retinal image, or point spread function (PSF), has a central, narrow, intense peak with a low-intensity peripheral contour. While the central peak is mainly degraded by wavefront aberrations (lower and higher order) causing light spreading over angles of around 0.1°,[27] scattering affects the PSF skirts, causing light to spread across angles larger than 1°.[21] The halo size measurement method gives estimates for an angle domain larger than 1°. The halo radius range in the present study was 2–5°, whereas, the average angle used to measure straylight by the C-Quant is 7° from fixation.[20] The observed relationship between halo radius and straylight could only explain 20% of the variance in healthy eyes. This relationship could be affected by the possible different distribution of retinal straylight when the line of vision changes as the patient views a different letter. However, this correlation was stronger than that reported in the single study addressing this relationship. The authors of the study in question were able to correlate the LDI and retinal straylight measures (r=0.338, p=0.044) in post-LASIK eyes but not in non-operated eyes.[24] A possible explanation for the difference between both studies is the difference in the method used to quantify halo size. The LDI was found to correlate (r=0.42; p=0.01) with higher-order aberrations,[28] and also with straylight, but only when changes in ocular media transparency were produced in post-LASIK eyes.[24]

We observed that most of the variations in photopic HC-VA and LC-VA measurements and halo were independent of each other. This independence of halo and VA may be understood if we bear in mind that VA is determined by the central peak and halo by the skirt of the PSF. Specifically, photopic VA values were limited to very small angles (range 0.7–2 arc min). Straylight is also thought to be fairly independent of photopic HC-VA,[6] though significant correlation has been reported between retinal log straylight values and best-corrected VA (r=0.379, p=0.002) in normal and post-LASIK eyes.[24] In everyday life, straylight[4] and halo phenomena will reduce a patient's quality of vision, but their effects on VA, as measured in an ophthalmic examination, are limited.

In our study, straylight and mesopic LC-VA could explain up to 33% of the variance in halo radius (r=0.45 and r=0.48, respectively) measured using the Vision Monitor MonCv3. Thus, halo radius increased as straylight rose and mesopic LC-VA worsened. The linear contribution of intraocular scattering (straylight) and wavefront aberrations (LC-VA) to the halo seems to be of similar proportion for both parameters. The mean LC-VA (20/110 Snellen) was approximately 0.1°, within the angle limit of the normal PSF central peak which is determined by ocular wavefront aberrations and where some scattering is expected. Pesudovs *et al*[25] argued that different information is provided by VA measured under photopic and mesopic conditions, mesopic testing being more sensitive to optical degradation than photopic testing. It should be noted, that in our study, the halo test was performed using a letter luminance level of 1 cd/m^2 instead of the normal level of 5 cd/m^2. Thus, the observed relationship between halo radius and mesopic LC-VA could be attributed to the similar visibility/recognition of optotypes in the halo and VA test. In a study quantifying halo size, it was also found (in line with our results) that ocular aberrations and intraocular scattering (Strehl ratio) contributed to the disturbance index. However, the correlation reported by these authors was high (r=0.84), most likely because the study eyes had been subjected to LASIK surgery.[19]

For our healthy persons under 45 years of age, disk halo size was a consequence of forward light scatter, and might also have been determined by ocular wavefront aberrations, which affect mesopic LC-VA.[25] Accordingly, measuring halo size can provide the clinician with additional information, especially when the patient complains of a loss in vision quality despite good VA.

Contributors MCP: Conception and design of the study, analysis and interpretation of data, writing the manuscript, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. MJP-C and CP-A: Conception and design of the study, data collection, drafting the work, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. BA and AB: Conception and design of the study, interpretation of data, critical revision of the manuscript, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Patient consent Obtained.

Ethics approval Ethical Committee of the San Carlos University Hospital Madrid (Complutense University).

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