Quantification and monitoring of visual disturbances for patients with cataracts using Halo v1.0 software

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Abstract. We objectively measured optical quality and quantified such night-vision disturbances as glare, starbursts, and halos perceived by patients diagnosed with cataracts. For this purpose, retinal-image quality was measured with a double-pass device (OQAS, Visiometrics SL). Visual-discrimination capacity was quantified by the disturbance index under low illumination (Halo v1.0 software, Laboratory of Vision Sciences and Applications). We took data for 15 normal subjects and 15 subjects affected by cataracts. Cataract patients had worse optical quality, and also showed a more extended double-pass image due to a higher contribution of ocular scattering and aberrations. Furthermore, results from the Halo test reflected a higher disturbance index for pathological subjects and, consequently, a deterioration in visual performance. Halo v1.0 software could be useful in daily clinical practice for characterizing the time course of visual disturbances shown by subjects with increased lens opacity, after ocular surgery or secondary to other ocular pathologies.

Keywords: cataracts, visual disturbances, optical quality, scattering, software.

1 Introduction

Cataract, an increased opacification of the crystalline lens, is the major cause of blindness and visual impairment in developing countries [1]. Numerous works have examined the impact of cataract on visual function. This condition compromises many aspects of vision including visual acuity [2] and contrast sensitivity [2], thus leading to a reduction in the quality of life, as demonstrated previously [3], [4]. In some cases, patients have a good visual acuity but may complain of night-vision disturbances such as glare, starbursts, and halos under low-illumination conditions. These disturbances are of critical importance in daily activities, such as night driving. Furthermore, the incidence of visual disturbances may rise with the increasing population of those who have undergone surgical procedures [5].

In the last decade, the use of optical devices that objectively characterize visual quality, such as aberrometers and double-pass devices, has increased [6], [7], [8]. The use of these devices is especially critical in clinical applications such as refractive or cataract surgery [6], [7], [8]. These techniques precisely and objectively measure the optical quality of the eye. However, disadvantages include the high cost of the apparatus and its failure measure visual performance directly. On the other hand, the most usual psychophysical tests are time consuming and require intensive cooperation from the patients, this being especially difficult for those of advanced age.

For patients with cataracts, the transparency loss in the lens leads to a higher level of intraocular scattering. However, aberrometers do not measure the loss of this ocular transparency [6]. For this reason, in the present study we used a double-pass device that allows the direct measure of the effect of higher-order aberrations and the scattering on the optical image quality of the eye. This greater scattering for patients affected by cataracts is reflected in a worsening of retinal-image quality [9], [10] and contributes to the sensation of glare as well as to the perception of halos around central lights, diminishing the overall visual performance of the subject [9], [10], especially under low-illumination conditions.

The most common measure by which vision is assessed is visual acuity. However, visual acuity is a measure of visual performance under optimal conditions and underestimates the degree of visual-function loss suffered under nonoptimal viewing conditions [11]. For these patients, visual function under everyday conditions is poorly predicted by classical Snellen acuity, grating acuity, and grating contrast sensitivity [12].

For all these reasons, we use a visual test called *Halo test*, conducted by the *Halo v1.0* software, for quantifying visual-discrimination capacity under low-illumination conditions [13], [14], this being an important function for quantifying the disturbances that affect visual performance [15], [16], [17], given that these disturbances constitute one of the main complaints of cataracts patients. Furthermore, the Halo software generates a graph of results showing the shape of the visual disturbances perceived by the observer (halos, starbursts or glare). Thus, this test could be used for optometrists and ophthalmologists for an early diagnosis of the pathology and monitoring changes in the ocular media over a period of time.

The aim of the present study was to determine objectively the optical quality with the double-pass technique and to quantify the night-vision disturbances for cataract patients. Furthermore, we compare these data with a control group of the same age and without any ocular pathology.

2. Methods

2.1 Participants

A total of 30 participants were studied, with ages ranging from 61 to 80 years. Of these, 15 subjects without any ocular disease (mean age 68.5 ± 4.4 years) and having best-corrected distance visual acuity equal to or better than 20/20 in both eyes and 15 subjects with bilateral cataract (mean age 71.4 ± 5.0 years) with visual acuity equal to or better than 20/25. The cataract was classified as nuclear in 13 patients and posterior subcapsular in 2 patients. No subject had any other ocular pathology or a history of previous ocular surgery. There were no significant differences in age between the subjects without any ocular diseases and those affected with cataracts.

The cataract group was diagnosed by the same ophthalmologist at the Adeslas S.A. Clinic of Granada (Spain). All participants in the study gave their informed consent in accordance with the Helsinki Declaration.

Snellen visual acuity was measured monocularly and binocularly for all participants with their best correction at a working distance of 6 m. The pupil diameter was measured with a Colvard pupillometer (OASIS, Glendora, CA) to ensure that all patients during visual-performance measurements (the visual-discrimination capacity) reached a pupil diameter greater than 4 mm. The lighting conditions used in this study were mesopic, a condition in which decreased contrast sensitivity function and the appearance of visual disturbances is more usual.

2.2 Double-pass device

Objective data were taken from an optical-quality device, OQAS (Optical Quality Analysis System, Visiometrics SL, Tarrasa, Spain), based on the double-pass technique [6], [7]. This device also includes information on diffraction, aberrations and intraocular scattering that diminish the image clarity, reducing visual quality of the subject. This objective optical device is useful in patients having an ocular pathology [18], [19], or in older patients for whom the influence of scattering could be great due to natural changes (mainly in the lens) caused by aging, therefore, resulting in a worse retinal-image quality. OQAS measurements were made for a 4-mm pupil and these data were taken without dilation in order to maintain natural conditions.

For a quantitative measurement of the visual quality, we took the Strehl ratio, a parameter commonly used for estimating overall optical quality [6], [7], defined as the ratio between the modulation transfer function (MTF) area of the eye and the diffraction-limited MTF area. The MTF represents the contrast loss resulting from the ocular optics on a sinusoidal grating as a function of its spatial frequency. The Strehl ratio ranges from 0 to 1. A lower value of this parameter indicates that there is a greater contribution of the aberrations and ocular scattering and therefore poorer optical quality. On the other hand, we analyzed the MTF cut-off, the spatial frequency, in cycles per degree (cpd), corresponding to a MTF value of 0. Finally, we also took the OSI, the only parameter that permits the objective quantification of the intraocular scattering. For younger eyes, the OSI value is lower than 0.5; for eyes with an early cataract, the OSI value ranges from 1.4 to 4 and, while for eyes with a cataract the value is higher to 4. More information on this device can be found elsewhere (e.g. [6], [7]).

2.3 Halo test: the visual-discrimination capacity

Visual-discrimination capacity is deteriorated in the presence of visual disturbances perceived by the observer, especially in subjects diagnosed with an ocular pathology such as cataract. To evaluate the discrimination capacity, we sought to quantify the visual disturbances perceived by the subject under low-illumination conditions. For this, we used *Halo v1.0* software (Laboratory of Vision Sciences and Applications, University of Granada, Spain). In this test, the patient was shown a central high-luminance stimulus over a dark background on a monitor and, progressively, peripheral luminous stimuli were shown around the central stimulus at different positions and distances from the main stimulus. The task of the observer was to discriminate each of the peripheral stimuli with respect to the central stimulus. This test measures night-vision disturbances and has been successfully used in patients who underwent LASIK refractive surgery [14] as well as in patients with other ocular pathologies [13].

Each experimental session was conducted as follows: after a 3-min adaptation period to darkness of the monitor background (0.71 cd/m^2), there was 1-min adaptation to the main stimulus (0.46º, 176.1 cd/m^2), and then the subject was randomly presented with peripheral stimuli (0.02º, 61.1 cd/m^2) around the central stimulus, to avoid learning effects. The patient, on detecting peripheral spots, pressed a button on the mouse, storing this information for subsequent treatment and calculation of the disturbance index (ρ_q) [13]. The patient was seated with the head supported by a chin and head rest and the test was conducted monocularly. The test distance was 2.5 m. The disturbance index takes values from 0 to 1. The greater value of this parameter indicates that there is a lower discrimination capacity, and thus the patient has more difficulties in detecting the peripheral stimuli near the central stimulus, indicating a greater influence of halos, glare or night-vision disturbances.

The monitor showed 72 peripheral stimuli around the central one, distributed along 18 semiaxes (four stimuli per semiaxis) in order to evaluate a higher area around the central stimulus. Each peripheral stimulus is presented 3 times, therefore, the monitor showed a total of 216 peripheral stimuli around the central one. The exposure time of each peripheral stimulus was 1s, and the time between stimuli (refresh) was 0.8-2s.

In addition to the disturbance index, the Halo software generates a graph of results, showing areas where the peripheral stimuli were not detected by the observer and areas where the peripheral stimuli were detected totally or partially. In the graph, the central stimulus is shown as well as the number of times that each peripheral stimulus is detected by the observer (X for being undetected, or 1, 2, or 3 if detected one, two or three times, respectively). These values (X, 1, 2 or 3) are placed in the corresponding position where each peripheral stimulus was shown. This graph describes the shape of the visual disturbances perceived by the observer (halos, starbursts or glare), showing information about areas around a high-luminance stimulus where the observer presents difficulties on detecting different luminous stimulus, and therefore giving complete information on the discrimination capacity. More information concerning this visual test can be found elsewhere [13], [14].

2.4. Statistical analysis

Statistical analysis was performed using the Mann-Whitney test, a non-parametric test for mean comparison of two independents groups (older subjects with and without cataracts). A p-value of <0.05 was considered to be statistically significant.

3. Results

For subjects with cataracts, the Strehl ratio ranged from 0.04 to 0.25 with a mean value of 0.12±0.05 (standard deviation). In the case of healthy subjects, the mean was 0.17±0.05, indicating a significantly lower value ($p<0.001$) in the Strehl ratio for subjects affected with cataracts. Regarding the OSI, for cataract patients we found a mean value of 2.91±1.55 (ranging from 0.5 to 7.0) and 1.15±0.51 for subjects without cataracts, the differences being significantly higher for the cataract group ($p<0.001$). The data reflect a clearly higher influence of aberrations and intraocular scattering for patients affected with cataracts. We found a mean MTF cut-off of 18.56±10.86 cpd for subjects having cataracts, this being significantly lower ($p<0.001$) that the MTF cut-off found for healthy subjects (29.67±10.73 cpd). Figure 1 shows the double-pass image for the 4-mm pupil for a healthy eye (left image) and for the cataract eye (right image) of the different subjects (OSI=1.5 and OSI=4.5, respectively). The effect of cataract is visible showing a broadening of the double-pass image owing to reflected and /or scattered light from the altered lens. In addition, the results showing a worse optical quality for the cataract eye with significant difference in the Strehl ratio.

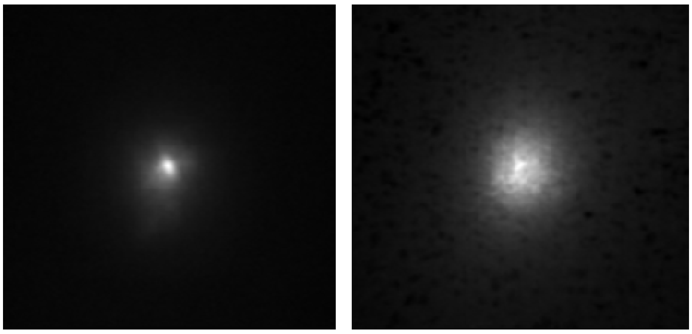

Fig. 1. Double-pass image for a healthy eye (left image) and cataract eye (right image) of the different patients, for 4-mm pupil.

Regarding the discrimination capacity, in cataract eyes the disturbance index ranged from 0.16 to 0.88, with a mean value of 0.50±0.25, significantly higher ($p=0.010$) than the mean for the healthy eyes, (0.24±0.08). The higher disturbance index indicates a deteriorated discrimination capacity resulting from the ocular pathology. As an example, Figure 2 shows the graphs pertaining to the Halo test for a healthy eye (left image) and for two pathological eyes of the different subjects with different degrees of cataracts: early cataract (middle image) and advanced cataract (right image). We found that a higher number stimuli that were undetected by the subjects affected with the pathology and a higher disturbance index, the highest being for the patient with the advanced cataract (left image, ρ_q= 0.16, middle image, ρ_q= 0.49 and right image, ρ_q= 0.86, respectively).

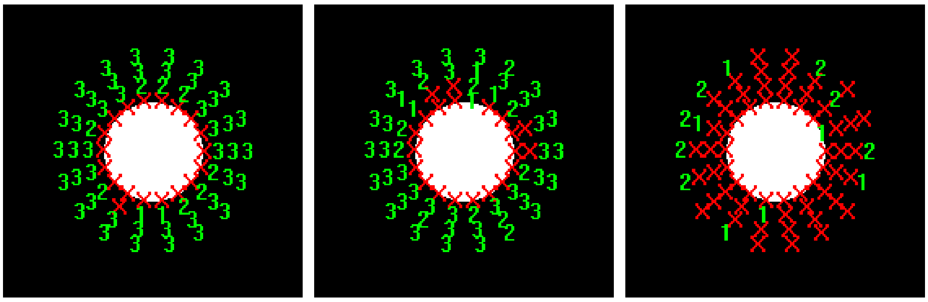

Fig. 2. Graphs made with the Halo v1.0 software for three different subjects: left image, a healthy eye (ρ_q= 0.16); middle image, an early-cataract eye (ρ_q= 0.49); right image, an advanced-cataract eye (ρ_q= 0.86).

4. Discussion

With age, ocular structures undergo changes, one of the most frequent being transparency loss in the lens, which can give rise to the formation of cataracts. These changes, whether a consequence of ageing itself or due to an eye disease, increase ocular scattering. This greater scattering affects the retinal-image quality [9], [10] and contributes to the sensation of glare as well as to the perception of halos around central lights, diminishing the contrast sensitivity and the ability to detect peripheral stimuli (reducing discrimination capacity), and therefore diminishing the overall visual performance of the subject [9], [10], especially under low-illumination conditions.

Our results from the double-pass device showed worse retinal-image quality for patients affected by cataracts. Due to this poorer optical quality for cataract eyes, we found a more extended double-pass image for a cataract eye than for a healthy eye (Figure 1). These results indicate a higher level of ocular scattering and a greater quantity of higher-order aberrations for cataract eyes, owing to increased lens opacity, diminishing the capacity to discriminate peripheral stimuli and, consequently, visual performance (Figure 2).

Optical devices have been used in numerous works to study optical quality, in particular retinal-image quality as a function of age [20], after LASIK [14], or for subjects affected by other ocular pathologies [18], [19]. However, although such devices provide an objective measure of the optical quality, a major disadvantage is that these devices do not take into account the neural processing of the subject and thus do not directly measure visual performance.

Patients affected by cataracts often complain of visual disturbances such as glare, starbursts, and halos, especially under low-illumination conditions. The quantification of these disturbances could provide an early diagnosis and enable the time course of the pathology to be studied. Even visual acuity is measured in clinical practice under optimal illumination conditions, but this test is inadequate for a complete evaluation of the quality of vision. It is important to point out that in our study, the subjects had good visual acuity (equal to or better than 20/25), however they suffer a deterioration in other important visual functions that can impede the safe performance of daily activities. On the other hand, visual disturbances are subjective complaints expressed by the observers, as it is sometimes difficult to correctly evaluate the effects of these disturbances on visual quality. However, an important aspect is that the Halo test generates a graph of results showing the shape of the visual disturbances perceived by the observer, and this could prove useful for optometrists and ophthalmologists.

Furthermore, the results found in previous studies have shown the effectiveness of the Halo software by a significant correlation between the objective measurements and the visual disturbances perceived by the subject [13], [14]. Others works [21], also have examined the visual impairment using an halometer test in older subjects, but without evaluating the optical quality with an objective method, this being important to completely determine the deterioration in visual performance. Therefore, based on our results and prior works, we conclude that *Halo v1.0* software offers an important service in daily clinical practice, especially for subjects who often complain of night-vision disturbances, due to increased lens opacity, after ocular surgery or secondary to other ocular pathologies. Finally, an important task is to develop of reproducible clinical tests which can quantify subjective complaints by patients.

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