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Computer Measurement of Central Visual Acuity under Mesopic and Glare Conditions in Eyes with Nuclear Cataract

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Abstract

Purpose: The CVA is an interactive, automated computer device that rapidly thresholds central acuity under conditions mimicking customary photopic and mesopic activities. In sequence, the CVA may test up to 6 environments, in this series under 3 mesopic environments (98%, 50% MC against 1.6 cd/m^2 background, 25% MC against 5 cd/m^2), then 3 glare environments (98%, 10% and 8% MC, against 200 cd/m^2). This report compares the CVA thresholded acuity with that measured with letter charts, as well as with C-Quant derived glare testing and patient responses to the Activities of Daily Vision Scale (ADVS) in eyes with nuclear cataract.

Methods: In 33 eyes with nuclear cataract compared with 69 emmetropic eyes without lens opacity, best refracted acuity was measured under CVA modules and with ETDRS charts presenting similar contrast and luminance. Both groups were also tested with 15% MC charts placed outdoors with sun overhead and with sun at 15° off-axis and compared with the CVA acuity at 10% MC and 8% MC thresholded in a darkened room. In 22 of the eyes with nuclear cataract, C-Quant analysis of straylight glare was also performed along with the ADVS.

Results: Acuities thresholded with CVA modules demonstrated high Pearson correlation coefficients, and Bland and Altman statistical similarity with the acuities measured from similar contrast charts. The acuities measured with CVA glare modules correlated significantly with charts placed in sun glare and with C-Quant measurements of straylight. Significant correlations were noted between CVA acuities and near vision as well as distance driving tasks.

Conclusions: The CVA demonstrates the ability to accurately threshold the acuity of eyes with nuclear cataract compared with chart acuity under conditions of contrast, luminance and fixation times simulating normal photopic and mesopic activities and to provide the physician with glare evaluation and ability to function under multiple types of activities.

Keywords: Central vision analysis; Activities of daily living vision function scale; Nuclear cataract; C-Quant straylight analysis

Background

Cataract lens opacification and color changes, occurring with age [1,2] and with systemic or ocular disease [3-5], world-wide have become the most common cause of visual complaints, primarily of glare and reduced contrast for multiple tasks in bright as well as dim light. Central visual acuity (VA), as measured by high contrast charts, has been demonstrated to be a poor determinant of visual function as well as patient complaints in eyes with significant cataract changes [6]. Patients having a cataract may demonstrate good visual acuity, whereas the contrast sensitivity testing demonstrates impairment even at early stages of the cataract development [3-5,7-9], especially when the eye is tested with off-axis glare. Bailey [10] and Lasa et al. [5] tested patients with cataracts using the Pelli-Robson and Vistech contrast sensitivity charts and reported that while both appear to evaluate visual function in moderate to advance cataracts, for early cataracts they and others [11] suggested that other techniques need to be developed including methods that utilize different luminance environments and off-axis glare elements in order to understand the range of visual disability under the varying environment conditions commonly presented during day and evening activities.

As the lens ages there is a linear increase in lens opalescence and absorption of light, especially for blue light [12-16]. The increased absorption by the lens reduces retinal illumination and the opalescence increases diffraction and forward scatter, causing reductions in contrast sensitivity and colour discrimination [17]. A loss of contrast

sensitivity has been observed with brunescence or opalescence of the lens causing loss primarily in the middle and high spatial frequencies [12]. This causes greater difficulty in vision under unfavourable lighting conditions especially at dusk where older individuals require higher contrasts to recognize and differentiate objects [10,18,19]. In addition, whereas the pupil diameter of a healthy 20-year-old on average is 5.3 mm in dim illumination, the pupil of a 60-year-old typically has a diameter of 3.2 mm [20] resulting in one third of the retinal illumination in dim environments. Contrast sensitivity testing has been demonstrated to remain stable until the age of approximately 65 years beyond which it and overall visual function decline rapidly [12,19], thought primarily due to senile miosis and progressive nuclear sclerosis, as well as with the aging of neural elements, both retinal and brain [20].

The increased opalescence of the lens with cataract development results in increased forward light scatter [21] that produces a veiling

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illuminance superimposed upon the retinal image, causing reduction of the retinal contrast. This may lead to a variety of complaints that are primarily described during activities performed within an environment associated with one or more sources of glare, whether that activity is performed in high photopic, low photopic or mesopic luminance of the visualized elements [2,4,5-9]. For the clinician, indications for cataract surgery are derived primarily from slit-lamp examination and visual acuity testing, but this evaluation is fraught with problems as the slit lamp image depends on backscatter while visual acuity, as has been noted, may frequently underestimate functional visual impairment impaired by forward scatter. Although cataracts have been grouped and graded according to opacification categories [2], no correlation has been observed between glare sensitivity demonstrated by a number of devices and the backscatter opacification assessed by the type or grade of cataract [21-24]. However, a weak relation has been noted by some investigators [21,22] between cataract grading and high contrast chart visual acuity that may be due to alterations in refraction.

Straylight, produced by optical media scattering, produces the greatest impairment of vision when glare sources are of 1° to 90° from fixation. The light scattering has been termed disability glare since it causes a veiling luminance over the whole retina that adds to the retinal projection of the visual scene, thereby reducing the contrast of the discriminated components of the image. Disability glare, as defined by the Commission International d'Eclairage, [25] corresponds to retinal straylight that is quantified by means of the concept of equivalent luminance (i.e., the external luminance that has the same visual effect as the glare source at some angular distance); its impairment of visual function has been well recognised by many investigators. After Cobb introduced the concept of "equivalent veiling luminance" as that produced by glare, several authors (Cobb [26], Holladay [27] and Stiles [28]) have applied the concept in a general disability glare formula [25] which has been amplified by Vos [29] who determined that central acuity reduction due to an off-axis, glare-producing source was dependent upon several factors, including the position off-axis of the glare source from the discriminated targets, the brilliance of the glare source above that of the discriminated target, the age of the person, and the pigmentation of the eye, and in follow up of this pioneering research, the CIE published the General Disability Glare Equation:

$$(L_{veil}/ E_{glare})_{general} = 10/\theta^3 + (5/\theta^2 + 0.1\, p/\theta).(1 + [Age/ 62.5]^4) + 0.0025\, p$$

in which θ is the angular separation of the glare source from the visual axis, L_{veil} is the luminance of the targets, expressed in cd/m², E_{glare} is the glare source luminance, expressed in lux, and p defines the status of ocular pigment, ranging from 0 for black eyes to 1.2 for very light eyes. From the formula, it can be appreciated that veiling glare varies with the brilliance of the glare source as θ approaches small angles (less than 10-20 degrees), the age dependency is most influential at moderate angles (approximately 20-30 degrees), and the dependence on ocular pigmentation is significant only at very large glare angles (more than 30 degrees) [29].

Multiple models of clinical glare testers have been introduced that most often consist of the patient reading a standard visual acuity chart [25,30-32] or contrast sensitivity chart (e.g., sinusoidal gratings, [33-36], Landolt rings, [34,37] or Pelli-Robson charts [38,39]) with and without a glare source presented at some angular distance from the targets visualised at fixation. Various methods that have been developed [6,40] differ with respect to test targets, glare light sources and luminance levels, but in most, the glare was produced by surrounding the discriminated targets with glare sources ranging between 6,000 and 25,000 cd/m². With these devices, in some trials, most patients had

a glare score that corresponded with their identified glare problems, as defined in visual function questionnaires (VFQ's) [6,36,41,42] suggesting a potential for the use of disability glare testing.

The outcomes of glare testing in clinical studies, however, most often have correlated poorly with various validity measures such as outdoor visual acuity in bright sunlight, [34,36], questionnaires assessing perceived visual disability, [23,24,35,38] or measured forward light scatter [23,35,38]. In addition, the repeatability, as well as the discriminative ability of those glare tests that have been studied were often found to be inadequate [24,39]. Because of these deficiencies, a standard method of glare measurement has never been adopted, as discussed in several papers [25,34,43-52].

Van den Berg in 1992 [50] proposed a new method to measure dysfunction caused by retinal straylight, termed the "direct compensation" method, in which a bright, ring-shaped, flickering light source was presented at an angular distance from a central visualized test field. Because of intraocular scatter, part of the light from the bright source is projected onto the retina at the location of the central testing (fovea), and induces a (weak) flicker within the test field. To determine the exact amount of straylight, a variable *counterphase* compensation light was presented to the central test field. By adjustment of the amount of compensation light, the flicker perception centrally could be extinguished. Advantages of the direct compensation method over alternative methods of assessing light scatter were primarily that it was independent of refractive blur, although one must realise that it does not necessarily determine the visual dysfunction during tasks that are performed under conditions of glare. From a review of the literature it appears that this technique offered greater sensitivity than other glare tests [52,53]. However, the direct compensation technique proved difficult in routine clinical, and therefore Van den Berg developed the "compensation comparison" method in which the instrument presents exactly the same stimuli to the subject as the direct compensation method, but the central target area was divided into two halves, one half flickering counter to the annulus of straylight, while the luminance of the test field was not flickered. The test field without compensation is black all of the time, but because of the straylight, the subject will perceive a flicker in that test field as soon as the ring starts to flicker. In the other half of the test field the same straylight also causes a flicker perception, but in this test field a compensation light is presented that is different for each stimulus. Depending upon the amount of compensating light, it can be more or less than the flicker in the test field without compensation. The endpoint is reached when there is no perceived flickering of the halves within the central test field (using a two-alternative, forced-choice approach in which the subject must decide for each stimulus which test field flickers stronger: left or right).

The Central Vision Analyzer (CVA, Sinclair Technologies, Media, Pa) is a device that has been reported to measure central visual function under conditions of contrast and luminance that mimic conditions encountered in routine mesopic and photopic activities of daily living. The device utilizes an interactive program in which Landolt C's are flashed for 250 msec (common durations of ocular fixations made during routine tasks such as driving, or reading) at the center of a large fixation cross randomly facing one of four positions, up, down, right or left. The patient responds to each presentation by either pressing one of four buttons or deflecting a joystick on a response pad in the direction of the C opening. The interactive program enlarges or shrinks the letter size in progressively smaller logMAR steps until a threshold is reached, defined by two correct identifications with two misses at the next smaller 0.05 logMAR step. The device thresholds in modular

fashion the central visual function for visualized targets that that have been defined as determinants for visualization tasks of commonly performed activities of daily living, ADL. These not only incorporate mesopic tasks but also tasks performed outside in conditions of sun glare, such as playing golf or tennis with the sun overhead or off-axis at 20 degrees. For the latter, the CIE equation was utilized to calculate the contrast reduction of the Landolt C's presented against the brightest screen background to mimic the contrasts of the targets observed while playing golf, which averaged 15% Michelson contrast, MC. When such a contrasted target is visualized by a 30 year old [29], this was calculated to reduce the contrast to 10% (representing the contrast when the sun is overhead) and to 8% representing the effective contrast of the target when the sun is off axis at 20 degrees.

We have previously validated the vision thresholded with the CVA in normal eyes of persons of varying age by comparing the acuity thresholded with each module of the CVA with that measured with lettered charts presenting similar luminance and contrast conditions in the same darkened room [54]. We have also validated the glare effect assumptions by comparing the acuities measured with the 10% and 8% MC CVA modules tested in the dark room with the acuity measured utilizing charts of 15% MC placed outdoors with the sun overhead and with the sun off-axis at 20 degrees [54]. In the study presented here we conducted the same validation studies in eyes with nuclear cataract and, as well, compared the results with acuities measured and reported previously in emmetropic eyes with no cataract [54]. We also sought in this study to define whether the acuities measured with any of the CVA modules in the eyes with cataract correlated with measurements of straylight glare determined by the C-Quant instrument (Oculus, Wetzlar, Deutschland). It must be remembered, however that the measurement of vision by any method or the measurement of disability glare infers a relationship with the ability or difficulty that a person may experience when performing common ADL tasks in environments with such glare. A number of visual function questionnaires, VFQ's, have been designed that evaluate the difficulty a person may experience due to his vision among which several were designed specifically to evaluate the effect of cataract: 1) the VF1 [55], 2) the Visual Activities Questionnaire (VAQ) [56], 3) the Activities of Daily Vision Scale (ADVS) [57,58], 4) the Visual Performance Questionnaire (VPQ) [59], 5) the 14-item Visual Functioning Index (VF-14) [60], and 6) the Visual Disability Assessment (VDA) [61]. In the study reported here we also sought to determine if there was a relationship between the acuities measured with modules of the CVA and patient disabilities defined from responses to a visual function questionnaire, and after review of the above VFQ options, the ADVS was selected since it has been used in many studies and has been validated, [57,61-70].

Patient Inclusion and Testing Methods

This study was designed to compare the acuities thresholded in normal emmetropic eyes of individuals, between the ages of 50 and 75, with individuals having eyes that demonstrated varying degrees of nuclear cataract (defined by the LOCS III photograding system as having opacification between NO3 and NO5 and color changes between NC3 and NC5 [3]). Exclusion criteria included any history of systemic disease felt to impair vision (e.g., diabetes mellitus) and any macular pathology (including drusen or retinal pigment epithelial disruption) as detected by 78D fundus biomicroscopy. Eyes were also excluded if any corneal surface irregularity was detected that was determined to cause an impact upon vision or if there was a colour vision deficit detected with the Hardy, Ritter, Rand colour plates as defined by Cole et al. [71] (22 of 24 plates required to be correctly identified for normal). The tear

film stability was assessed by evaluating tear film break up times [72] with a break-up time of 10 seconds or greater considered normal.

Central acuity was measured in all eyes using habitual spectacle correction or a trial lens if significantly different upon refraction (myopia greater than -0.5 or hyperopia greater +0.5 astigmatism greater -0.5), with both the CVA and a series of logMAR letter charts that were presented in the same order as that of the CVA modules. Testing was begun with either the CVA or with the charts in random order with randomization as well of the right or left eye tested first, and all vision testing was performed in the same room darkened to 3 kd/m² (except as noted below for the chart testing conducted under the glare conditons). Chart testing was performed using standard ETDRS 0.1 logMAR configuration charts [12] with back lighting provided in a standard ETDRS cabinet (Precision Vision, La Salle, IL). The charts were obtained with gray-black letters against a white background at a Michelson contrast that matched each CVA module. For the mesopic modules, the luminance of each chart was reduced to that presented in the CVA respective module by using neutral density filters placed over the chart (Sapsis Rigging, Landowsne, Pa). The luminance and contrasts of each CVA module and the chart to which it was compared are presented in Table 1 a and b.

The monitor luminance and contrasting C's in the CVA testing were controlled with colorimeter recalibration monthly using a Huey Colorimeter and software (Pantone, Carlstadt, NJ) while the contrast and luminance of the charts was confirmed with a spot photometer. Testing with the charts was performed as per the recommendations of the ETDRS manual [13] with regard to the termination criteria and the methods for recording responses; the acuity was scored by total letter count (TLC) and converted to logMAR [13,16]. A subgroup of the eyes with nuclear cataract was also submitted to evaluation of stray-light glare by testing with the C-Quant, and these patients completed an ADVS questionnaire. IRB approval was obtained for this study, and all persons signed informed consent to participate.

Statistics

For every CVA module the mean and standard deviation of the acuity result was calculated as well as for the ETDRS acuity for each of the two groups. The difference between the normal and cataract groups was evaluated for significance with a Tukey Post hoc test for each of the 6 CVA modules utilizing a significance level 0.05. The normality of the data distribution was evaluated by Levene's Test for Equality of Variances, and for those normally distributed, calculations of the Pearson Correlation Coefficient and Bland and Altman [73] statistics were applied to examine for agreement between the two testing methods. Comparisons were made as well between the acuity measured with the 10% and 8% CVA glare modules in the darkened room and the acuity measured with the 15% ETDRS chart placed in the daylight environment with the sun overhead, and with the sun off-axis by 15 degrees. Pearson correlation coefficients were also calculated to examine the relationship between the CVA module acuities and the C-Quant stray-light meter scoring, while Spearman non-parametric correlation was used to determinate the relationship between the acuity measured with each CVA Module and the C-Quant stray-light meter scoring (log s) and the scores obtained on the ADVS questionnaire among the subgroup analyses of car driving, short distance tasks, and long distance tasks (please see Table 2 for the components of each task group).

All statistical analyses were subjected to GEE and GLM model analysis [74] to evaluate for the effect on outcomes of utilizing both eyes

Table 1a

	CVA modules	MC Michelson Contrast	Letter	Letter luminance cd/m²	Background luminance cd/m²	Test simulates
1	CVA98% Mes.	98%	White	220	1.6	Mesopic – high contrast
2	CVA25% Mes.	25%	Grey	8.4	5	Mesopic – restaurant dining
3	CVA50% Mes.	50%	Grey	4.8	1.6	Mesopic – driving at dusk
4	CVA98% Pho.	98%	Black	1.6	220	Photopic –high contrast
5	CVA10% Glare	10%	Grey	180	220	Photopic – sun over head while playing golf or tennis
6	CVA8% Glare	8%	Grey	186	220	Photopic - sun 15° off-axis while playing golf or tennis

Table 1b

	Chart tests	MC Michelson Contrast	Letter	Letter luminance cd/m²	Background luminance cd/m²	Test simulates
1	ETDRS 97%	97%	Black	1.6	100	Mesopic high contrast
2	ETDRS 25%	25%	Grey	8.5	5.1	Mesopic restaurant
3	ETDRS 50%	50%	Grey	1.6	4.8	Mesopic driving at dusk
4	ETDRS 10%	10%	Grey	81	100	Photopic –sun over head while playing golf or tennis
5	ETDRS 8%	8%	Grey	85	100	Photopic- sun 15° off-axis playing golf or tennis

Table 1 a and b: Tables presenting the background luminance and luminance of the contrasted letter C presented for the CVA modules and Sloane letters for the charts, as well as the ADL conditions for the vision tasks simulated.

		CVA 98 % Mesopic	CVA 25% Mesopic	CVA 50% Mesopic	CVA 10% Photopic	CVA 8% Photopic	CVA 98% Photopic	C Quant: log(s)
Car driving: Driving at night Driving with oncoming headlights Driving in unfamiliar areas	Spearman Correlation Coeff.	0.851	0.573	0.761	0.046	0.197	0.874	0.587
	p value	0.001	0.016	0.001	0.864	0.464	0.001	0.074
	Number of patients	18	17	17	16	16	17	17
Near distance tasks: Reading a newspaper Read food labels Thread a needle	Spearman Correlation Coeff.	0.857	0.382	0.546	0.591	0.656	0.845	0.548
	p value	0.001	0.118	0.019	0.012	0.004	0.001	0.101
	Number of patients	19	18	18	17	17	18	17
Long distance tasks: Use public transport Walk downstairs	Spearman Correlation Coeff.	0.344	0.243	0.398	0.387	0.419	0.306	0.822
	p value	0.192	0.364	0.127	0.138	0.106	0.250	0.004
	Number of patients	16	16	16	16	16	16	16

Table 2: Spearman Correlation Coefficients and *p* value of ADVS subgroup analysis compared with CVA module acuities and C-Quant straylight measurements. (Statistically significant values, *p*<0.05 are marked in yellow).

of an individual [75,76], and all results are reported after correction for those effects.

Results

The CVA and chart acuities were measured in 33 eyes with varying degrees of nuclear cataract and compared with 59 normal, emmetropic eyes of age-matched individuals. The mean and standard deviation of the ages and refractive errors for both groups are presented in Table 3; borderline differences were noted only for the degree of astigmatism.

The alterations of CVA measured acuities in the eyes with cataract are shown in comparison with that of the normal emmetropic eyes in Figure 1. The mean, standard deviation, and standard error are presented in Table 4 with the Tukey post hoc testing for significant differences between the groups presented in Table 5. Significant differences were noted among the eyes with nuclear cataract in comparison with normal eyes in all modules (even in the maximum contrast black C presented against the white screen), except for the CVA 98% white-on-black mesopic module.

In the eyes bearing cataracts when the acuity measured with each CVA module was compared with the acuity measured with a similar contrast ETDRS chart placed in a darkened room, the Pearson

Eye Group	Age (years)	Spherical Refraction	Astigmatic Refraction	Number of eyes
Normal Emmetropic	54.88 (± 3.25)	0.00 (± 0.24)	-0.05 (± 0.15)	59
Cataract	56.08 (± 4.9)	0.95 (± 2.68)	0.53 SD (± 0.20)	33

Table 3: Table of mean ± 1 standard deviation for the ages and refractive error of each group comparing emetropic normal with eyes having nuclear cataract.

correlation coefficients varied between 0.75 and 0.96 (Table 6); all correlations were statistically significant (p <0.01 in all cases). The correlations were similar to those previously reported for this same group of normal emmetropes [54]. Although paired *t*-test evaluation of the differences between the acuity measured with each CVA module and the ETDRS acuity demonstrated statistical significance for all modules except for the 10% glare module (Table 6), in all cases the differences ranged between 0.03 to 0.11 logMAR, which is less than the test-retest reliability of both testing procedures reported previously in these normal subjects [54].

When the studies were examined between the acuities measured out-of-doors with the 15% contrast charts placed with the sun overhead Table 7 presents the mean and standard deviation of the differences of the testing procedures along with the *p* values (paired *t*-test). Although a significant difference was noted for the comparison of the 8% glare

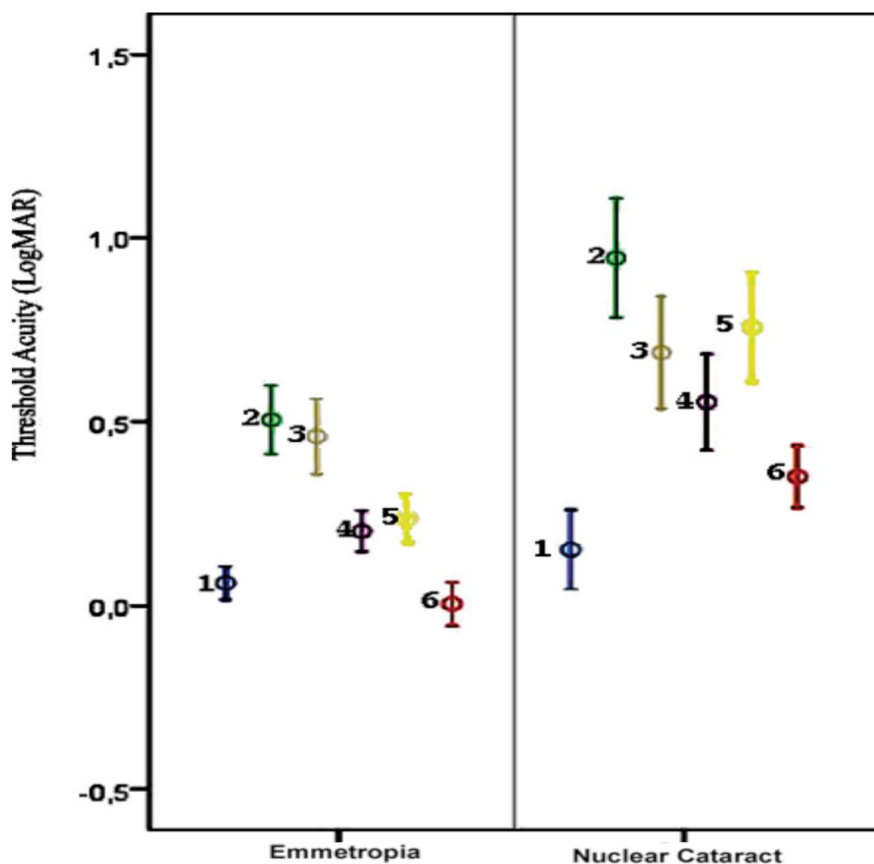| Order of presentation	CVA module	Colour	Michelson Contrast	Test simulates
1	CVA 98% Mes.	1	98%	Mesopic - high contrast
2	CVA 25% Mes.	2	25%	Mesopic - restaurant
3	CVA 50% Mes.	3	50%	Mesopic – driving at dusk
4	CVA 10% Glare	4	10%	Photopic glare – sun over head
5	CVA 8% Glare	5	8%	Photopic glare – sun 15° off-axis
6	CVA 98% Pho.	6	98%	Photopic – high contrast

Figure 1: The mean and 95% confidence interval LogMAR of thresholded for each of 6 CVA modules.

	Group	N	LogMAR Mean	Std. Deviation	Std. Error
CVA 98% Mesopic	Emmetropic. NI	59	0.06	0.17	0.02
	Cataract	33	0.11	0.26	0.04
CVA 25% Mesopic	Emmetropic, NI	59	0.5	0.36	0.04
	Cataract	33	0.94	0.4	0.07
CVA 50% Mesopic	Emmetropic, NI	59	0.45	0.39	0.05
	Cataract	33	0.68	0.37	0.07
CVA 10% Photopic	Emmetropic, NI	59	0.2	0.21	0.02
	Cataract	33	0.49	0.31	0.05
CVA 8% Photopic	Emmetropic, NI	59	0.23	0.24	0.03
	Cataract	33	0.66	0.38	0.06
CVA 98% Photopic	Emmetropic NI	59	0.004	0.22	0.02
	Cataract	33	0.31	0.2	0.03

Table 4: Number of eyes and mean logMAR acuity with the SD and std. error measured for each CVA module among normal, emmetropic eyes, eyes with cataract, and eyes with maculopathy.

Dependent Variable	Group	Group	Group Diff	Std. Error	Sig.
CVA98% Mesopic	Emmetropic nl	Cataract	-0.05	0.06	0.717
CVA25% Mesopic	Emmetropic nl	Cataract	-.44*	0.08	0
CVA50% Mesopic	Emmetropic nl	Cataract	-.22*	0.08	0.033
CVA10% Photopic	Emmetropic nl	Cataract	-.29*	0.06	0
CVA8% Photopic	Emmetropic nl	Cataract	-.42*	0.06	0
CVA98% Photopic	Emmetropic nl	Cataract	-.30*	0.06	0
*The mean difference is significant at the 0.05 level.					

Table 5: Tukey Post Hoc Tests for each CVA module comparison between emmetrope and cataract eyes with mean difference, std. error, and significance at a level of 0.05.

Differences CVA-TLC (logMAR) VA / T-Test p (Significance)	ETDRS 97% Mean diff (± 1SD)	ETDRS 25% Mean diff (± 1SD)	ETDRS 50% Mean diff (± 1SD)	ETDRS 10% Mean diff (± 1SD)	ETDRS 8% Mean diff (± 1SD)
CVA 98% Mesopic	0.04 (± 0.07) p=0.02				
CVA 25% Mesopic		0.03 (± 0.07) p=0.04			
CVA 50% Mesopic			0.03 (± 0.07) p=0.02		
CVA 10% Photopic				0.06 (± 0.15) p=0.09	
CVA 8% Photopic					0.09 (± 0.19) p=0.03
CVA 98% Photopic	0.11 (± 0.20) p=0.01				
Pearson correlation coefficient (*r* with *p* values)					
CVA 98% Mesopic	0.86 (*p*=0.01)				
CVA 25% Mesopic		0.95 (*p*=0.01)			
CVA 50% Mesopic			0.94 (*p*=0.01)		
CVA 10% Photopic				0.79 (*p*=0.01)	
CVA 8% Photopic					0.75 (*p*=0.01)
CVA 98% Photopic	0.75 (*p*=0.01)				

Table 6: The mean and standard deviation (SD) of the difference of acuities between each CVA module and a similar contrast ETDRS chart (both presented indoors) among the cataract group.

Differences CVA- chart (logMAR) VA	Number of Eyes	ETDRS 15%, sun over head Mean diff (± 1SD)	ETDRS 15% sun 15° off-axis Mean diff (± 1SD)	Landolt C 15%, sun over head Mean diff (± 1SD)	Landolt C 15%, sun 15° off-axis Mean diff (± 1SD)
CVA10% photopic	20	0.02 (± 0.16) p =0.54		0.009 (± 0.16) p =0.81	
CVA 8% photopic	19		0.03 (± 0.08) p =0.06		0.08 (± 0.08) p =0.01
ETDRS 15% sun over head	20			0.03 (± 0.13) p =0.46	
ETDRS 15%, sun 15° off-axis	20				0.04 (± 0.14) p=0.32
Pearson correlation coefficient (*r* with *p* values)					
CVA10% photopic	20	0.73 p=0.01		0.73 p =0.01	
CVA 8% photopic	19		0.84 p =0.01		0.83 p =0.01

Table 7: Mean (± 1SD) differences in logMAR acuity measured with the 10% and 8% CVA glare modules compared to the 15%MC ETDRS chart placed out of doors with the sun overhead and with the sun off-axis at 15 degrees from the chart. The Pearson correlation coefficients are also presented along with the *p* value of the correlation. (Statistically significant values, *p*<0.05 are marked in yellow).

CVA module with the 15% Landolt C chart placed with the sun off-axis, the difference was only 0.08 log MAR, below that noted for the test-retest reliability of either test procedure. Within the cataract group a significant correlation was observed between the acuity measured

with the 10% glare module and both the 15% ETDRS charts positioned with the sun overhead (Pearson correlation coefficient, r=0.73, p=0.05 in each case, Table 7) and between the acuity measured with the 8% CVA glare module and both charts placed with the sun off axis at 15° (Pearson correlation coefficient r=0.83 and 0.84, with p=0.01, Table 7).

Bland & Altman plots (plots of the differences in measured acuities with each test against the average of the two measurements, [73]) were constructed comparing the difference of the acuity obtained with the two tests as well as between the 10% CVA glare module tested indoors with the acuity tested with the 15% ETDRS placed with the sun overhead (presented in Figure 2), and between the 8% CVA glare module tested indoors and the acuity obtained with the 15% ETDRS chart placed out of doors with the sun 15 degrees off-axis. All evaluations appeared to demonstrate good agreement between the two testing methods, similar to the findings previously presented among normal subjects with emmetropic, normal eyes [54].

Among 22 eyes with nuclear cataract (of 22 patients) C-Quant analysis was performed; the LOCS III grading, CVA acuities and C-Quant straylight results obtained for each of the eyes is shown in Table 8. To evaluate correlations between the acuities obtained with the CVA modules and the straylight log(s) measurements obtained with the C-Quant, the C-Quant data was first assessed for normality of distribution using a Kolmogorov-Smirnov Test (p>0.05); the data was observed to be normally distributed. Pearson correlation coefficients were examined between the two testing methodologies and are presented in Table 9. Significant correlations were observed only for the 10% CVA glare module, (r=0.53, p=0.02) and the 8% CVA glare module (r=0.64, p=0.003).

It should be noted that the measure of straylight obtained with the C-Quant instrument in each case was accompanied by Esd and Q values that are measures of the quality of the measurement, with an Esd below

0.08 and Q above 1.0 indicating a reliable measurement [77]. As shown in Table 8, for 9 of the 22 eyes with moderate nuclear cataract (LOCS III grade of NO3, NC3), the C-Quant straylight values indicated a poor quality measurement. The eyes with unreliable C-Quant values overall also demonstrated much poorer CVA acuities (mean difference 0.45), although statistical significance could not be demonstrated (because of the marked spread of the acuity values caused by three severe outliers, patients #3, #6, #8 and #11, Table 8). A scatter plot is presented in Figure
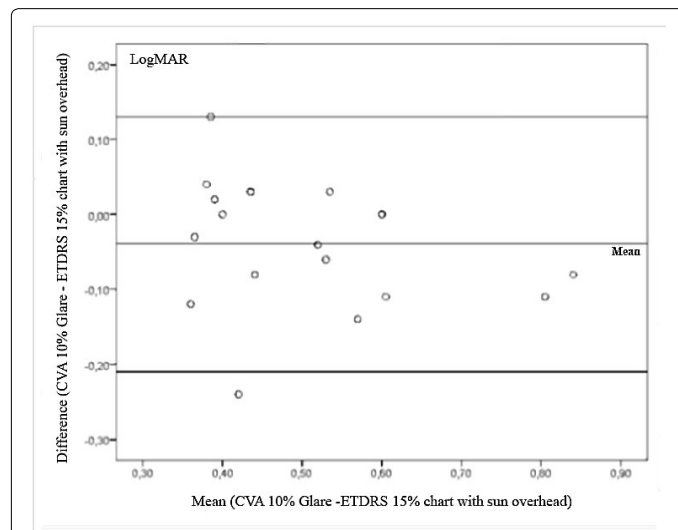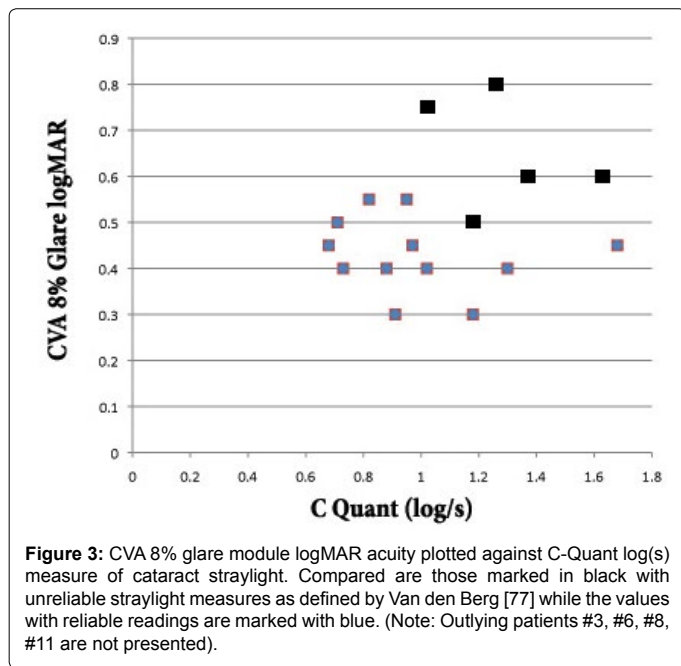

Figure 2: Bland and Altman plot presenting the logMAR acuity results of 20 eyes with cataract tested with 15% ETDRS chart positioned with the sun overhead, compared with the 10% CVA module conducted in a darkened room. Results are presented for TLC scoring converted to logMAR. Upper and lower lines represent 95% confidence limit.

	LOCS III	C-Quant	Reliability of C-Quant		CVA 98% Mesopic	CVA 25% Mesopic	CVA 50% Mesopic	CVA 10% Photopic	CVA 8% Photopic	CVA 98% Photopic
	NO,NC Grading	Log(s)	SD of Straylight	Reliability coefficient Q	logMAR	logMAR	logMAR	logMAR	logMAR	logMAR
1	NO3NC3	0.91	0.08	1.01	-0.07	0.09	0.39	0.17	0.3	-0.3
2	NO3NC3	1.37	0.05	2.09	0	0.3	0.7	0.3	0.6	0.3
3	NO4NC4	-3	0.93	3.89	0.15	0.4	0.7	0.3	0.5	0.25
4	NO4NC3	1.26	0.08	0.85	0.3	0.85	1.15	No	No	No
5	NO3NC3	0.82	0.07	1.25	0.05	0.65	0.65	0.5	0.55	0.05
6	NO5NC6	3.04	0.66	-0.41	1.2	No	No	No	No	1.5
7	NO3NC3	0.71	0.19	0.32	0	0.2	0.4	0.45	0.5	0.1
8	NO3NC3	3	0.93	3.89	0	0.2	0.35	0.25	0.35	0.05
9	NO3NC3	0.88	0.07	1.34	0.2	0.35	0.35	0.35	0.4	0.25
10	NO3NC3	1.68	0.06	0.78	0.05	0.1	0.2	0.2	0.45	0.1
11	NO4NC5	1.68	0.06	2.07	0.6	0.85	0.9	1.25	1.6	0.75
12	NO3NC3	1.26	0.06	1.74	0.15	0.2	0.4	0.5	0.8	0.4
13	NO3NC3	1.02	0.06	0.91	0.1	0.1	0.3	0.25	0.4	0
14	NO3NC3	1.02	0.07	1.21	0.3	0.8	0.7	0.65	0.75	0.4
15	NO3NC3	0.95	0.07	1.23	0.1	0.3	0.55	0.35	0.55	0.05
16	NO3NC3	0.73	0.22	0.71	0.2	0.35	0.35	0.35	0.4	0.25
17	NO3NC3	0.97	0.07	0.91	0.2	0.65	0.95	0.35	0.45	0.2
18	NO3NC3	1.18	0.06	1.53	0.2	0.2	0.4	0.55	0.5	0.3
19	NO3NC3	1.18	0.07	0.99	0.05	0.2	0.25	0.2	0.3	-0.1
20	NO4NC3	1.3	0.05	2.02	0.2	0.3	0.4	0.2	0.4	0.25
21	NO3NC3	0.68	0.36	0.65	0.05	0.35	0.35	0.35	0.45	0.25
22	NO4NC3	1.63	0.06	2.09	0	0.4	0.7	0.3	0.6	0.3

Table 8: The LOCS III grading of nuclear cataract, C-Quant straylight log(s) values, and the logMAR acuity measured with each of the CVA modules for each of the 22 right eyes measured. ("No"=could not be measured).

		CVA 98 % Mesopic	CVA 25% Mesopic	CVA 50% Mesopic	CVA 10% Photopic	CVA 8% Photopic	CVA 98% Photopic
C-Quant log(s)	**Correlation _r_**	0.387	0.171	0.079	0.530	0.641	0.347
	_p_ value	0.101	0.485	0.749	0.020	0.003	0.145

Table 9: Pearson Correlation coefficient and significance of correlation expressed between the C-Quant log(s) value and the CVA module vision results. (Statistically significant values, _p_<0.05 are marked in yellow).

Figure 3: CVA 8% glare module logMAR acuity plotted against C-Quant log(s) measure of cataract straylight. Compared are those marked in black with unreliable straylight measures as defined by Van den Berg [77] while the values with reliable readings are marked with blue. (Note: Outlying patients #3, #6, #8, #11 are not presented).

3 demonstrating the C-Quant log(s) data and the CVA acuity tested with the 8% glare module for both groups without these severe outliers and demonstrates the differences of the two groups.

The responses to the Activities of Daily Vision Scale questionnaire were divided into three groups of vision tasks (Table 2), each calculated by averaging the responses to 1) vision problems experienced while driving during day or night or with headlamp glare; 2) vision difficulties resulting in problems with short distance tasks, such as reading paper text, food labels or reading text on monitors; and 3) long distance vision problems, including difficulties with public transport use, reading signs recognising faces at distance, or negotiating stairs in dim or bright light.

When the ADVS was administered, a number of patients had missing data because, in some instances, they were not currently driving or cooking, but not because of their vision problems. The correlations of the ADVS task scores and the CVA visions defined in the cataract group as well as with the C-Quant data are presented in Table 2. The ADVS scores for driving difficulty provided the best correlation with the acuities measured with both of the low contrast mesopic CVA modules (Spearman correlation coefficient, _r_=0.761, _p_=0.001 for 50% mesopic CVA and _r_=0.573, _p_=0.016 for the 25% mesopic CVA module), as well as with both full contrast CVA 98% Mes. and 98% Pho. modules (_r_=0.851 and _r_=0.874, _p_=0.001 in each case); however, the ADVS driving task did not correlate with the C-Quant data. ADVS near vision tasks were significantly correlated with all CVA modules except for the 25% mesopic CVA module, but this task and did not correlate with the C-Quant straylight measurement data. The ADVS long distance task score correlated significantly with the C-Quant log(s) data (Spearman correlation _r_=0.822, _p_=0.004), but not with any of the CVA modules.

Discussion

The influence of cataract on glare and the resulting reduction in contrast sensitivity are well known [12-16,78]. In this study the effect of glare caused by cataracts on central vision measured by the CVA was significant. In the low contrast mesopic modules, acuity declined by 50% or more from similarly aged eyes without cataract. In the photopic modules simulating outdoor activities with sun glare, the decline in visual acuity was even greater. This occurred in spite of no change in the acuity of the full contrast mesopic module when compared with the normal group, similar to the findings for persons of a similar age by Hohberg et al. [79], Haegerstrom-Portnoy et al. [12], Riva et al. [13], Said and Weale [14], Mellerio [15], Boettner and Wolter [16], and Abrahamsson and Sjostrand [78].

In the validation portion of this study, the acuities measured with the CVA modules in a darkened room closely acuities that were obtained with ETDRS charts that presented similar contrasts and luminance, emmetropic eyes of similarly aged individuals [54], validating the CVA thresholding methodology in these eyes. Furthermore, the acuities measured with the 10% glare CVA module closely resembled the acuities measured with a 15% ETDRS chart that was placed in an outdoor environment with the sun overhead while the acuities measured with the 8% glare CVA module closely resembled the acuities measured with the same ETDRS chart, but positioned with the sun 15 degrees off-axis, expanding the validation. As reported previously [54] a 15% Michelson Contrast chart was chosen since it approximates the commonly encountered contrast of elements visualised in outdoor activities, such as playing golf or tennis. Small significant differences were noted, but they were all less than test-retest differences previously reported for either method performed under similar conditions [54].

A significant correlation was observed in this study between the C-Quant log(s) meaurements of straylight impinging upon the retina in each eye and the decrease in vision measured with both the 10% and 8% glare modules (Table 8; Figure 3), whereas no correlation was observed with any of the mesopic CVA measured acuities or with the high contrast photopic CVA module. Other authors measuring straylight in cataract eyes with the C-Quant device similarly have observed either no or minimal relationship between the log(s) values and high contrast acuity [22,51,52,80]. Some authors have noted a relationship between log(s) straylight and chart contrast sensitivity testing [22], while others have not [51,80] and some only with certain types of cataract but not others [33].

Contrast sensitivity (CS) is an extremely difficult and complex psychometric function to measure and is very dependent upon the method utilised. Most often measurements are performed only under moderate photopic conditions in the physician's office with the chart lit at 85 cd/m², although it should be understood that an entire family of curves exist for other levels of luminance [29,81-84]. In the photopic environment most often one of four charts is utilised; Regan charts are the only type that present single contrast letters with the threshold being reached by the smallest line of letters that are identified. However, when testing with Regan charts, many charts are required prolonging the testing time, a significant drawback in the clinic. Measurements of

CS are more often conducted by charts that present standard resolution targets of particular spatial frequencies, either letters or sinusoidal gratings, at progressively diminishing contrast, with a threshold being reached when the target can no longer be correctly identified. The Pelli-Robson chart, which presents letters only of one size (equivalent to approximately one cycles/degree [85,86]), and the Ginsberg [11,46] and Holladay [86] charts, which present gratings at spatial frequencies of 3 and 6 cycles per degree, evaluate the contrast sensitivity function over the portion of the curve that is relatively flat and at very low contrasts. At these contrasts, the 95% confidence limits of test-retest reliability for those charts is +0.15 log unit contrast [18,38] which means that the veiling glare must reduce the contrast of the target by a greater amount in order to barely detect an effect, and even greater to define a proportional relationship. The C-Quant device utilises an annulus of glare at 5-10 degrees, which in effect is equivalent to an off-axis glare source at 7 degrees. At this angle of scatter, according to the observations of Vos, an annulus luminance of 30,000 cd/m² would be required to produce a reduction of, for example, 0.16 log unit contrast when targets of 1-2% MC are presented at 85 cd/m². For a glare source to cause a reduction in the maximum, high contrast visual acuity, it must reduce the contrast by more than 90% to cause a reduction in acuity greater than 0.12 logMAR, equivalent to the 95% confidence limits of the test-retest reliability observed by us and reported previously [54]. In order for the glare source to cause this reduction in perception of high contrast acuity, it would require a glare source of 3,000 cd/m² because of the steep curve at the higher contrast spatial frequencies. However, when evaluating contrasts between 10% and 2%, the curve flattens considerably; therefore the luminance of a glare source must be only 600 cd/m² to cause a log MAR 0.12 change in threshold letter determination for targets of 100 cd/m². For these reasons, therefore, straylight caused by the glare source in the C-Quant device is adequate to reduce the contrasts sufficiently to cause an alteration of the acuity measured with the CVA photopic glare modules. Examination of the CS curve also would explain why cataracts that produce only transmitted straylight glare would have less effect than those that also cause blur due to index refraction clefts within the lens, especially when the pupil dilates in mesopic environments.

Among the 22 eyes that were measured with the C-Quant, unreliable readings were obtained for 9, as defined by an Esd below 0.08 and Q of above 1.0 [80]. As demonstrated in Figure 3 and Table 7, these were clustered primarily among the eyes with more dense LOCS III gradings and poorer acuities, but with wide dispersion. The reasons for the unreliable Esd and Q are unknown.

Other authors, as noted in the introduction, have attempted to evaluate whether there is a correlation between the degree of lens opacification (reflected dispersion), that is perceived by the clinician on slit lamp examination, and the reduction in vision measured by high contrast acuity [25,30-32] or by contrast sensitivity [33-39], or whether it is correlated with the increased measure of straylight assessed by the C-Quant [25,34,45-52]. In the study presented here, this was difficult to assess because the cohort was small and consisted primarily of eyes with moderate nuclear cataracts. Among the 22 eyes, only 6 were noted to have more significant nuclear opacification grades than the moderate NO3, NC3.

Finally, a correlation was evaluated between any of the CVA acuities or C-Quant measurements and the impairment of a number of activities evaluated with the ADVS questionnaire. The subgroup analysis of the ADVS for driving problems provided the best correlation with the acuities measured with both of the low contrast mesopic CVA

modules (Spearman correlation $r=0.761$ for 50% mesopic CVA and $r=0.573$ for the 25% mesopic CVA module), and also with both full contrast CVA modules ($r=0.851$ and $r=0.874$, see Table 9). This suggests that low contrast as well as high contrast acuities provide the greatest determinant for performing these tasks rather than the effect of glare, but since this group of tasks did not correlate with the C-Quant data or the glare acuities, it is suggestive that either they were not so severe in this group or were not determinants of the difficulties with driving. Difficulties encountered with near distance tasks correlated strongly with both high contrast CVA modules, and less well, but significantly, with the other CVA modules, except for the 25% mesopic CVA module. This is understandable since the near tasks primarily involve reading tasks that are affected to a greater degree by blur, but, as suggested by the lack of correlation with the C-Quant straylight measurement data, they are not as severely affected by glare among this group of patients. Finally, the group of long distance task problems failed to correlate with any of the CVA modules, but did correlate significantly with the C-Quant log(s) data. This result appeared confusing as these tasks are performed in both daylight and dark environments and would therefore not appear to be necessarily related to straylight abnormalities. However the questions of the ADVS that comprise this group are very heterogeneous, and perhaps the patients may have weighted certain tasks greater than others when answering. The relationships will have to be investigated with further studies before any conclusions can be drawn.

Conclusion

This study has demonstrated, similar to others, that cataracts cause a deterioration in vision under low contrast environments when high contrast acuity is little disturbed and that the C-Quant derived straylight abnormalities correlated with the results observed under the 10% and 8% glare modules. It was reassuring to demonstrate that 10% and 8% glare modules did produce the same acuities, when testing in a darkened room, as when tested with 15% charts placed in sun-filled environments, the latter with the sun off axis at 15 degrees validating the prior observations and calculations of ourselves [54] and Vos [29]. However, it is recognised that additional studies are required to test other types and degrees of cataract to substantiate these relationships. Finally, the observations of correlation between the acuities measured with the CVA under various environments and the VFQ measures of difficulties experienced by these individuals in a variety of tasks will have to be further investigated to elucidate the reasons why they experienced the problems and whether this was due to the glare or other influencing problems.

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